

The copyright of this thesis vests in the author. No quotation from it or information derived from it is to be published without full acknowledgement of the source. The thesis is to be used for private study or non-commercial research purposes only.

Published by the University of Cape Town (UCT) in terms of the non-exclusive license granted to UCT by the author.

RAPID ASSESSMENT USING AUTOMATED MARKING

# Rapid Assessment using Automated Marking

By

CHIBILA FRANCIS ULAYA

BEng (University of Zambia)

Submitted in fulfilment of the requirements for the degree of  
Master of Science in Engineering  
in Mechanical Engineering  
Faculty of Engineering and the Built Environment  
University of Cape Town

Cape Town  
August 2008

**ACKNOWLEDGEMENTS**

It was going to be easy to just give up and not complete this work. But you did not give up on me but continued to push this work to completion. Thank you very much Dr. Brandon Reed for your support and help. This one is for you.

I would also like to thank my wife and kids for being my best friends during this study period. You are the best.

Mom and Dad, it took long but here it is.

University of Cape Town

RAPID ASSESSMENT USING AUTOMATED MARKING

**DECLARATION**

1. I know that plagiarism is wrong. Plagiarism is to use another's work and to pretend that it is ones own.
2. I have used the convention for citation and referencing. Each significant contribution to, and quotation in, this report from the work, or works, of other people has been attributed, and was cited and referenced.
3. This report is my own work.
4. I have not allowed, and will not allow, anyone to copy my work with the intention of passing it off as his or her own work.

Chibila Francis Ulaya

Signed by candidate

Date ..... 27 / 08 / 08 .....

### ABSTRACT

It becomes increasingly difficult to monitor academic progress of students in a class that is too large to allow for individual attention by a lecturer. What are required are modes of assessment which are both informative and rapid. One way to achieve this is by utilising automated marking of examination or test scripts. The ability to mark test papers by computer has a number of benefits. One, being that it speeds up the assessment process and statistical information can be obtained easily and quickly which would greatly assist lecturers in monitoring the effectiveness of their lectures and give them the ability to obtain rapid feedback of an informative nature. This gives students a chance to implement corrective measures while the material is still fresh in their minds.

Automated marking is heavily dependent on image acquisition and processing routines. Therefore ways of formatting examination and test papers were sought which allow for automated marking. Current marking machines utilise scanners to digitize answer scripts for marking purposes. These are more often than not, quite expensive. In investigating affordable ways of digitising answer scripts, the imaging device of choice was found to be a web camera. This was so because web cameras are readily available and are more affordable than scanners. This allowed the building of a prototype marking machine which was tested and performed as expected.

In operation, the camera is connected to a desktop computer via a USB port and captures images automatically after being triggered by a sensor. These images are then processed to achieve marking. To further reduce costs, paper transportation through the prototype marking machine relies on gravity therefore paper moves through the machine under its own weight, eliminating the need for motors to direct paper through the machine.

The machine has exhibited the ability to identify numeric as well as alpha numeric characters. This is a great improvement to the current marking machines capabilities which are primarily used for multiple-choice question marking. The ability to identify numbers written by students in a test eliminates the need to restrict automated assessment to multiple choice questions which are prone to accurate guessing leading to inaccurate diagnostic feedback in tests.

**TABLE OF CONTENTS**

Acknowledgements.....	2
Declaration.....	3
Abstract .....	4
Table of Contents.....	5
List of Figures.....	7
List of Tables .....	9
1. Introduction.....	10
2. Literature Review.....	15
2.1 Objectives .....	15
2.2 Limitations .....	15
2.3 Plan of Development.....	15
2.4. Economic Challenges.....	16
2.4.1 Globalisation.....	16
2.4.2 Lack of Skilled Workforce.....	16
2.5 Education Challenges.....	21
2.5.1 Lack of Preparation and Poor Attitude.....	21
2.5.2 Lecturing Problems.....	22
2.6 Currently Available Marking Machines .....	24
2.7 Assessment.....	28
2.7.1 Multiple Choice Questions .....	28
2.7.2 Advantages of MCQ.....	28
2.7.3 Disadvantages of MCQ.....	29
2.7.4 Alternative Uses of MCQ .....	30
2.8 Educational Framework.....	31
2.9 Conclusion .....	34
3. Method.....	35
3.1. Proposed Assessment Methods.....	35
3.1.1 Question Structuring.....	35
3.1.2 Multiple Choice Questions .....	35
3.1.3 Calculations.....	41
3.2. Analytical Approach.....	44
3.2.1 Image Acquisition.....	44
3.2.1.1 Camera Operation.....	44
3.2.1.2 Trigger Mechanisms .....	46

## RAPID ASSESSMENT USING AUTOMATED MARKING

3.2.2	Image Acquisition in Matlab .....	47
3.2.3	Actual Image Acquisition .....	48
3.3	Image Processing .....	49
3.3.1	RGB to Greyscale Conversion.....	51
3.3.2	Selection of Pixels of Interest .....	52
3.3.3	Individual Character Extraction.....	56
3.3.4	Cropping Individual Characters.....	57
3.4.	Neural Network Application.....	59
3.4.1	Neural Network and Character Recognition.....	59
3.4.2	Training Neural Networks .....	59
3.4.3	Student Number Identification.....	67
4.	Prototype Marking Machine .....	71
4.1.1	Prototype Machine Performance.....	73
4.1.2	Machine Description.....	73
4.2	Machine's Frame .....	74
4.2.1	Electrical Components .....	75
4.2.1.1	Web Camera.....	75
4.2.1.2	Sensor.....	76
4.2.1.3	Microcontroller board and Data Acquisition Unit.....	77
4.2.2	Machine Operation.....	79
4.2.3	Summary of Machine Operation.....	81
5.	Testing and Results .....	83
5.1	Experiment.....	83
5.2	Test One .....	84
5.3	Test Two .....	85
6.	Conclusion .....	91
7.	Recommendations.....	92
8.	References.....	96
	Appendix A — Specifications .....	98
	Appendix B — Conceptual Design.....	104
	Appendix C — Detailed Design .....	122
	Appendix D — Code Listing.....	132
	Appendix E — Drawings.....	151

LIST OF FIGURES

Figure 1: Events of Learning and Instruction .....	11
Figure 2: Katse Dam, 1 <sup>st</sup> of 5 Dams in the Lesotho Highlands Project .....	17
Figure 3: Artists impression of the ‘Gautrain’ [26] .....	18
Figure 4: The Nelson Mandela Bridge.....	18
Figure 5: Support to Professional Engineers .....	20
Figure 6: The DRS CD230 Optical Mark Reader.....	25
Figure 7: The DRS CD360 Marking Machine.....	25
Figure 8: The DRS CD400 Optical Mark Reader.....	26
Figure 9: The DRS CD860 Automatic Optical Mark Reader.....	27
Figure 10: The DRS PS900 Photo Scribe Optical Mark Reader .....	27
Figure 11: The Learning and Assessment Framework .....	33
Figure 12: First Example Question in MEC1004W .....	36
Figure 13: Second Example Question from MEC104W .....	40
Figure 14: Alternative Structuring of Example Question 2 .....	40
Figure 15: Marking Key Image Captured by Camera .....	42
Figure 16: Black And White Image of Marking Key .....	43
Figure 17: Cropped Regions of Interest.....	43
Figure 18: Image Absolute Difference .....	43
Figure 19: USB Web Camera .....	45
Figure 20: CCD Camera Operation [18].....	45
Figure 21: A Photoelectric Barrier Trigger [18].....	46
Figure 22: Logitech QuickCam Pro 4000 Web Camera.....	47
Figure 23: Answer Script Snapshot .....	49
Figure 24: A 3 by 4 matrix.....	49
Figure 25: Square pixels in an Image .....	50
Figure 26: First Area of Interest Crop.....	52
Figure 27: Black and White Image after Conversion .....	53
Figure 28: Cleaned Up Image .....	54
Figure 29: Image before using ' <i>bwareaopen</i> ' Function.....	55
Figure 30: Clean Image after ' <i>bwareaopen</i> ' Function.....	55
Figure 31: Bounding Box around Cropped Character .....	57
Figure 32: Required Image Size .....	58
Figure 33: A Perceptron Model .....	59
Figure 34: Neural Network Training Process .....	60
Figure 35: Multiple Inputs – Multiple Outputs Perceptron .....	60
Figure 36: Number ‘2’ as a Column Vector of Height 35 .....	62
Figure 37: Number ‘2’ as a Column Vector of Size ‘140 by 1’ .....	63
Figure 38: Test Question Answers.....	65
Figure 39: Student Number and Answers Screenshot .....	68
Figure 40: Automatic Marking Machine .....	71

Figure 41: Prototype Marking Machine.....	72
Figure 42: Marking Machines Frame .....	74
Figure 43: Logitech QuickCam Pro 4000 Web Cam.....	75
Figure 44: Electrical Components under Paper Tray.....	76
Figure 45 : Photo Reflective Sensor Position .....	76
Figure 46: Sensor Circuit.....	77
Figure 47: Microcontroller Board.....	77
Figure 48: The Data Acquisition and Control Unit .....	78
Figure 49: Fans for Paper Transportation .....	79
Figure 50: Marking Machine Mode of Operation.....	80
Figure 51: Component Connections to Microcontroller .....	80
Figure 52: Stages in the Computer Program of Marking Machine.....	82
Figure 53: Machine Tested on Multiple Choice Questions .....	84
Figure 54: 100% Character Recognition.....	87
Figure 55: Marking Machine Performance during Testing .....	90
Figure 56: Comparison of Means .....	90
Figure 57: ‘Number Line’ Question Structure.....	93
Figure 58: ‘Free Body Diagram’ Question Structure .....	94
Figure 59: ‘Labelling’ Question Structure.....	95
Figure 60: Fixed Base Marking Concept.....	106
Figure 61: Fixed Base Marking Machine Picture .....	107
Figure 62: Sliding Tray Mechanism .....	108
Figure 63: Sliding-Base Marker Mechanism.....	109
Figure 64: Sliding Tray Mechanism during Testing.....	109
Figure 65: Sliding Paper Mechanism.....	110
Figure 66: Sliding Paper Test Rig.....	111
Figure 67: Design Concepts.....	112
Figure 68: Placing Answer Sheet on Marking Machine.....	116
Figure 69: Paper Sliding Down the Smooth Markers Surface.....	116
Figure 70: Paper Sensor Used As Camera Trigger .....	117
Figure 71: Data Acquisition and Control Unit.....	117
Figure 72: Snapshot of Moving Paper Taken Upon a Trigger Event .....	118
Figure 73: Snapshot of Moving Answer Paper.....	118
Figure 74: Image Converted to a Binary Image.....	119
Figure 75: Clean Image used for Analysis.....	120
Figure 76: Seven Segment LED Board Showing Mark Obtained .....	120
Figure 77: Paper Feed Tray.....	125
Figure 78: Side Panel Layout for Marking Machine .....	126
Figure 79: Base Mounting Plate .....	127
Figure 80: Cover and Camera-Handle Location Hole .....	129
Figure 81: Marking Machine Main Frame.....	130

**LIST OF TABLES**

Table 1: Number of Professional Engineers in South Africa .....	19
Table 2: Alternative Answer Grid Format of First Example .....	37
Table 3: Table of Terms Taught in MEC1004W .....	38
Table 4: Test Paper with Answers Entered in Red .....	39
Table 5: Test Results after Automated Marking.....	69
Table 6: Test-Two Results.....	86
Table 7: Improved Answer Legibility Increases Marking Accuracy.....	88
Table 8: Final Machine Test Results .....	89
Table 9: Concept Selection Weightings.....	113
Table 10: Paper Tray Dimensions.....	125
Table 11: Side Panel Dimensions .....	127
Table 12: Base Mounting Plate Dimensions.....	128

University of Cape Town

## 1. INTRODUCTION

As suggested by the title, 'Rapid Assessment using Automated Marking', this study investigated the usage of computer based marking machines in marking examination and test scripts. It also looked at how the capabilities of these machines could be improved upon. Various methods of formatting questions and answer sheets have been suggested in the report which adds to the variety of what can be marked by machines.

In a report entitled 'Involvement the cornerstone of excellence' [1], Astin cites student involvement, setting high expectations, fair assessment and rapid feedback as the necessary ingredients for fostering true educational effectiveness. This reasoning has been supported by other researchers example being 'The Study Group on the Conditions of Excellence in Higher Education' [2] who suggest in their report that an excellent learning environment is characterised by at least these conditions namely student involvement, setting high expectations, fair assessment and rapid feedback. Astin however, says that 'involvement' is really the cornerstone of this mini theory, in the sense that the setting of high expectations and giving timely feedback is part of actually enhancing student involvement. Stated simply, students learn best by becoming involved. Here 'student involvement' means the amount of physical and psychological energy that the student devotes to the academic experience. This aids in the educational process because it allows for better direct observation and measurement of student progress [1].

Research was undertaken in the 1970s and early 1980s to discover the elements of effective direct instruction lessons. For example, Robert Gagné [3] proposed a model based on information-processing theory in which essential events of instruction correspond with key events in the learning process. Gagné's model is presented in Figure 1 and according to him an act of learning includes eight phases which are shown on the left hand side of the boxes. These are external events that can be structured by the teacher. Each of these phases is paired by events that take place in the students mind during learning. These are presented inside the boxes. Gagné's strategy for lesson presentation, listed on the right, suggests that teachers lead students through a series of events that have been identified as necessary for learning [4].

## RAPID ASSESSMENT USING AUTOMATED MARKING

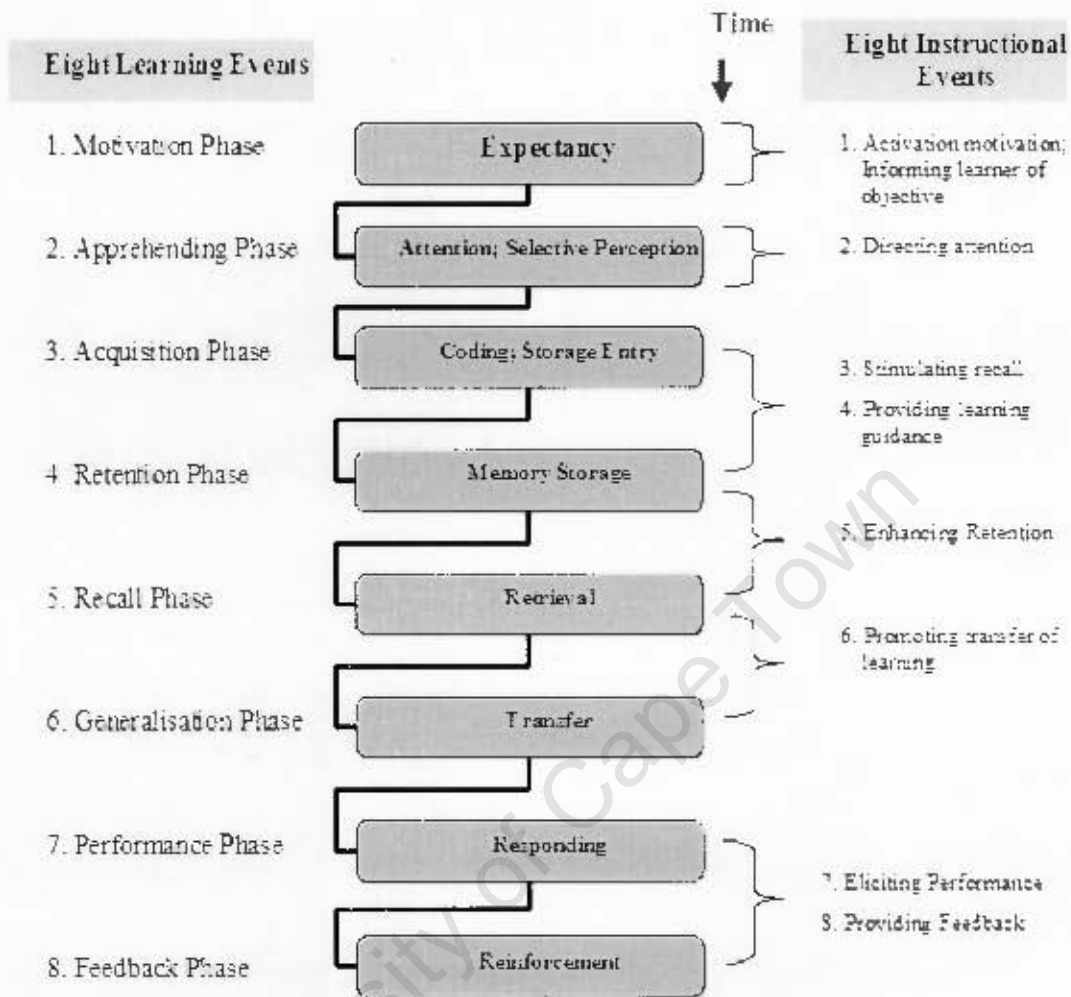


Figure 1: Events of Learning and Instruction

A short description of the parts of a direct instruction lesson can be as presented below [4]:

1. **State learning objectives and orient students to the lesson:** Students are told of what they will be learning and what performance is expected of them.
2. **Review prerequisites:** This is done by going over any skills or concepts needed to understand the current lesson.
3. **Present new material:** The lesson is presented, presenting information, giving examples, demonstrating concepts etc.
4. **Conduct learning probes:** Pose questions to students to assess their level of understanding and correct their misconceptions.
5. **Provide independent practice:** provide students an opportunity to practice new skills or use new information on their own.
6. **Assess performance and provide feedback:** Review independent practice work or provide a short quiz. Give feedback on correct answers and re teach skills if need be.

7. **Provide distributed practice and review:** Assign homework to provide distributed practice on the new material. Review material in later lessons, and provide practice opportunities to increase chances to remember what they learned and will be able to apply it in different circumstances.'

With the stages of direct instruction as presented above, it is clear that two stages in the learning process require some form of inquisition by the instructor by means of quiz or test. These are stages number four and seven. In stage number four, the learning probe might be a quiz or a short test. When the number of students in a class is large this is difficult to conduct due to the burden of marking. The same can be said about marking homework assignments as presented in stage number 7. It is for these challenges that methods are being sought to easily and quickly assess large numbers of students in classes.

In an article in the 'Business Day' newspaper of 26 October 2004 [5], it was noted that the shortage of engineers in South Africa was so severe, that it could stop the completion of projects as the economy grows and major constructions begin. Chris Reay, Chief Executive of Engineer Placements, and in charge of communications, specialist groups and strategic planning at the South African Institution of Mechanical Engineers was quoted by Mzwandile Faniso in an article entitled 'South Africa looks overseas to recruit engineers', in the 'Cape Times' newspaper of 17<sup>th</sup> June 2005 [6] as saying that South Africa was facing an acute shortage of engineers which the country needed for its multibillion-rand infrastructural projects. Projects such as the construction of power stations, railways and stadiums for the 2010 soccer world cup which would need highly specialised and experienced engineers, which the country currently only had but a few. This would lead companies to source the skills from foreign countries. This shortage of skilled engineers has been recognised by people in the political sphere and also by those in industries who are now advocating for an increase in the numbers of graduates from tertiary educational systems.

In response, institutions like the University of Cape Town are expected to produce more graduates for the South African (or indeed the African continent's) workforce because the prosperity of Africa depends on each country's ability to succeed technologically and in so doing, improve their economies [7]. Dr Frank Press, in a report entitled 'The Role of Education in Technological Competitiveness' [8] made the following statement:

*"It is now self-evident that the ability of industrialised countries to maintain a relatively high standard of living depends directly on the quality of their workforce."*

Markets have become global, and success in global markets, especially for high technology products and processes, depends on the quality of the products produced. Is the product – be it a car or a chip – reliable? Does it reflect state-of-the-art technology? Some of the questions being asked by consumers in the market place are making it imperative for academic institutions to produce graduates of a high calibre. With this comes a new problem. In the process of admitting more students to university and ensuring that the base of the technological personnel is broad, the admitted students now come from diverse educational backgrounds, ranging from seriously disadvantaged to very privileged, often depending on the schools they have attended [7].

Coupled with this marked difference in academic backgrounds is the decline in the secondary educational standards which have resulted from a steady decline in background preparation, self-discipline for serious study and genuine desire to learn by students leaving high school and entering first year [9]. This trend appears to apply to a large fraction of engineering students and could have negative consequences for this country's future.

Educating students with this wide variation in backgrounds is difficult in particular because resources have remained almost the same. If, for example, a slower pace is chosen to accommodate those slow to learn or that lack some of the basic building blocks and therefore have holes and gaps in their background education, one runs the risk of not completing the course material and at the same time bores the other students who feel the pace is too slow. The opposite of this is true in the sense that by going too fast one runs the risk of losing the slow learners. John Greene [10] has described the six fallacies in engineering education. Of direct relevance is the following statement he makes: *'The "dynamic range" of our students' ability is extraordinarily large. I have never been comfortable, in teaching a class of 100 students, that I have been able adequately to address the needs of either the brightest or the weakest in the class.'*

Such a situation makes it essential to easily and quickly identify the students with problems and who need the extra help to cope. It can be compared to a production line where, when there is a particular section where defects (problems) arise, if left uncorrected, the product will remain defective and many others that follow will be lost.

Traditionally, student progress has been monitored by means of assignments, tests and laboratory experiments resulting in a considerable marking load taking up valuable time and resources which could have been invested in helping the students with problems. The marking could be given to student lecturing assistants but this usually impacts negatively on fairness and quality control as most

lecturing assistants are busy pursuing their studies at university, doing this part time to earn some money. Typically they will try and make this money in the least effort and time consuming way possible. This invariably means less energy and concentration is applied to marking tasks so that they can concentrate on their studies. This leads to students receiving marks from someone who does not know them and who has barely read their assignments. The result of this is that some students who actually have problems because they lack understanding of study material are allowed to progress sometimes even graduating without their ignorance and problems being exposed and corrected.

It is advantageous for the lecturer to know without delay which aspects of the course material students understand. In this way those points they fail to understand can be re emphasised with minimum delay. The effect of delaying returning marked scripts should not be underestimated. For example, using multiple choice questions, where very little work goes into writing out the answer in the form of an explanation, students concern themselves mainly with the grade they obtained and very little on where they went wrong when there is a delay in handing back answer scripts. It would be beneficial if students knew immediately where they erred in a test or assignment while the questions are still fresh in the mind, compared to returning scripts at a later time when many of the nuances of the test would have been forgotten and interest is focused on other issues. A much bigger problem, however, in Multiple Choice Questions (MCQ) is that the answer sheet and the question paper are separate. The student retains the question paper and the answer sheet is handed in. During revision, the student does not recall what answer they gave for a particular question. It would be pedagogically better if the questions and the answers were on the same page enabling a comparison to be made.

This called for a way to get rapid feedback to and from students so that they could monitor their own progress in understanding engineering principles and lecturers could emphasise on the problem areas and monitor where those students who are struggling are and corrective measures implemented. One way of achieving this was seen as automated marking of students test and examination scripts by means of a marking machine. Using such technology would speed up the assessment process and make marking of scripts fair since it would be less susceptible to human error. With this, a great advance would have been made in one of the major ingredients that foster true educational effectiveness – rapid feedback.

The next chapter which is a literature review takes a deeper look at various challenges faced in educational institutions with respect to provision of timely instruction and assessment. Also presented are current assessment methods and the machines used in automated assessment.

## 2. LITERATURE REVIEW

The increase in demand for more graduates from universities to fill up positions of responsibility in the growing economy has led to the increasing numbers of students that are entering university at first year. This is exemplified by the increasing numbers of students entering the University of Cape Town in the faculty of Engineering and the Built Environment.

The rapid increase in student numbers requires that new methods of testing and assessing their progress be found and done rapidly. With lack of financial resources, it becomes increasingly difficult. The use of automated marking provides a solution to this challenge. This has been dubbed “rapid feedback” in this report.

### 2.1 Objectives

The objective of this section of the report is to present to the reader-

- reasons behind the increment of numbers of students entering university;
- the challenges faced in the education process due to the increasing numbers of students;
- an overview of the classification of ‘learning’ and how to assess each class;
- an outline of reasons for the need to speed up the rate of assessment; and
- methods to achieve rapid assessment and improve educational effectiveness.

### 2.2 Limitations

The theory behind assessment methods and their application in the educational process is quite vast. The review does not intend to analyse the whole spectrum of assessment but that which is used for assessing knowledge and measurable skills, for example, multiple choice questions.

### 2.3 Plan of Development

The appendix begins with a discussion on the economic challenges facing Africa and South Africa in particular in terms of the need for a skilled labour force and the need to educate more engineers. From this need, an overview is presented on the challenges faced in educating increased numbers of students. The learning process is broken down into specific classes which are assessed differently hence modes of assessment are presented. A brief discussion is then presented on the currently available marking machines and the technology they utilise and finally image acquisition and processing is presented.

## 2.4. Economic Challenges

### 2.4.1 Globalisation

The world as it was known has changed in the way it conducts business. The barriers to trade have been broken down and it has become what is now called a 'global village' where business is conducted wherever you want. This has increased the level of competition in the market place as those countries with advanced technologies in their production processes produce goods of very high quality and reliability, and reflect state-of-the-art technology. To be able to compete with these countries one has to produce goods of better or similar quality because the market is always looking for the best product there is, because they do not want to settle for less.

### 2.4.2 Lack of Skilled Workforce

Dr Frank Press [8] clearly stated the challenges that are facing the American economy in his report on the role of education in technological competitiveness. Since the first world countries are what third world countries are competing with, it is worthwhile to observe what they consider necessary for prosperity.

His report emphasised the point that a quality workforce is necessary to foster a high standard of living. This workforce must be 'skilled' and 'adaptable'. *Skilled* meaning that the workforce must be well trained with literacy in both words and numbers and having the ability to think critically about complex matters and perform demanding tasks. It must be *adaptable* as well, since, due to globalisation, there are constant changes in the marketplaces.

Customisation leads to a market that is less predictable due to the ever changing requirements by customers in the functionalities of new products. In order to remain competitive, manufacturers have to become very innovative in the design of their products. This is a mixture of good and bad news. The good news being that, the more innovative organisations get, the bigger the share they get in the market, and the opposite is true for the less innovative ones.

Press continued by saying that students' academic achievements were still failing to keep pace with the competitive requirements of the global market. Not only do prospective workers face this predicament but also the current workforce, that has skills which are fast becoming obsolete if no continuous upgrading of qualifications is undertaken due to rapid advancements in technology. These, together with other economic factors are what the first world countries consider essential. The same can be said about the developing countries where there is need to become more competitive in order to survive in this global economy. For Africa to compete in a global economy, it must be able to come to

this level of competitiveness in the quality of its products. This brings with it the need for highly skilled engineers in the economy to steer the production industry.

Researchers in the field of economics have given some insight into what is necessary to compete favourably. In her report, Sue Blaine [5] cited some leading engineers like Dr Azar Jammine who was the Director of Econometrix Consultancy, saying that the South African economy may not have enough Engineers to take full advantage of the economic growth of the country.

An example of projects that need qualified engineers is the Lesotho highlands water project. Out of the five planned dams, one has already been built and is called the 'Katse Dam' (shown in Figure 2 below). Four more hydro-projects are planned and work has already begun [25].



Figure 2: Katse Dam, 1<sup>st</sup> of 5 Dams in the Lesotho Highlands Project

Another project which demands trained engineers is the 'Gautrain' Bullet train project. This is the construction of a high speed rail link between Johannesburg, Pretoria and the Johannesburg international Airport which began in 2006 [26]. An artist's impression of the bullet train is shown in Figure 3 .

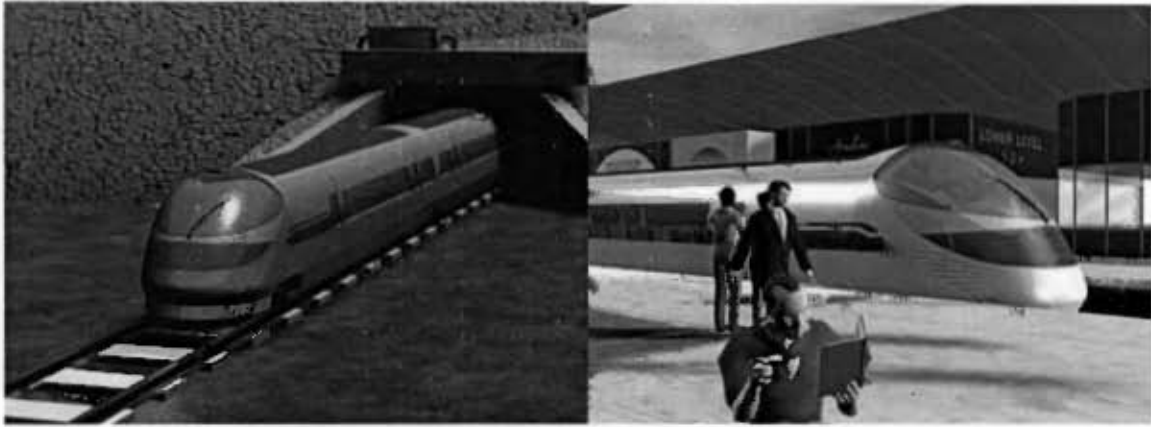


Figure 3: Artists impression of the 'Gautrain' [26]

To build the 'Nelson Mandela Bridge' shown in Figure 4 below, engineers were required to work on the project. These projects serve as examples of the need for qualified engineers in the economy. If the projects are left to unqualified personnel, there will be a number of lives lost due to poor workmanship.



Figure 4: The Nelson Mandela Bridge

A good example might be the coming soccer World Cup in 2010. To prepare for it, South Africa will need to build world-class stadiums to host the games, the construction of which requires skilled engineers. The fact remains, that the games will be held in South Africa and the buildings will have to be built. If the status quo remains with few engineers available, other countries will send their engineers to do the work that could have been done by South African engineers.

Blaine went on to quote Andy Kousaris, who at the time was professor of metallurgical engineering at the University of the Witwatersrand, as saying that South Africa needed to produce between 300 and 350 engineers for every million of the population to compete with its largest trading partner, Europe.

## RAPID ASSESSMENT USING AUTOMATED MARKING

Meaning that between 13,420 and 15,680 engineers should graduate from all South African Universities each year [5]. At the time of publication of her report only 3,037 candidate engineers had been registered with the Engineering Council of South Africa (ECSA). Even though registration is voluntary, this clearly shows that the country is lagging behind. It is generally agreed therefore that more engineers are needed for this country to continue developing.

In a report by Michael D. Hosking B. Ing entitled 'There is no shortage of Engineers' [27], he states that the statistics about the number of engineers in South Africa are worse than reported by Faniso [6]. He listed the figures as of July 2005 which are reproduced in

Table 1 below.

Registration Category	31-03-2002	31-03-2003	31-03-2004	31-03-2005
<b>EMF</b>				
International Professional Engineers			9	15
<b>Professionals</b>				
Professional Engineers	14,593	14,687	14,728	14,754
Professional Engineering Technologists	2,184	2,357	2,522	2,617
Professional Certificated Engineers	760	792	793	803
Professional Engineering Technicians	70	395	800	1,094
<b>Candidates</b>				
Candidate Engineers	2,999	3,093	3,234	3,269
Candidate Engineering Technologists	435	507	543	646
Candidate Certificated Engineers	75	100	103	106
Candidate Engineering Technicians	445	563	699	833
<b>Specified Category</b>				
Registered Lift Inspectors		160	155	161
<b>Dormant (since 28 August 2001)</b>				
Registered Engineering Technicians	1,480	1,332	1,224	1,156
Reg. Eng Technicians (Master)	553	529	504	495
<b>TOTAL</b>	<b>23,594</b>	<b>24,515</b>	<b>25,338</b>	<b>25,949</b>

Table 1: Number of Professional Engineers in South Africa

In his explanation he states that although Faniso says that there were 26,300 registered professional engineers, the fact was that there were only 14,754 who were registered. This paints an even grimmer picture on the current state of supply of engineers in South Africa.

Other observations that he made from

Table 1 were that compared to most countries in the world where a professional engineer is supported by about 4-16 technicians/technologists, in South Africa four professional engineers share one technician. He illustrated this as shown below.

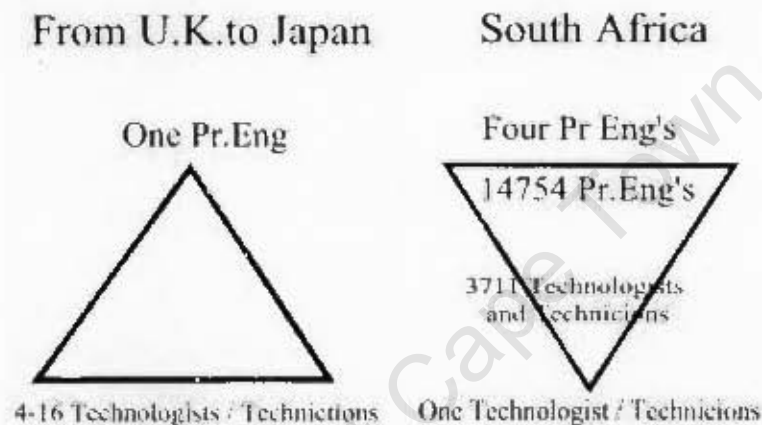


Figure 5: Support to Professional Engineers

In quoting the ECSA chief executive officer, Paul Roux, Blaine warned that there was also a shortage of Black engineers especially experienced ones and a lack of female engineers as a whole.

Employment equity is important in a sector which was historically white and male dominated, but pushing experienced engineers out of jobs for employment equities sake is leaving a wide and dangerous gap in the engineering field that the mentorship process is overwhelmed. A graduate engineer needs three years to complete candidacy and be eligible for registration as a professional engineer. This means that if fresh graduates were just placed into the economy without proper training they may end up taking up jobs they were not ready for or qualified to do. Hence more engineers are needed for training and even more for mentoring fresh graduates as the economy grows.

Many projects, if undertaken, would require a large workforce to see them to completion. A shortage of skilled labour may constrain progress of these projects. There is need therefore to encourage more people to take up engineering careers. If engineering was portrayed as the interesting career it is, more people would take up technological studies and engineering to meet the needs of industry and other facets of the economy.

With this shortfall in the numbers of technical personnel, comes the need to educate more Engineers. This is not as simple as it sounds due to the challenges faced as will be shown in the following section.

## **2.5 Education Challenges**

### **2.5.1 Lack of Preparation and Poor Attitude**

The educational process in secondary schools is facing a number of challenges. There is a noted decline of academic standards as Meriam showed in his article “The Decline of Academic Standards” [9]. Meriam argues that students today are simply unable to handle problems, which were routinely solved by students a decade or more ago and that they lack the adequate grasp of the basic principles or interpretations of mathematics. This is caused mainly by lack of experience and interest in physical and geometrical applications of mathematics.

A few first year students dealt with in 2004 had difficulties handling questions that required the drawing of free body diagrams (FBD) to obtain their mathematical relationships during their assignments in MEC104W in the Engineering and Built Environment Faculty of the University of Cape Town. This could have resulted from Physics and Mathematics instructors who put more emphasis on theory and logic in secondary schools, than allowing students to practice it by applying it. Students therefore enter university ill equipped to handle the pressures of university analysis.

The attitude that most university entrants have also creates a problem in the educational process. Most view tertiary life as a place for fun and games instead of viewing their educational opportunities as a serious commitment. Students are being more and more conditioned to receive information than to generate ideas. Most are just content to do enough just to get by and are not motivated to do well [9]. Therefore, lack of proper preparation and a poor attitude towards education are contributing to the downward trends in academic standards.

Due to the need to increase the number of engineers in industry, an increased number of students have to be taken in at first year. Women are also increasingly being encouraged to take up programmes in the engineering field. As a drive towards equality, students from different ethnic backgrounds are now being accorded opportunities to study in this field. Some of these are coming from previously disadvantaged educational systems. They are now taking up courses in the field, which was previously dominated by white male students. This is good for the country, but the challenge that it brings is the difficulty for instructors to fully address the problems or challenges encountered by all the students. Some are not as conversant with English, as it is their second language and some do not have a firm

grounding in the sciences that lead into the engineering discipline. John Greene cites six things that tertiary educators are struggling with in giving instruction or lectures to students [10]. These are discussed in the following section.

### **2.5.2 Lecturing Problems**

The report on the six fallacies in engineering education which Greene states as being applicable in every field of study makes mention of the following challenges encountered in the education process in most tertiary institutions.

The first fallacy is that students learn more if they are taught more. This is not true at all as teaching students more deprives both the better students, of the satisfaction of having deeper understanding and the weaker ones of the satisfaction of finding new information on their own hence receiving the much needed intellectual self-confidence.

The second fallacy is that by packaging lectures more elegantly and concisely in more abstract illustration more information can be fit into lectures. As a lecturer becomes more and more accustomed to the material of a specific course, there is a great temptation to teach course material more economically by say, combining two theories which are related, as one block theory. The lecturer gets more insight but the mystery is compounded in the student and he or she ends up studying it for the examination as an abstract theory.

The third fallacy is that generally students get a sound grounding in the fundamentals. Not all fundamental principles are well grounded in students. If any average engineering student in the third or fourth year were to be asked what the relationship between the Fourier and the Laplace transforms was or why metals reflect light, the answers received would rarely be correct. Therefore it is very important to emphasise the internalisation of these theories so as to be able to apply them to any given relevant situation.

The fourth fallacy is that students are being prepared for lifelong learning in a continuously changing field. Greene states that enough has been said about the need for continuous self-education but the trends are not changing. The ability to learn independently is a vital and teachable skill. If students are to become independent learners, such behaviour must be demanded of them, facilitated and rewarded as it is not enough to ask of them to continuously learn, just say it and hope they will absorb it as if by some miracle.

The fifth fallacy is that engineering students can be treated as a homogeneous group. The dynamic range of the student's ability is extraordinarily large. It is difficult to fully address the individual needs

of either the brightest and or the weakest in the class. This problem is more pronounced here in South Africa by the presence of students from widely differing educational backgrounds. This emanates from the widely differing early background and schooling and exposure to a 'technological culture'. This is one of the most challenging factors in the fundamental years at university. Much as the aim may be to readily ground students in the basic principles in their respective fields of study, the varying degrees of absorption of course material can be mind boggling. Hence, a way must be found to reduce the divide to focus on helping both groups of students.

The final fallacy that Greene states is that, familiarity with the world of engineering can be assumed in the students. He states that there is little sense of vocational commitment or special interest in studying engineering in students. The general approach by most students to this field is that it is the next best choice after failing to get into medicine, or that it is the obvious thing to do if you are good in mathematics. Making the assumption that student's will come to this field of study with a passion to be engineers would be to deceive one self.

