DEVELOPMENT OF AN INDUSTRIAL PICK AND PLACE MACHINE FOR GAUGE REPEATABILITY AND REPRODUCIBILITY (GRR) MEASUREMENT OF VISION MODULES

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF AN INDUSTRIAL PICK AND PLACE MACHINE FOR GAUGE REPEATABILITY AND REPRODUCIBILITY (GRR) OF VISION MODULES"** was prepared by **TAN JON WEN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering at Universiti Tunku Abdul Rahman.

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Specially dedicated to

my mother who has always encouraged me to believe that I can

and my father who is my greatest source of inspiration

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ABSTRACT

Consumer demand for electronic products like smart phones and tablet computers have been steadily increasing, causing heavy demands in the electronics manufacturing industry. High speed vision systems are needed to inspect integrated circuit (IC) packages as small as 2mm × 2mm. Current IC test handlers which include IC inspection have reached speeds in excess of 20, 000 units per hour (UPH) and vision systems require reliable software to keep up. Gauge Repeatability and Reproducibility (GRR) is a method of measuring the reliability of a vision system by gauging its capability to obtain the same measurement every time the measurement is taken with certain parameters held constant. The current method of conducting GRR is by holding the IC units above the vision and continuously triggering the software to conduct inspection and take measurements. This approach does not simulate the actual conditions vision systems face, where units are constantly being moved from one station to another. This report highlights the development of an automated machine to effectively conduct dynamic GRR. Design considerations are included when designing a machine dealing with vision systems and methods to increase speed and accuracy is proposed. The outcome is a machine that is able to achieve speeds of up to 1500UPH using a simple design and readily available industrial components.

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LIST OF SYMBOLS / ABBREVIATIONS

µm	Micrometer, $\times 10^{-6} m$
ms	Micro seconds, $\times 10^{-3} s$
G	G force, gravity acceleration $9.81 \times m/s^2$
W	Lifting Force, N
P	Vacuum Pressure, kPa
S	Pad Area, cm^2
T	Safety factor
d	Diameter, m

GRR	Gauge repeatability and reproducibility
MVS	Machine vision systems
IC	Integrated circuit
UPH	Units per hour
QFN	Quad flat no leads
QFP	Quad flat package
SOT	Small outline transistor
SOIC	Small outline integrated circuit
MLP	Micro leadframe package
MFC	Microsoft foundation class
SMT	Surface mount technology
SMD	Surface mount device
FRL	Filter regulator lubricator
CPH	Chips per hour
DOF	Degree of freedom
CAD	Computer aided design
DOF	Degree of freedom
IO	Input output
GUI	Graphical User Interface

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CHAPTER 1

INTRODUCTION

1.1 Background

Measurement is defined as the process of determining the value of some quantity in terms of a standard unit (McGraw-Hill, 2003). Therefore a measurement system is a piece of equipment used to determine the values of the measured item. This information is then used to make further decisions. In measurement systems, accuracy is important as it is used as a control variable to determine if the measured unit is accepted or rejected. Besides accuracy, measurement systems should always provide consistent values or have a high repeatability. The reliability of the measurement system needs to be tested with a method commonly used in the industry called Gauge Repeatability and Reproducibility (GRR).

The effectiveness of a measurement system depends upon accurate gauges and proper gauge use. (Smith, McCrary, & Callahan, 2007). GRR is a method used to evaluate measurement systems. It measures the capability of a gauge to obtain the same measurement reading every time the measurement is taken with certain parameters held constant. In general, the GRR indicates the consistency and stability of the measurement equipment. Repeatability is the variation in measurements obtained by one operator using the same gauge measuring the same parts while reproducibility is the variation in the average of measurements made by different operators using the same gauge measuring the same parts (Perez-Wilson, 2007).

A Vision Inspection system is a type of measurement system which consists of a camera, light source, frame grabber, computer and the image processing algorithm. In industrial environments, Machine Visions Systems (MVS) are commonly used as measurement systems to measure items with sub-pixel accuracy (within the micron range). Vision systems require high reliability in order to single out defects of inspected units. One method to verify the reliability of a vision system is by obtaining the GRR value of the system.

In this report, a highly accurate and precise pick and place machine is developed to conduct the GRR for vision systems.

1.2 Motivation

1.2.1 Growth of Electronics Industry

The sales value of the manufacturing sector in June 2011 posted a year-on-year double digit growth of 12.9% (RM5.8billion) to record RM50.8 billion as compared to RM45.0 billion reported in June 2010 (Department of Statistics Malaysia, 2011). This demonstrates the strong growth of the manufacturing industry in Malaysia despite a slow and cautious global economic recovery. Moreover, (Invest Penang, 2009) states that the electrical and electronics industry is the leading sector in Malaysia’s manufacturing sector contributing to the country’s manufacturing output (29.3%), exports (55.9%) and employment (28.8%). This includes consumer electronics such as home theatre systems, blue ray and digital cameras, electronic components such as semiconductor devices, passive components and printed circuits and finally electrical components such as household appliances.

On the global stage, Singapore Economic Development Board (EDB) Review 2010 reported that the electronics manufacturing output grew 26.9% in 2010 to reach S$89.9bil, far surpassing the industry growth of 9.3% (Bernama, 2011). World shipments by 22 suppliers for the leadframe type IC unit shipments are also showing signs of recovery (Tracy, 2009). This will increase the demand of semiconductor manufacturing equipment. Worldwide semiconductor equipment sales for the year 2005 by product type are shown in Figure 1.1. Front end equipment which includes wafer processing equipment include a total of 77% of the total market while back end equipment total to 23% of the market (United States International Trade Comission (USITC), 2006). Majority of the equipment will require high speed and precise pick and place mechanisms to function.