Greene went on to list the general strategies to remedy the difficulties mentioned above. He states that instructors should-

- try and teach theory in the context of application to reality, therefore improving student involvement
- address the issue of an early positive orientation towards engineering
- proceed from the concrete to the abstract
- seriously address the question of independent learning and
- try and evolve more satisfactory forms of laboratory work.

These challenges face the educators in the faculty of engineering. The learning process itself has been subject of many researchers. One much respected research group is the Engineering Professors' Council (EPC) which exists to promote excellence in engineering in higher education. It provides a unique forum for senior academics responsible for engineering teaching and research in higher education. In their publication of December 1992 entitled 'Assessment Methods in Engineering Degree Courses' [13], they advise that, since the learning process of any student is categorised into four classes namely knowledge, measurable skills, complex skills and understanding, to achieve productivity, educators ought to adopt assessment methods which are suited to each class of learning. According to their recommendations, knowledge and measurable skills can be assessed in a single paper and they can both be computer marked, since correct performance can easily be specified. These two classes of learning can be assessed by means of computer mark able multiple choice questions. On

the other hand, complex skills and understanding cannot be assessed as easily, since the outcomes cannot be specified. For example, a design problem can have multiple solutions. Hence assessment of these two classes of learning has to be left to highly specialised personnel.

## **2.6 Currently Available Marking Machines**

The simplicity of marking multiple-choice questions makes their use even easier to manage in that computer based marking machines can easily do the marking. These machines are currently available and several companies manufacture and supply them to institutions that readily use them. An example of such a company is the DRS Data & Research Services PLC based in England [15]. Most of their machines perform multiple tasks and are not just biased to marking examination scripts. They supply machines to institutions that deal with statistical analysis like census, general survey departments, examination authorities, electoral bodies, passport offices and general organisations that process large volume, time critical and complex projects.

The operation of the current marking machines can be summarised into the following steps:

- the paper which is being processed is fed into the machine
- an image of the paper is taken by means of a scanner
- multiple areas of interest are clipped from the scanned form and saved to memory, each clip having its own selectable format. The captured clips are stored in the desired orientation, regardless of the orientation of the forms when scanned
- these machines run advanced computer programmes capable of performing independent image processing applications on different sections of the same paper and
- to minimise computing time required per sheet of paper, these machines utilise a technique called dropout imaging where the image processing programme concentrates only on those sections of interest and mask out the rest, thus lowering storage and post processing costs and delays.
- The following are examples of currently available machines produced by DRS Data & Research PLC.

### **2.6.1 The DRS CD230**

The first machine presented below in Figure 6 is the CD230 which utilises manual feeding of paper into the machine and is the cheapest of their products. This machine is capable of processing about

## RAPID ASSESSMENT USING AUTOMATED MARKING

500 forms in an hour due to the feeding mechanism used and is therefore ranked one of low speed machines.

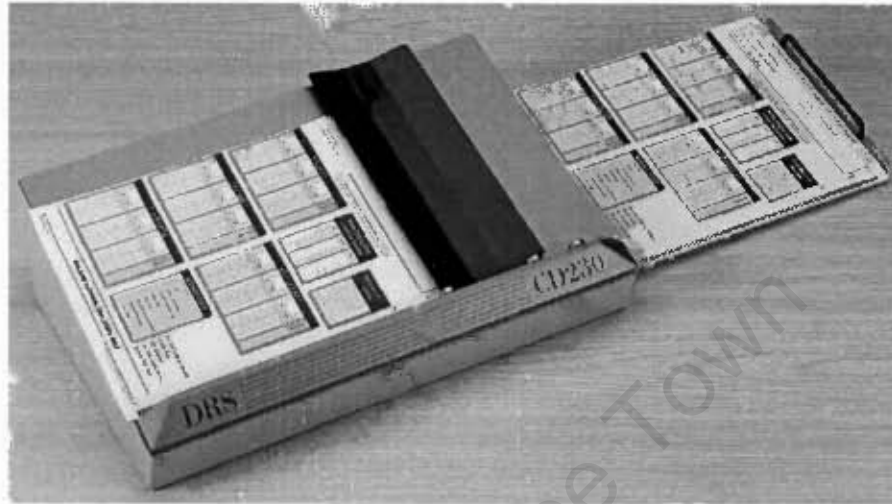


Figure 6: The DRS CD230 Optical Mark Reader

The CD230 marking machine can read pencil or pen marks on the answer sheet and can be used with a computer that supports a serial interface for communication. The data it captures can be transported to any spreadsheet or database for data analysis. As a hand fed machine this can be used in institutions that do not have heavy data capturing requirements. If the quantity of data to be captured is very high, other machines capable of handling higher volumes of data can be used. Some of the high volume machines are presented below.

### 2.6.2 The DRS CD360

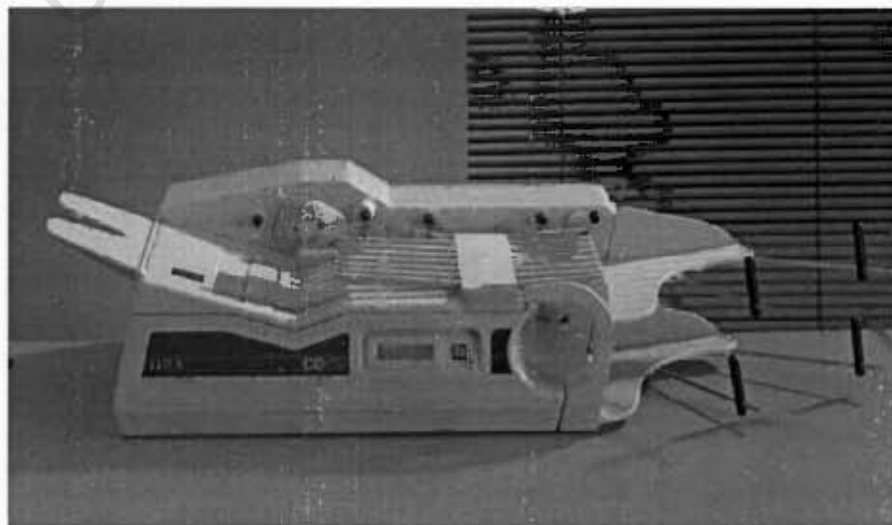


Figure 7: The DRS CD360 Marking Machine

## RAPID ASSESSMENT USING AUTOMATED MARKING

The CD 360 optical mark reader can be used to process a higher number of papers than the CD 230. This machine is capable of processing 2,400 single sided forms per hour.

### 2.6.3 The DRS CD400

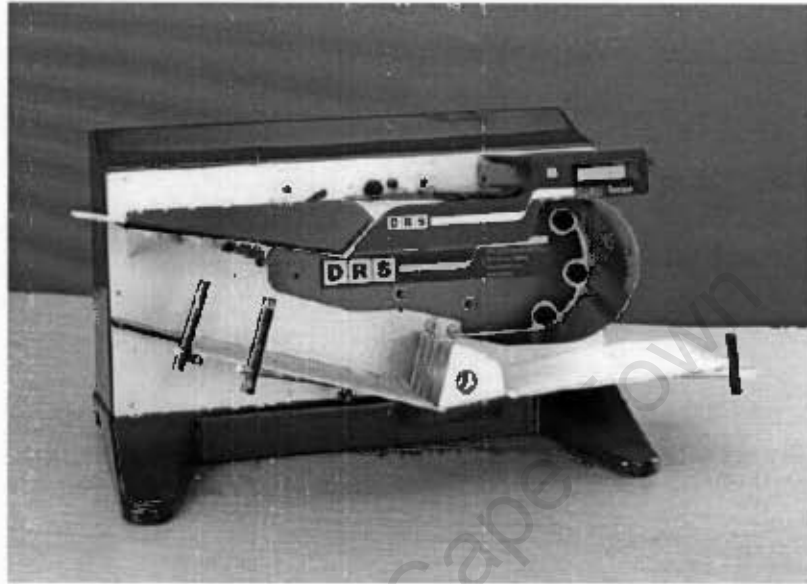


Figure 8: The DRS CD400 Optical Mark Reader

The CD400 can process a higher volume of data compared to the machines described above. This machine has the capability to process 7,500 forms per hour. It can be used in applications with high volumes of data collection. This machine is classified as being in the middle range machine application due to the fact that DRS produce machines which have an even higher processing speed.

### 2.6.4 The DRS CD860

Among the high end machines is the CD860 automatic optical mark reader (shown in Figure 9), capable of processing about 8,600 sheets of paper per hour. This is mostly used in government institutions for data collection like census and elections data. This machine is also utilised in examination marking institutions to speed up the marking of high volume data. It also boasts the ability to mark or read papers printed on both sides while maintaining the same throughput as when processing one sided pages.

## RAPID ASSESSMENT USING AUTOMATED MARKING

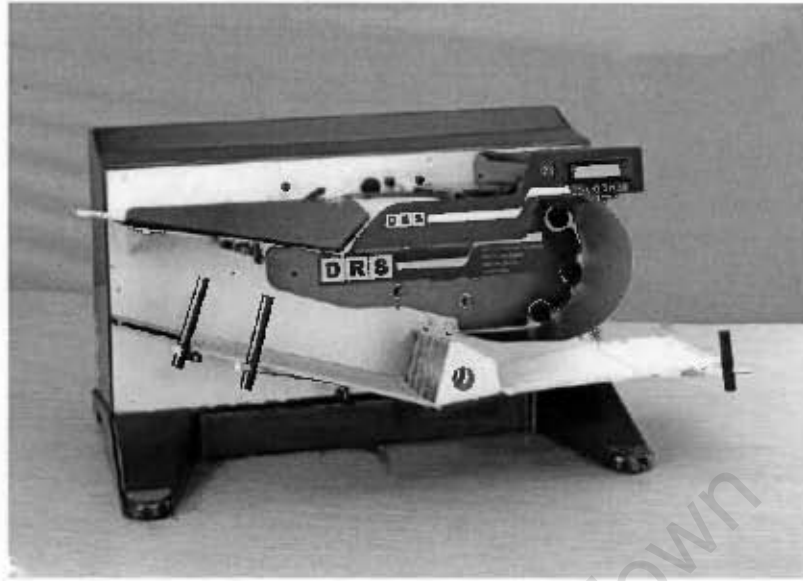


Figure 9: The DRS CD860 Automatic Optical Mark Reader

The final machine presented below is the latest product from the same company. The DRS PS900 Photo scribe Optical Mark Reader.



Figure 10: The DRS PS900 Photo Scribe Optical Mark Reader

The DRS PS900 is said to be a network ready optical mark reader capable of reading in jpeg images and text. It is used for large scale data collection applications. It can maintain a through put of up to 8,000 sheets per hour.

The cost of purchasing these machines can sometimes get quite high and to put a value to this, a machine of this sort solely dedicated to marking multiple-choice questions could cost around the equivalent of R10,000.00 [16].

## 2.7 Assessment

### 2.7.1 Multiple Choice Questions

The University of Cape Town (UCT) handbook on designing and managing ‘multiple choice questions (MCQ)’ [14] defines a multiple choice question as a question in which students are asked to select one alternative from a list of alternatives called “*distracters*” in response to a “*question stem*”. This handbook was written and aimed primarily at UCT staff to familiarise them with the benefits and limitations of using MCQ. It was also to provide lecturers and departments with basic advice and guidelines about designing, administering and marking MCQ. The handbook gives the basic structure of a multiple choice question with the usual format of the ‘question stem’ and its ‘alternatives’ as follows:

*"What type of a simple machine is the handle of a wheel barrow?"*

Alternatives: A. Pulley      B. Lever      C. Inclined Plane      D. Gear      E. Wheel and Axle

The student answers the question by marking a letter A-E, and enters this mark either on a form provided for the purpose or at a computer keyboard. In this example, the correct alternative (the "answer") is B.

Experience has shown that the use of MCQ has not resulted in the lowering of standards of certification, and there is a good correlation between results obtained from such tests and more traditional forms of assessment, such as essays, hence the justification of its use for assessment in some tests [14]. The handbook lists a number of advantages and disadvantages associated with the use of MCQ.

### 2.7.2 Advantages of MCQ

Multiple choice questions have rendered themselves useful in assessment since they can easily be marked by a computer. This ability makes it easy to assess a larger number of answer sheets compared to that by a human being in the same amount of time. Statistical information can also be gathered more quickly when these results are automatically stored in a database lessening the time required to enter marks manually into the computer. This can then be taken advantage of in situations where there are a high number of students in a class and making marking of test scripts and recording of marks a less daunting task. When administered frequently, the statistical information can give a gradual indication of the level of grasping lecture material by students.

Another advantage of the use of MCQ is that it can easily be designed with a diagnostic end in mind. When course material has been covered in a lecture, to assess students’ grasp of the content, a test can

be set so as to determine which parts of the material was not understood, and therefore prepare better revision material for the class. In instances when a lecturer would like to find out how much of the course material students have grasped prior to a class, a MCQ test can be used as a tool to investigate this.

Some of the students at university use English as a second language. When a test is set up and has questions which are descriptive in nature and the answer is required to be descriptive as well, the chances of getting the wrong answer are high if the student uses English as a foreign language. They might not fully understand what the question requires of them, but are still required to provide appropriate answers in a language they cannot even write properly. This makes it difficult to tackle such kind of questions and that is why MCQ can be used with some options already laid down so the student need not struggle to explain their answer thus reducing the mistakes associated with the use of a foreign language.

The use of MCQ also eliminates the human error in marking particularly when several people are involved in marking large numbers of scripts. Marking of essay questions is notoriously time consuming due to the time involved in reading before marking, such that after marking for a long time when one is tired, the possibility of giving wrong marks is very likely. MCQ help to reduce this likelihood.

The final advantage of the use of MCQ as recorded in the handbook is the ability for them to have a wider coverage of course material in a test and thereby broadening the scope of the test. Questions in the test can be structured with varying grades of difficulty thereby give a clearer picture of how students understood the full course.

### **2.7.3 Disadvantages of MCQ**

The use of MCQ has disadvantages associated with it. Among those stated in the handbook on multiple choice questions was the difficulty in constructing good test questions. This requires special attention and for that reason can be time consuming. This is so because a good question stem in a test must be accompanied by good distracters. The distracters should not be very distant from the correct answer so as to be too easy to eliminate and not too close to the right answer to confuse the students.

In situations where students are not normally assessed with MCQ, it may be necessary to win the acceptance of the students to this type of testing. Proper communication to the students should be given and the students may have to be asked if they are comfortable with this type of assessment. This then may be a challenge if the students reject it or are not comfortable with the way marks are given

since in most MCQ tests, an incorrect answer may lead to a negative mark. This usually leads to students disliking the use of such type of tests.

The final recorded disadvantage has to do with the input from students in a MCQ test. Student creativity could be quite difficult to test with MCQ tests as they do not have much input than just to label the correct answer compared to a detailed methodology of finding the correct answer. It becomes important sometimes not only to look at the answer given but also the method of getting to this answer. Students can then be offered a platform to defend their solution by a methodological approach which may be correct but whom, due to the slip in writing, may have written the incorrect values during the calculation.

#### **2.7.4 Alternative Uses of MCQ**

The handbook finally lists other uses of MCQ tests. Among these is that a tutorial could be designed around a few questions to stimulate discussion in a study group so that those students, normally reserved, may speak in defence of their choice of answer thus satisfy the need to communicate and to escape from isolation.

When the number of students in a class increases, there is likelihood that some will be quiet in a class and unable to communicate with other classmates. To enable good communication among students, tests such as these can be used as ice breakers and for interactive learning. They can also be used to foster discussion in a big class if it was subdivided and all the members allowed voicing their opinion so that students go back after class with some of their questions and problems answered or tackled. In this way most of the class is covered and individual problems addressed.

Other advantages, disadvantages and alternative uses could be added to what has been stated here. The discussion is not exhaustive on MCQ but simply highlights some of the points presented in the stated handbook on the administration and use of MCQ [14].

Of the above mentioned advantages of the use of multiple choice questions, the first one (of marking using a computer) is the most used. The ability to be marked by computer has led to a number of organisations making machines that can mark multiple choice tests. In answering the questions in a test or exam, students fill in an answer sheet or form having sets of oval shaped spaces, usually five per question. After the examination or test these answer sheets are collected and marking can be carried out by using these machines. The usual working principle of the marking machine is to obtain an image of the answer form by means of a scanner. The image is then processed by means of computer programmes and a grade given.

As has been shown in the section above, multiple choice questions have found tremendous applications in the field of rapid assessment because of the ease of use with computer based marking machines. The next section though shows that not all types of educational instruction can be marked by computer due to the various aspects of student learning which are explained as an educational framework.

## 2.8 Educational Framework

To achieve rapid feedback, educational institutions use examination or test questions which are easy and quick to mark, multiple choice tests being a typical example. Examination questions are set to test different aspects of students learning. This comprises three aspects namely *information*, *knowledge* and *understanding* [12]. Therefore, during studies at university, one is expected to make progress in all three aspects of learning. The terms information, knowledge and understanding though used interchangeably do not necessarily mean the same thing. For instance, during a lecture, the lecturer delivers ‘*information*’ in the form of a number of true statements. When this ‘*information*’ reaches the student by whichever means, be it sound or sight, it remains for the student to sit down, read through these sets of true statements and make sense out of them. When this is done the student gains ‘*knowledge*’ because the information obtained has now been converted into a usable format. Therefore information is converted to knowledge by students through studying it and making it their own. Both information and knowledge consist of true statements, but knowledge is information that has a purpose or use [12]. When knowledge is gained, it does not just end there, the student has to apply it to real problems and situations. When a student is able to apply knowledge then it means that, the student has gained ‘*understanding*’. There is therefore a need to find ways in which these three aspects of learning can be assessed.

In a document by the Engineering Professors Council’s (EPC) ‘Working Group on assessment methods’ entitled ‘Assessment methods in engineering degree courses’ [13], the learning process is categorised into three main aspects-Knowledge, Skills and Understanding. The document describes these aspects as follows:

- **Knowledge**-Knowledge is defined as information which has been memorised and can be recalled in answer to a question. Knowledge is not knowledge until it is well remembered;
- **Skills**-Skills are things one can do without thinking too much about how to do them, which can be learnt by experience. Skills are broken down further into two categories namely measurable

and complex skills. Measurable skills can be assessed by means of tests, while complex skills need specialised expertise for assessment;

- **Understanding**-This is viewed as the capacity to use explanatory concepts creatively and is reported to be the basis of 'thinking' especially logical thinking. The assessment method recommended for this one is by means of oral examination.

As a recommendation from the EPC working party, it was shown that, of the above mentioned classifications, marking machines can be used in the assessment of knowledge and measurable skills for which expected outcomes can easily be quantified into correct and incorrect answers. Complex skills and understanding on the other hand can only be assessed by specialised personnel, who are highly qualified in the specific fields, be it through a design or an oral assessment.

A summary of their report is presented diagrammatically in Figure 11. The figure shows the three aspects of learning. These are defined differently and do not mean the same thing. Skills are further divided into measurable and complex skills. Complex skills on the other hand need specialised expertise to properly assess someone, for example, a student's ability to effectively communicate. Communication is relative as what might seem to be good communication to one might not be as good to the other. Therefore, for complex skills, correct performance cannot be clearly specified leading to the need for highly qualified personnel to perform the assessment.

It is noteworthy that in their report, the working party advised that knowledge and measurable skills can be assessed together in a single examination paper but not together with complex skills and understanding. Separate examination papers must be prepared to test complex skills and understanding.

It is clear therefore that in the early courses of engineering, where students are grasping the fundamentals to engineering concepts, appropriate modes of assessment must be used. Most of the test questions would need to target the student's ability to recall what they have learnt and to test their ability to solve problems by performing calculations and giving appropriate answers. Measurable skills and knowledge would constitute much of the assessment in the first year. As shown in the assessment section of Figure 11, these can be assessed by use of multiple choice questions. This helps to detect the areas students are struggling with as they are guided in seeking some grounding in the fundamental principles of engineering.

## RAPID ASSESSMENT USING AUTOMATED MARKING

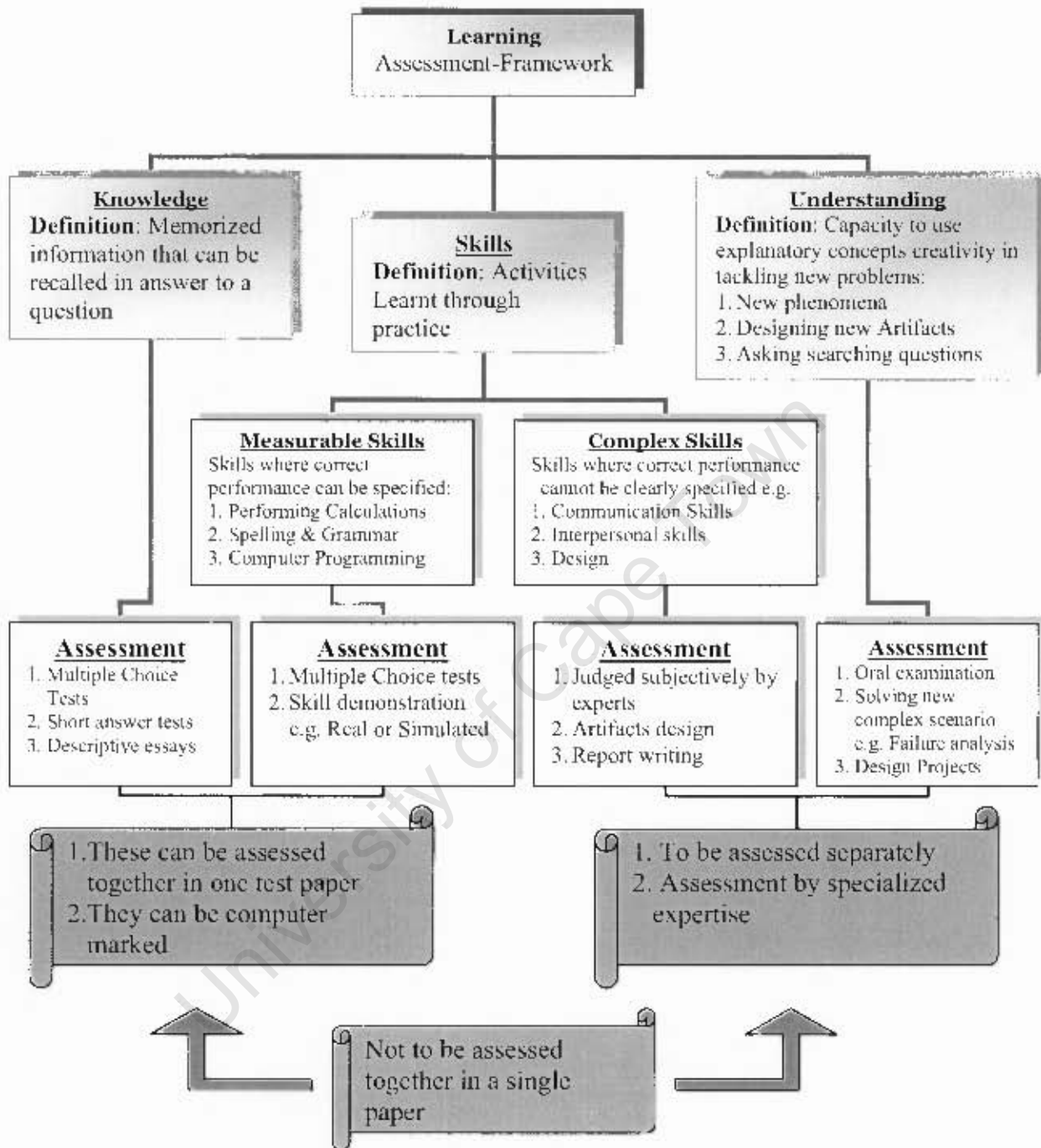


Figure 11: The Learning and Assessment Framework

## 2.9 CONCLUSION

The literature review has illustrated the vast challenges that exist for educational institutions dealing with increasing numbers of entrants. These challenges require further research into ways to cost effectively educate students. South Africa being one of the leading nations in Africa, would serve as the best example for practices to use in dealing with educational challenges faced due to the ever increasing numbers of university entrants, pertaining to assessment.

It has been shown that rapid assessment can be carried out by use of automated marking machines. To improve the assessment, it was viewed that automated marking machines could be designed, which could mark scripts other than multiple choice question answer scripts. This could reduce the amount of guessing and therefore improve the feedback obtained in assessment.

Marking machines do exist and more are being designed and made. From the survey conducted, no machine capable of marking numerical answers had been made. If machines with the capability to mark numerical answers are made available and more affordable, tertiary institutions and secondary schools can afford them, leading to great advancement in improving assessment. The use of locally available components like web cameras and data acquisition boxes simplifies the design of marking machines.

In the next chapter, several proposals are made in structuring questions so as to increase the variety of questions that can be assessed by computer based marking machines. These pertain to enhancements that could be made to the formatting of multiple choice questions and other question formats not currently in use which if used could revolutionise rapid assessment.

---

### 3. METHOD

---

#### 3.1. Proposed Assessment Methods

##### 3.1.1 Question Structuring

The uniqueness of the system being developed does not lie in the technology of the marking machine but in the unique way questions are formulated to allow for automated marking. As it was explained in the introduction, research has been done in the area of assessment [13], and is currently ongoing with reference to what can and cannot be tested by machine marking systems. The underlying objective though, is to reduce marking loads in the assessment of measurable skills and knowledge for which expected outcomes can be quantified into correct and incorrect answers.

##### 3.1.2 Multiple Choice Questions

The system being produced goes beyond multiple choice type questions that have been used so far. These questions still have their place but suffer a number of disadvantages. The most important disadvantage is the lack of specific feedback to students. Answers are marked on a special answer sheet which is processed and a mark declared. The feedback provided by this one mark does not inform the student or the teacher where actual mistakes were made or where the specific problems are. Therefore to overcome this setback, an alternative format of multiple choice tests can be used where, the question stem and answer options are placed on the same page, a student simply highlights the correct answer. When the test paper or answer script is handed in, the paper is automatically marked and graded and this can be used later on during revision as the student will know on which section of the test they lost marks.

If a test was given to students and had the following question:

*"What type of a simple machine is the handle of a wheel barrow?"*

1. Pulley
2. Gear
3. Wheel and Axle
4. Lever
5. Inclined Plane

The students would then be required to fill in the correct answer on the answer script. This would then be handed in at the end of the test, possibly never to be seen again.

The alternative would be to have the questions and answers on the same paper but with the difference that, the correct answer has to be indicated on the very same paper. This can be done as shown below:

## RAPID ASSESSMENT USING AUTOMATED MARKING

For example, instead of indicating that parts A, B, C and D are valves, a student can be asked what parts these are to see if they possess knowledge of the material presented in class about this pump. Therefore this question could be used to test the student's knowledge and engineering judgment about the figure presented by rephrasing this question to a format as follows:

*The sectional front and side views of a pump are shown below (as in the figure above). Eight of the parts have been labelled A through to H.*



















1. What are parts A, B, C and D called?									
2. What are parts E and F called?									
3. Among parts A, B, C and D which are the inlet ones?	<table border="0"> <tr> <td>A</td> <td>B</td> <td>C</td> <td>D</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>	A	B	C	D				
A	B	C	D						
									
4. What provides the force to drive parts E and F?									
(a) For the suction stroke of the pump									
(b) For the delivery stroke									
5. Part G is a?									
6. Part H is a?									

Table 2: Alternative Answer Grid Format of First Example

The main difference between the formats of questions in Figure 12 to those in Table 2 is the way the answers are entered in response to the question. To answer questions as presented Table 2, the student would be provided with options, similar to the way they are supplied in multiple choice tests except that instead of supplying the student with only five options, a table of options is provided from which to draw the answers (shown in Table 3). By so doing the chances of accurate guessing are minimised and the marks obtained by a student in a test like this would give a much clearer indication of the level of understanding of the course material.

In answering question 1 the student would have to look at Table 3 below to find the term they think is the correct answer. In this case, parts A, B, C and D in Figure 12 happen to be valves. The student would be required to find from Table 3 the number representing valves. From the table, it can be seen

## RAPID ASSESSMENT USING AUTOMATED MARKING

that 'valve' is located as number '51'. It is this number that the student enters on the answer sheet as the response to question 1.

1. Atomiser	14. Electric Motor	27. Kinetic Energy	40. SABS
2. Bearing	15. Electrical Energy	28. Left Hand Rule	41. Screw
3. Bolt	16. Facing	29. Lever	42. Second Class Lever
4. Boring	17. First Class Lever	30. Light Energy	43. Shaft (Cam Shaft)
5. Bs	18. Follower Gear	31. Magnetic Field	44. Solar Energy
6. Carburettor	19. Force	32. Milling	45. Spring
7. Centre of Gravity	20. Fulcrum	33. Moment of Force	46. Tapering
8. Clockwise	21. Gear	34. No Movement	47. Thermal Energy
9. Composite	22. Gearing Down	35. Nut	48. Third Class Lever
10. Compound Gear	23. Gearing Up	36. Potential Energy	49. Threading
11. Counter-Clockwise	24. Grinding	37. Pulley	50. Turning
12. Drilling	25. Idler Gear	38. Ram	51. Valve
13. Driver Gear	26. ISO	39. Right Hand Rule	52. Washer

Table 3: Table of Terms Taught in MEC1004W

The answer entered by a student is therefore a number instead of the actual part's name. To make the input from students to have a similar layout and not suffer from differences in handwriting, they would be required to enter answers in the seven-segment notation supplied (shown in Table 2). The answer sheet would then appear as shown below in Table 4.



















1. <i>What are parts A, B, C and D called?</i>									
2. <i>What are parts E and F called?</i>									
3. <i>Among parts A, B, C and D Which are the inlet ones?</i>	<table border="0"> <tr> <td>A</td> <td>B</td> <td>C</td> <td>D</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>	A	B	C	D				
A	B	C	D						
									
4. <i>What provides the force to drive parts E and F?</i>									
(a) <i>For the suction stroke of the pump</i>									
(b) <i>For the delivery stroke</i>									
5. <i>Part G is a?</i>									
6. <i>Part H is a?</i>									

Table 4: Test Paper with Answers Entered in Red

This kind of response makes automated marking for numerical answers possible. To enable the usage of a camera in marking, it is necessary to have a format that is unambiguous therefore the seven-segment number notation was used.

The answers to the other questions can be entered in the rest of the seven-segment notation as shown in Table 4. The options for these questions, instead of coming in the normal format of four or five options MCQ which are leading, can be given in a table of terms as shown in Table 3. This table of terms could be used for all the questions in the test or examination. In answering the above questions, the student looks at the table to select the number they feel is appropriate and indicate it by filling in the two seven-segment number notations.

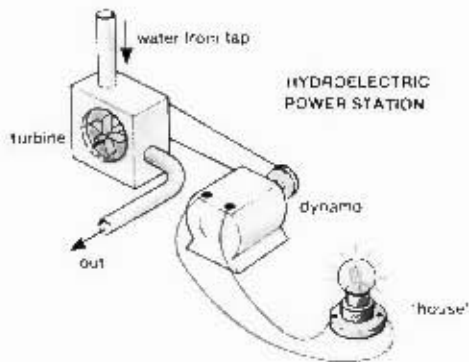
To answer question 4 (a) on the force for the suction stroke, it is clear that the spring is the device that will provide the force to push the “rams (which is the answer to question 2)” down. Therefore the student would look in the table for “spring” and from the table, spring is number 45. This number would then be written down in the seven-segment number notation as described for question 1.

The answers to the other questions can be obtained the same way. Part G so happens to be a bearing (number 2 in the table) and part H is a gear (number 21).

Another question in the same test paper was as follows:

## RAPID ASSESSMENT USING AUTOMATED MARKING

Name **in order** the four main energy transformations that occur in the system shown below.



Answers:

1:

2:

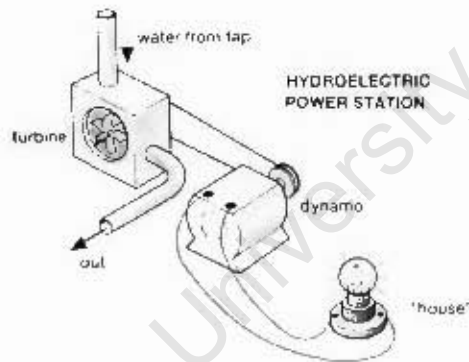
3:

4:

Figure 13: Second Example Question from MEC104W

Again, in this situation, the student writes down the answers in the spaces provided. To be able to mark this by machine, the same format for phrasing the question as in the previous case can be used. Here the answer options are taken from Table 3 as the question is in the same test paper as the previous example. This question can be restated as:

Name **in order** the three main energy transformations that occur in the system shown below.



From



to



to



to



Figure 14: Alternative Structuring of Example Question 2

The correct sequence of energy transformation for the hydroelectric power station representation on the left hand side are Gravitational potential energy (number 36 in Table 3), to kinetic energy (number 27), to electric energy (number 15) and finally to light energy (number 30). These values would be entered in the appropriate fields to be processed later by the computer based marking machine.

Using this method, guessing in tests can be reduced and when used as a diagnostic tool it can closely monitor the progress students are making with their study material. 'Accurate' guessing is reduced by limiting the probability of getting an accurate guess from 52 options compared to that which would be if only 5 options were used. This is not intended to fail students, but to minimize guessing therefore obtain a true picture of student knowledge and also as a means to more accurately measure student progress.

The method described above shows how multiple choice techniques can be extended to cover this format of setting questions. The benefit to students is that they have their marked answer scripts with them as they leave the examination room. They can revise more effectively when compared to having no marked script with them during the revision process.

### 3.1.3 Calculations

Another way that the seven-segment number representation can be used is in questions that require students to perform some calculation and give a numerical answer. Instead of having this answer as one of the answer options in a multiple choice test, students would be required to fill in the answer grid as explained previously. An example of this would be;

A centrifugal pump whose efficiency is 60% raises water to a height of 15 meters. If water is being delivered at a rate of 360 kg/min, how much power must be supplied to the pump? Use  $g = 10 \text{ m/s}^2$  (acceleration due to gravity) and  $1000 \text{ kg/m}^3$  as density of water.

The answer to this question is 1500 kilowatts. This value would then be entered as follows in the answer grid provided:

After further investigation, the idea of the seven segment bit representation was adapted to several other modes which were termed 'modified seven-segment number representation'. This number representation can be used for binary notation. For example;

*Q. In the 8 blocks given below write, in binary notation, the byte of information that represents the decimal number 170.*

The answer to this question is  $10101010_2$ . The student would then be required to present the answer as shown below-

## RAPID ASSESSMENT USING AUTOMATED MARKING

Several tests were carried out on the marking machine while its operation was being refined. In the early stages of the research the tasks that were given to the machine to perform were simply to mark by comparing the image of a student's answer script to that of a lecturer's marking key. In these tests, when an image of the students answer script was taken, areas of interest from the two scripts would be compared by performing image absolute difference between them. For example, supposing the correct answers in a test as given by a lecturer were entered on the marking key as shown below in Figure 15, during marking, comparisons would be carried out for each answer given.

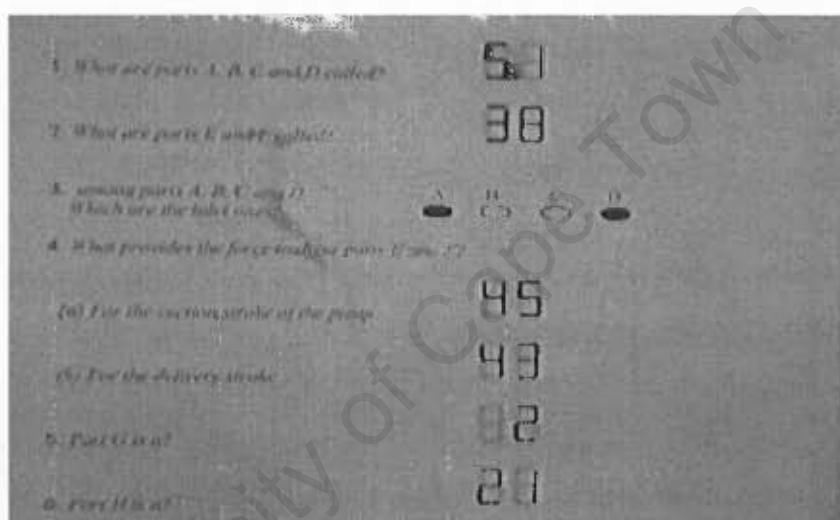


Figure 15: Marking Key Image Captured by Camera

In this case, a student's answer to question two would be compared to that provided by the lecturer, here being the value '38'. After the image is converted to a 'computer friendly' black and white image, it would look as shown in Figure 16. From this image, the area of interest would be isolated for comparison purposes. If the student's answer to question four were '41', the marking key above shows that the answer ought to be '45'.

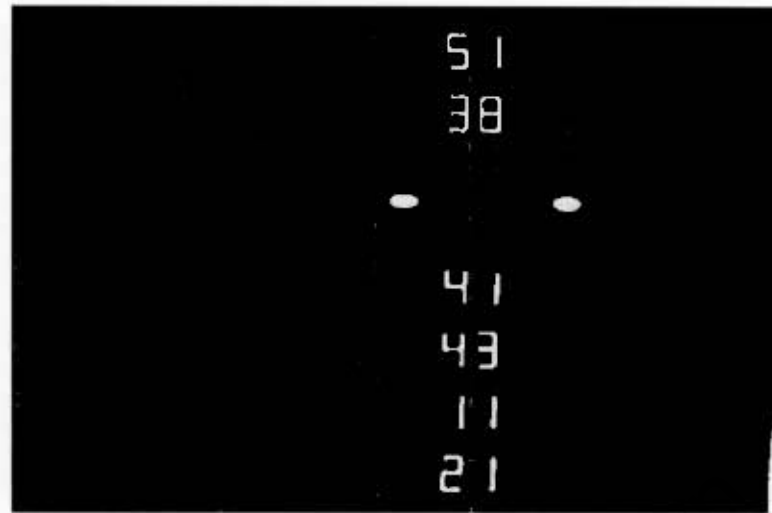


Figure 16: Black And White Image of Marking Key

Cropping the two areas from the marking key and the students answer script would result in images as shown in Figure 17. These regions are well aligned due to the orientation provided by the tray in the machine. Once the two regions are cropped from their respective images, to perform a comparison between them, image absolute difference was used. If the absolute difference image still had white 'Logical 1' pixels in it, the answer was considered wrong.



Figure 17: Cropped Regions of Interest

Performing image absolute difference on the two regions above would result in the image shown in Figure 18. The absolute difference image here clearly shows that the '4' digit has been removed leaving only the differences in the '5' and '1' of the images above.



Figure 18: Image Absolute Difference

This was the original procedure used to evaluate scripts. This procedure could only give the total marks obtained by a student but lacked the ability to identify students by means of their unique student numbers. Without capturing student's unique identities, the automated marking process would lose the very purpose being advocated for here since no meaningful assistance would be given to students that need the help as there would be no means of identifying them. Originally, to capture the students' identity numbers meant having to write them down into the computer manually. This was viewed as a slow process therefore an alternative method of application was sought. The solution was found in

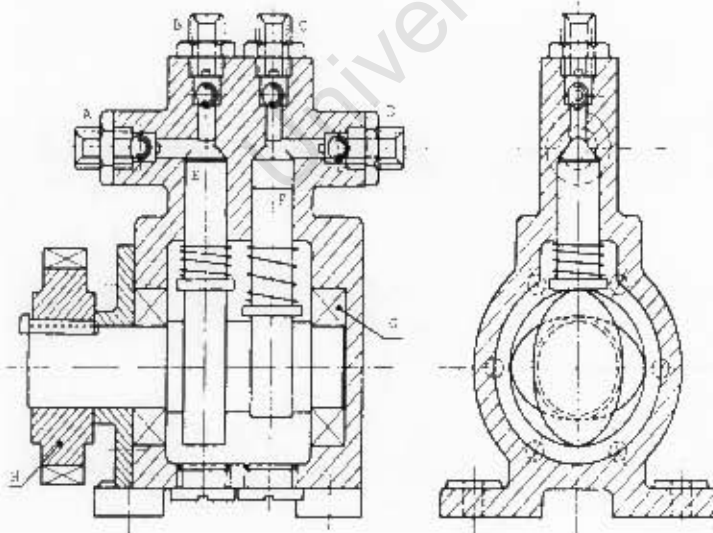
"What type of a simple machine is the handle of a wheel barrow?"

- Pulley
- Gear
- Wheel and Axle
- Lever
- Inclined plane

The student only has to shade the oval shape (  ) for the correct answer. When marked by computer, the student will still have the question paper and the answer sheet with him or her when revising and will check to know which question they had answered incorrectly.

Owing to the difficulty of finding suitable detractors associated with MCQ tests and the ability of some students to accurately guess the correct options, a database of questions can be developed with associated answers in a separate table and provided to students during assessment. The major difference of this type of MCQ test is the way answers are indicated. One way was to use seven segment number presentations. For example, a test question paper in MEC1004W had the following question:

*The sectional front and side views of a pump are shown below. The four valves have been labelled A, B, C, and D. The two rams have been labelled E and F. Which of the valves are inlet valve, what provides the force to drive the rams for the suction stroke of this pump and what provides the force for the delivery stroke, and name the parts labelled G and H.?*



Answers- Inlet valves are:

Force for suction stroke:

Force for delivery stroke:

Part G is a:

Part H is a:

Figure 12: First Example Question in MEC1004W

In this question, a student is required to write down the letters and names of the required parts. One can see that the question gives a lot of information freely from which other questions can be derived.

combining image processing and neural networks to intelligently identify each number in the image. In this way, for example, the numbers in Figure 16 would be identified by the computer as the actual numbers 51, 38 etc.

The following section looks at image acquisition, image processing and the usage of neural network routines and how they can be used in marking the answer structures suggested in this chapter. It is not the intention of the following section to give a full exposition of the three topics mentioned above but to explain the aspects deemed necessary for the current application.

### **3.2. Analytical Approach**

#### **3.2.1 Image Acquisition**

In the process of automated marking, image acquisition is the first step and is done by an image acquisition device. Image acquisition devices vary in acquisition procedures depending on which technique is best suited for the situation. If what is of most importance is the picture quality and not image size, a scanner can be used. However, if image acquisition speed, processing and size of the image in memory is of importance, high speed cameras can be used instead. Owing to the need for high speed image acquisition and processing in the transcripts that would be used for tests, the image acquisition device of choice would be a camera. The operation of cameras is detailed below.

##### **3.2.1.1 Camera Operation**

According to the “Imaging Source” website [18], cameras used in the field of digital image processing consist of two primary parts- the image acquisition unit and the image output unit. It is stated that the acquisition unit is based on either pick-up tubes or CCD (Charge Coupled Device) chips, the latter being the most dominant today. An important aspect of the CCD chips is that they consist of separated light sensitive elements each of which represents one pixel. Thus they already deliver a 2-dimensional spatially discrete image. Moreover they are small in size and weight, have a high dynamic linearity, high resistance against mechanical, magnetic and optical impacts and due to mass production for the consumer market, they are relatively low in price [18]. An example of an image acquisition device is a web camera shown in Figure 19.



Figure 19: USB Web Camera

This method of operation can be explained with reference to Figure 20.

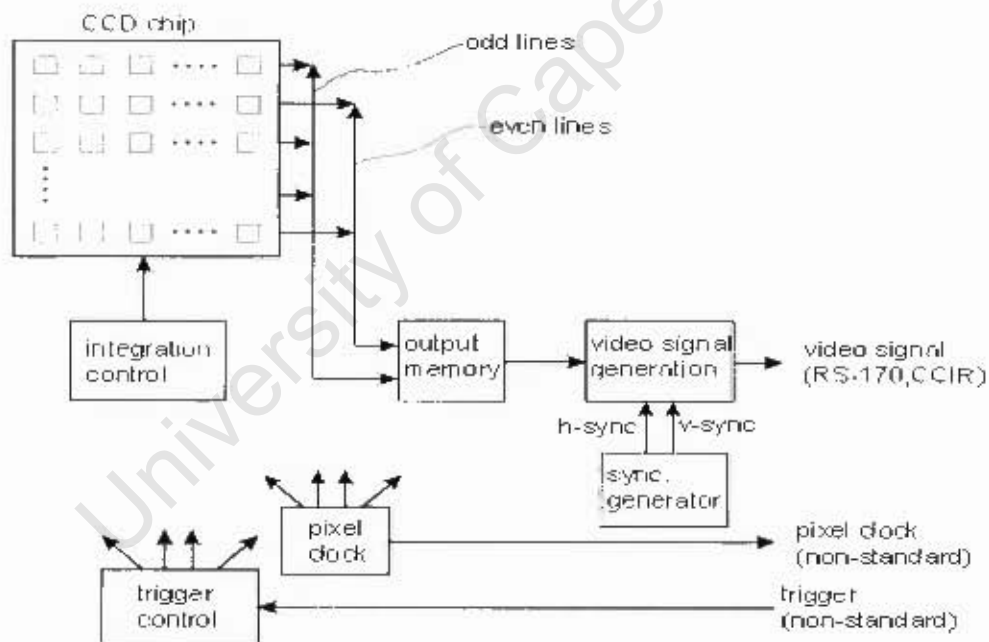


Figure 20: CCD Camera Operation [18]

The acquisition unit consists of a 2-dimensional matrix of light sensitive elements so-called 'pixels' which change the incoming photons to electrons and thus accumulate a charge. The exposure time (called integration time in the context of CCD cameras) is electronically controlled. After the integration, the pixel charge is transferred to a read out buffer. Based on the content of this buffer, the output unit generates the video signal according to one of the video standards, CCIR (Comité Consultatif International des Radiocommunications) or EIA (Electronics Industries Association). For the purpose of precise measurement, the pixel clock, which controls the transport of the pixel content

from the CCD chip to the output unit, should be made available for the succeeding image processing devices. The trigger input allows any external event to reset the camera and to restart the integration [18].

CCD chips do not have any inherent ability to discriminate colour i.e. the different wavelengths or different energy of photons. Therefore, in colour cameras the light is split into its primary colours red, green and blue (RGB) by filters and prisms. The distribution of the colour components to the CCD chip follows two schemes. The most obvious method is to use one prism, which splits the light entering the camera into three colours (red, green and blue) and each of the three rays of light is shone onto a separate CCD chip. Cameras using this technique i.e. 3CCD cameras guarantee the highest quality but are highly priced, additionally special lenses have to be used. The more simple approach uses a structure of small filters called mosaic filters which distribute the colour components pixel-wise on only one chip. Thus we seem to have red, green and blue neighbour pixels similar to the cones in our eyes. Cameras that use this technique are good value for money and do not require special lenses. The drawback is that their resolution is low [18].

### 3.2.1.2 Trigger Mechanisms

Imagine objects on an assembly line as depicted in Figure 21 have to be inspected by a vision system. An image of a single object must be acquired at exactly the time when it is in front of the camera. The solution for this is based on a photoelectric barrier, which triggers the frame grabber and at the same time triggers the restart or reset signal from the camera [18]. Additionally a strobe may help to freeze the movement. The successful realization of triggered image processing systems requires specialized knowledge in the field because, though easy to explain, in practice it is quite troublesome.

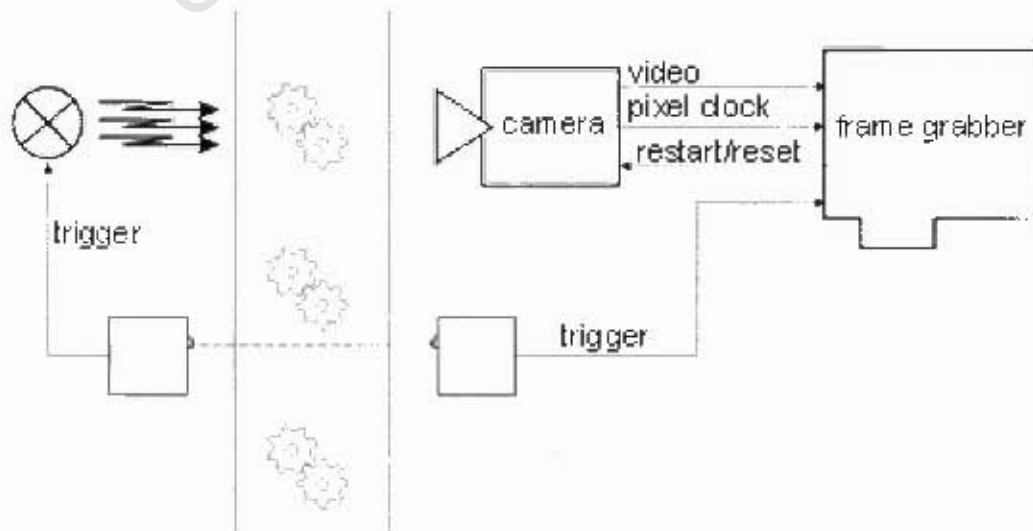


Figure 21: A Photoelectric Barrier Trigger [18]

One of the applications in which cameras are used as depicted in Figure 21 is in bottling companies. A computer may be used to assess if the bottles are filled to the required level. This kind of application has to be automated such that the moment the bottle is at the most suitable position in the field of view of the camera, a snapshot of it is taken and later analysed by the control computer. If a bottle does not conform to the required filling, it is rejected and removed from the line of bottles that are going for packaging. The images obtained are processed by a computer so that decisions are made based on the subject of the investigation.

In the case of the current project, the software platform chosen was Matlab which is a programming language for technical analysis and is a product of The MathWorks Inc [17]. Upon consideration, it was viewed by the author of this report that this programming language was relatively easy to learn, widely used at the University of Cape Town and there was abundance of expertise in the language, especially in the Mechanical Engineering Department.

For the machine to be able to mark answer scripts, an image of the answer script must be supplied to the computer for image processing as presented above. The image acquisition device used for this purpose was a Logitech QuickCam Pro 4000 web camera (shown in Figure 22) which has an adequate video resolution of 640 by 480 pixels in video mode.



Figure 22: Logitech QuickCam Pro 4000 Web Camera

### 3.2.2 Image Acquisition in Matlab

Before embarking on image acquisition, the image acquisition object has to be created. Note that in Matlab, all the lines of code that begin with the percentile (%) sign are considered comments.

```

%% The Image acquisition object creation
%% Image acquisition
clear all                %This clears the workspace
close all               %This closes all open ports
clc                    %this clears the command window
    
```

```

%% Creating Video input object
vid = videoinput ('winvideo',1,'RGB24_640x480');
%% Preview the image to adjust focus
preview (vid)
%% Close the preview window
%closepreview (vid) %Leave the camera running until the end

```

In the code above, the line '*clear all*' is used to clear the Matlab workspace of any variables present. This is followed by closing all ports that are currently open using the '*close all*' command and finally clearing the screen with '*clc*'. The importance of this section of code is the creation of the image acquisition object without which none of the processes can be carried out. The creation of the image acquisition object is performed by the line '*vid = videoinput ('winvideo',1,'RGB24\_640x480')*'. '*Videoinput*' command constructs the video object '*vid*', which establishes the connection that Matlab will have with the image acquisition hardware and '*winvideo*' represents the adaptor used to communicate with the hardware. The number '*1*' represents the acquisition device. In cases where there are more than one image acquisition devices, each one will have a different number. The format of the images obtained will be of true colour (red, green and blue) and the images will have a resolution of 640 by 480 pixels. All this information formats the image acquisition device to operate as required. If a lower resolution is required, the values in the resolution command can be changed to a lower one, say 480 by 320 pixels. For the marking machine, a good resolution is required therefore the highest resolution was used.

Sometimes the camera may not be oriented in the right position and may also be out of focus. To correct this, a preview of the camera's view can be shown using the '*preview*' command together with the image acquisition object created earlier ('*vid*' in this case). It was noticed during testing that, if the preview mode of the camera was stopped, the command is issued to take a snapshot of the paper, the pictures came out blurred. Therefore, it proved advantageous to have the camera running in preview mode for consistency until the final task was completed thereafter it could be stopped.

### 3.2.3 Actual Image Acquisition

```

%% Obtain picture for comparison
pic1 = getsnapshot (vid);

```

To obtain a picture, Matlab issues the command '*getsnapshot*' to the image acquisition object and saves the image to the workspace as '*pic1*'. A sample of the image obtained at this stage is shown below in Figure 23. This is a snapshot of a student's answer script from a test given in MEC1004W, a first year course in mechanical engineering, on Levers and Pulleys.

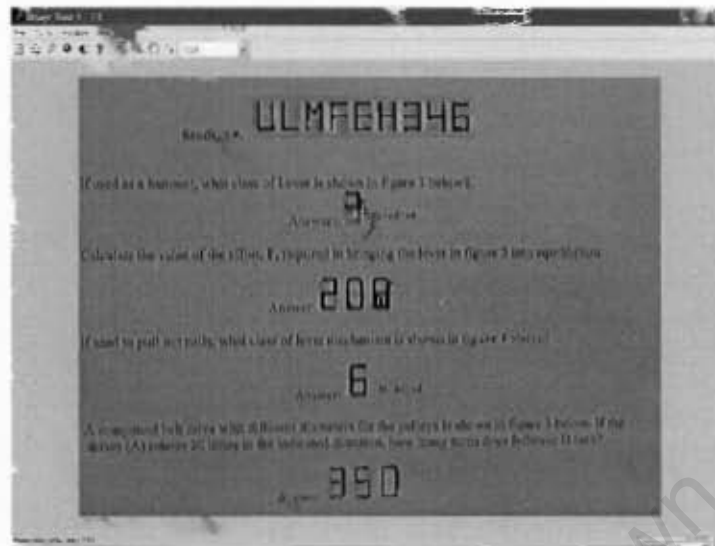


Figure 23: Answer Script Snapshot

### 3.3 Image Processing

Matlab was chosen because it comes with built in functions (in the form of toolboxes) for image acquisition and processing. One of its many advantages was the ease with which it operates on mathematical arrays such as matrices. Since digital photographic images are captured in the form of matrices, Matlab processed images with the great ease. A matrix is defined as a rectangular array of numbers. An example of a matrix is shown below and has three rows and four columns.

$$\begin{array}{c}
 \text{4 Columns} \\
 \begin{array}{c} \text{3} \\ \text{Rows} \end{array} \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \end{bmatrix}
 \end{array}$$

Figure 24: A 3 by 4 matrix

A picture taken from a colour camera is made up of pixels (short for picture elements), a term used in digital image processing to describe the basic building blocks of all bitmap images – the individual elements that are combined to form a picture which has a unique colour or brightness value [19]. This can be thought of as being made up of tiny squares of information like a checkerboard shown in Figure 25.

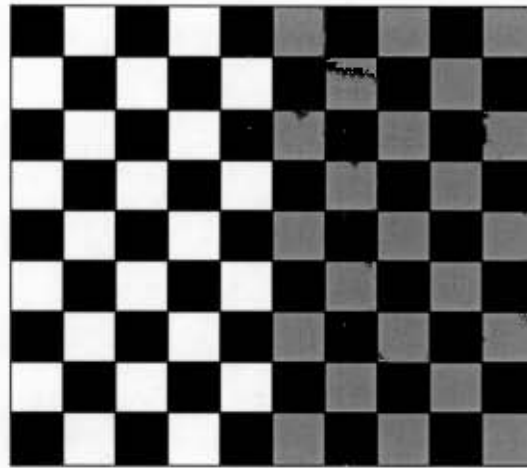


Figure 25: Square pixels in an Image

Each pixel is made up of Red, Green and Blue sub pixels. These sub pixels are the smallest addressable units in an image [19]. Therefore for each colour image, the pixels are made up of 3 layers of light intensities in Red, Green and Blue. These intensities come in the form of numbers depending on the colour depth, which is the number of bits of information used to represent the colour of a pixel called the bit depth resolution. This is one of the most misunderstood concepts in computer graphics. A simple explanation of this term is that, the bit depth of an image referred to as the image's colour resolution, is the number of bits per pixel. For example, a greyscale image that had 8 bits of colour information per pixel would mean that the colour resolution of the image would be 8 bits per pixel. Therefore for an 8-bit image one would have a total of  $2^8$ , or 256 possible colours [12]. Most computers come with colour intensities of up to 256 but some with higher bits per colour are available. Red therefore has intensity ranging from 0 to 255, the same for Green and Blue, meaning that the Red layer is an  $n \times m$  matrix of red light intensities for each pixel. The same can be said for the Green and blue layers, thus forming  $n \times m \times 3$  matrixes.

When the images are captured by camera, they are further processed by Image processing applications to make useful information from them. Unless the image processing utilises coloured images in their original state, they are normally converted to either greyscale or black and white images. This is done by the use of image processing applications like directly converting an image from its true RGB colour to a greyscale one. Grey scale images then can be converted to black and white images for further processing.

### 3.3.1 RGB to Greyscale Conversion

Once the snapshot is taken, the image is converted to a grey scale image using the following lines of code.

```
% Convert Image from an RGB to a greyscale image
pic1_gry = rgb2grey (pic1);
```

The captured image is in true colour format; three layers of arrays of red, green and blue. The image therefore has to be converted to a greyscale image, the format that the rest of the image processing routines require. This conversion is done using the command '*rgb2grey*' which changes the red-green-blue (RGB) image to a greyscale image and saves it as variable '*pic1\_grey*'.

The program was written to save memory space while processing the image. the reason for this is that most computers are built according to the architectural principles of computer pioneer John von Newmann, who determined that machines should work on each task serially, one step at a time with the central processing unit (CPU) directing the movement of information as well as performing all computations. Inherent in this design is the possibility of bottlenecks which are a result whenever a processor has so much time directing the flow of information to and from memory that its processing speed is reduced [11]. Thus, in an effort to increase the processing speed, instead performing the remaining routines on the whole image, special regions were cropped from the original image and worked on sequentially starting with the 'name', then the questions in the order they appear. These areas are termed regions of interest and are defined in the variable '*roi*' as shown below. These are the regions on which the remainder of the computer program will perform further image processing tasks.

```
% This code crops several regions of interest in figure X1 for processing
roi = [148 118 42 26;238 90 47 81;328 116 44 26;553 87 45 82];
str_ell = ones(3);
```

The variable '*roi*' stands for region of interest. These values represent the pixels in the image within which the characters of interest will be found and are the regions where the answers given by students are located. Notice that '*roi*' is made up of a '4 by 4' matrix, meaning that four questions were given in the test requiring four answers. The first row of the region of interest matrix is made up of the following numbers: [148 118 42 26]. This means that the upper left corner of this region of interest is found in the pixel located at 148 on the horizontal axis from left to right and 118 on the vertical axis from the top downwards. This region is 42 pixels wide and 26 pixels high. When the image processing routine is invoked each row of the matrix is called one after the other processing each region and identifying the numbers in those regions. The line '*str\_ell*' is a structuring element used in image processing. It is used to eliminate small objects in the region of interest and will be explained later. It only appears here for initialisation purposes.

### 3.3.2 Selection of Pixels of Interest

Once the whole picture has been converted from its original 'RGB' format to a greyscale image, the pixels of interest have to be extracted from the image. Pixels of interest form the shape of the character to be extracted so that a neural network can identify each of them.

As mentioned above, the regions of interest are defined by the matrix '*roi*'. Working in a loop by selecting a single row of '*roi*' at a time the computer crops the designated region as shown in the first line of code below.

```

crop = imcrop(pic1_gry, [roi(m,:)]);
BW = imrotate(crop, -90);
BW = im2bw(BW, graythresh(BW));
BW = medfilt2(BW);
BW = imclose(imopen(BW, str_ell), str_ell);
base = bwareaopen(BW, 50);

```

The command '*imcrop*' crops the region identified by *roi* (*m*, :) in the image. The letter 'm' comes from the loop counter variable. The first number passed to it is number '1', meaning that the first row of the matrix '*roi*' is taken as the first region of interest. The cropped area of the answer to the first question is shown below in Figure 26 and shows that the student entered the value 'three' as the answer to this question.

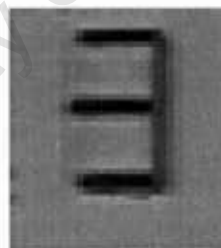


Figure 26: First Area of Interest Crop

The second function called that manipulates the cropped image is the '*imrotate*' function. This is required because the camera used was set to a resolution of 640 by 480 pixels. What this means is that the width of the entire image (x-axis) is 640 pixels long and 480 pixels high. To take a picture of a larger area of the paper, the camera was aligned so that the width of the camera was in line with the length of the paper. The images as captured are therefore at 90 degrees in a counter-clockwise orientation. To bring them into the upright orientation for easy number identification, the images are rotated 90 degrees clockwise.

After aligning the image, the next task is to convert the image into black and white by selecting the pixels with particular intensity. This can be performed in different ways. One such way is to use an automatic threshold-level detection mechanism on the image and the other is a manual selection of a

range of intensities to retain and convert the rest to black. Using the automatic threshold level of the cropped image the command '*im2bw*' is used to convert the cropped greyscale image to a black and white image. The advantage of using the automatic threshold level is that it can be done without interaction; perfect for the current application. Once the command to convert the image from its original greyscale image to a black and white image is issued, the outcome is as shown below in Figure 27. The number now appears clearly to be the number '3' and is almost ready for identification.



Figure 27: Black and White Image after Conversion

When the image is converted to black and white, some pixels still appear 'loose' around the required image. This is termed 'salt and pepper' noise. These pixels are removed by the '*medfilt2*' command. When the image is cleaned up like this, small lines and small objects may still exist in the image. To remove them a structuring element is used. When the structuring element is used together with the '*imopen*' function it removes small objects in the image while preserving larger ones. Since the background pixels are the 'black' ones, representing logical zero, the foreground pixels are 'white' representing logical one. The structuring element tries to fit into these foreground pixel clusters and if it does not fit, that cluster is converted to be part of the background leaving only those clusters big enough for the structuring element to fit in. In turn, the structuring element can fit in the foreground pixel cluster, that object is retained.

As shown in the lines of code at the beginning of this section, two functions '*imopen*' and '*imclose*' have been used together. The first function to operate on the image is '*imopen*' which erodes the image first. This is followed by image dilation. The second function '*imclose*' performs the same tasks as '*imopen*' except it performs them in reverse. The image is first dilated and then eroded by the structuring element. After the image is cleaned up, it appears as shown below in Figure 28.



Figure 28: Cleaned Up Image

After a combination of image dilation and erosion by the `'imopen'` and `'imclose'` functions, there may still be some unwanted pixel clusters in the image. By taking several tests on the image in measuring the sizes of the characters expected, the minimum number of pixels to make up the smallest character can be known. For example, when working with numbers, the number formed by the least number of pixels is the number 'one'. The other numbers are made up of several strokes, but the number 'one' is only made up of two segments if represented on a seven segment number representation. Taking the number of pixels to make the number 'one' can give a clue of the smallest expected character. If 'one' were made up of seventy pixels, then anything with less than fifty pixels may be removed from the image. An allowance here has been made of twenty pixels so that in case the number 'one' was not well printed on the paper and comes out having less than seventy pixels, it can still be retained if the pixels that make it up are more than fifty. To perform this task, the function `'bwareaopen'` erases all clusters formed by equal or less than fifty pixels in the image 'BW'. For example, Figure 29 below is the image of the answer script before the removal of smaller objects. As can be seen, the image does not look 'clean' enough for the computer to make sense out of it. This is the reason why the cleanup function is used.



Figure 29: Image before using '*bwareaopen*' Function

Once the '*bwareaopen*' function is used on the image, smaller objects are removed and what remains is a clean image as shown in Figure 30.



Figure 30: Clean Image after '*bwareaopen*' Function

### 3.3.3 Individual Character Extraction

Once the image has been cleaned by the preceding operations, the characters in the image have to be extracted individually and automatically to avoid human intervention. This takes several operations that are performed on the image. The following lines of code are used to perform these tasks [20] and [21].

```

%3 Bounding box creation for each character [20]
[BW_label num] = bwlabel(base);
BW_props = regionprops(BW_label);
BW_box = [BW_props.BoundingBox];
BW_box = reshape(BW_box, [4 num]);

%4 Obtaining the centroid of each character
BW_c = [BW_props.Centroid];
BW_c = reshape(BW_c, [2 num]);
BW_c = BW_c';
BW_c(:,3) = (mean(BW_c.^2,2)).^(1/2);
BW_c(:,4) = 1:num;
BW_c2 = sortrows(BW_c,2);

```

The first task that is performed is to create a bounding box tightly around each character's edge in the image. The characters in the image are first labelled so that each continuous cluster of pixels has a specific label. The label is in the form of numbers, where the first identified cluster of numbers is given the number '1' the second '2' and so on. The coordinates of the bounding box are returned in '*BW\_box*' which is a '*4 by n*' matrix where '*n*' stands for the total number of continuous clusters identified. The first row in the matrix identifies the top left corners horizontal coordinate of all the labelled clusters/characters. The second row identifies vertical coordinates. The third and fourth rows represent the width and height of the rectangle that bounds the character. In this operation therefore, the program identifies individual characters in readiness for character identification by the neural network.

The second section of code identifies the 'centre of gravity' or centroid of individual objects so that any further processing is referenced to the centre of the character. In case a comparison is to be performed between the identified character and another character in the target vector, the anchor point for the two characters with each other will be the centre point. This centre point is returned as the vertical and horizontal coordinate of the centre in '*BW\_c2*'.

Note should be taken with reference to the last line of code in the above section of the code. It is not always that the left most character in the image will be given the first or highest label number. To make sure that the characters appear in the required order, the characters have to be arranged in the order that they appear in the image. To do this, once the centroid of each character is obtained, the

horizontal component of the centre of the image is used as the governing value during the sorting of the characters. Thus '*sortrows*' performs this re ordering of components in the desired order.

### 3.3.4 Cropping Individual Characters

After identifying the centre of the individual characters and their boundary boxes, the next operation is to save these variables to an array called '*img*', this is then passed to the cropping function to perform the cropping operation on the characters [21].

```
for cnt = 1:num
    img{cnt} = imcrop(base,BW_box(:,ind(cnt)));
end
```

Once this operation has been performed, the image cropping function '*im\_crop*' is used to remove the desired character from the image and pass it on to the resizing function '*im\_resize*' [21]. The main aim of these two functions is that, when the character is cut out from the image, it has to be modelled into one which the neural network is formatted to recognise. As will be explained in the next chapter, the neural network used is one for character recognition and its inputs need to be of a specific format before it is called upon to work.

The network in use can only recognise characters formatted as a 14 by 10 matrix. In Figure 28, the number '3' was cropped from the main image. A bounding box would then be created tightly around this character as shown in Figure 31 and the dimensions of the bounded image measured.



Figure 31: Bounding Box around Cropped Character

Normally the image size changes with respect to the character. The cropped image for the number '1' for example could have the dimensions say, 5 by 20, when fixed in a bounding box. Unless this character's image is resized and located in a bounding box of dimensions 10 pixels wide and 14 pixels high it cannot be passed on to the neural network. The number '3' in Figure 28 therefore has to be resized so that it is 10 pixels wide and 14 pixels high as shown in Figure 32 (ideal pixel arrangement).

This image is later converted to a column vector of 140 rows and submitted to the neural network. White pixels take up the binary number '1' and the black ones '0' in the vector. This marks the importance of the cropping and resizing stages in the character recognition procedure as one of the most vital.



Figure 32: Required Image Size

The cropping and resizing of the characters is done in a loop for each character in the regions of interest using the following lines of code.

```
for cnt = 1:num
    bw2 = im_crop(img{cnt});
    charvec = im_resize(bw2);
    out(:,cnt) = charvec;
end
```

From the code above, the variable '*out*' contains the column vector of each character that is available in the specific region of interest in the image. After one region of interest is cropped characters resized and sent to the neural network, the program goes on to other regions of interest until all the characters are identified. These are then passed on to the neural network for identification.

So far it has been shown how individual characters are picked from an image in preparation for character identification. The next chapter deals with how the character identification is carried out by the computer using trained neural networks.

### 3.4. Neural Network Application

#### 3.4.1 Neural Network and Character Recognition

Computers have provided the best platform for experimenting since they can be programmed to simulate many physical symbols. The ability for computers to serve as arbitrary symbol manipulators was noticed very early in the history of computing. In the quest to build intelligent machines, there is one naturally occurring model: the brain. One obvious idea of artificial intelligence, then, is to simulate the functioning of the brain directly on the computer. This is the background on which neural network architectures are built. The new neural network architectures are dubbed ‘connectionist’ architectures because for the most part they are not developed to mimic the operation of the human brain but to receive inspiration from known facts about how the brain works [22].

#### 3.4.2 Training Neural Networks

Rosenblatt in 1962 invented what was called the *perceptron*. This was one of the earliest neural network models. The perceptron models the neuron by taking a weighted sum of its inputs and sending the output ‘1’ if the sum is greater than some adjustable threshold value otherwise it sends a ‘0’. This is depicted in Figure 33.

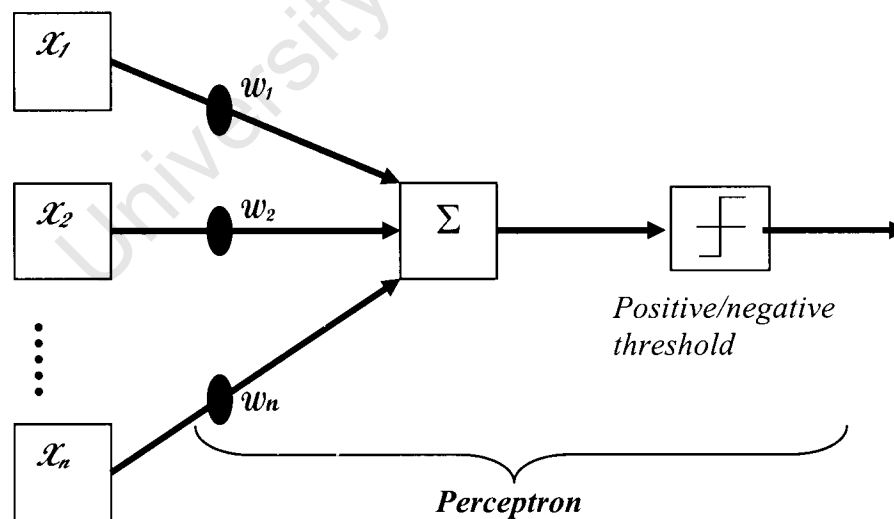


Figure 33: A Perceptron Model

The inputs ( $x_1, x_2, \dots, x_n$ ) and weights ( $w_1, w_2, \dots, w_n$ ) in the figure are typically real values, both positive and negative. If the presence of some feature ‘ $x_i$ ’ tends to cause the perceptron to fire, the weight ‘ $w_i$ ’ will be positive but when it inhibits the perceptron to fire, the weight will be negative. The perceptron itself consists of the weights, the summation processor and the adjustable threshold

processor. Learning is the process of modifying the values of the weights and the threshold [22]. Stated differently, a neural network can be trained to perform a particular function by adjusting the values of the connections which in the figure above are the weights between elements. Neural networks are usually adjusted, or trained, so that a particular input leads to a specific target output. Such a situation is shown below. The network is adjusted based on a comparison of the output and the target, until the network output matches the target (*error* is reduced) [23].

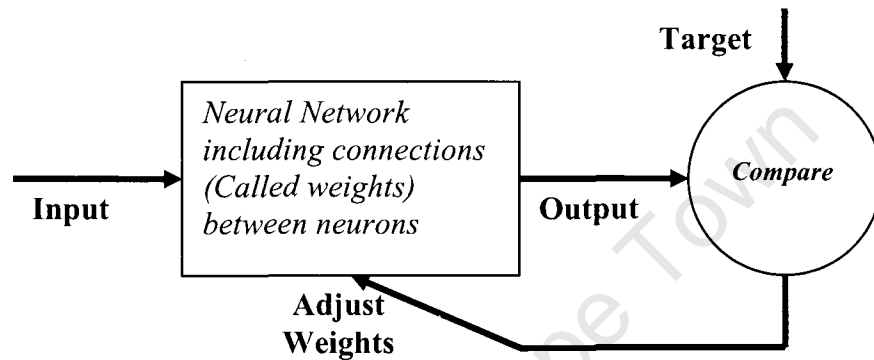


Figure 34: Neural Network Training Process

Typically many such input/target pairs are needed to train a network. An example of a multiple input and multiple output perceptron architecture is shown in Figure 35 [22].

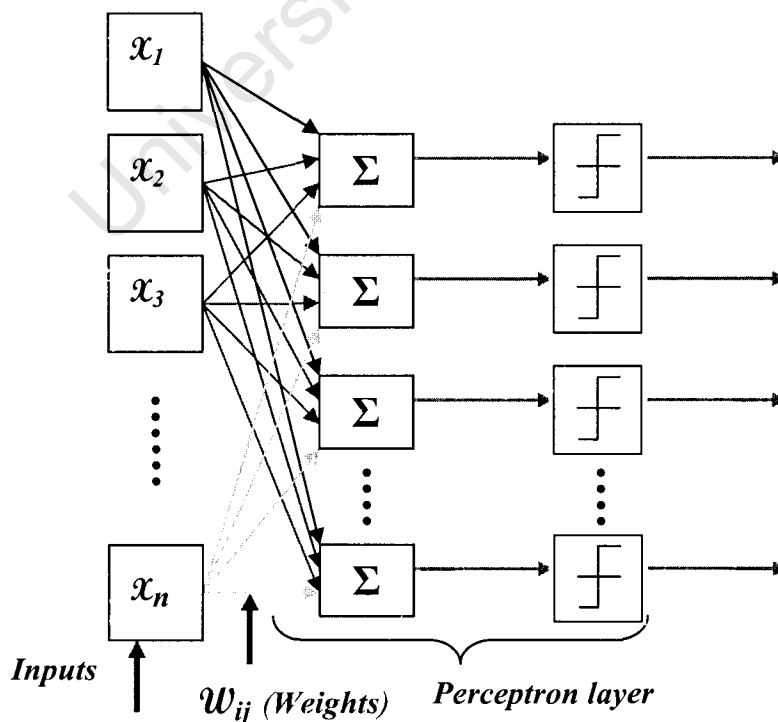


Figure 35: Multiple Inputs – Multiple Outputs Perceptron

Neural networks have been trained to perform complex functions in various fields, including pattern recognition, identification, classification, speech recognition, vision and control systems. Today neural networks can be trained to solve problems that are difficult for conventional computers or human beings [23].

In trying to adapt neural networks to perform the task at hand of marking answer scripts by ‘character recognition’ one technique came in very handy. It has been mentioned that neural networks are trained several times on a set of data before they can be deployed to assess data of similar formatting. In the current application, this would mean training the neural network to identify each student’s writing pattern before it can be used to identify the characters the student writes in a test. This would be nearly impossible and would not be worth doing for the current application. But there are new neural network architectures which do not need training on every ‘source’ data set like student’s handwriting. These use what is called ‘*back propagation*’ technique.

In back propagation, input vectors and the corresponding target vectors are used to train a neural network until it can approximate a function by associating input vectors with specific output ones, or by classifying input vectors in an appropriate manner, and that, done automatically not programmed. Properly trained back propagation networks tend to give reasonable answers when presented with inputs that they have never seen. Typically, a new input leads to an output similar to the correct output for input vectors used in training that are similar to the new input being presented. This generalization property makes it possible to train a network on a representative set of input/target pairs and get good results without training the network on all possible input/output pairs [23].

Neural networks are created and trained on a set of target vectors so that when provided with an input and tasked to recognise it, they will search in the target’s array and find a character the input most closely resembles. For example if an image of the number 2 is taken and has to be identified, the network will check its target array and check for similarities between the input and the target vectors. In the target vector, the number 2 can be represented in various ways. Two examples are shown below as Figure 36 and Figure 37.

```
[1 1 1 1 1 ...
 0 0 0 0 1 ...
 0 0 0 0 1 ...
 1 1 1 1 1 ...
 1 0 0 0 0 ...
 1 0 0 0 0 ...
 1 1 1 1 1 ]';
```

Figure 36: Number '2' as a Column Vector of Height 35

Looking at Figure 36, one can see that the numbers '1' in the image represent the numerical character '2' as would be written in the seven-segment numerical notation. Note that Figure 36 though looking like a 7 by 5 matrix, it actually is a column vector of 35 rows. The 1's in the image can be compared to the strokes created on a paper when hand written and the '0's' represent the plain paper. The neural network during training would be trained on this character arrangement and when in use would try to identify any number provided to it as 35 by 1 column vector by comparing it with the expected arrangement of 'on and off' pixels as arranged in Figure 36. The network receives the 35 Boolean values as a 35-element input vector. It is then required to identify the letter by responding with a 10-element output vector (Ten because there are ten numbers i.e. 0 to 9). If the network is identifying alphabetic characters, it would respond with a 26-element output vector. Here the 10 elements of the output vector each represent a number. To operate correctly, the network should respond with a 1 in the output vector on the position it feels closely matches the input. All other values in the output vector should be '0' [23]. To work successfully, the network is trained on characters with some noise because it is very rare for a neural network to be presented with perfect characters for identification in the input vector.

Seeing that Figure 36 is a 35 element vector, the neural network will need 35 inputs and 10 neurons in the output layer, one for each number, to identify the numbers. Using a network with 35 inputs which are required in identifying characters such as Figure 36 posed great difficulty especially when using a camera for image acquisition due to the fact that images from a camera were not very clear as would be if a scanner were used because during the resizing process, a lot of information in the image is lost and the image lacks a lot of information to correctly be recognised. To remedy this, the input and target vectors of the number '2' can be increased in size to one say '14 by 10' in size resulting in a column vector of 140 rows. The advantage of this is that the strokes of the number can be thickened as shown in the second example of the representation of number '2' in Figure 37. This is still a representation of the number '2' but with a thickness of two pixels across each stroke compared to a

number representation of one pixel thickness which is difficult to use if a low resolution imaging system is used.

In the current application, due to the use of a web camera for image acquisition and for the need of perfect identification, the characters used in the target vectors are all made of two pixel thickness for each stroke and are designed to be used in conjunction with the seven-segment number representation. Therefore the numbers are not designed to follow the free hand strokes but rather those restricted to the seven segment number representation.

```
[1 1 1 1 1 1 1 1 1 1 ...
 1 1 1 1 1 1 1 1 1 1 ...
 0 0 0 0 0 0 0 0 1 1 ...
 0 0 0 0 0 0 0 0 1 1 ...
 0 0 0 0 0 0 0 0 1 1 ...
 0 0 0 0 0 0 0 0 1 1 ...
 1 1 1 1 1 1 1 1 1 1 ...
 1 1 1 1 1 1 1 1 1 1 ...
 1 1 0 0 0 0 0 0 0 0 ...
 1 1 0 0 0 0 0 0 0 0 ...
 1 1 0 0 0 0 0 0 0 0 ...
 1 1 0 0 0 0 0 0 0 0 ...
 1 1 1 1 1 1 1 1 1 1 ...
 1 1 1 1 1 1 1 1 1 1 ]';
```

Figure 37: Number '2' as a Column Vector of Size '140 by 2'

The neural network is therefore designed to have 140 inputs and 10 output neurons for numbers and 26 output neurons for the neural network dedicated to identifying alphabetic characters. It must be mentioned here that in this marking machine, two neural networks were created; one to identify numbers the other to identify characters of the alphabet. The two layer neural network is created by using the command *'newff'* in the following lines of code:

```
S1n = 10;
netn = newff(minmax(numbers), [S1n S2n], {'logsig' 'logsig'}, 'traingdx');
netn.LW{2,1} = netn.LW{2,1}*0.01;
netn.b{2} = netn.b{2}*0.01;
```

To create a network that can handle noisy input vectors it is best to train the network on both ideal and noisy vectors. To do this, the network is first trained on ideal vectors until it has a low sum-squared error. Then, the network is trained on 10 sets of ideal and noisy vectors. The network is trained on two copies of the noise-free numbers/alphabet at the same time as it is trained on noisy vectors. The two copies of the noise-free number/alphabet are used to maintain the network's ability to classify ideal input vectors. Unfortunately, after the training described above the network may have learned to

classify some difficult noisy vectors at the expense of properly classifying a noise-free vector.

Therefore, the network is again trained on just ideal vectors. This ensures that the network responds perfectly when presented with an ideal letter. All training is done using backpropagation with both adaptive learning rate and momentum with the function '*trainbpx*' [23] as shown in the following lines of code. First, the network is trained on characters formatted like Figure 37 without noise:

```
netn.performFcn = 'sse';           % Sum-Squared Error performance function
netn.trainParam.goal = 0.1;       % Sum-squared error goal.
netn.trainParam.show = 20;       % Frequency of progress displays (in epochs).
netn.trainParam.epochs = 5000;   % Maximum number of epochs to train.
netn.trainParam.mc = 0.95;       % Momentum constant.
Pn = numbers;
Tn = targets_n;

[netn,trn] = train(netn,Pn,Tn);
```

After training the network on characters without noise, it is presented with characters with increasing levels of noise by these lines of code:

```
netn_n = netn;
netn_n.trainParam.goal = 0.6;     % Mean-squared error goal.
netn_n.trainParam.epochs = 300;  % Maximum number of epochs to train.

% The network is trained on 10 sets of noisy data.

Tn = [targets_n targets_n targets_n targets_n];
for pass = 1:10
    fprintf('Pass = %.0f\n',pass);
    Pn = [numbers, numbers, ...
          (numbers + randn(Rn,Qn)*0.1), ...
          (numbers + randn(Rn,Qn)*0.2)];

    [netn_n,trn] = train(netn_n,Pn,Tn);
    echo off
end
echo on
```

After training the neural network on noisy data it is re trained on clean characters:

```
% The second network is now retrained without noise to
% insure that it correctly categorizes non-noisy numbers.

netn_n.trainParam.goal = 0.1;     % Mean-squared error goal.
netn_n.trainParam.epochs = 500;   % Maximum number of epochs to train.
netn_n.trainParam.show = 5;       % Frequency of progress displays (in epochs).

Pn = numbers;
Tn = targets_n;

[netn_n,trn] = train(netn_n,Pn,Tn);
```

Using the same procedure, the neural network dedicated to identifying the letters of the alphabet is also trained. After being trained, the numbers given to the NN as inputs, which in this situation come in the form of an array called 'out', (image processing section) are identified. The output from the NN will be the position of the identified number in the 'target's' array. The number '1' occupies the first position in the 'target's' array, the number '2' position two and so on and finally the number '0' in position ten. The computer then converts these into real numbers which can be checked with the marking key to see if the answers provided by the student in the answer sheet are what the examiner expected. This continues for every test paper until the whole class has had their answer script marked.

Once the NN is created and trained, the inputs are provided to it by the following lines of code:

```
Psim = out(:,1:num);
[A,B] = min(sim(netn_n,Psim))
```

Here, the variable '*Psim*' takes all the character arrays outputted by the function '*out*' and are sent to the neural network called '*netn\_n*' for identification. Each character recognised has its position returned in the variable 'B'. It is these values in the variable 'B' that are used to create the actual character represented by the number. For example the number zero would return '10' in the variable 'B' because in the targets vector, '1' is first and '0' is tenth. Taking Figure 30 as the input image to the neural network for identification produces the following results as answers to the test questions (shown in Figure 38).

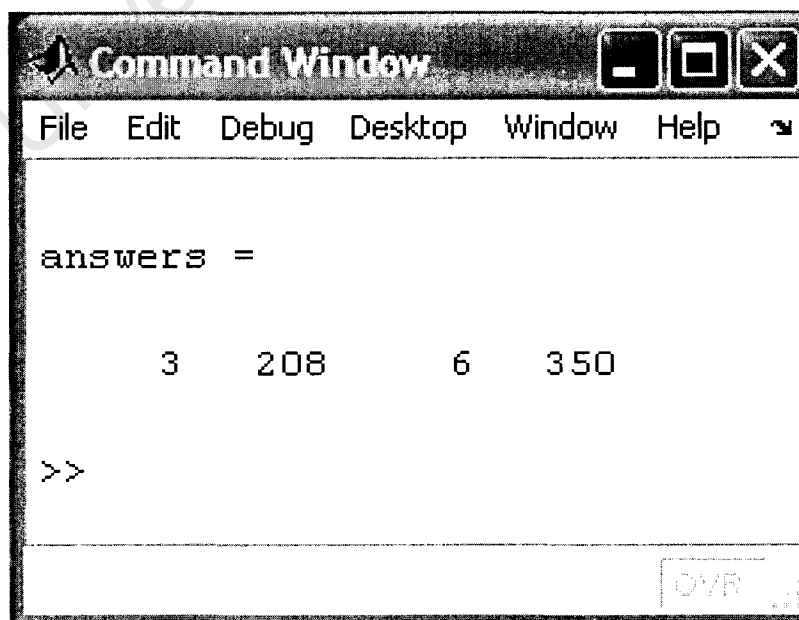


Figure 38: Test Question Answers

When the neural network is required to identify characters as described above, the target matrix will only have ten possible solutions (if the characters are numerical). After comparing the provided character with those characters in the target vector, the neural network returns the error between the two characters in the variable 'A'. The character identified as having the minimum error compared to the target vector characters is what the neural network returns as the correctly identified character. This is the function of '*min*' in the above lines of code, to search for the minimum error between the input and the target column vectors.

For example, if the computer was required to identify the number 'six', which in Figure 30 is an answer to question number three, the computer measures the input vector for number 'six' against all the target vectors. After comparing them against each other, it shows that the minimum error between the input and target vectors is located at target vector number six. This is as shown below:

```
Psim = out(:,1:num);
[A,B] = min(sim(netn_n,Psim))
A =
1.0e-003 *
0.1754
B =
6
```

What these numbers signify is that the error between the input and target vector has a minimum at position 'six' and is '0.0001754'. The other error margins are too big for this input character. Thus, the correct target vector for this input vector is number six. This is done for all the input vectors and in that way the neural network is able to identify characters.

To create a usable number from the indices returned in array B, the following line of code is used.

```
value = str2num(char(nbrs(B)));
```

This is because in ASCII, each character, be it a comma, number or a space, has its own identifying number. For example, the number '1' is uniquely identified by the number '49', the number '2' by '50' and a space by '32' and so on. To identify the actual values in the image, the characters returned in 'B' are used to map on to another target vector made up of the ASCII number representations for each number. This vector is as shown below:

```
nbrs = [49 50 51 52 53 54 55 56 57 48];
```

The vector '*nbrs*' represents the ASCII value of the numbers 1, 2, 3, up to 9 and the last value '48' represents the number '0' in position ten. Thus, in the previous section of code, the innermost function (*nbrs*(B)) uses the values returned in 'B' to extract any of the ASCII numbers in vector '*nbrs*'. When these numbers are extracted from '*nbrs*', they are converted to a single character by the function

*'char'*. This means that as depicted above for the number 'six', the returned vector of  $[6]$ , returns another vector  $[54]$  which after being passed to the function *'char'* returns the ASCII character '6'. This number is in string format and must be converted to a number by the function *'str2num'*. This number is then saved in the variable *'value'* for further application. This is how characters in Figure 38 were obtained.

When all the numbers that the students wrote on their answer sheets are processed as explained above, they can be compared to the expected answers from the examiner that are supplied in the form of an 'answer' vector. For every correct answer, the comparison process will give a '1' for the correct answer and '0' for the wrong answer. These can then be sent to an excel file where each correct answer is multiplied by a weighting factor and total marks awarded.

### 3.4.3 Student Number Identification

To automate the entire data acquisition process, the student identification numbers have to be automatically captured as well. The procedure for this is the same as for numbers except that two Neural Networks are used to avoid confusion of characters. If the same network were to identify numbers and the letters of the alphabet, confusion would occur for characters with similar array representation. For example the number '0' and the letter 'O' in the character representation have a similar array in the characters 'target' vectors. Hence another network called *'netL\_L'* was created to identify only the letters of the alphabet in its target vector. The section of code which performs this is as listed below:

```
name_letters = out(:,1:6);
name_numbers = out(:,7:9);
[st_l,n_letters] = min(sim(netL_L,name_letters));
[st_n,n_numbers] = min(sim(netn_n,name_numbers));
```

At the University of Cape Town, student numbers are made up of six characters from the alphabet and three more characters from the numbers zero to nine, for example 'ULMFEH346'. Thus, in identifying student numbers, the first six characters are sent to the letter identification network (*netL\_L*) and the last three are sent to the number identification network (*netn\_n*). The two sections are then merged to form a student's number.

To extract a student's number, the process is similar to that taken in converting vectors to numbers. This is dependent on the fact that each letter of the alphabet in ASCII representation is identified by a unique number. The letter 'A' is represented by the number '65', letter 'B' by '66' and so on up to the

letter 'Z' represented by '90'. The ASCII representation for each letter of the alphabet is represented in vector '*alph*' as shown below:

```
alph = [65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 ...
        87 88 89 90];
```

When the neural network that identifies the letters of the alphabet returns the indices of the identified letters from the target vector in the variable (*n\_letters*), these indices are used to extract the ASCII representation numbers from vector *alph* by '*alph(n\_letters)*'. The letters extracted in this format are combined with their 'number' counterparts saved in '*nbrs(n\_numbers)*'. When these two parts of a student's number are merged, the entire string of numbers is converted to a string by the function '*char*' as shown below and the student number is saved in the variable '*student\_number*'.

```
student_number = char ([alph(n_letters) nbrs(n_numbers)]);
```

The figure below is a screenshot from the computer after identifying the student number and the answers from the test paper. The recognition program still needs fine tuning as it can be seen here that two letters in the student number have not been correctly identified. The procedure of identifying the student number and the answers in a test are carried out for each student's script in the marking process and these results are sent to an excel file with the student number as the identifying character.

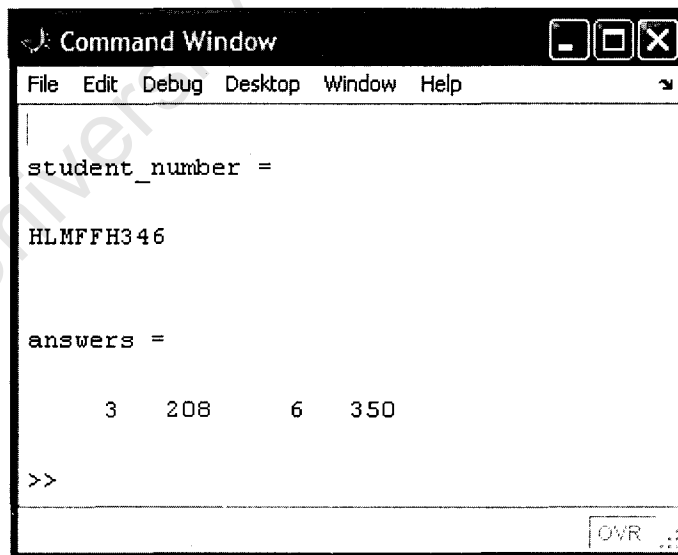


Figure 39: Student Number and Answers Screenshot

After the neural network has recognised the characters, the answers are compared to the required answers provided in a matrix by the examiner. If the answer to question one was '3' the student would then be given an appropriate mark, say one mark and so on. These marks are then sent to an excel file against the students number for analysis of the results and the drawing of conclusions from the

## RAPID ASSESSMENT USING AUTOMATED MARKING

exercise (shown in Table 5). From this table it can be seen that students struggled to answer questions number one and two. Emphasis would then be applied to these two during revision. In this way, the machine is able to mark answer scripts and quickly provide the examiner with vital information which can be used to administer corrective measures.

The computer program segments as presented above pertaining to image acquisition, image processing and character recognition by the neural network all work together to perform the ultimate goal of marking. To bring them all together in serving their purpose, a prototype marking machine was built to test the theory presented. It must be mentioned that, of interest in this research was how the questions can be structured and marked by a computer using the most affordable technology at present.

Therefore the structure of the machine was not the focus of the research but what it stood to perform.

STUDENT NUMBER	SURNAME	INITIAL(S)	Q 1	Q 2	Q 3	Q 4
BCKBRA002	BOCK	BD	0	1	1	1
BRMROH001	BIERMAN	R	0	1	1	1
CLXNON003	CELE	NA	1	0	1	0
DLLANN002	DALLAMORE	AAD	0	1	1	1
DLMDEL002	DLAMINI	DK	1	0	1	1
DSXFOR001	DOUSE	FW	1	1	1	1
HLSTHO001	HALSE	TH	1	1	1	1
HNSPET007	HENSON	PMA	0	1	1	1
IRNPET002	IRUNGU	P	1	1	0	1
KLPNAT001	KLOPPERS	NI	0	1	1	1
LGDTUM001	LEGODI	T	1	0	1	1
MBNISA004	MABONDA	IM	1	0	1	1
MSMJAB002	MSIMANGA	JJB	0	0	0	1
MTHNDA002	MUTHADI	NI	1	1	0	1
MWLPLA001	MAWELLE	PN	1	0	1	1
MYNGIL001	MAYNARD	GAP	1	1	1	1
OZNADA001	OZINSKY	A	0	0	1	1
PCKERI002	PICKERING	EG	0	1	1	1
RBNADA001	RABINOWITZ	AJ	1	1	1	1
RNNTSE001	RANNEILENG	T	1	0	1	0
RNWNZUOO1	RANWAHA	NI	0	1	1	1
RSSRUD001	ROSSOUW	RM	1	1	1	1
RWLBRI001	ROWLAND	BK	1	1	1	1
SPLMZW001	SPELE	MG	1	0	1	1
SPLPHI001	SAPULA	P	1	0	1	1
VIJDAV002	VILJOEN	DMR	0	1	1	1
<b>Total Correct</b>			<b>16</b>	<b>16</b>	<b>23</b>	<b>24</b>

Table 5: Test Results after Automated Marking

## RAPID ASSESSMENT USING AUTOMATED MARKING

The following chapter is a presentation of the actual machine rig used to test the proposals presented above. The chapter looks at the physical components of the machine and their interaction during marking. A brief description is also presented to connect the computer programme sections that have already been explained at length in this and previous chapters.

University of Cape Town

#### 4. PROTOTYPE MARKING MACHINE

Marking machines are currently available and several companies manufacture and supply them to institutions that readily use them. An example of such a company is the DRS Data & Research Services PLC [15]. Most of their machines perform multiple tasks and are not biased to marking examination scripts. They supply machines to institutions that deal with statistical analysis like census, general survey departments, examination authorities, electoral bodies, passport offices and general organisations that process large volume, time critical and complex projects.

An example of a machine produced by this company is shown in Figure 40 which is said to be a network ready optical mark reader capable of reading in jpeg images and text. It is used for large scale data collection applications and can maintain a through put of up to 8,000 sheets per hour [15].



Figure 40: Automatic Marking Machine

The operation of the current marking machines can be summarised into the following steps [15]:

- the paper which is being processed is fed into the machine;
- an image of the paper is taken by means of a scanner;
- Multiple areas of interest are clipped from the scanned form and saved to memory, each clip having its own selectable format. The captured clips are stored in the desired orientation, regardless of the orientation of the forms when scanned;
- these machines run advanced computer programmes capable of performing independent image processing applications on different sections of the same paper as they extract meaningful information from the scanned image; and
- to minimise computing time required per sheet of paper, these machines utilise a technique called dropout imaging where the image processing programme concentrates only on those

## RAPID ASSESSMENT USING AUTOMATED MARKING

sections of interest and mask out the rest, thus lowering storage and post processing costs and delays.

The cost of purchasing these machines can sometimes get quite high and to put a value to this, a machine of this sort solely dedicated to marking multiple-choice questions could cost around the equivalent of R10, 000–00 rand [16]. Therefore this research investigated the usage of much more affordable means of conducting automated assessment to make it readily available to local institutions.

A prototype marking machine was designed and produced as shown in Figure 41 above. It has been built with the capability to perform character recognition of not only numerals but letters of the alphabet. In this way, the machine is able to identify student's unique identity numbers and also perform marking.



Figure 41: Prototype Marking Machine

The machine's components and capabilities are explained below. As a machine designed for marking, the prototype was designed around an image acquisition device as the prime component. All the other components on the machine aided in the automatic operation of paper transportation and camera image acquisition.

#### 4.1.1 Prototype Machine Performance

- Able to mark multiple choice questions
- Able to mark numerical answers and identify student numbers
- The machine is capable of a throughput of 15 papers per minute
- Majority of materials used in the construction of the machine are locally available
- Total mass of 3.95kg
- Machine dimensions (mm): 700 (Length), 450 (Height), 230 (Width)
- Image acquisition web camera capable of a 1280 × 960 pixel resolution at 30 frames per second
- 12 volts DC voltage required for machine operation

#### 4.1.2 Machine Description

The machine has been built with the capability to mark numerical answers hence broadening the scope of questions that could be marked by a computer based marking machine. Machines that exist currently are primarily capable of marking multiple choice questions entered on specially designed papers, restricting the use of automated marking by making examination bodies totally dependent on machines supplied by specific companies, which also supply the answer sheets. The only input by the examiners is to set questions in an examination paper and handover the papers for marking to these organisations. This research looked to move away from a dependence on machine suppliers for automated assessment. This new machine would be equipped with better capabilities, could be produced locally and enable examiners to design both the test question and answer sheet suitable to their requirements. The machine comprises the following:

- the main frame which holds everything in position;
- paper input and orienting tray for paper feeding;
- Logitech® QuickCam Pro 4000 USB web camera;
- photo-reflective sensor driven camera trigger mechanism;
- microcontroller circuit board (for machine control and automation); and
- data acquisition board for computer - marking machine communication and signal transmission.

## 4.2 Machine's Frame



Figure 42: Marking Machines Frame

Figure 42 above shows the machine's layout after construction. The side and base panels offer support for the machine cover and paper tray. For rigidity and reduction in the total mass of the machine, these parts were made of 1.6 mm thick aluminium plates.

The cover (shown above) supports the camera handle onto which the camera is fixed. It is made of four millimetre thick blue translucent Perspex material. The colour was decided upon to help minimise the amount of external light interference with the field of view of the camera during operation. The cover minimises the effects of shadows that may appear in the field of view of the camera and also the effect of differing light intensities in the room where the machine may be in use. It was noticed during testing that there were differing light intensities in the room, which required the computer code settings to be adjusted accordingly. This was due to the fact that, the computer program produced different results depending on the lighting in the room. To eliminate this, the ability of the camera to work in low light was taken advantage of and hence the cover was built. In future, the cover can be removed to allow more light in if the image processing code is restructured.

As can be seen from above, the cover is positioned well above the paper input and orienting tray because for the camera to capture a substantial area of the paper script there had to be a clearance of

more than 250mm. If a camera requiring less clearance were to be used, the size of the cover could be reduced accordingly. The camera and electrical components below the paper tray are used for the automatic operation of the machine. These are described below.

### 4.2.1 Electrical Components

#### 4.2.1.1 Web Camera

For the machine to mark answer scripts, an image of the answer script must be supplied to the computer for image processing. The image acquisition device used for this purpose was a Logitech QuickCam Pro 4000 web camera (shown in Figure 43) which has an adequate video resolution of 640 by 480 pixels. This camera is capable of a good resolution of 1280 by 960 pixels for still images. The challenge faced with using the still image facility in an automatic image acquisition process was that the camera took about 3 seconds to stabilise. At a speed of 30 frames per second, 90 unclear image frames would have passed before a usable frame was logged in. Added to this, the stable state of camera was not repeatable in terms of image brightness and clarity. This posed a challenge since it greatly lengthened the time to mark a script. After several tests, were done on the still image acquisition setting with its associated lack of repeatability and time consumption, it was decided that the video format be used. This was much faster since the image acquisition process only required logging in a single stable frame from a continuous stream. The images were both clear and had a consistent image quality.



Figure 43: Logitech QuickCam Pro 4000 Web Cam

## RAPID ASSESSMENT USING AUTOMATED MARKING

Underneath the paper tray are other electrical and electronic components used for automatic operation of the machine (shown in Figure 44).

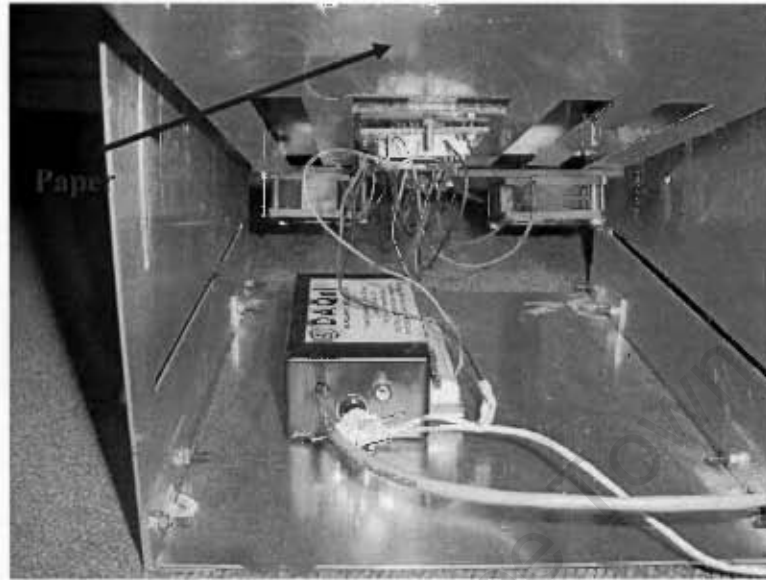


Figure 44: Electrical Components under Paper Tray

### 4.2.1.2 Sensor

The camera takes a snapshot of the students answer script when it receives the trigger command from the host computer. This trigger event begins when the photo reflective sensor detects a paper on the tray. This sensor is positioned underneath the tray (shown in Figure 45).



Figure 45 : Photo Reflective Sensor Position

## RAPID ASSESSMENT USING AUTOMATED MARKING

The circuit to the sensor is shown in Figure 46. The sensor used was a TLP photoreflective sensor which is mainly for paper direction in copiers, fax machines, printers etc. When the paper is above the photo emitting diode, it becomes a reflective surface hence activating the whole circuit which eventually sends out a 5 volt pulse.

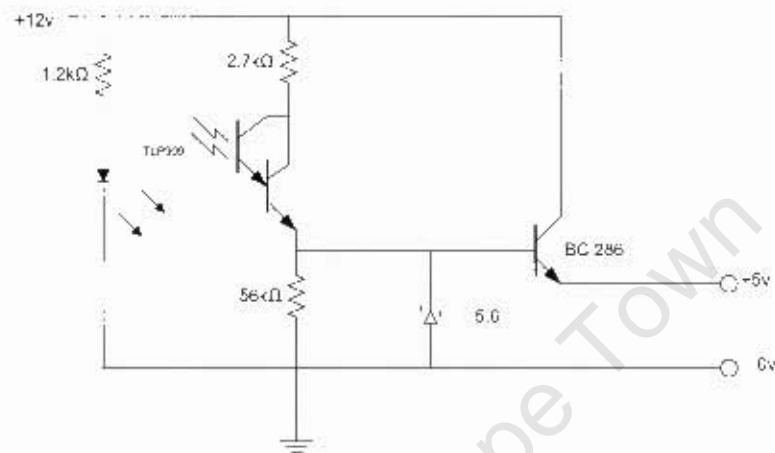


Figure 46: Sensor Circuit

### 4.2.1.3 Microcontroller board and Data Acquisition Unit

As mentioned above, the emitter voltage of the sensor circuit rises to 5 volts, when the sensor detects the presence of paper. This line is connected to input port 'I0' of the microcontroller (shown in Figure 47). The microcontroller used on the marking machine has six input and seven output ports as shown below. Depending on the settings on the function switch, it can perform numerous controlling tasks seeing as it comes pre-programmed hence its name 'Poly Block'. In this report, this component will simply be called a microcontroller.

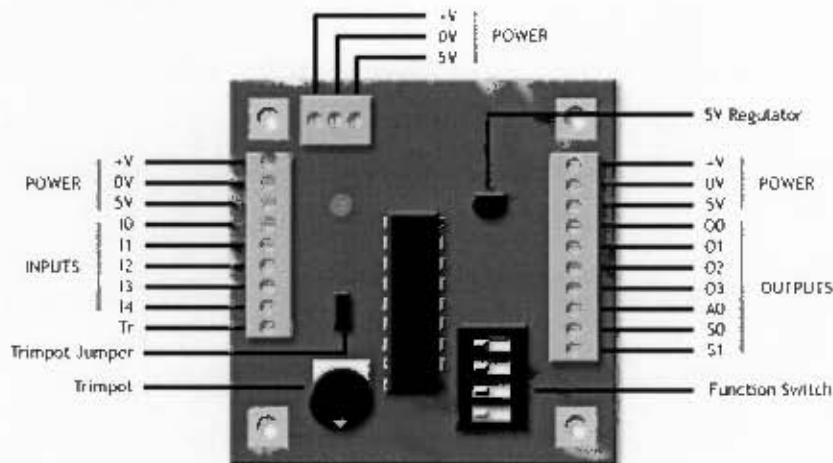


Figure 47: Microcontroller Board

## RAPID ASSESSMENT USING AUTOMATED MARKING

The moment the microcontroller senses the 5 volt signal on the input port, it sequentially outputs 5 volt signals on its output channels starting with **O0** to **S1**. These output channel signals are used to trigger the camera for image acquisition and to operate the fans to push the paper out of the machine after the image acquisition process is complete. Output port **O0** is used for camera triggering. The output signal on this channel is connected to input channel **A1** of the Data Acquisition Unit (shown in Figure 48 ) which converts the analogue signal of 5 volts to a digital signal of '1'. This digital signal is sent to the host computer via an RS232 port as the trigger signal for the camera to take a snapshot. The host computer after receiving the trigger signal takes a snapshot of the answer script and begins the image processing routines on the image preparing it for character recognition. As the computer is still performing image processing and character recognition routines, the students answer script is still on the paper tray and needs to be ejected in readiness for the next paper. The microcontroller therefore switches on the fans to eject the paper.



Figure 48: The Data Acquisition and Control Unit

The machine currently only needs to operate the camera and the fans hence only two output ports of the microcontroller are used i.e. ports **O0** and **S1**, where output port **S1** works as a switch for the two fans. The fans are connected to the **+V** and **S1** ports of the microcontroller. This is because all the ports labelled '**+V**' on the microcontroller board have the same voltage rating, which in this case is equal to the power supply voltage of 12 volts. This is the voltage required to run the fans (shown in Figure 49).

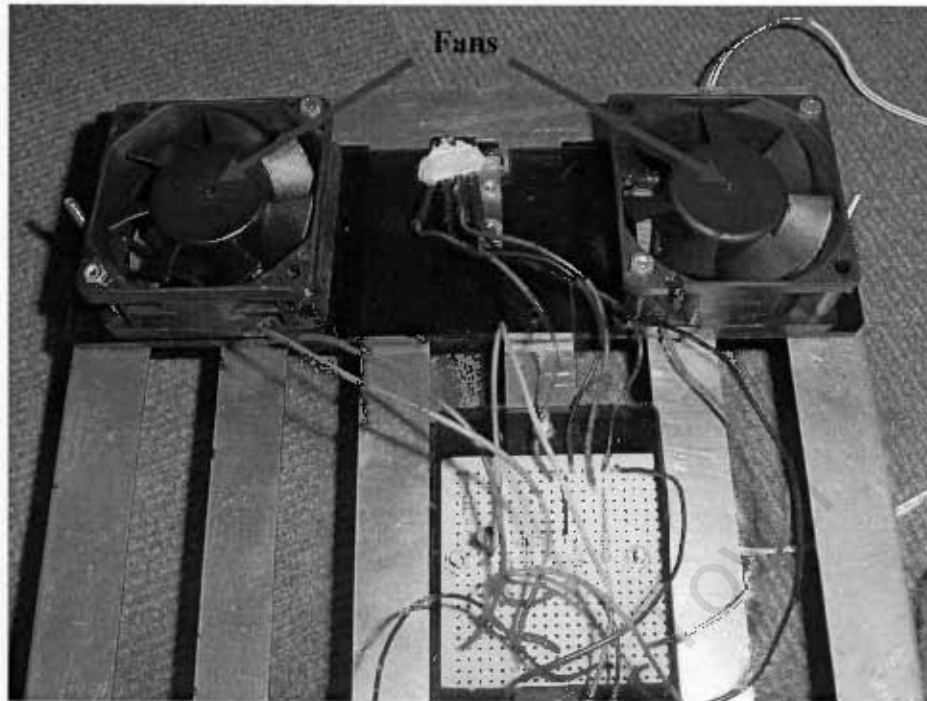


Figure 49: Fans for Paper Transportation

#### 4.2.2 Machine Operation

Figuratively, the electrical components work together as shown in Figure 50 to achieve automated marking. The stages of operation of the marking machine are as shown in Figure 50. Once the paper is placed on the paper tray it slides down the inclined plane due to gravity, eliminating the need for a motor driven paper transportation system. Two protrusions at the end of the tray stop the motion of the paper. With the paper in position, the photo reflective sensor at the bottom of the tray detects the paper's presence above it and sends a 5 volt pulse to the microcontroller's input port 'I0'. Once the signal is received on its input line; the microcontroller sequentially sends 5 volt signals to all its output channels using the adjustable timer function. The first output line of the microcontroller 'O1' is connected to the first input port 'A1' of the Data acquisition board (shown in Figure 50 and Figure 51).

## RAPID ASSESSMENT USING AUTOMATED MARKING

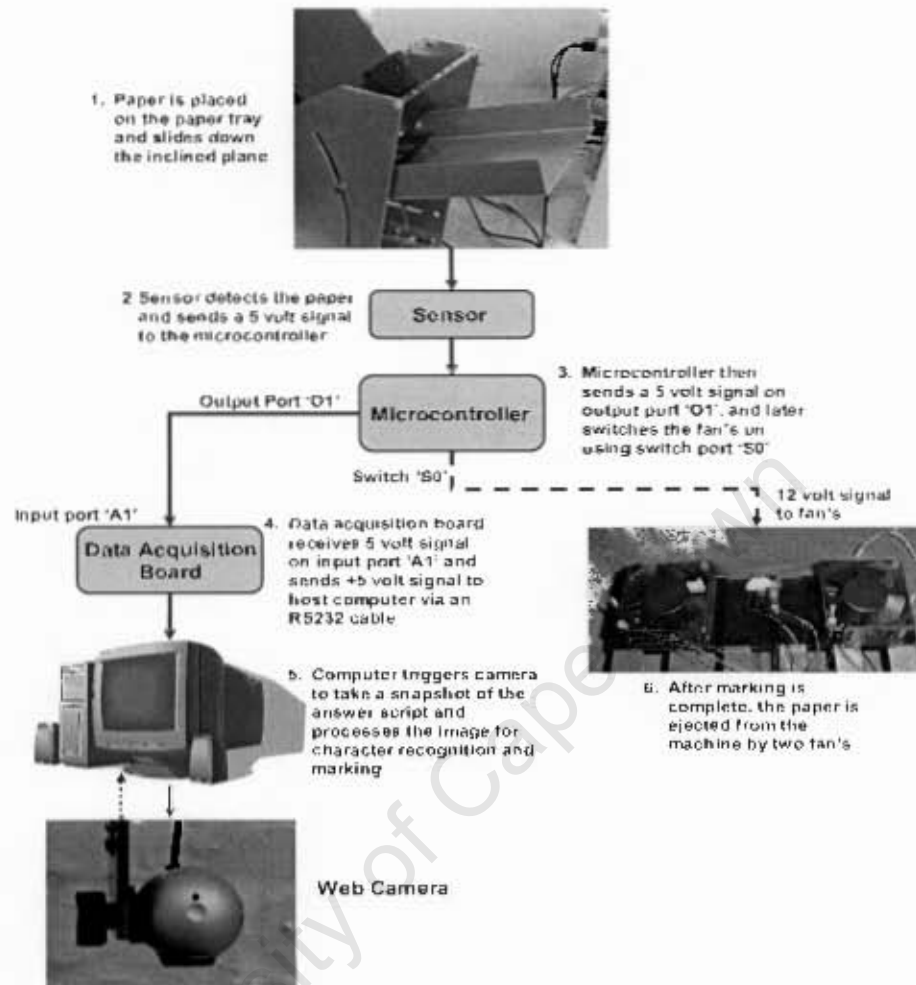


Figure 50: Marking Machine Mode of Operation

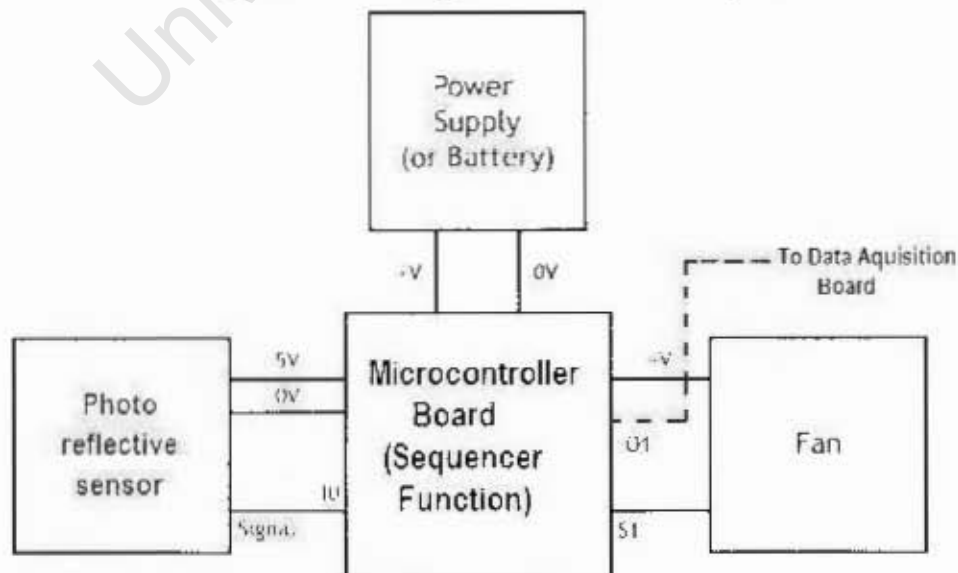


Figure 51: Component Connections to Microcontroller

The data acquisition board receives the trigger voltage on its input port and sends a +5 volt signal to the host computer via an RS232 line. This is the signal the host computer interprets as the trigger command to the USB web camera. This command initiates the image acquisition, processing and character recognition routines. After the image is captured and processing begins, the microcontroller switches on the fans using switch port 'S1' (shown in Figure 51) to eject the paper in preparation for the next operation.

It must be mentioned that early in the experimental stage, it was noticed that the version of matlab used at the time (Matlab Release 7) would cause the computer to freeze when the computer was running the image acquisition routine together with the data acquisition software (which ran successfully on matlab release 6) which controlled the fans and camera triggering for the data acquisition device. This led to the use of the microcontroller to free the computer of computing time in controlling the transportation of paper through the marking machine. Hence the use of the microcontroller was merely to free up the computer to concentrate on the core task of marking.

### **4.2.3 Summary of Machine Operation**

The most critical part of the prototype machine lays in its ability to extract meaningful information in the marking process. This information is extracted by a number of applications put together in a computer program written on the Matlab platform. The applications that have been used for the purpose of data collection are based on applications which are shipped with Matlab namely, Image acquisition, Image processing, Neural Networks and the database toolboxes. The various stages of the marking procedure are broken down diagrammatically as shown in Figure 18 below.

## RAPID ASSESSMENT USING AUTOMATED MARKING

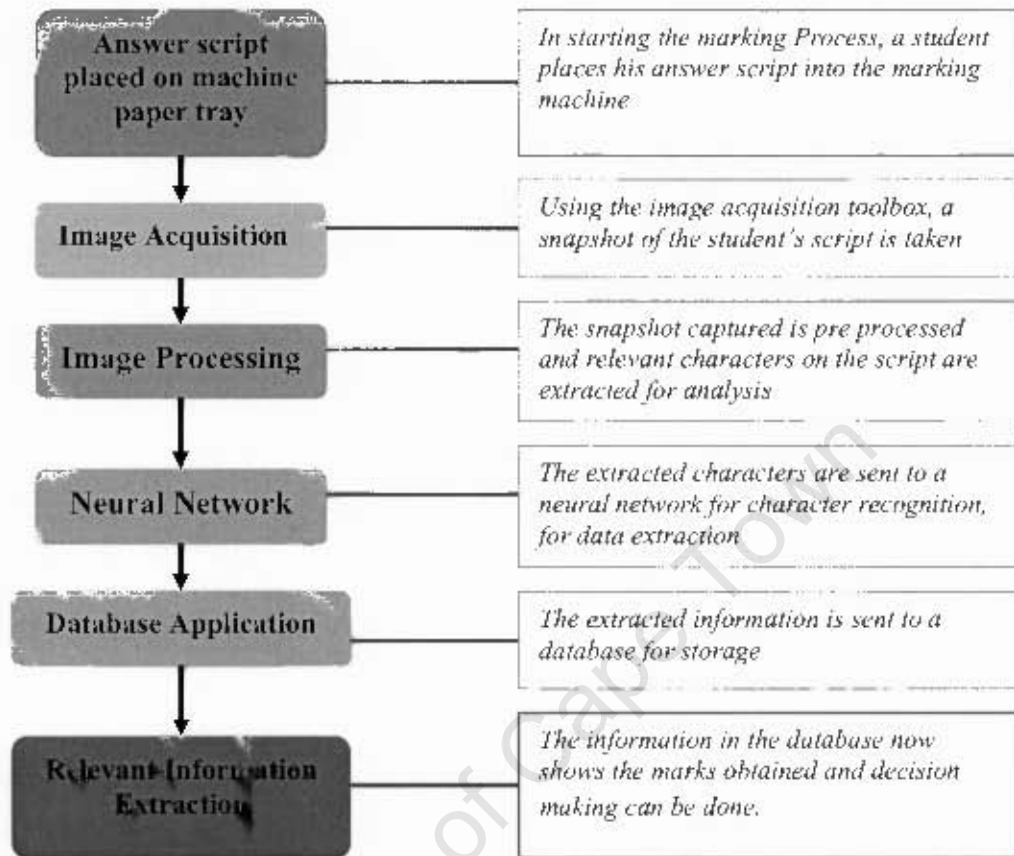


Figure 52: Stages in the Computer Program of Marking Machine

The machine was tested several times as the computer programmes were being developed. The following chapter presents the outcomes of the various tests carried out on the marking machine. The imaging device used, utilised the highest possible video image resolution in capturing images hence the bulk of the challenges faced stemmed from this. Though this was the best resolution for the imaging device, it still fell very short of the routines in use today i.e. scanners. But with such a formidable challenge, the machine performed beyond expectation in testing.

## 5. TESTING AND RESULTS

### 5.1 Experiment

An experiment is a series of tests in which purposeful changes are made to input variables of a process or system so that changes in the output responses can be observed and identified [24]. The objective of the experiment was to:

- test the marking machines capability to mark test questions whether they were multiple choice or numerical in nature,
- determine which input variables are most influential on the output of the machine and
- where to set input variables to obtain optimal results.

The measurable output from the test therefore would be the ability for the machine to mark test scripts. Marking of scripts depends largely on the ability of the machine to recognise hand written characters. Therefore, an observable and identifiable output response from the machine was the ability to digitise hand written characters

It must be mentioned that this experiment was not carried out to see the effect of automated marking on student performance. It was a test aimed to verify whether computers could be used to mark numerical and non numerical answer tests. For the machine to pass as having performed the required task, it had to recognise at least 85% of the characters it was provided with. This was used as the figure of merit for testing the prototype. With further refinement the figure of merit should be set even higher. Several variables existed in the testing process i.e. how legible the input characters were, the colour of marker used in answering questions, image processing program functions used and image acquisition settings.

The first test was carried out in April 2005 and was made up of multiple choice questions only. At that time, the numeral identification routines had not yet been fully developed. The second test was carried out when the numeral identification routine had been completed. In this second test, four classes of 24 students each were given a four question test paper requiring numerical answers. The routine for identifying student numbers had not been developed since identification was expected to be done by scanning student's fingerprints, a routine that was being developed in another department. However, after realising the possibility of identifying student numbers by routines similar to those for numerical identification, this was incorporated into a third and final test which was conducted on a fully functioning system.

## 5.2 Test One

As mentioned above, the first test was conducted early in the research and was limited to multiple choice questions as shown in Figure 53.

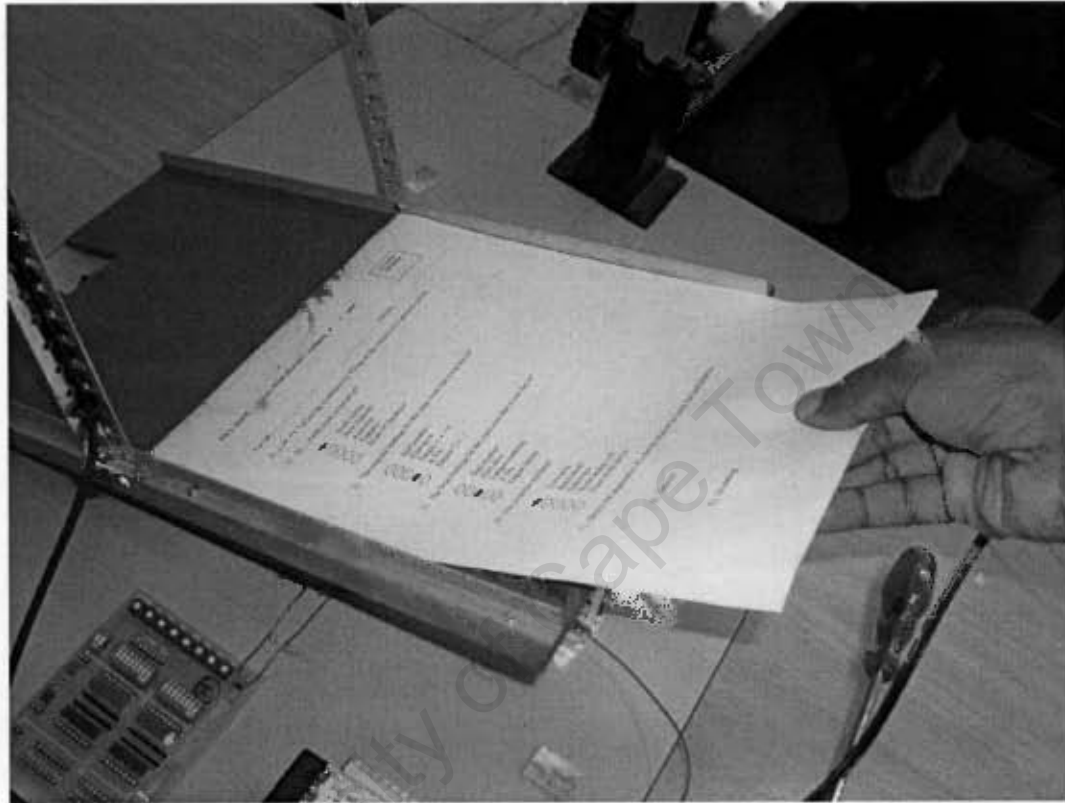


Figure 53: Machine Tested on Multiple Choice Questions

During this test, the machine was only able to perform image comparisons between students' answer scripts and the marking key. This was achieved by conducting image absolute-difference marking. This required subtracting two cropped regions from both the student's script and the marking key answer sheet to obtain the absolute difference between them. If the absolute difference of the two regions was not zero (meaning the two areas were not alike) the student's answer would be marked as incorrect. However, if the absolute difference was zero, the student would be given a full mark as his or her answer was the same as that supplied by the examiner.

The machine performed as expected. It was able to mark student's scripts with very few errors. Errors appeared due to student input errors in things such as incomplete rubbing when an answer was changed. Hence the machine would identify the absolute difference between the two images as not equal to zero. Other sources of errors had to do with student's input not being legible enough for the computer to recognise. Other than these instances, the first test was a success and led to development of other routines to expand the capability of the machine.

### 5.3 Test Two

After investigating the field of optical character recognition and neural networks, a computer programme was written that was capable of identifying numerical characters. To develop this further, a test was set up with similar questions to those given the previous year but this time instead of using multiple choice questions, students were asked to provide numerical answers on a specially formatted test paper.

This test revealed how heavily dependent the character recognition routines were on the legibility of the answers on the answer sheet. Only a few answer sheets per class were able to be assessed correctly. Those students whose answers were entered using light coloured pencils and pens could not be read correctly and thus the image processing program deleted certain answers from the images by recognising them as noise. On the other hand, students who had used dark pens, and had followed the instructions properly on how to indicate their answers, provided the best input for the computer to work on. In such cases the machine worked as expected with minimal errors.

Students were asked to answer four questions on two topics they had covered the previous day. Table 6 below shows the performance of the machine when used to assess students in the class.

## RAPID ASSESSMENT USING AUTOMATED MARKING

1	SA	3	60	2	25	50
	MRA	32	68	2	25	
2	SA	3	60	2	25	75
	MRA	8	60	2	25	
3	SA	3	60	1	25	50
	MRA	3	58	3	25	
4	SA	3	60	1	25	50
	MRA	3	80	6	25	
5	SA	3	30	1	25	75
	MRA	3	30	5	25	
6	SA	1	60	3	25	75
	MRA	1	68	3	25	
7	SA	3	60	1	25	50
	MRA	93	66	1	25	
8	SA	1	60	2	25	50
	MRA	3	60	1	25	
9	SA	3	60	3	25	100
	MRA	3	60	3	25	
10	SA	3	20	3	4	50
	MRA	3	28	3	9	
11	SA	1	60	1	25	75
	MRA	1	60	3	25	
12	SA	1	60	1	25	75
	MRA	2	60	1	25	
13	SA	3	60	1	25	75
	MRA	3	66	1	25	
14	SA	3	60	3	25	100
	MRA	3	60	3	25	
15	SA	3	60	3	25	100
	MRA	3	60	3	25	
16	SA	3	60	1	25	75
	MRA	3	60	3	25	
17	SA	3	60	3	20	75
	MRA	3	60	3	28	
18	SA	1	60	2	25	50
	MRA	3	68	2	25	
19	SA	1	60	2	25	75
	MRA	1	68	2	25	
20	SA	1	860	1	25	50
	MRA	2	860	2	25	
21	SA	1	60	1	25	75
	MRA	1	68	1	25	
22	SA	1	40	3	16	75
	MRA	1	68	3	16	
23	SA	3	20	3	4	50
	MRA	3	28	3	9	
24	SA	1	60	2	25	75
	MRA	1	68	2	25	
25	SA	3	60	2	25	75
	MRA	522	60	2	25	

Table 6: Test-Two Results

In the table above, 'SA' stands for 'Students Answer' and 'MRA' stands for 'Machine Recognised Answer'. During marking, the machine would try to identify the student's answer. For example, student number one answered question one as '3'. During image processing and character recognition, the machine produced the number '32' as the answer to this question. This is clearly the machine's

error in recognition. The errors are highlighted in red to show where the machine failed. Thus, for each answer to a question the student supplies (SA); the machine produces what it has recognised (MRA).

It was discovered that, for most of the answer sheets, the students had used light graphite lead pencils which were not legible enough for the image acquisition device. This therefore was noted as an input variable. To overcome this, dark coloured liquid pens were used and it was noticed that they produced much better legibility which dramatically improved numerical character recognition. A screenshot of the computer correctly identifying the characters in the image after making the answers more machine-readable is shown in Figure 54.

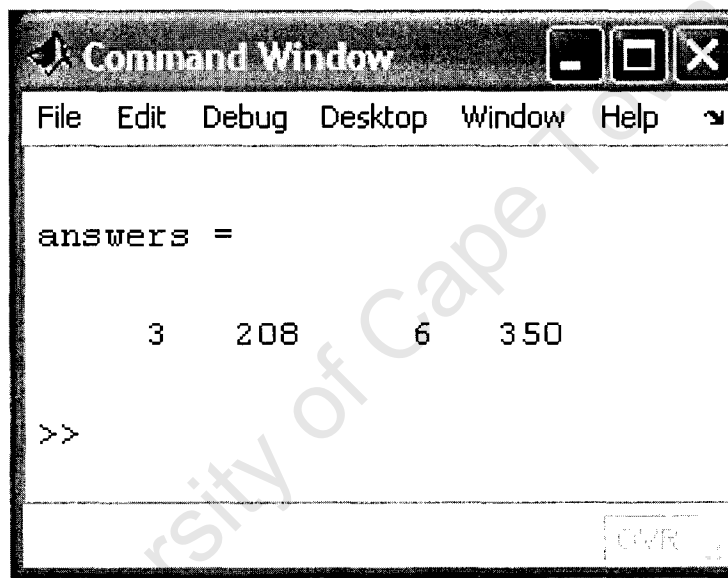


Figure 54: 100% Character Recognition

Table 7 below shows the improvement in the marking accuracy of the machine when the answers were written with a darker more legible coloured pen. This test was carried out on the same answer sheets as those used in test two that produced the results in Table 6. As can be seen above, the more readable the characters are to the camera, the higher the marking accuracy of the machine. This is because the platform on which the computer program runs (Matlab) has the maximum allowable video image resolution of 640 by 480 pixels. Therefore, if the characters are not legible enough the captured image will lack the vital information required by the image processing routines. The alphanumeric character recognition routine is one area that needs further development because it still has low recognition accuracy due to the relatively high number of characters (26) as opposed to number of numerals to be identified (10).

RAPID ASSESSMENT USING AUTOMATED MARKING

1	SA	3	60	1	25	75
	MRA	3	60	3	25	
2	SA	1	060	1	025	100
	MRA	1	060	1	025	
3	SA	3	40	1	25	100
	MRA	3	40	1	25	
4	SA	3	60	1	25	100
	MRA	3	60	1	25	
5	SA	1	060	3	025	75
	MRA	1	068	3	025	
6	SA	3	40	1	25	100
	MRA	3	40	1	25	
7	SA	3	40	1	100	75
	MRA	3	40	3	100	
8	SA	1	60	1	25	100
	MRA	1	60	1	25	
<b>Machine Accuracy with Higher Answer Legibility</b>						

Table 7: Improved Answer Legibility Increases Marking Accuracy

From this test, vital information was captured in terms of developing guidelines for ensuring high levels of accuracy of recognition. These included aspects such as which colours to use for answering questions, and how to format the question paper to ensure that the camera captures only the relevant areas by moving it as close as possible to this region to increase image resolution. When the camera is more than 250mm above the answer sheet, the characters of interest become too small for proper image recognition. To minimise character identification errors even further, it was noticed that when the answer grids are printed in a light shade of grey, they are completely removed as noise during processing of the image leaving the desired characters only in the image.

Students were asked to write down the numbers **2**, **65**, **40** and **3** on sheets of paper which were to be identified by the marking machine. The machine was judged on correct identification of the whole number. This was an effort to improve the performance of character recognition routines by putting together all the information gathered in previous tests relating to character legibility and answer-grid formatting. Answer-grid formatting was considered as one of the causes of low performance of the machine because, if the answer-grids are too dark on the answer sheet, the image processing routine considers them to be characters even if no actual writing has taken place in that grid. Thus, if someone wrote the number '2' in the seven-segment answer grid the machine would see the number '8' due to the dark colours of the grid. In this test, the marking machine performed as shown below.

### RAPID ASSESSMENT USING AUTOMATED MARKING

1	SA	2	65	40	3	100
	MRA	2	65	40	3	
2	SA	2	65	40	3	75
	MRA	2	65	50	3	
3	SA	2	65	40	3	100
	MRA	2	65	40	3	
4	SA	2	65	40	3	100
	MRA	2	65	40	3	
5	SA	2	65	40	3	75
	MRA	2	55	40	3	
6	SA	2	65	40	3	100
	MRA	2	65	40	3	
7	SA	2	65	40	3	100
	MRA	2	65	40	3	
8	SA	2	65	40	3	75
	MRA	2	65	40	5	
9	SA	2	65	40	3	100
	MRA	2	65	40	3	
10	SA	2	65	40	3	100
	MRA	2	65	40	3	
11	SA	2	65	40	3	100
	MRA	2	65	40	3	
12	SA	2	65	40	3	100
	MRA	2	65	40	3	
13	SA	2	65	40	3	75
	MRA	2	65	40	5	
14	SA	2	65	40	3	100
	MRA	2	65	40	3	
15	SA	2	65	40	3	100
	MRA	2	65	40	3	
16	SA	2	65	40	3	100
	MRA	2	65	40	3	
17	SA	2	65	40	3	100
	MRA	2	65	40	3	
18	SA	2	65	40	3	75
	MRA	2	65	90	3	
19	SA	2	65	40	3	75
	MRA	2	65	40	5	
20	SA	2	65	40	3	100
	MRA	2	65	40	3	
21	SA	2	65	40	3	75
	MRA	2	55	40	3	
22	SA	2	65	40	3	100
	MRA	2	65	40	3	
23	SA	2	65	40	3	100
	MRA	2	65	40	3	
24	SA	2	65	40	3	75
	MRA	2	95	40	3	
25	SA	2	65	40	3	75
	MRA	2	55	40	3	

Table 8: Final Machine Test Results

This can be considered a good performance of the machine as the input was from students who had varying ways of writing down the numbers. Some wrote down the numbers in a hurry but the machine still managed to make sense of their input. This performance is much better than that shown in Table 6 due to the updated set of instructions given to students. The improvement was simply due to correct

## RAPID ASSESSMENT USING AUTOMATED MARKING

answer sheet setup, correct instructions and using darker, more legible markers and further supported the use of the marking machines as an assessment tool.

To illustrate the improvement of the marking ability of the machine from the first test to the third, a comparison of the means was done and this is shown below. From the graph it is clear that the marking accuracy of the machine increased from a mean of 69 and standard deviation of 16.58 to that of 91 having standard deviation of 12.25. The two graphs below show a significant improvement on the ability for the marking machine to read hand written characters from the two tests.

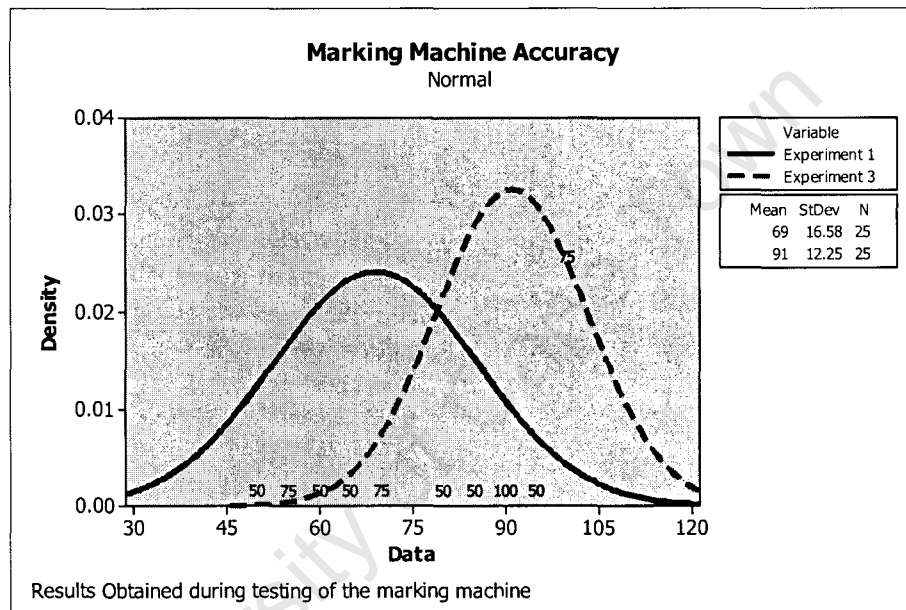


Figure 55: Marking Machine Performance during Testing

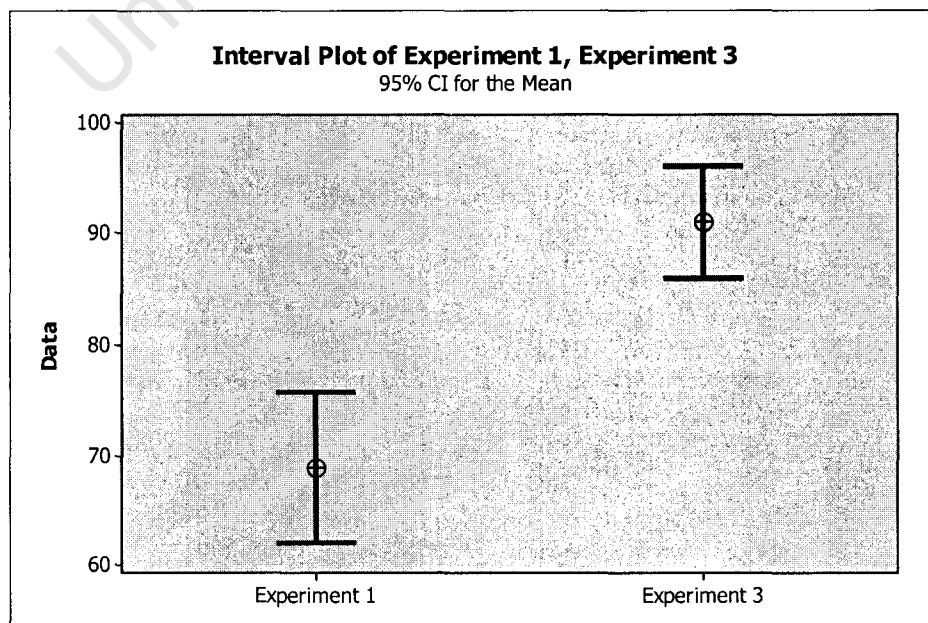


Figure 56: Comparison of Means

## 6. CONCLUSION

Rapid, accurate and fair assessment can be achieved by setting test questions in a format that can be marked by computerised marking machines. This will improve the effectiveness of assessment by reducing 'accurate guessing' that is normally the case in multiple choice tests. It will also increase the time lecturers can devote to assisting those students with academic problems in specific courses.

This project has shown that automated marking can be achieved by making use of cheaper materials than are currently used in marking machines. Since digitisation of answer scripts is one of the most costly operations a marking machine can have beside paper feeding mechanisms, if the cost is reduced in these two processes, the overall cost of the product reduces and many more academic institutions will be able to afford marking machines and achieve 'Rapid Assessment by using Automated Marking'.

The marking machine developed in this project achieves the required objective of proving that automated marking can also be adapted to numerical answers thus improving the rate of assessment for such tests. This would give enough time for lecturers to concentrate on delivering information and conducting corrective measures in areas where it is most needed.

There are many ways in which the current format of questions can be converted to those that can be machine scored. A few examples of question and answer formatting have been shown to support this but these are not the only possible options. There are still others to be developed and tested to enable a variety of questions to excite students and accurately assess their academic progress.

With this proposed formatting of questions, the two areas of interest of this project namely, rapid assessment and automated marking can be achieved. This is because the questions can be marked by machine, using locally available components, and due to the speed at which these can be marked the goal of Rapid Assessment is achieved.

A lot of time was dedicated to writing computer programmes for the machine because the student working on the project did not have prior computer programming skills to the levels required in the project. Therefore there are still a number of things that need to be developed on the marking machine and its associated marking routines. These recommendations are presented in the next chapter.

## 7. RECOMMENDATIONS

The prototype marking machine developed fulfils the required specifications of being able to mark test questions in numerical or multiple choice format. Although the machine has these capabilities, it still needs to be developed further for commercialisation. Below are some of the recommendations for further development of the marking machine.

### 7.1 Graphical User Interface

The current marking machine cannot be used by someone without knowledge of the Matlab programming language. The code in use requires human input in terms of selecting regions of interest in the answer script that contain answers and name fields. This is due to the fact that there is no specific layout of answer scripts. Lecturers can decide where the name and answer fields should be located and the computer has to prompt the user to use a place-and-drag area selection which is simpler than inputting values on the key board, as currently employed.

### 7.2 Program Flow and Layout

This project was not about developing an expert computer code. Therefore the computer code in use requires further refinement.

### 7.3 Machine Design

The machine performs the required task of automatically marking student academic scripts but further improvements need to be carried out to improve its aesthetics. Some parts are currently difficult to reach, for example, when adjusting the positioning of the camera, a number of screws have to be removed. Hence the machine needs further ergonomic improvements.

### 7.4 Question Formats

It was wished at the commencement of this project that the marking machine be able to mark free body diagrams. This area needs to be investigated further. As a suggestion, free body diagram force lines could be digitized and converted to vectors and manipulated for magnitude and direction.

### 7.5 Character Identification

One of the challenges faced in the machine during testing was that during marking, if the characters were not printed dark and visible enough, the computer could not isolate and identify them. Further research therefore needs to be done to find ways to identify characters with differing legibility's seeing as it is impossible to assume students will identically fill in their answer scripts.

An alternative to using the seven-segment or alternative seven-segment number representation is the use of a number line. An example of this is shown below -

Q. Assume the pulley system shown below is frictionless and that the six people shown in the diagram each have a mass of 60 kg. What is the tension in the rope holding pulley A? What is the tension in the rope holding pulley B? And what force must P1 provide to ensure that the cages stay stationary where they are?

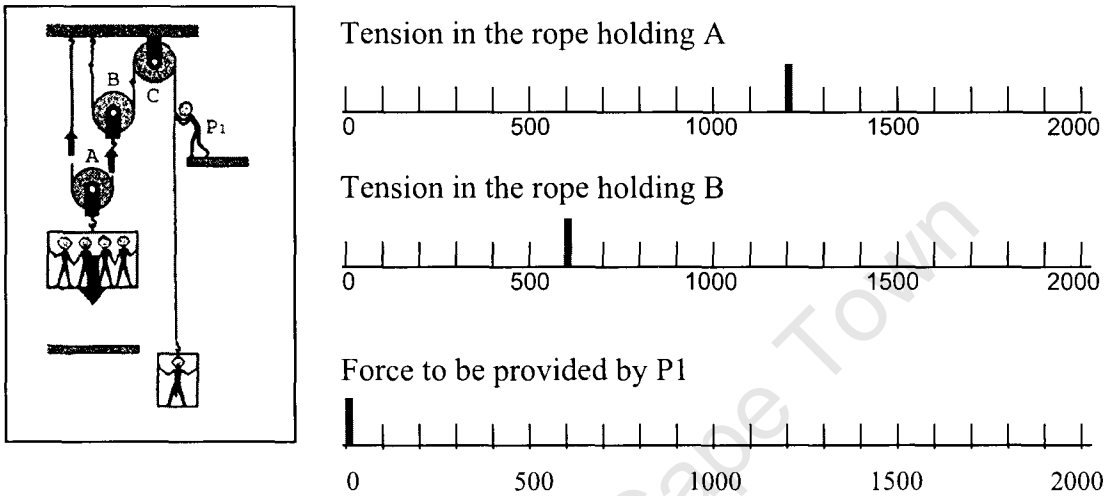


Figure 57: ‘Number Line’ Question Structure

The student here would analyze the diagram and where necessary bring in the relationships they learnt about in class to solve the problem at hand. In answering the questions, the student would indicate their answer on a number line by using a coloured pencil, as shown in the illustration above. This method was suggested by John Greene [10]. A number line given with logarithmic spacing can be used effectively where answers are large such as those relating to electrical resistors that range from a single ohm to thousands of ohms.

### 7.6 Free Body diagrams

Some engineering problems require students to present their solution in the form of free body diagrams. Here, the forces acting on a body have to be drawn and associated mathematical relations deduced from them. For example, a question presented to first year students went as follows:

*A rear-wheel drive motor vehicle with mass of 1 ton is accelerating just below wheel spin on a straight, level tarred road. Neglecting the effects of rotating parts and all air and rolling resistance, complete the free-body diagram of the car. **Line lengths for vectors to be scaled so that each 1 mm of length represents 500 N.***

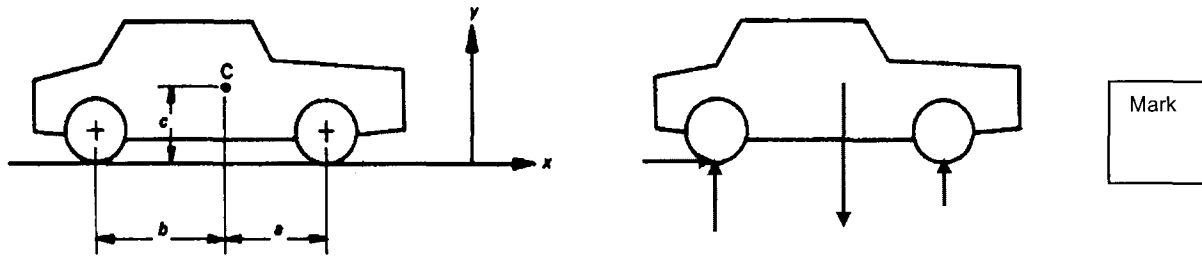


Figure 58: 'Free Body Diagram' Question Structure

Students in answering the question are required to show all the forces acting on the motor vehicle at the stated condition. These forces are as indicated above, marked in red, and their magnitude related to the length of the arrow.

It is noteworthy to recognize that this type of question could not have been asked in a multiple choice examination and requires a sound understanding of dynamics to unpack the question and answer correctly. For example, the two arrows pointing upwards must have the sum of their lengths equal to the arrow pointing downwards for equilibrium, while the horizontal arrow, the driving force for acceleration, is unbalanced. On a tarred road, the co-efficient of friction will be high and at just below wheel spin the driving force vector will be slightly shorter than the reaction force vector on that wheel. It is for situations like this that the need to rapidly assess student measurable skills and understanding require a way to mark questions of this sort. Using the technology developed for this project, the marking machine isolates the force arrows that are drawn in red and performs vector comparison with that of the marking key. If the forces are within reasonable magnitude and direction, the student is awarded the marks appropriate.

When the marking of free body diagrams was considered, additional possibilities for use of this new technology arose. If for example, when students are required to label a diagram, they could be asked to match provided words to their associated parts. An example question of this kind could be,

*Q. Complete the diagram below by drawing a red leader line from each of the Label-boxes to the part associated with the label.*

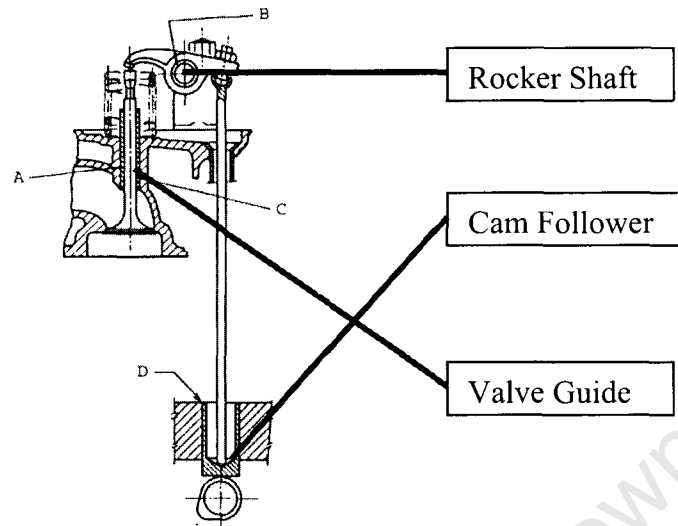


Figure 59: 'Labelling' Question Structure

Looking at the diagram, the students were originally required to provide appropriate names to the parts labelled from A to D on a separate answer sheet or by writing down the name of the part. To enable marking by computer, students could be provided with label-boxes as shown on the right hand side of the diagram and only required to draw a line from the label box to the associated part (shown here with the red lines). These lines when converted to vectors can be compared to the marking key since they will possess magnitude and direction rendering them candidates for automated marking.

## 8. REFERENCES

- [1] Astin, A.W., (1985b), "Involvement: The cornerstone of Excellence." (July/August), pp. 35-39.
- [2] Study Group on the Conditions of Excellence in Higher Education, (1984), "Involvement in Learning: Realizing the Potential of Higher Education", Washington D.C. National Institute of Education.
- [3] Gagné, R.M., *et.al*, (1992), "Principles of Instructional Design." 4<sup>th</sup> Edition, Wadsworth Publishing, (January), pp. 125–276
- [4] Slavin, R.E., (1997), Educational Psychology, "Theory and Practice: What is direct instruction" 5<sup>th</sup> Edition, Allyn and Bacon, pp. 232 – 235.
- [5] Blaine, S., (2004), Business Day, "Too few to Engineer South Africa's future growth." (October)
- [6] Mzwandile, F., (2005), Cape Times, "Business Report: SA looks overseas to recruit engineers." (June)
- [7] Martin. J., Dean of Engineering (1992), "Redressing the imbalance: Academic issues in Engineering at UCT." UCT news magazine (May), p.13.
- [8] Dr. Press, F., (1990), "The Role of Education in Technological Competitiveness: Siemens Review," (June) p.4.
- [9] Meriam, J.L, 1991, "The Decline of Academic Standards: Engineering Education," (May/June) pp. 405-407.
- [10] Greene. J., (1991). "Towards Realism in Electrical Engineering Education: Proceedings of the Second Biennial Conference of the society of Electrical Engineers". (February)
- [11] Time-life Books, (1990), "Understanding Computers, Computer Images: Altering Images in the Machine", 5<sup>th</sup> Edition, Brepols S.A, pp. 56 – 60.
- [12] Corrigan. J., (1994), Computer Graphics, "Secrets and Solutions: Resolution", 1st Edition, Sybex, pp. 51 – 55.
- [13] Buckingham. D., *et.al*, (1992), "EPC Occasional paper № 5: Assessment methods in engineering degree courses," (December) [Online], Available: <http://www.engprofc.ac.uk/op/op05.html>
- [14] Masters, K., Delpierre, G., Carneson, J., (1998), "Designing and Managing Multiple Choice Questions" Chap. 1-4.
- [15] DRS Data & Research PLC, (2004), "Optical and Image Mark Readers", [Online], Available: <http://www.drs.co.uk/products/omr.asp>
- [16] Trax (UK) Ltd, (1997), "Software Reviews: Psychology Software News", (June) Vol 7, Number 3.
- [17] The MathWorks Inc, (1994 – 2006), [Online], Available: <http://www.mathworks.com/>
- [18] The imaging source, (2003), " Introduction to cameras", (June), [Online], Available: <http://www.theimagingsource.com/prod/cam/c1#c1>
- [19] Corrigan. J, (1994), Computer Graphics, "Secrets and Solutions: Bitmap Graphics", 1<sup>st</sup> Edition, Sybex, p. 5 – 23.
- [20] Blogger, (2005), "Character recognition Example (II): Automating Image Pre-processing" (September), [Online]: <http://basic-eng.blogspot.com/2005/09/character-recognition-example.html>

- [21] Blogger, (2005), “Character recognition Example(III): Training a simple NN for classification”, (October), [Online]: <http://basic-eng.blogspot.com/2005/10/character-recognition-example.html>
- [22] Knight. R., (1991), “Artificial Intelligence: Learning in Neural Networks”, 2<sup>nd</sup> Edition, McGraw Hill, Inc, pp. 7, 492 – 522.
- [23] Matlab Release 14, The MathWorks Inc, Documentation, “Neural Network Toolbox: What is Neural Networks?”
- [24] Montgomery, D.C., (1997), “Design and Analysis of Experiments,” 4<sup>th</sup> ed., Wiley & Sons.
- [25] SouthAfrica.info reporter, (2004), “International Marketing Council of South Africa: Africa's biggest water project”, (March)
- [26] Davie. L., (2005), “International Marketing Council of South Africa: Gauteng's bullet train on track,” SouthAfrica.info reporter, (August).
- [27] Hosking. M.D., B. Ing, (2005), “There is no shortage of Engineers”, [Online], Available: [http://www.e-engineersonline.com/Engineering\\_Reports.htm](http://www.e-engineersonline.com/Engineering_Reports.htm), (July).
- [28] South African Weather Service, “Climate Data: Cape Town”, [Online], Available: <http://www.weathersa.co.za/Climat/Climstats/CapeTownStats.jsp>
- [29] Matlab Release 14, the MathWorks, Inc Documentation, “Neural Network Toolbox: Character Recognition Example.”
- [30] Department of Trade and Industry (2003), Government Gazzette, “Schedule 1: Issue of New Standards”, (June)

RAPID ASSESSMENT USING AUTOMATED MARKING

**APPENDIX A — SPECIFICATIONS**

University of Cape Town

## **A.1. INTRODUCTION**

For the design process, a list of targets and requirements that a piece of equipment must achieve had to be listed. To that effect, a table of specifications was drawn up which would determine the conformity of the final product to the specifications.

### **A.1.1 Objective**

The objective of this section was to make a list of demands that were to be met at the end of the design, and other aspects wished for in the equipment. These were to guide in the calculations, for verifications purposes.

### **A.1.2 Breakdown**

The specifications were broken up into sections comprising application requirements, minimum marking rate, hardware configuration, software requirements, operation and safety.

## A.2. PRODUCT SPECIFICATION TABLE

Desired/Wish	SPECIFICATION	DETAILS	RELATED
	<b>Application requirements: Machine to be able to mark:</b>	A.3.1	
D	<ul style="list-style-type: none"> <li>Multiple choice questions (MCQ)</li> </ul>	A.3.1.1	
D	<ul style="list-style-type: none"> <li>Unconventional MCQ and numerical answers</li> </ul>	A.3.1.2	
W	<ul style="list-style-type: none"> <li>Free body Diagrams</li> </ul>	A.3.1.4	
	<b>Marking speed</b>	A.3.1.5	
D	Mark a minimum of 8 scripts per minute		A.3.1.5
	<b>Hardware</b>	A.3.2	
D	<b>Image Acquisition</b> Use of rapid image acquisition device	A.3.2.1	
W	<b>Mechanical components</b> <ul style="list-style-type: none"> <li>Few or no moving parts</li> </ul> Machine construction to be simple for easy- <ul style="list-style-type: none"> <li>Maintenance; and</li> <li>Use in tertiary institutions schools</li> </ul>	A.3.2.2	
W	<b>Mass</b> Machine to be portable	A.3.2.2	
	<b>Software</b>	A.3.3	
D	<b>Image processing</b> Program to be able to process at least 8 scripts per minute	A.3.3.1	
	<b>Operation</b>	A.3.4	
W	<b>Usability</b> Machine to be simple to operate, i.e. interactive and user friendly.	A.3.4.1	
D	<b>Repeatability</b> Machine to operate continuously without affecting accuracy	A.3.4.2	
W	<b>Temperature</b> Able to operate between 8 to 28° Celsius	A.3.5	
	<b>Safety</b>	A.3.6	
D	To conform to South African safety standards SANS IEC 60950 for information technology equipment and related equipment such as computers, printers, copiers		A.3.6

### A.3. PRODUCT SPECIFICATION JUSTIFICATION

#### A.3.1 Application requirements

The prototype machines main characteristic was to mark student's scripts. The major answer formats to be marked were-

##### A.3.1.1 Multiple Choice Question (MCQ)

In order to improve on the capabilities of the current machines, this machine was to have the ability to mark MCQ as the current commercial machines are able to;

##### A.3.1.2 Unconventional MCQ

In order to reduce the possibility of students guessing the answers and in so doing attain a true picture of students levels of assimilating study material, the use of a more stringent format of MCQ was viewed as an option. The machine therefore had to have the ability to mark this unconventional format of MCQ;

##### A.3.1.3 Numerical answers

To make a positive contribution to automated assessment, the marking machine has to be capable of marking numerical answers. This aspect has received little attention and therefore limiting automated assessment to multiple choice tests;

##### A.3.1.4 Free body diagrams

Students in engineering perform analysis on engineering problems by firstly; noting the forces involved in a system, then the system is simplified down to form a free body diagram. Thus it was desired that the machine have the ability to mark free body diagrams;

##### A.3.1.5 Marking speed

In the biggest of classes in the first year, the number of students has reached 120. Using a time frame of only 10 minutes in which to do the assessment, 120 students answer scripts are to be marked in ten minutes. This would mean a minimum of 12 students' scripts per minute;

Assuming the following timing per student to-

- move to the machine = 1.5 seconds;
- place paper onto machine = 0.5 seconds;
- time for machine to mark paper = 1.5 seconds;
- time to clear away from machine = 0.5 seconds.

The total time per student would be = 4 seconds

Therefore in one minute, the machine would approximately assess fifteen student's scripts per minute.

This rate is above that required one for a class of hundred and twenty students and therefore became the target rate of assessment;

## **A.3.2 Hardware**

### **A.3.2.1 Image Acquisition**

With the aim of performing rapid assessment, it would be advantageous if the process of image acquisition were sped up. The current machines utilise scanners in their image acquisition routine. Scanners have the advantage of capturing images with very high resolution but work at a relatively slow pace when compared other image acquisition devices like cameras. The image acquisition device to be used therefore was to be faster than a scanner.

### **A.3.2.2 Mechanical components**

The machine must be simple in construction and to have few or no moving parts. This would therefore reduce on the number of drivers like motors required, making it light in weight for easy portability. The simplicity in the design was to also make the machine easy to use in schools and easily serviced in case of mishandling.

## **A.3.3 Software**

### **A.3.3.1 Image processing**

When the image is acquired, it would be sent to a computer program which would perform image processing by extracting required characters in the original image in preparing it for character recognition. Therefore the program must be simple and fast, so that it takes the least amount of time in processing.

## **A.3.4 Operation**

### **A.3.4.1. Usability**

The machine was to be simple for the operator to use. Owing to its simplicity in construction, the machine would therefore be simple to operate and a maximum time of 30 minutes would be needed to train the operator.

### **A.3.4.2. Repeatability**

Due to the fact that the machine construction would have few moving parts, there would be less need to stop the machine for repairs as is the case for machines with moving parts. This, therefore, for situations of very high loads of work would be required to operate continuously without affecting the accuracy of the marking.

### **A.3.5. Temperature**

According to the South African weather service [28] the maximum temperatures in Cape Town are usually in February and are about 28° Celsius and the minimum temperatures are experienced in June, July and August and are about 8 ° Celsius. The machine was to be capable of working in such temperature ranges.

**A.3.6. Safety**

To avoid injury to the operators the machine was to conform to South African safety standards SANS IEC 60950 [30] for information technology equipment and related equipment such as computers, printers, and copiers. This stipulates the guidelines for designing products with facilities to prevent injury to the operator by eliminating the chance of say, accidental electrical shock to the operator, cuts due to sharp edges and many more.

University of Cape Town

University of Cape Town

## B.1 INTRODUCTION

### B.1.1 Objective

The objective of this section are-

- present a variety of probable solutions for the marking machine;
- gauge the probable solutions against each other by putting them to a comparative test; and
- choose the most suitable concept for design.

### B.1.2 Limitations

This section documents several possible design solutions which were considered in the conceptual design phase. The governing factor in this stage of the design was cost. Concepts which could have resulted into excessive cost, as a result of complicated mechanisms were discarded or rejected.

### B.1.3 Plan of Development

The section begins with the presentation of the proposed concepts along with their operation mechanisms beginning with the least complicated. These are then compared to each other and the most effective concept chosen. To verify the operability of the chosen concept, a brief explanation is presented on its performance during testing. The testing was done for presentation to the supervisor on the expected performance of the concept.

Note should be taken that at the time of testing the various concepts, most of the computer code had not been written to perform the tasks the final prototype machine would do. The chosen concept was only tested on multiple choice questions and the result or mark obtained in a test was viewed by means of a light emitting diode (LED) board. At this stage the machine had not been used with input from students since the idea was simply being developed. To show the marks obtained in a test to students on their answer sheets, the final product was going to have an integrated printer (a component that was to be purchased) hence the use of the LED board connected to the computer via the printer port. The integrated printers found at that time were quite expensive for the budget at hand hence it never materialised.

## SURVEY OF POSSIBLE CONCEPTS

**B.2.1 Introduction**

The effectiveness of the designed marking machine relied mostly on the ability to acquire images of student's answer scripts rapidly in the marking process. Hence the concepts drawn were variants of the image acquisition mechanism.

**B.2.2 Fixed Base Mechanism**

The fixed base marking machine mechanism was the least complicated of all the considered concepts in that it had no moving parts. The paper is placed on the marked area, and then a picture taken by means of a web camera, the picture is then processed by an image processing program.

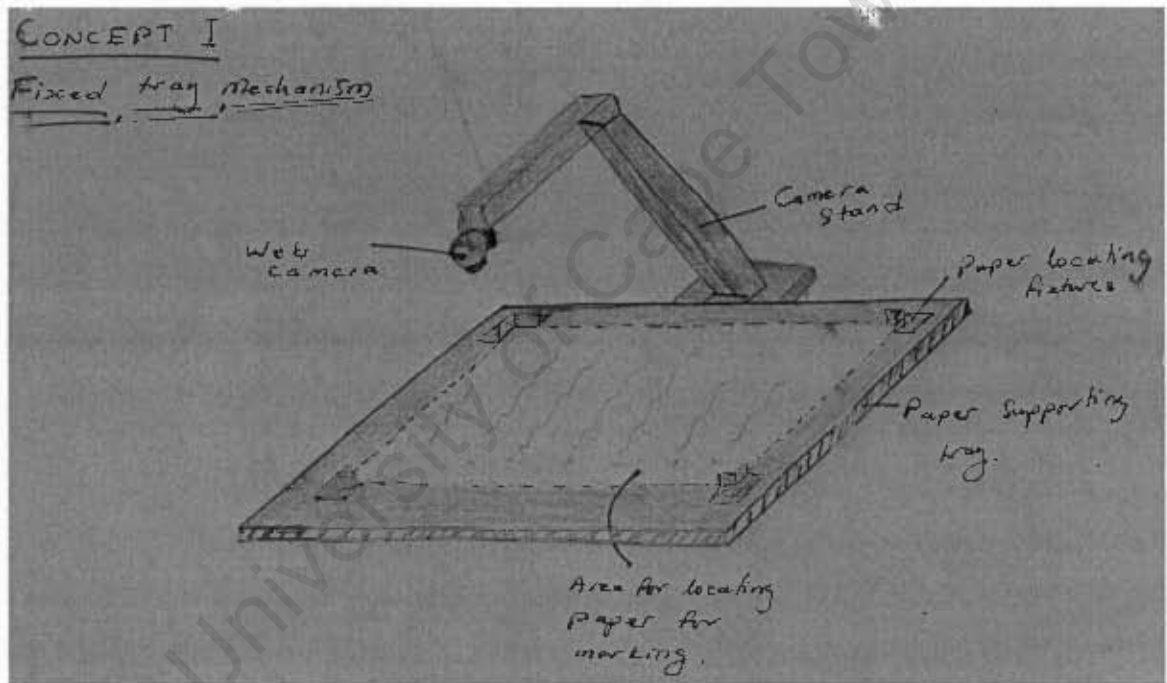


Figure 60: Fixed Base Marking Concept

**B.2.2.1 Advantages**

- Very simple to use as pictures are taken manually
- Materials readily available
- Can be made easily

**B.2.2.2 Disadvantages**

- Takes up too much time since it requires the operator to place the paper on the machine, take a picture of it and remove it.

### RAPID ASSESSMENT USING AUTOMATED MARKING

This mechanism was tested as shown below in Figure 61. Time was wasted mostly in placing the paper on the tray.

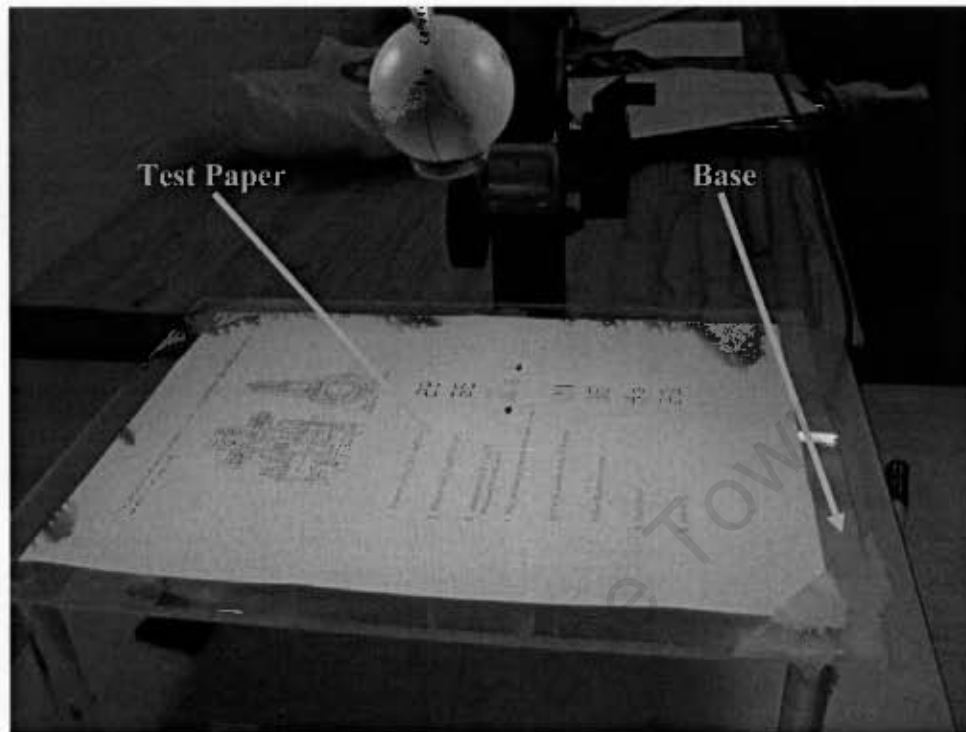


Figure 61: Fixed Base Marking Machine Picture

### B.2.3 Sliding Tray Mechanism

The sliding tray mechanism had a sliding tray having the marking area which rocked back and forth on a fixed supporting base by being pushed manually.

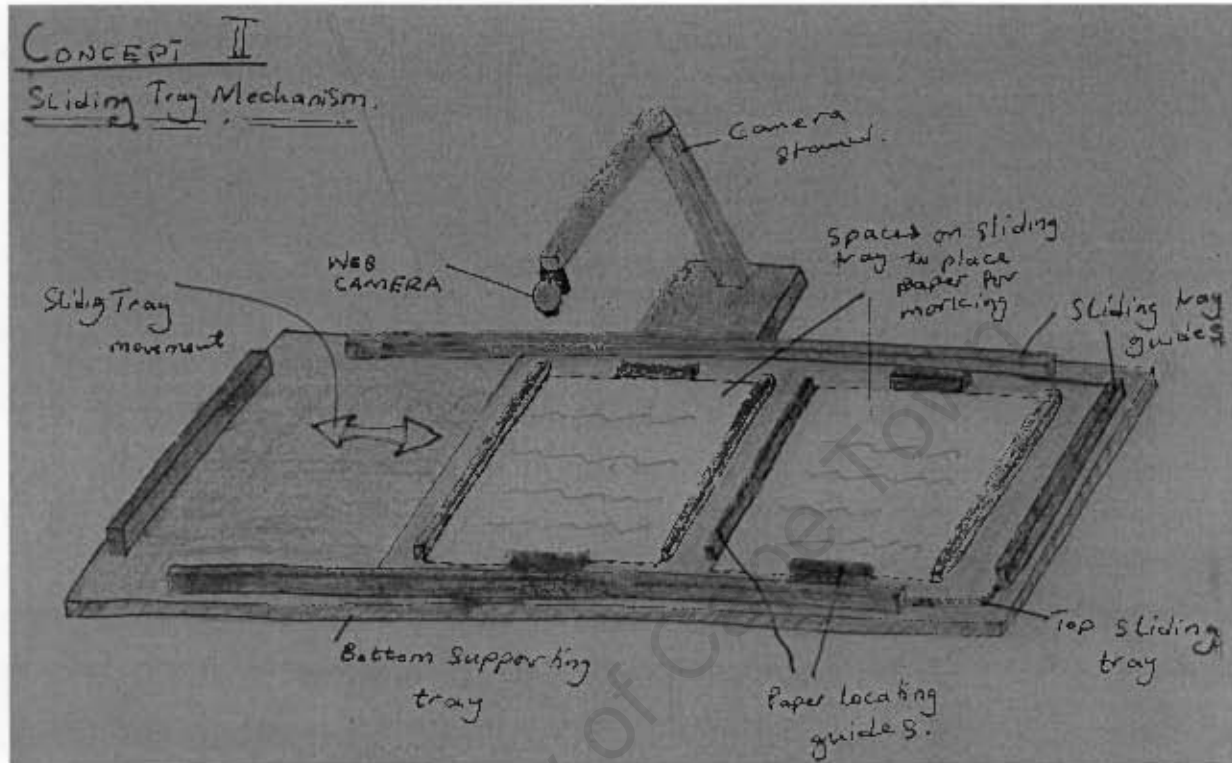


Figure 62: Sliding Tray Mechanism

The mode of operation of this concept can be explained as follows:

- Paper is placed on the sliding tray
- The tray is manually pushed to the other end and by doing so the paper is located centrally below the camera
- At the end of the base on which the sliding tray slides is a sensor which triggers the camera automatically
- A picture is taken and processed to obtain the marks.

#### B.2.3.1 Advantages

- This mechanism can easily be made with wooden materials.
- Reduced cost due to simple materials

**B.2.3.2 Disadvantages**

- To operate this marker it would be best if the mechanism were operated by two people. One to slide the tray and the other to place and remove paper on the tray. This would therefore not be very easy to use.
- The materials that would slide on each other would wear easily.
- The mechanism as conceptualised required much more space owing to the need for two A4 papers to be placed on either end of the sliding tray. This could be overcome by using only one A4 paper locator thus halving the total size.

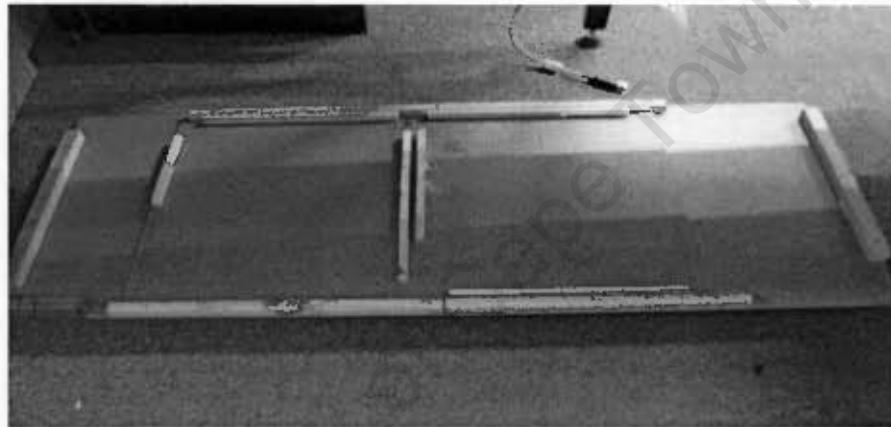


Figure 63: Sliding-Base Marker Mechanism

This concept was made and tested as shown below in Figure 64. The contact sensor is used as a triggering mechanism for the camera to start image acquisition.

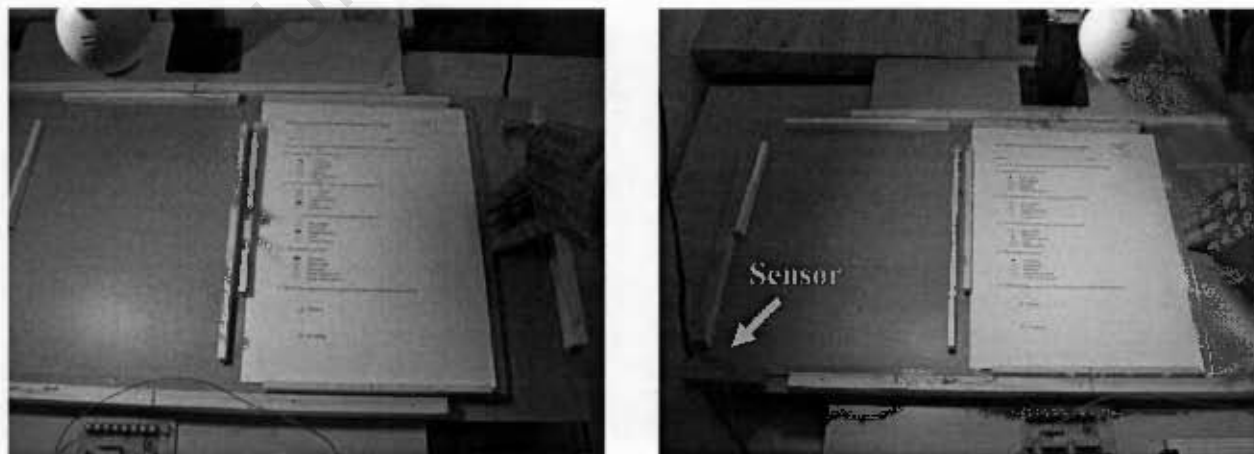


Figure 64: Sliding Tray Mechanism during Testing

### B.2.4 Sliding Paper Mechanism

This mechanism had no moving parts; the only thing that moved was the paper as it was allowed to slide down the inclined plane of the marking machine. The schematic drawing of the machine is as shown in Figure 65.

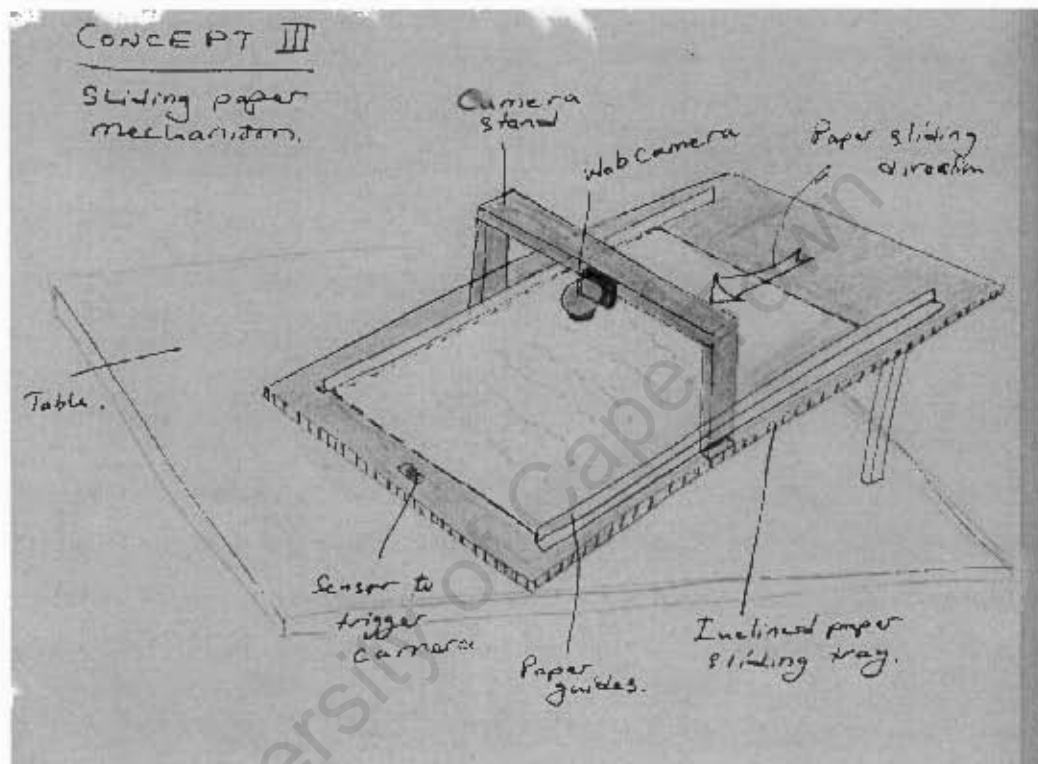


Figure 65: Sliding Paper Mechanism

The mode of operation of this concept was such that:

- A paper is placed at one end of the inclined paper sliding tray, and as a result of gravity and low friction between the paper and the tray's surface the paper slides down the inclined plane by its own weight.
- As the paper crosses the photo-reflective sensor, a trigger event occurs and a camera takes the picture of the paper that is moving underneath it.

## RAPID ASSESSMENT USING AUTOMATED MARKING

### B.2.4.1 Advantages

- No moving parts
- Concept was relatively simple to use due to reduced moving parts
- Very little human effort required

### B.2.4.2 Disadvantages

- To take a picture of a moving paper requires the use of a high speed camera which would be quite costly
- To automate the mechanism would require the use of moving parts hence make the product more complicated

Like the other two concepts this concept was built and tested to verify mode of operation. A picture of the test rig for the sliding paper concept is as shown below in Figure 66. The green arrow shows where the photo-reflective sensor was placed.

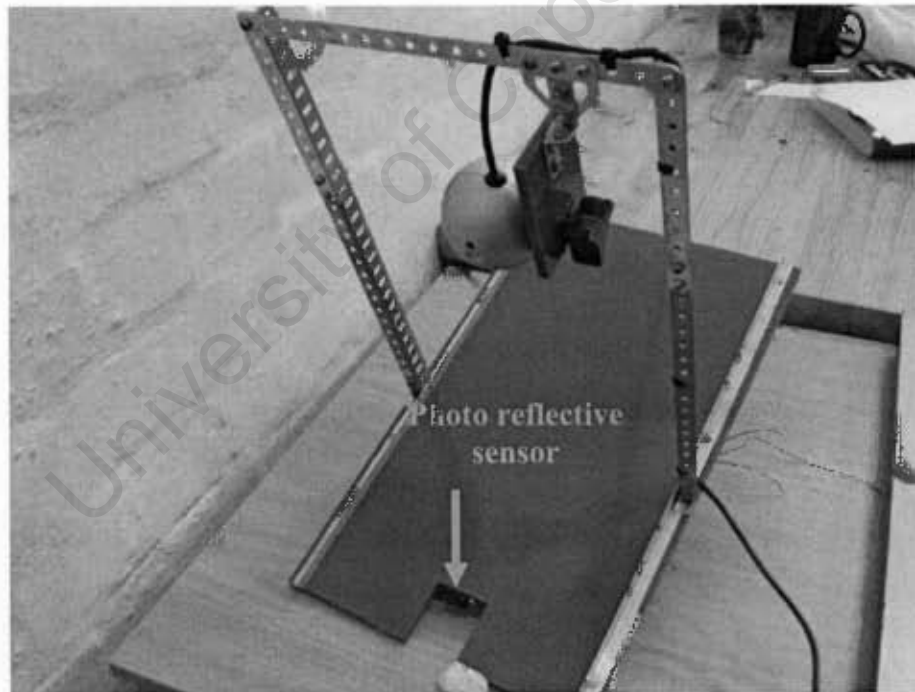


Figure 66: Sliding Paper Test Rig

**B.3 SELECTION AND JUSTIFICATION****B.3.1 Actuation****B.3.1.1 Paper Feed Mechanism**

Tests that were carried out revealed that the only distinguishing factor of the various considered concepts was the paper feed mechanism for the image acquisition process, and the triggering mechanism involved in camera activation. To make a selection of the concept to be developed further, comparisons of the strengths and weaknesses of each of these concepts were compared and weighed against each other. The concept with the highest score was accepted for further development. The three concepts are placed here in their respective order: fixed base concept, sliding tray and sliding paper mechanisms.

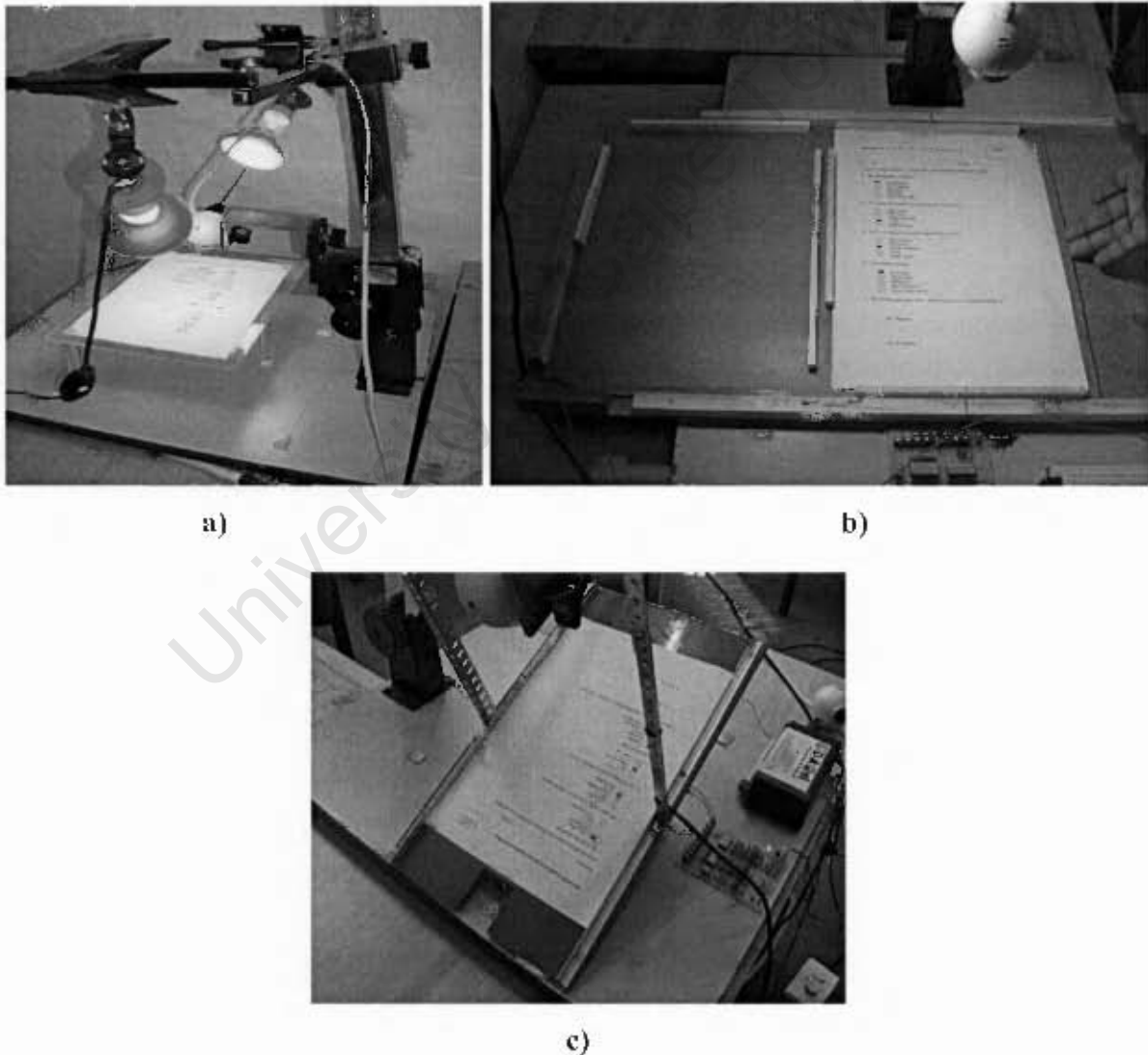


Figure 67: Design Concepts

A) Fixed Base B) Sliding Tray C) Sliding Paper

### RAPID ASSESSMENT USING AUTOMATED MARKING

Using the fixed base concept as the '*datum*', the other two concepts were weighed against it. Where "+" stood for better/easier, "-" stood for worse/harder and "S" stood for same. The total was taken, the concepts ranked with the highest rank chosen for further development.

CRITERIA	FIXED BASE CONCEPT	SLIDING TRAY CONCEPT	SLIDING PAPER CONCEPT
Ease of Use	D	-	+
Manufacturability	A	S	-
Low Weight	T	-	-
Cost	U	-	-
Safety	M	-	+
Visual Appeal		+	+
Size	D	-	+
Rate of Operation	A	+	+
$\Sigma^+$	T	2	5
$\Sigma^-$	U	5	3
$\Sigma^s$	M	1	0
<b>Net Score</b>	<b>0</b>	<b>-3</b>	<b>2</b>
<b>Rank</b>	<b>2</b>	<b>3</b>	<b>1</b>

Table 9: Concept Selection Weightings

From Table 9 above, the concept with the highest rank was the sliding paper concept. Its advantage over the other concepts stemmed from the ease of operation. The operator simply has to place the paper on the tray and the paper will:

1. Slide down the inclined plane due to its own weight
2. Automatically trigger the camera and the computer to execute the image processing code

### **B.3.1.2 Safety**

From a safety point of view, this concept was much safer to use than the other two. The fixed tray mechanism involved a lot of hand movement under the camera in placing paper on the marking space; this would lead to high probability of damage to the equipment and injury to the operator. Looking at the sliding tray mechanism, this was the only concept with moving parts. Though the reason for having the moving part was good i.e. to aid the operator trigger the camera automatically, the physical pushing and pulling of the tray makes it cumbersome to use and poses some danger to the operator.

University of Cape Town

## **B.4 CONCLUDING REMARKS**

### **B.4.1 Paper Feed Mechanism**

The concepts considered for prototype marking machine differed with the other by way of the paper feeding mechanism for image acquisition and processing. The concept that involved the least effort from the operator was the sliding paper mechanism. Though the other concepts had the potential for further improvement and development, time constraints led to the choice of the present 'best' choice. Due to the aim of finding a marking machine that could be produced with the least moving parts and ease of operation, the considered concepts were those that utilized the least technology to minimize complexity. All the considered concepts were tested and worked well, therefore rendering them suitable for development.

### **B.4.2 Trigger Mechanism**

During testing of the sliding paper mechanism, it was noticed that the camera in use was not capable of taking clear pictures of a fast moving paper. When paper was in free movement down the inclined plane, the moment it crossed the photo-reflective sensor barrier, the camera was triggered but gave a blurred image that was not suitable for processing. Among the options to resolve this hurdle was to purchase a new, faster camera, capable of obtaining clearer images of a moving paper than the current camera, i.e. obtain more than 30 frames per second. This would have increased the cost of the machine, therefore to try and keep the cost low, an idea was investigated which involved the temporary stopping of the paper for image acquisition after which it could be freed to proceed.

Several options were considered in stopping the paper. One option was to have some circuitry built using a solenoid switch which would be triggered by a sensor to open or close and hence achieve the required goal of blocking the paper. This was built by an undergraduate student and seemed to work well. The only challenge that was reported by the student as giving problems was the overheating of the solenoid which led to a gradual decline in responsiveness and hence reduction of repeatability. An alternative mechanism was then constructed and worked better than the solenoid. This involved the location of two permanent protrusions on the inclined plane of the marking machine tray which served two purposes that of stopping and aligning the paper. Upon being stopped the paper would trigger the camera by means of a photo reflective sensor after which, the same sensor would switch on two fans to propel the paper off the inclined plane. This proved to be an inexpensive and easily achievable task costing only R80.00 for the fans compared to spending more than R500=00 for a new, faster, camera.

**B.5 PROTOTYPE TESTING**

The concept chosen was designed to have few or no moving parts so as to make it simple in construction. The easiest way to achieve this was viewed to be a paper feed mechanism which was dependent mostly on gravity. The figures below show the stages of operation of the machine. Firstly the paper is fed onto the machine manually, just like a student would after writing a test, this is shown in Figure 68,

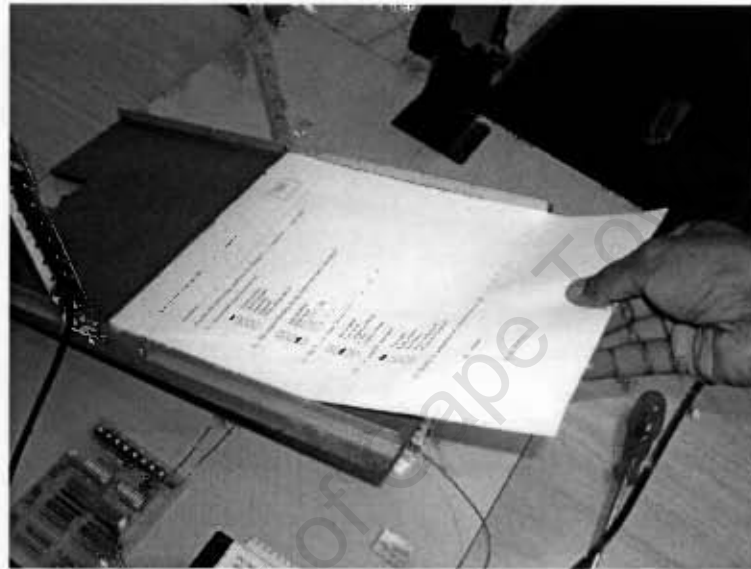


Figure 68: Placing Answer Sheet on Marking Machine

When the paper is placed on the machine, it starts to slide down the inclined smooth surface of the marker.

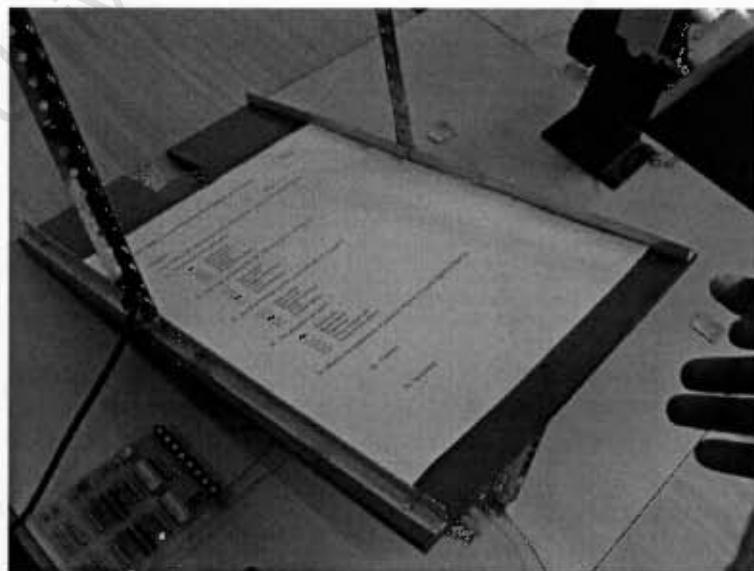


Figure 69: Paper Sliding Down the Smooth Markers Surface

## RAPID ASSESSMENT USING AUTOMATED MARKING

At the bottom end of the markers inclined plane (Figure 70) is a small slot in which a photo reflective paper sensor is fixed so that the moment the paper begins to cross the sensor rays, a trigger is sent to the camera to take a snapshot.

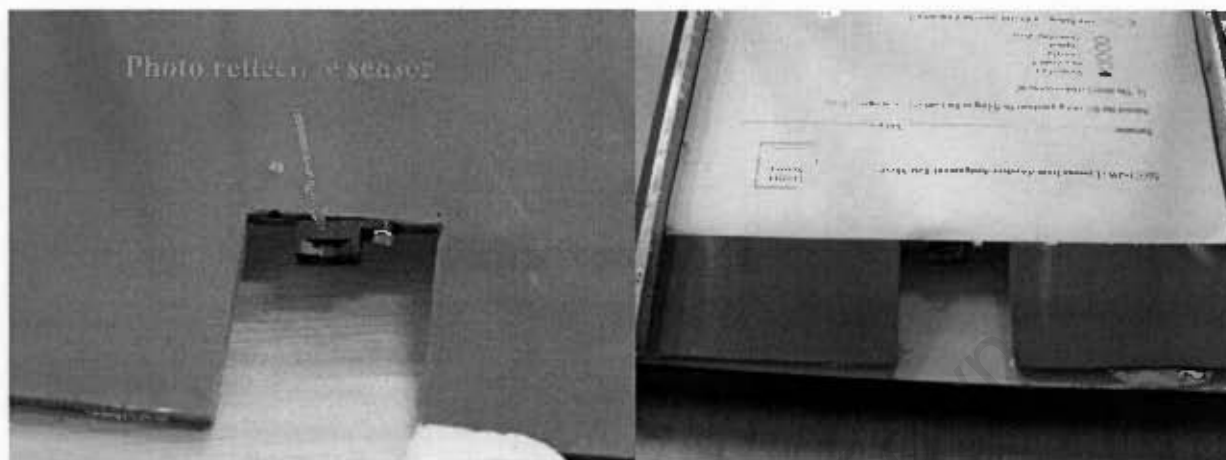


Figure 70: Paper Sensor Used As Camera Trigger

Figure 71 below shows a Data Acquisition box which is a versatile computer interfacing unit that allows easy and efficient connection of devices to a personal computer. The unit is connected to the host computer via a standard RS232 serial port. This data acquisition board has 18 input and output lines, which can be connected to a wide variety of peripherals. It is to this unit that the photo reflective sensor is connected for trigger events.



Figure 71: Data Acquisition and Control Unit

## RAPID ASSESSMENT USING AUTOMATED MARKING

When a trigger occurs, the signal is transmitted to the acquisition box which communicates with the host computer to which a camera is connected and, by using appropriate commands, the computer commands the camera to take a snapshot of the paper passing below it as shown in Figure 72.

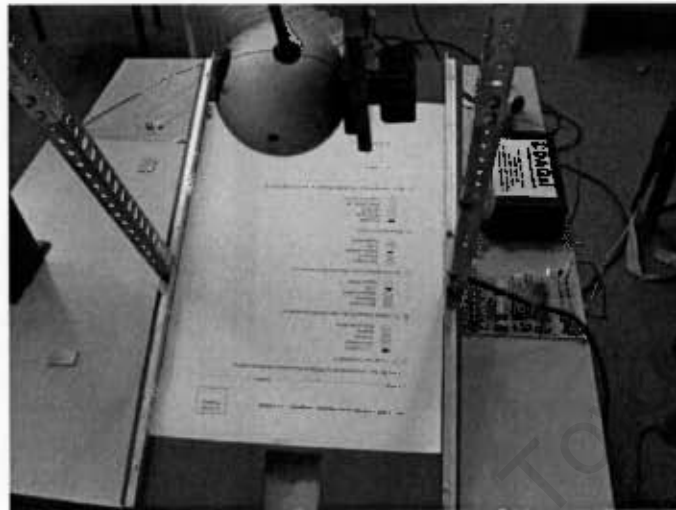


Figure 72: Snapshot of Moving Paper Taken Upon a Trigger Event

Below is a figure showing a snapshot taken as the paper crossed the photo reflective barrier Figure 73. As it can be seen, the picture still had lines of sentences and rectangular answer boxes which were either filled-in or empty. The filled-in ones were the answers given by the person tackling the test. The letters and unfilled-in boxes therefore constitute noise and have to be removed.

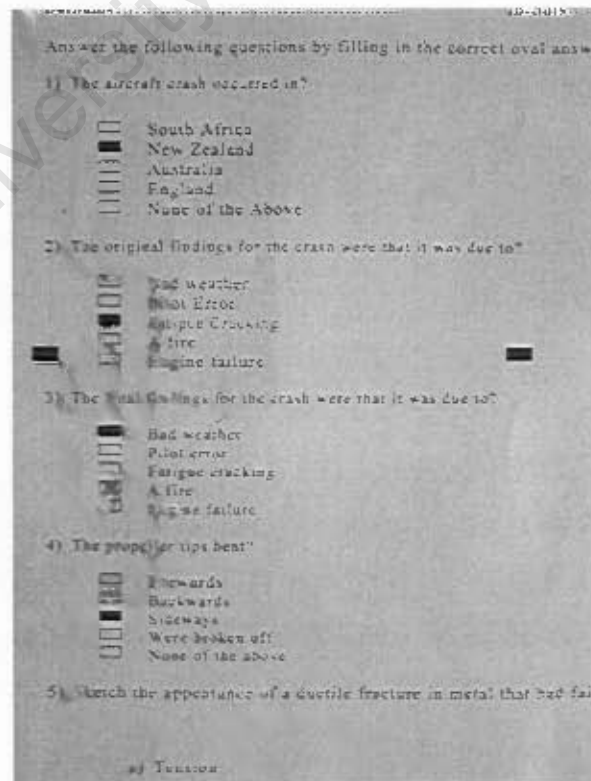


Figure 73: Snapshot of Moving Answer Paper

## RAPID ASSESSMENT USING AUTOMATED MARKING

Cleaning up of the image is done over a number of steps to complete. Figure 74 below is the same image as in Figure 73 after it has been converted to a binary image and appears to still have a lot of 'salt and pepper' noise on it. This 'noise' in the image has to be removed first before further processing of the image takes place.

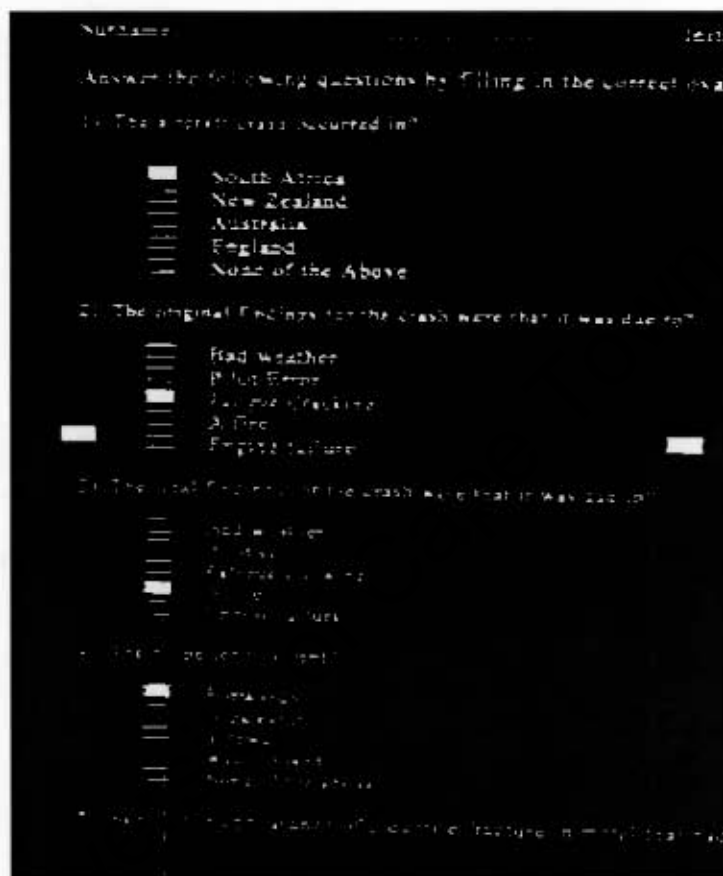


Figure 74: Image Converted to a Binary Image

Using the command 'medfilt2' this image was cleaned up automatically by the computer to produce a cleaner image while maintaining the edges of the larger objects as shown in Figure 75. For image registration (aligning one image with another) two larger rectangular points are used (shown in Figure 75) and the remaining smaller rectangles are the answer options entered by a student from Figure 73.

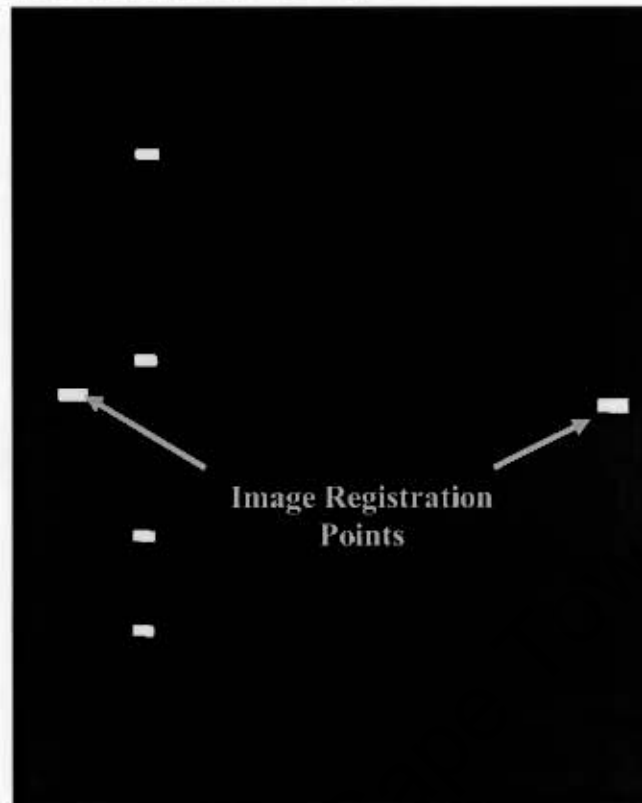


Figure 75: Clean Image used for Analysis

The image thus produced was compared to a marking key of a similar page setup but having the correct answers. The image comparison was done one question at a time by selecting successive regions of interest. At the end of the analysis, the result is printed on a 7 segment LED board as shown below in Figure 76 through the parallel port. There were four questions in the test and the LED board indicates that the student obtained a total of 4 marks, meaning that the student got all the questions correct.

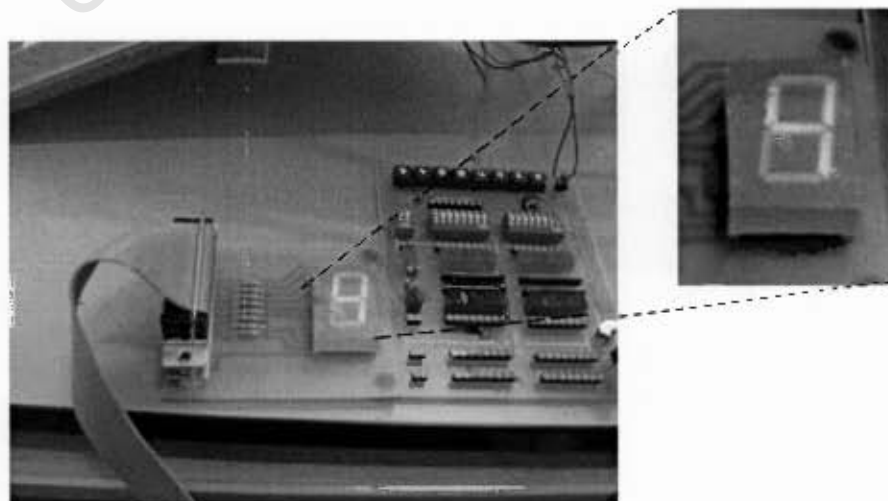


Figure 76: Seven Segment LED Board Showing Mark Obtained

#### RAPID ASSESSMENT USING AUTOMATED MARKING

By the time of testing, the camera in use was a Logitech 4000 web camera with a speed of 30 frames per minute. This restricted the experimentation to be limited to hand feeding of the papers to reduce the speed of the paper through the machine.

The explanation above has shown the practicality of the chosen concept in terms of its mode of operation and ease of use. Further advances were taken on this chosen concept to bring it to a standard that could be capable of marking not only multiple choice tests but also tests that have numerical answers.

University of Cape Town

University of Cape Town

## **C.1 INTRODUCTION**

### **C.1.1 Objective**

The purpose of this appendix was to further develop the ideas from the chosen concept in the conceptual design phase. From this section, the detailed drawings of all the parts of the machine would be drawn.

### **C.1.2 Limitations**

No major limitations existed in this section, except that due to time constraints, rapid advances were taken towards producing a prototype machine. This therefore meant that not all possible layouts of the final prototype were considered. An easily workable design was considered for the sake of time. To avoid further delays, locally available materials (University of Cape Town, Mechanical Engineering Department workshop) were used in building the frame.

### **C.1.3 Plan Of Development**

The section begins with the mechanical components that were required to develop the frame for the prototype machine. All the drawings were generated in ProENGINEER Wildfire 2. After a description of the mechanical components, the electrical components required for the machine are discussed.

## C.2 MECHANICAL COMPONENTS

### C.2.1 Paper Tray

The distinguishing factor in the chosen concept was the paper feed mechanism. The concept was based on the ability for paper to slide down an inclined plane, with reduced tilt in its orientation. This therefore led to designing a tray that could self align the paper as it went down the slope. Due to this, the tray was designed to have guides on each side.

#### C.2.1.1 Material

To reduce the weight of the machine for easy portability, a light weight material was chosen for production. The machine had to be rigid enough to withstand rough handling and drops. With this point in mind, the choice material which was both light and rigid-enough was 1.6mm thick Aluminium. The other reason for this choice was its availability in the Mechanical engineering workshop hence the component was locally made.

#### C.2.1.2 Design

From the required performance characteristics of the marking mechanism chosen, paper had to slide down the inclined plane using its own weight as the force. The inclined marking machine tray was therefore made to allow the paper to freely slide down without inhibiting its movement. When constructed, the tray was designed to have a variable angle of inclination. This therefore called for one end to be the pivot point and another to freely be adjusted up or down in the side panels.

The tray therefore was designed to have four holes, two in front and two at the back. To offer the operator enough room to place the paper on the tray, it was made a little less than two lengths of A4 paper i.e. 500mm. The Aluminium plate was bent on the two sides to create guides for paper orientation, and therefore reduce the computer program length by eliminating image registration. To further reduce the weight of the paper tray, 5 slots were made of 20mm in width and 260mm in length.

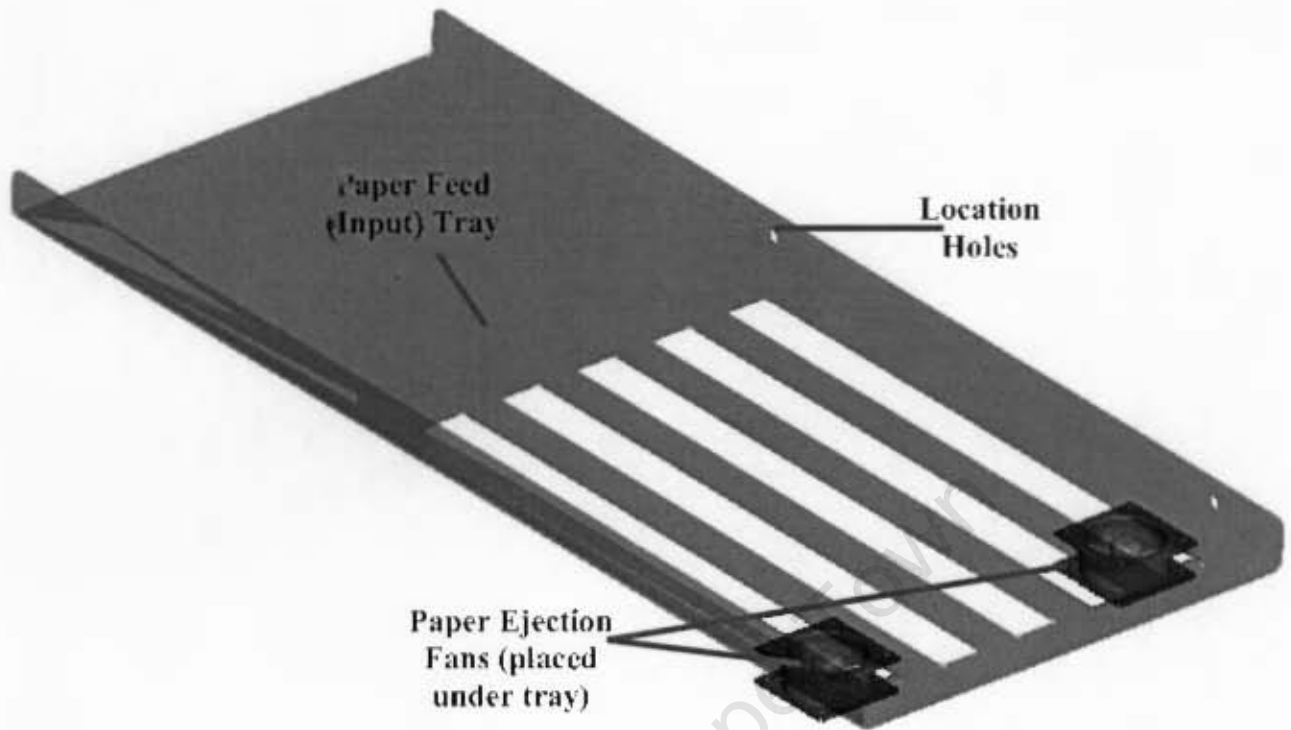


Figure 77: Paper Feed Tray

As can be seen in Figure 77, the tray was made to be longer than the lengths of an A4 paper so as to allow the paper to self align as it went sliding down the inclined tray. The four holes were made for the purposes of location and alignment to other mechanical components.

Dimensions	Length (mm)	Width (mm)	Height (mm)
Paper Tray	500	213.2	20

Table 10: Paper Tray Dimensions

**C.2.2 Side Panel**

To support the paper feed tray mechanism, two side panels would be needed, one on each side of the tray. It was designed to have a slot as shown so that the angle of inclination of the tray could be altered when in use depending on the speed of marking required. The higher the angle the faster the paper would slide down the tray and the opposite is true.

**C.2.2.1 Material**

Light weight material was also chosen for the side panels to help in reducing the weight and provide rigidity. Therefore, the choice material was again 1.6mm thick Aluminium.

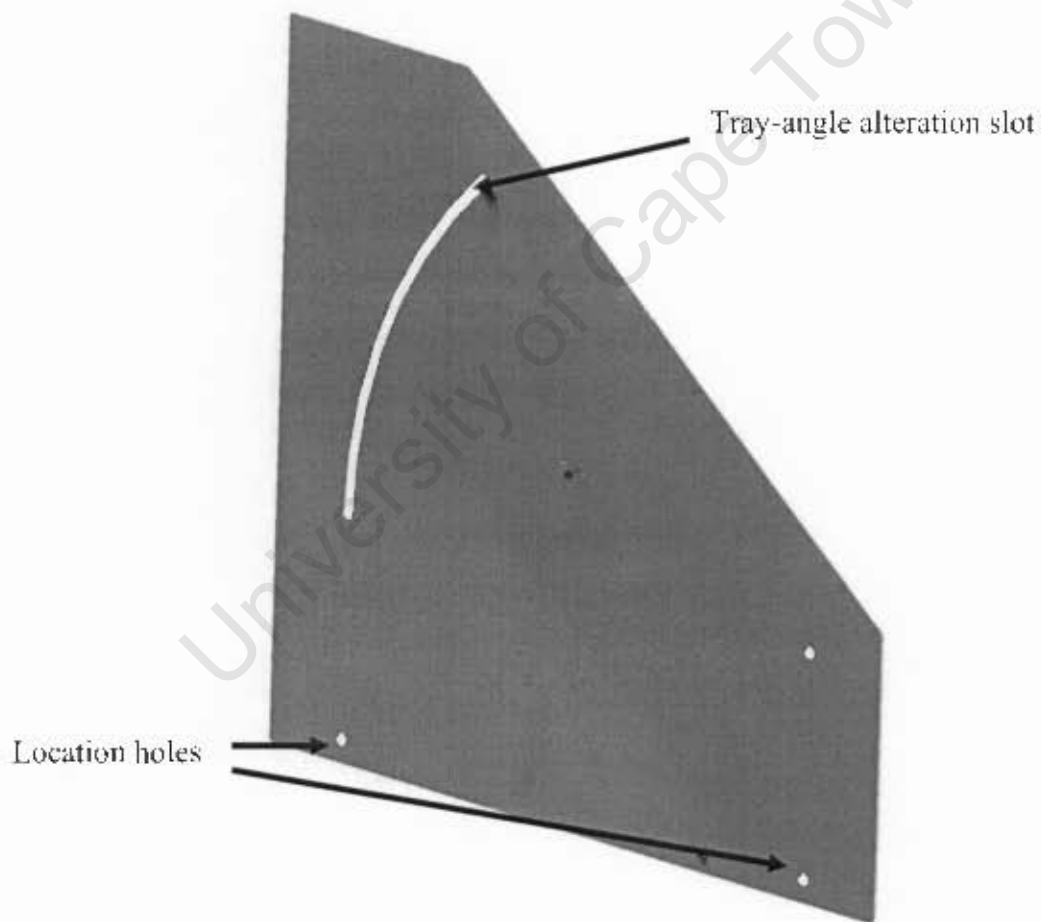


Figure 78: Side Panel Layout for Marking Machine

**C.2.2.2 Design**

The tray was to be supported by the side panels. The paper sliding down the tray was also to be given enough clearance to be collected at the bottom end of the tray. The supporting side panels were therefore designed to have a higher value for height and have enough location and support holes as shown in Figure 78.

Dimensions	Length (mm)	Thickness (mm)	Height (mm)
Side panels	340	1.6	350

Table 11: Side Panel Dimensions

**C.2.3 Base Mounting**

As an aid in support and stability, the side panels would be secured at the bottom through the location holes to the base mounting plate which was also made of 1.6mm thick aluminum. In this way, the assembly would have more stability from this base. The component was not made as shown in the figure below but was made by spot welding of the two side panels to a flat sheet of aluminium with added reinforcement by means of "L" shaped plates. This change did not change did not affect the design intent in anyway as it performed the task expected of the original base mounting.

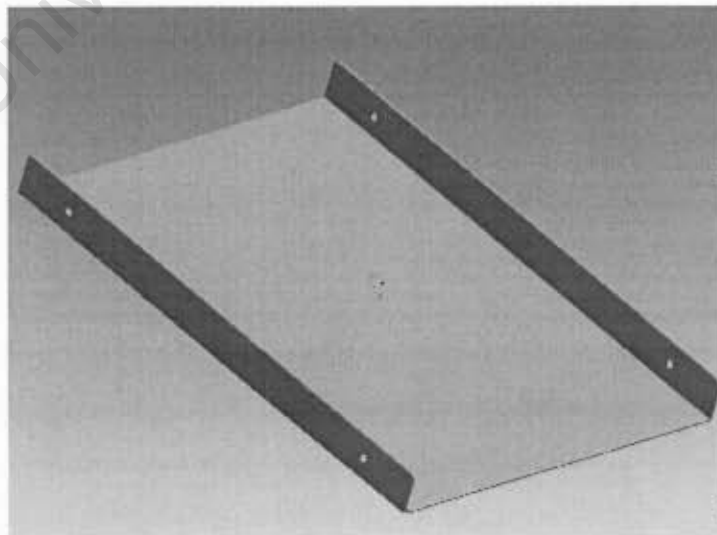


Figure 79: Base Mounting Plate

The basic dimensions for the base are as shown below in Table 12. Holes were drilled in the plate for location purposes and for mounting the side panels.

Dimensions	Length (mm)	Width (mm)	Height (mm)
Base Mounting Plate	340	221	350

Table 12: Base Mounting Plate Dimensions

#### C.2.4 Tray Cover

It was noticed during testing in the conceptual phase that, the marking machine had inconsistencies in its output depending on the brightness of the room. Varying light intensity in the room led to the inconsistencies in the image processing stage of the marking process. To solve this challenge, investigations were conducted into ways to maintain a constant illumination in the camera's field. It was noticed that the camera had a low light filter, which automatically increased its own ability to capture images in a low light environment. This ability was taken advantage of; as a result, a translucent cover to restrict the amount of light entering the camera's view was designed.

##### C.2.4.1 Material

With the requirement of reducing the amount of external light entering the camera's view, a Perspex cover was designed and was noticed to work very effectively by minimizing the 'noise' caused by external light influence.

##### C.2.4.2 Design

The cover had to achieve two purposes; to minimize the amount of light entering the camera's view and hold the camera in place. This was achieved by drilling a hole through the top of the cover (shown in **Figure 80**) for the placement of the camera holding fixture (camera handle and support). These also enabled the ability to lower, raise and orient the camera without having to dismantle the cover once in place.

RAPID ASSESSMENT USING AUTOMATED MARKING

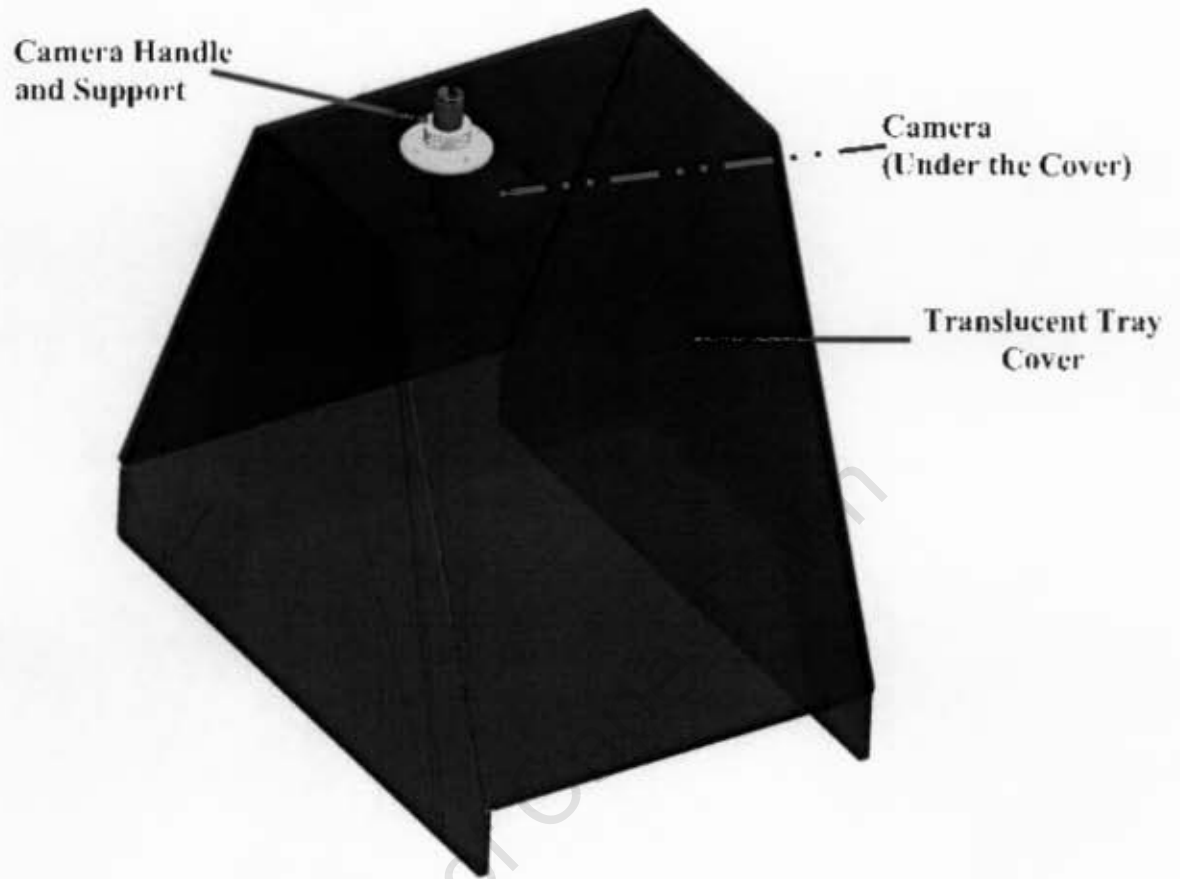


Figure 80: Cover and Camera-Handle Location Hole

## C.2.5 Complete Assembly

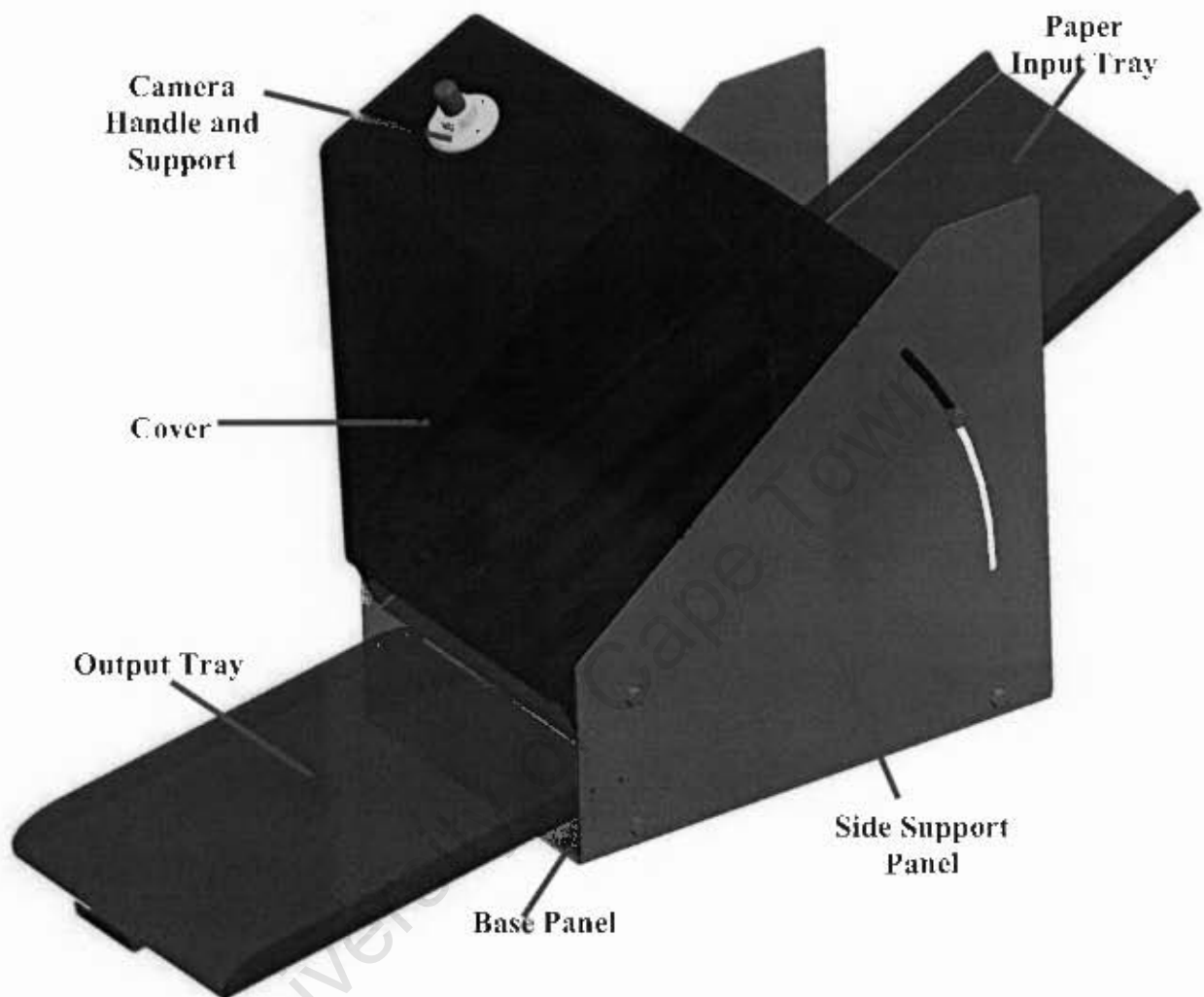


Figure 81: Marking Machine Main Frame

When all the parts are placed assembled, the marking machine takes up the form depicted in Figure 81 above. The figure illustrates the design intent in that it shows the slope required in the tray and the support provided by the side panels and the base plate. Once the required slope of the tray is decided upon and adjusted accordingly, the bolts are fastened to hold the tray in place for the running of the machine. After marking is over and the paper has been ejected from the machine, it is collected on the output tray to avoid papers flying around or dropping to the floor.

### C.3 CONCLUDING REMARKS

The design of the prototype marking machine presented in this section proves the theory that marking of students scripts can be performed by using parts that are locally available or can be sourced easily by interested personnel.

The frame of the machine has been made from Aluminium and therefore is quite light and portable. It can also withstand some reasonable amount of shock due to the rigidity of the frame. The cover is made of 4mm thick perspex which reduces the amount of light entering the field of the camera to minimise effects of external light and also serves the purpose of holding the camera in place. To lower or raise the camera for the purpose of focusing and orienting it is achieved by pushing and pulling the shaft to which it is fastened.

The electrical components can be sourced from local shops but require some familiarity with computer programming to correctly interface them for correct application. Otherwise they are not computer programming intensive.

The software part of the machine is the most critical and performs most of the tasks that the machine is expected to do. Further modifications need to be done to have the computer programming functioning accurately and needing very little effort from the operator. It must be mentioned here that character recognition by means of web cameras has just only began to be investigated due to the relatively poor quality of images from cameras compared to those obtained from scanners. This gap is becoming ever so small with the new cameras produced pictures of very high quality.

**APPENDIX D — CODE LISTING**

University of Cape Town

## **D.1 INTRODUCTION**

### **D.1.1 Objective**

The purpose of this appendix is to list all the computer programmes used in operating the marking machine. Here, the actual code is explained especially pertaining to the most important functions that each section of code performs.

### **D.1.2 Plan of Development**

The Image acquisition, Image processing and character recognition sections of the code are listed first.

### **D.1.3 Limitations**

The author is proficient with Matlab as a computer programming platform, but is not an expert in computer programming. Therefore, the code listed here leaves room for improvement by computer programming experts.

University of Cape Town

## D.2 CODE LISTING

```

%% Image acquisition
% The purpose of this section of the program is to create an image
% acquisition object.

clear all           %This clears the workspace
close all          %This closes all open ports
clc                %this clears the command window

%% Creating Video input object
vid = videoinput('winvideo',1,'RGB24_640x480'); %This creates the input object

%% Preview the image to adjust focus
preview(vid)       %Preview the image stream from video camera

%% Several regions of interest of figure X1 are declared here for processing
roi = [148 118 42 26;238 90 47 81;328 116 44 26;553 87 45 82];

%% Name and answer's Identification
N_field = [140 26 45 248]; % Region in image with students number

alph = [65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 ...
        87 88 89 90];

nbra = [49 50 51 52 53 54 55 56 57 48];

%% This section lists the regions of interest in image X1 for processing
str_all = ones(3); %Structuring element

%=====

```

## RAPID ASSESSMENT USING AUTOMATED MARKING

```
function [numbers,targets_n] = numsech()[29]
% NUMSECH Character recognition problem definition
% [NUMBERS,TARGETS_N] = NUMSECH() Returns:
% CHARACTERS - 140x10 matrix of 10x14 bit maps for the numbers 0 to 9.
% TARGETS - 10x10 target vectors.
```

```
number0 = [0 1 1 1 1 1 1 1 0 ...
            1 1 1 1 1 1 1 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 0 0 0 0 0 0 1 1 ...
            1 1 1 1 1 1 1 1 1 ...
            0 1 1 1 1 1 1 1 0 ]';
```

```
number1 = [0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 0 1 1 0 0 0 0 ...
            0 0 0 1 1 1 0 0 0 0 ...
            0 0 0 1 1 1 0 0 0 0 ]';
```

```
number2 = [1 1 1 1 1 1 1 1 0 ...
            1 1 1 1 1 1 1 1 1 ...
            0 0 0 0 0 0 0 0 1 1 ...
            0 0 0 0 0 0 0 0 1 1 ...
            0 0 0 0 0 0 0 0 1 1 ...
            0 0 0 0 0 0 0 0 1 1 ...
            0 0 0 0 0 0 0 0 1 1 ...
            0 1 1 1 1 1 1 1 1 ...
            1 1 1 1 1 1 1 1 0 ...
            1 1 0 0 0 0 0 0 0 0 ...
            1 1 0 0 0 0 0 0 0 0 ...
            1 1 0 0 0 0 0 0 0 0 ...
            1 1 0 0 0 0 0 0 0 0 ...
            1 1 1 1 1 1 1 1 1 ...
            0 1 1 1 1 1 1 1 1 ]';
```





## RAPID ASSESSMENT USING AUTOMATED MARKING

SUCTNUM number recognition [29]

```

% NEWFF - Initializes feed-forward networks.
% TRAINGDW - Trains a feed-forward network with faster backpropagation.
% STM - Simulates feed-forward networks.

% NUMBER RECOGNITION:
% Using the above functions a feed-forward network is trained
% to recognize NUMBER bit maps, in the presence of noise.

% DEFINING THE MODEL PROBLEM
% -----
% The script file NUMSECH defines a matrix NUMBERS
% which contains the bit maps of the numbers 0 to 9.
% This file also defines target vectors TARGETS for
% each number. Each target vector has ten elements with
% all zeros, except for a single 1. One has a 1 in the
% first element, Two in the second, etc.

[numbers,targets_n] = numsech;
[Rn,Qn] = size(numbers);
[S2n,Qn] = size(targets_n);

% DEFINING THE NETWORK
% -----
% The character recognition network will have 25 TANSIG
% neurons in its hidden layer.

S1n = 10;
netn = newff(minmax(numbers),[S1n S2n],{'logsig' 'logsig'},'traingdx');
netn.LW(2,1) = netn.LW(2,1)*0.01;
netn.b(2) = netn.b(2)*0.01;

% TRAINING THE NETWORK WITHOUT NOISE
% -----

netn.performFcn = 'sse'; % Sum-Squared Error performance function
netn.trainParam.goal = 0.1; % Sum-squared error goal.
netn.trainParam.show = 20; % Frequency of progress displays (in epochs).
netn.trainParam.epochs = 5000; % Maximum number of epochs to train.
netn.trainParam.mc = 0.95; % Momentum constant.

Pn = numbers;
Tn = targets_n;

[netn,trn] = train(netn,Pn,Tn);
% TRAINING THE NETWORK WITH NOISE
% -----

% A copy of the network will now be made. This copy will
% be trained with noisy examples of numbers.

netn_n = netn;

netn_n.trainParam.goal = 0.6; % Mean-squared error goal.
netn_n.trainParam.epochs = 300; % Maximum number of epochs to train.

```

## RAPID ASSESSMENT USING AUTOMATED MARKING

5 The network will be trained on 10 sets of noisy data.

```
Tn = [targets_n targets_n targets_n targets_n];
for pass = 1:10
    fprintf('Pass = %d of %d\r', pass);
    Pn = [numbers, numbers, ...
          (numbers + randi(Rn, Qn)*0.1), ...
          (numbers + randi(Rn, Qn)*0.2)];
    [netn_n, trn] = train(netn_n, Pn, Tn);
    echo off
end
echo on
```

5 TRAINING THE SECOND NETWORK WITHOUT NOISE

5

5 The second network is now retrained without noise to  
5 insure that it correctly categorizes non-noisy numbers.

```
netn_n.trainParam.goal = 0.1; % Mean-squared error goal.
netn_r.trainParam.epochs = 500; % Maximum number of epochs to train.
netn_r.trainParam.show = 0; % Frequency of progress displays (in epochs).
```

```
Pn = numbers;
Tn = targets_n;
```

```
[netn_n, trn] = train(netn_n, Pn, Tn);
```

## RAPID ASSESSMENT USING AUTOMATED MARKING

```
function [alphabet,targets] = charsech()
% CRSECF Character recognition: problem definition
% [ALPHABET,TARGETS] = CFARSECF() Returns:
% ALPHABET - 140x26 matrix of 10x14 bit maps for each letter of the
% alphabet.
% TARGETS - 26x26 target vectors.
```

```
letterA = [0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 1 1 1 1 0 0 0 ...
           0 0 1 1 0 0 1 1 0 0 ...
           0 1 1 0 0 0 0 1 1 0 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 1 1 1 1 1 1 1 1 ...
           1 1 1 1 1 1 1 1 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ]';
```

```
letterB = [1 1 1 1 1 1 1 1 0 0 ...
           1 1 1 1 1 1 1 1 1 0 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 0 ...
           1 1 1 1 1 1 1 1 1 0 ...
           1 1 1 1 1 1 1 1 1 0 ...
           1 1 0 0 0 0 0 0 1 1 0 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 1 1 1 1 1 1 1 0 ...
           1 1 1 1 1 1 1 1 1 0 ]';
```

```
letterC = [0 0 1 1 1 1 1 1 0 0 ...
           0 1 1 1 1 1 1 1 1 0 ...
           1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 1 1 ...
           0 1 1 1 1 1 1 1 1 0 ...
           0 0 1 1 1 1 1 1 0 0 ]';
```











## RAPID ASSESSMENT USING AUTOMATED MARKING

```
letterX = [1 0 0 0 0 0 0 0 0 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           0 1 1 0 0 0 0 1 1 0 ...
           0 1 1 0 0 0 1 1 0 0 ...
           0 0 1 0 1 1 1 0 0 0 ...
           0 0 1 1 0 1 1 0 0 0 ...
           0 0 0 1 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 1 1 0 1 1 0 0 ...
           0 0 1 1 0 0 1 0 0 ...
           0 0 1 1 0 0 0 1 1 0 ...
           0 1 0 0 0 0 1 1 0 ...
           1 1 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 1 1 ]';
```

```
letterY = [1 1 0 0 0 0 0 0 1 1 ...
           1 1 0 0 0 0 0 0 1 1 ...
           0 1 1 0 0 0 0 1 1 0 ...
           0 1 1 0 0 0 0 1 1 0 ...
           0 0 1 1 0 0 1 1 0 0 ...
           0 0 1 1 0 0 1 1 0 0 ...
           0 0 0 1 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ...
           0 0 0 0 1 1 0 0 0 0 ]';
```

```
letterZ = [1 1 1 1 1 1 1 1 1 1 ...
           1 1 1 1 1 1 1 1 1 1 ...
           0 0 0 0 0 0 0 0 1 1 ...
           0 0 0 0 0 0 0 0 1 1 ...
           0 0 0 0 0 0 0 0 1 0 ...
           0 0 0 0 0 0 1 0 0 0 ...
           0 0 0 0 0 1 1 0 0 0 ...
           0 0 0 0 1 0 0 0 0 0 ...
           0 0 0 1 0 0 0 0 0 0 ...
           0 0 1 0 0 0 0 0 0 0 ...
           0 1 1 0 0 0 0 0 0 0 ...
           1 1 0 0 0 0 0 0 0 0 ...
           1 1 1 1 1 1 1 1 1 1 ...
           1 1 1 1 1 1 1 1 1 1 ]';
```

```
alphabet = [letterA, letterB, letterC, letterD, letterE, letterF, letterG, letterH, ...
            letterI, letterJ, letterK, letterL, letterM, letterN, letterO, letterP, ...
            letterQ, letterR, letterS, letterT, letterU, letterV, letterW, letterX, ...
            letterY, letterZ];
```

```
targets = eye(26);
```

## RAPID ASSESSMENT USING AUTOMATED MARKING

NETCHAR character recognition. [29]

```

% NEWFF - Initializes feed-forward networks.
% TRAINGDx - Trains a feed-forward network with faster backpropagation.
% SIM - Simulates feed-forward networks.

% ALPHABET LETTER RECOGNITION:
% Using the above functions a feed-forward network is trained
% to recognize ALPHABET bit maps, in the presence of noise.

% DEFINING THE MODEL PROBLEM
% =====

% The script file CRSECH defines a matrix CHARACTERS
% which contains the bit maps of the 26 letters of the
% alphabet.

% This file also defines target vectors TARGETS for
% each letter. Each target vector has 26 elements with
% all zeros, except for a single 1. A has a 1 in the
% first element, B in the second, etc.

[alphabet,targets] = charsect;
[RL,QL] = size(alphabet);
[S2L,QL] = size(targets);
% DEFINING THE NETWORK
% =====
% The character recognition network will have 25 TANSIG
% neurons in its hidden layer.

S1L = 10;
netL = newff(minmax(alphabet),[S1L S2L],{'logsig' 'logsig'},'traingdx');
netL.LW{2,1} = netL.LW{2,1}*0.01;
netL.b{2} = netL.b{2}*0.01;

% TRAINING THE NETWORK WITHOUT NOISE
% -----

netL.performFcn = 'mse'; % Sum-Squared Error performance function
netL.trainParam.goal = 0.1; % Sum-squared error goal.
netL.trainParam.show = 20; % Frequency of progress displays (in epochs).
netL.trainParam.epochs = 5000; % Maximum number of epochs to train.
netL.trainParam.mc = 0.95; % Momentum constant.
PL = alphabet;
TL = targets;
[netL,trL] = train(netL,PL,TL);
% TRAINING THE NETWORK WITH NOISE
% =====
% A copy of the network will now be made. This copy will
% be trained with noisy examples of letters of the alphabet.

netL_L = netL;
netL_L.trainParam.goal = 0.6; % Mean-squared error goal.
netL_L.trainParam.epochs = 300; % Maximum number of epochs to train.

% The network will be trained on 10 sets of noisy data.
TL = [targets targets targets targets];

```

## RAPID ASSESSMENT USING AUTOMATED MARKING

```
for pass = 1:10
    fprintf('Pass = %.0f\n',pass);
    Pn = [alphabet, alphabet, ...
        (alphabet + randn(RL,QL)*0.1), ...
        (alphabet + randn(RL,QL)*0.2)];
    [netL_L,trl] = train(netL_L,Pn,Tn);
    echo off
end
echo on

% TRAINING THE SECOND NETWORK WITHOUT NOISE
% =====
% The second network is now retrained without noise to
% insure that it correctly categorizes non-noisy letters.

netL_L.trainParam.goal = 0.1; % Mean-squared error goal.
netL_L.trainParam.epochs = 500; % Maximum number of epochs to train.
netL_L.trainParam.show = 5; % Frequency of progress displays (in epochs).

PL = numbers;
TL = targets_n;
[netL_L,trl] = train(netL_L,PL,TL);
```

University of Cape Town

## RAPID ASSESSMENT USING AUTOMATED MARKING

```

%% Main Code Begins Here

%% Obtain picture for comparison
pic1 = getsnapshot(vid);

%% Convert Image from an RGB to a greyscale image
pic1_gry = rgb2gray(pic1);

crp = imcrop(pic1_gry,N_field); % Name Field pre processing
bw_level = graythresh(crp);
BW = im2bw(crp,bw_level);
BW = imrotate(BW,-90);
BW = imcomplement(BW);
BW = medfilt2(BW);
BW = imclose(imopen(BW, 'str_e11'), 'str_e11');
base = bwrc2open(BW,40);
imtool(base)

%% Bounding box creation for each character
[BW_label num] = bwlabel(base);
BW_props = regionprops(BW_label);
BW_box = [BW_props.BoundingBox];
BW_box = reshape(BW_box, 4 num);

%% Obtaining the centroid of each character
BW_c = [BW_props.Centroid];
BW_c = reshape(BW_c, [2 num]);
BW_c = BW_c';
BW_c(:,3) = (mean(BW_c.^2,2)).^(1/2);
BW_c(:,4) = 1:num;
BW_c2 = sortrows(BW_c,2);

%%
for cnt = 1
    BW_c2((cnt-1)*num+1:cnt*num,:) = sortrows(BW_c2((cnt-1)*num+1:cnt*num,:),4);
end

BW_c3 = BW_c2(:,1:2);
ind = BW_c2(:,4);

for cnt = 1:num
    img(cnt) = imcrop(base,BW_box(:,ind(cnt)));
end
%%
for cnt = 1:num
    bw2 = imcrop(img(cnt));
    charvec = im_resize(bw2);
    out(:,cnt) = charvec;
end

name_letters = out(:,1:6);
name_numbers = out(:,7:9);
[st_l,n_letters] = min(sim(netL_5,name_letters));
[st_n,n_numbers] = min(sim(netn_n,name_numbers));

st_number = char([alph(n_letters) nbrs(n_numbers)]);

%% This section of code goes through a loop to process each answer in the

```

## RAPID ASSESSMENT USING AUTOMATED MARKING

88 image. Note that this section utilises the same variables as the  
89 previous section. This works well and also reduces memory usage.

85 Pre processing the image for numbers

```
m=0;
answers = [];
for k = 1:size(roi,1)
    m = m + 1;
86
    crop = imcrop(pict_gry, [roi(m,:)]);
    BW = im2bw(crop, graythresh(crop));
    BW = imrotate(BW, -90);
    BW = medfilt2(BW);
    BW = imclose(imopen(BW, str_c11), str_c11);
    base = bwareaopen(BW, 50);
```

87 Bounding box creation for each character

```
[BW_label num] = bwlabel(base);
BW_props = regionprops(BW_label);
BW_box = [BW_props.BoundingBox];
BW_box = reshape(BW_box, [4 num]);
```

88 Obtaining the centroid of each character

```
BW_c = [BW_props.Centroid];
BW_c = reshape(BW_c, [2 num]);
BW_c = BW_c';
BW_c(:,3) = (mean(BW_c.^2,2)).^(1/2);
BW_c(:,4) = 1:num;
BW_c2 = sortrows(BW_c,2);
```

89

```
for cnt = 1
    BW_c2((cnt-1)*num+1:cnt*num,:) = sortrows(BW_c2((cnt-1)...
        *num+1:cnt*num, :),4);
end
```

```
BW_c3 = BW_c2(:,1:2);
ind = BW_c2(:,4);
```

```
for cnt = 1:num
    img(cnt) = imcrop(base, BW_box(:, ind(cnt)));
end
```

90

```
for cnt = 1:num
    bw2 = im_crop(img(cnt));
    charvec = im_resize(bw2);
    out(:,cnt) = charvec;
end
```

```
Psim = out(:,1:num);
[A,B] = min(sim(netn n, Psim));
value = str2num(char(nbrs(B)));
answers = [answers value];
```

end

University of Cape Town

---

**E.1 INTRODUCTION**

---

The design process carries with it the requirements of assembly and part drawings. To that effect, a set of drawings for the marking machines frame are here incorporated.

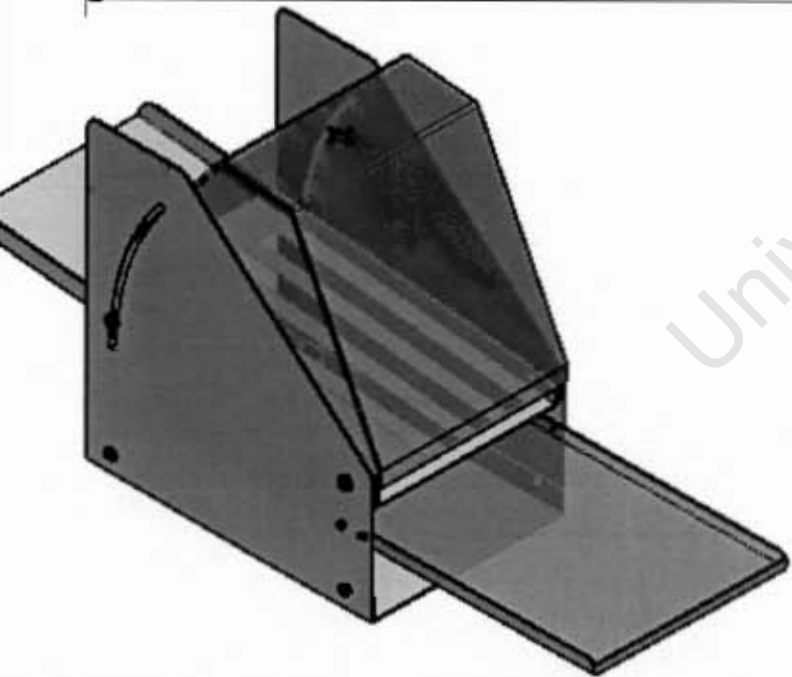
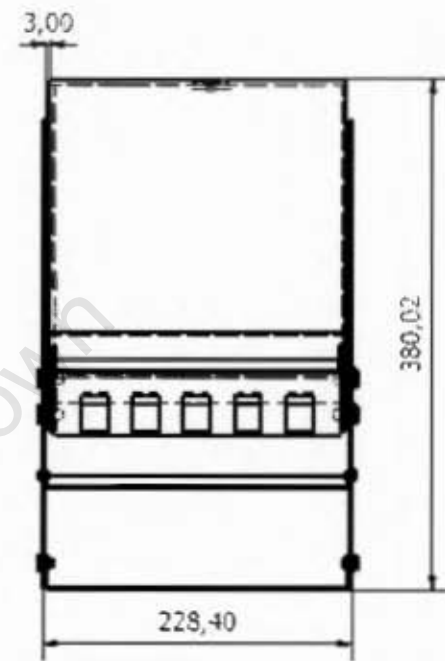
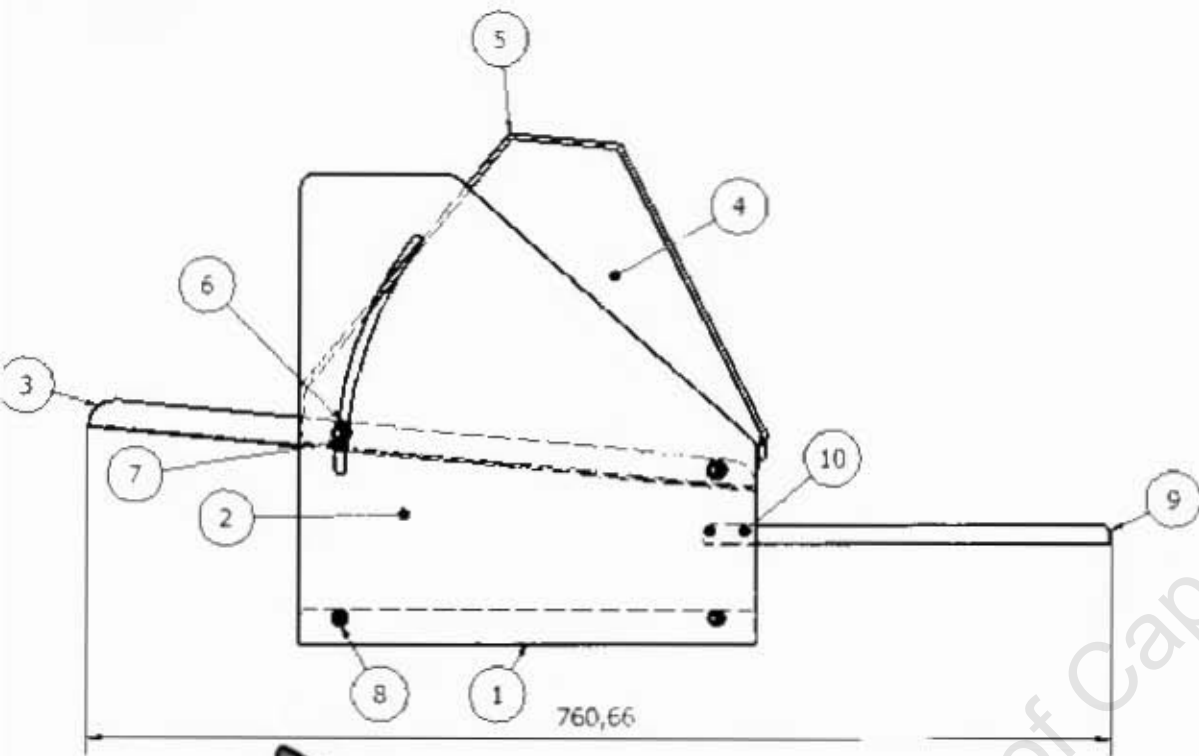
**E.1.1 Objective**

The objective of this section was to present the drawings used for producing the marking machine. Only the mechanical frame and paper transportation tray drawings are presented.

**E.1.2 Breakdown**

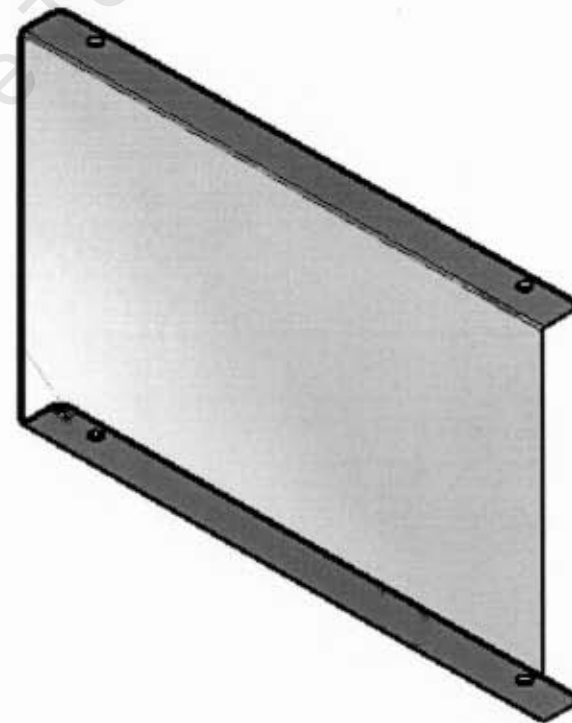
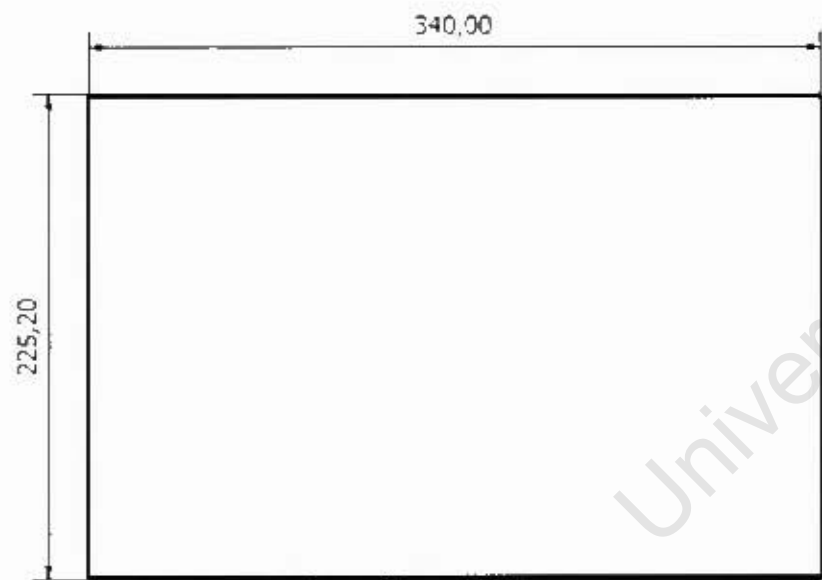
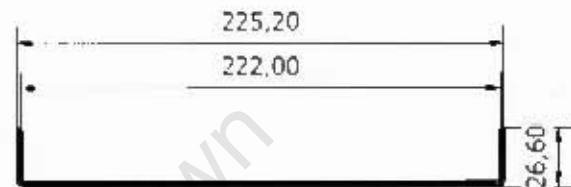
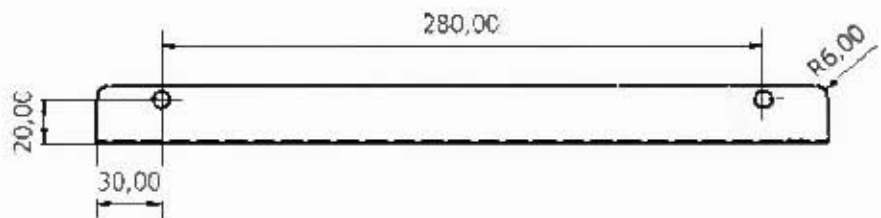
The first drawing shows the full assembly of the marking machine. Then the various part drawings are presented.

University of Cape Town

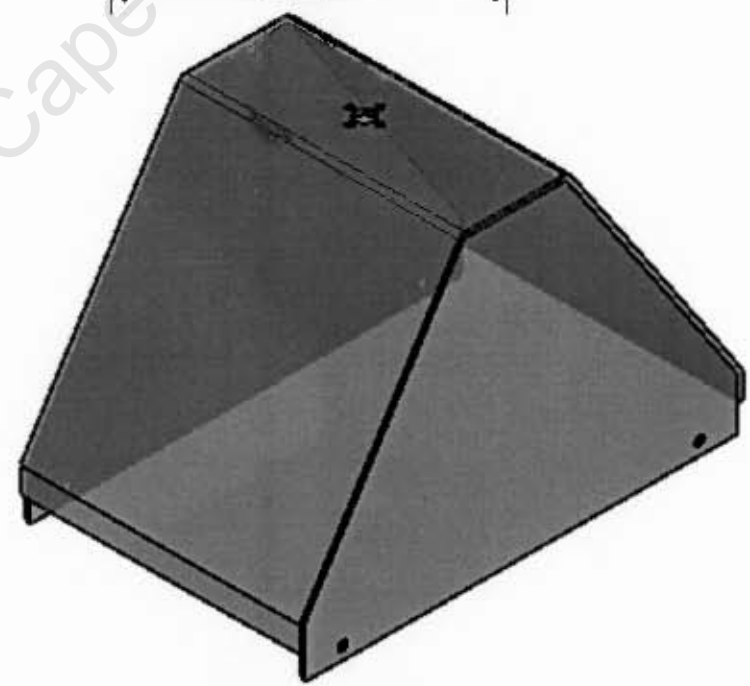
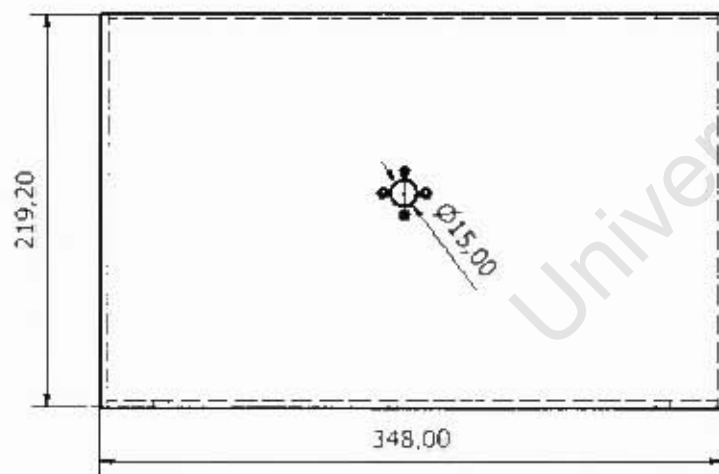
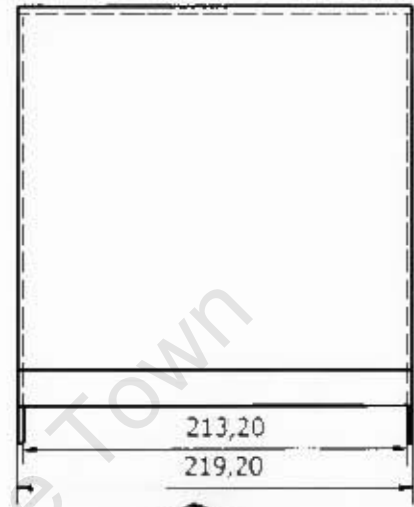
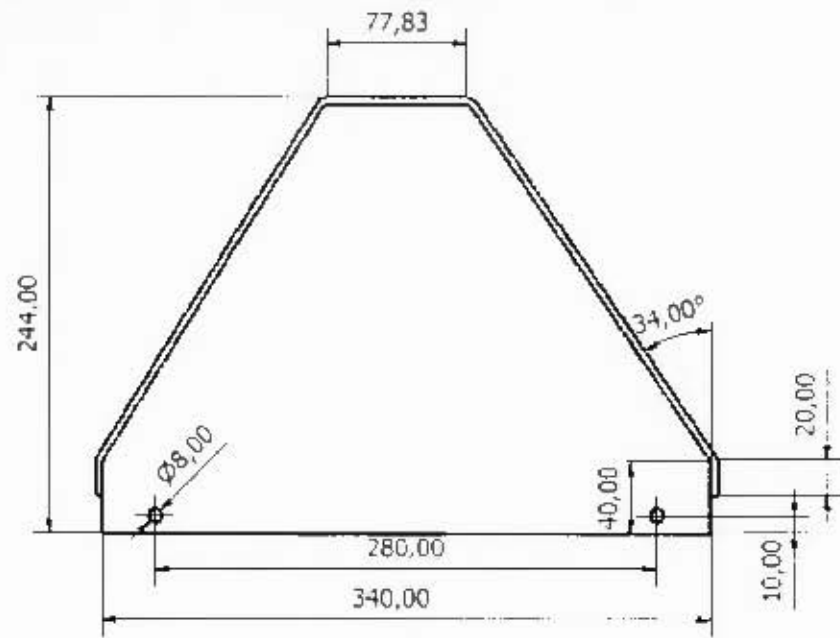


Parts List			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Base	1.6 mm Aluminium
2	2	Panel	1.6 mm Aluminium
3	1	Tray	1.6 mm Aluminium
4	2	Shield	4mm Perspex
5	1	Top	4mm Perspex
6	4	Spacer	3mm Washer
7	4	Bolt	Tray Holding Bolt
8	4	SmallBolt	Frame Support Bolt
9	1	Out_Tray	2mm Perspex Output Hopper
10	4	TrayBolt	Tray Mounting Bolts

Designed by ULYCH001	Checked by	Approved by	Date 2008/03/11
UNIVERSITY OF CAPE TOWN		MARKING MACHINE	
2008-001-1		Revision 1	Sheet 1 / 1

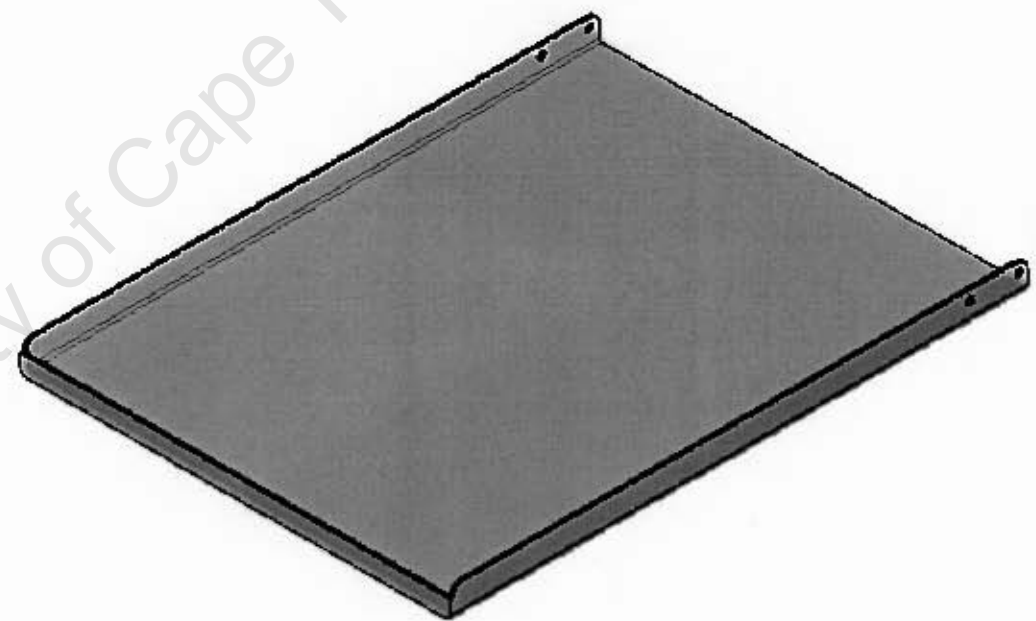
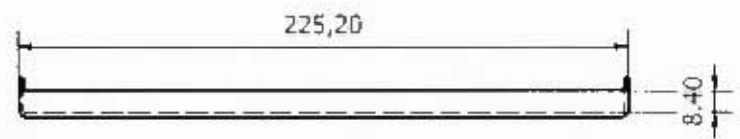
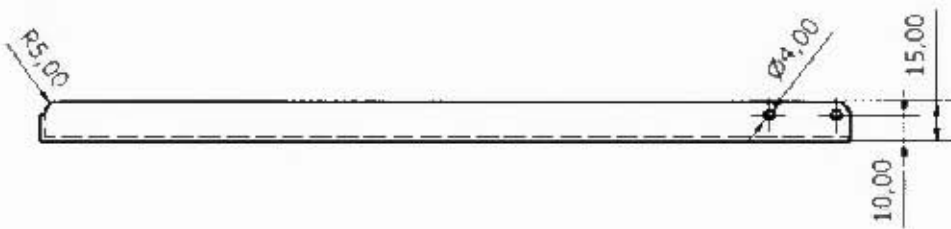


Designed by WLYCH001	Checked by	Approved by	Date 2008/03/31
UNIVERSITY OF CAPE TOWN		BASE MOUNTING	
2008-005-1		Revision 1	Sheet 1 / 1



Designed by ULYCH001	Checked by	Approved by	Date	Date 2008y03/11
UNIVERSITY OF CAPE TOWN			MARKING MACHINE	
2008-004-1			Edicn: 1	Sheet 1 / 1

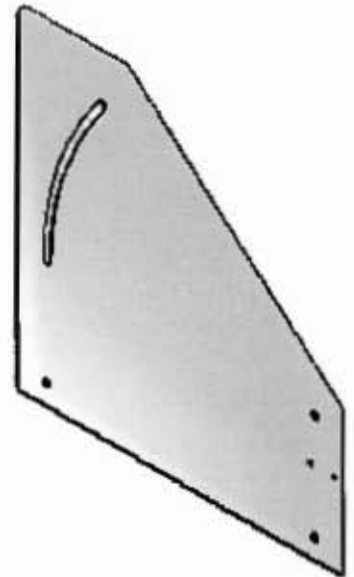
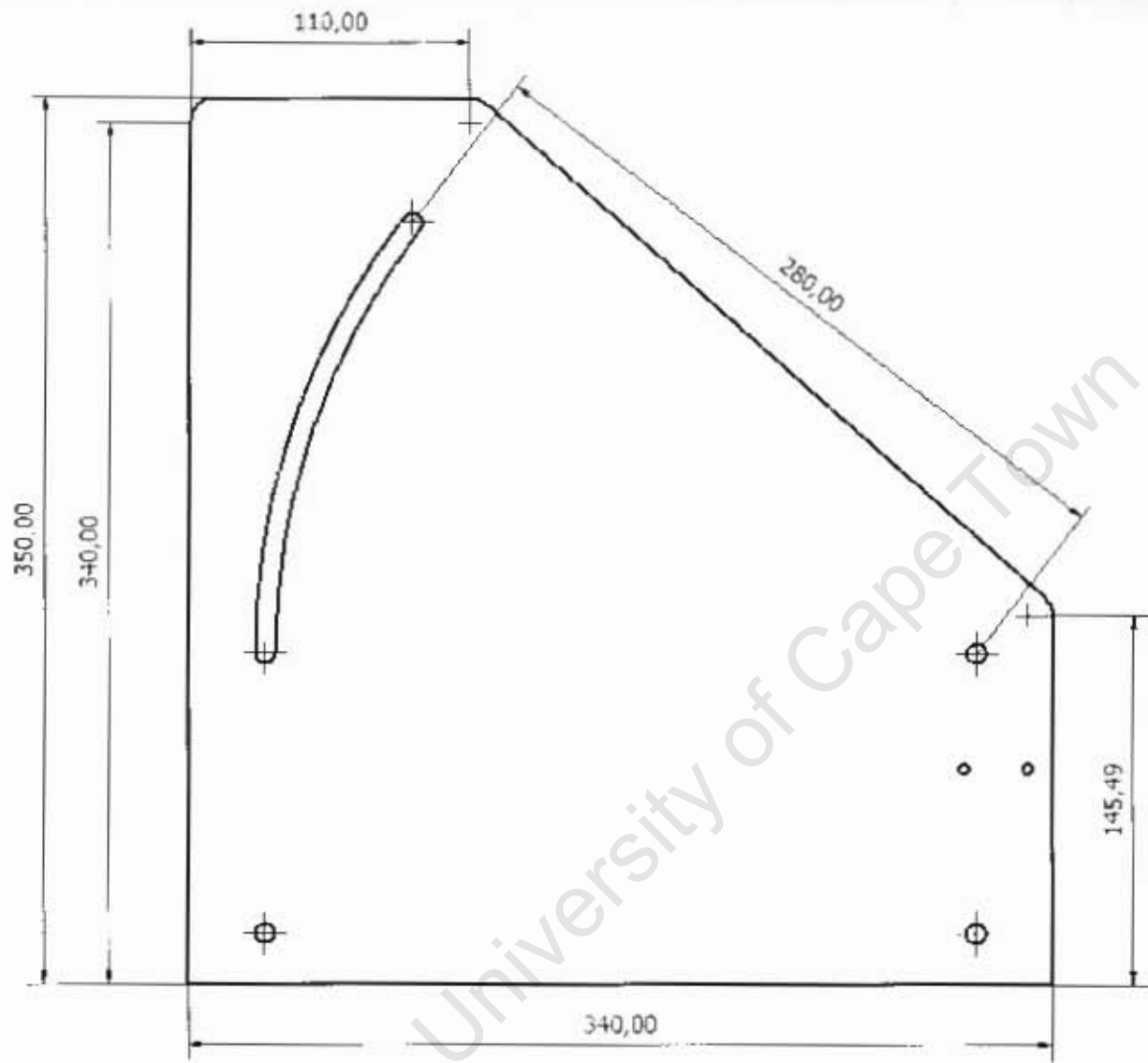
6 1 5 1 4 A 3 1 2 1 1



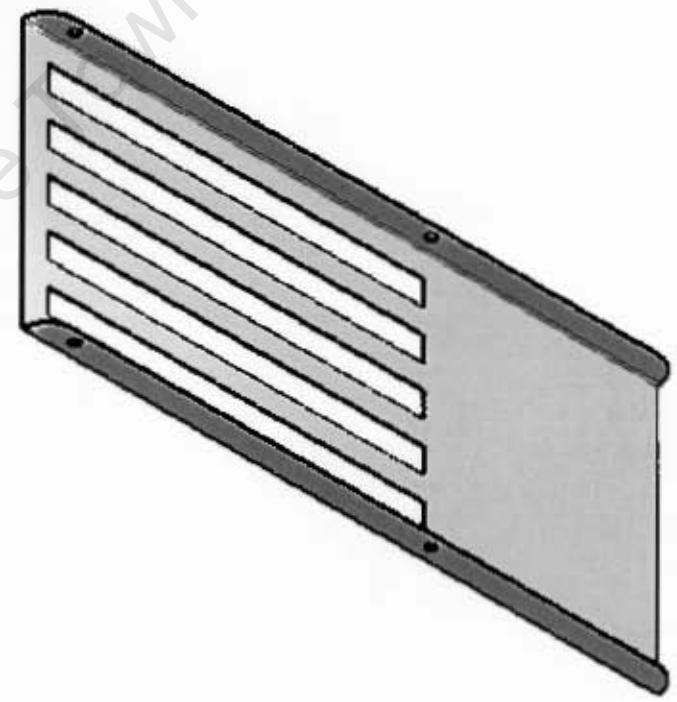
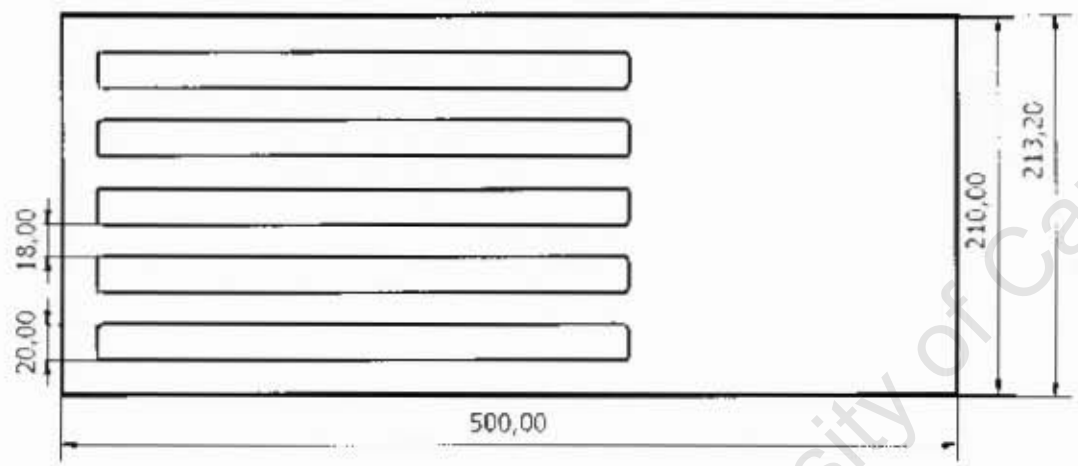
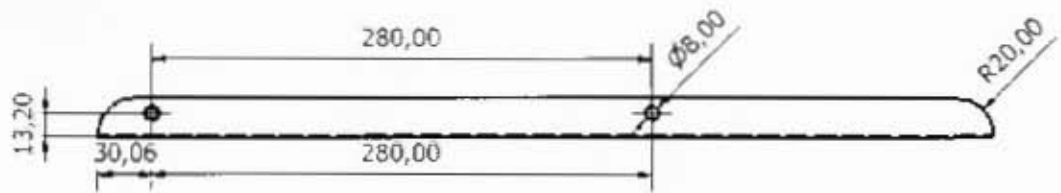
University of Cape Town

Designed by ULYCH0001	Checked by	Approved by	Date	Date 2008/03/31
UNIVERSITY OF CAPE TOWN			OUTPUT TRAY	
2008-006-1			Revision	Sheet 1 / 1

6 1 5 4 A 3 2 1



Designed by ULYCH001	Checked by DR. B. REED	Approved by	Date 2008/03/31
UNIVERSITY OF CAPE TOWN		SIDE PANEL	
2008-003-1		Edition 1	Sheet 1 / 1



Designed by ULYCH001	Checked by	Approved by	Drawn	Date 2008/03/31	
UNIVERSITY OF CAPE TOWN			PAPER TRAY		
2008-002-1				Edition	Sheet 1 / 1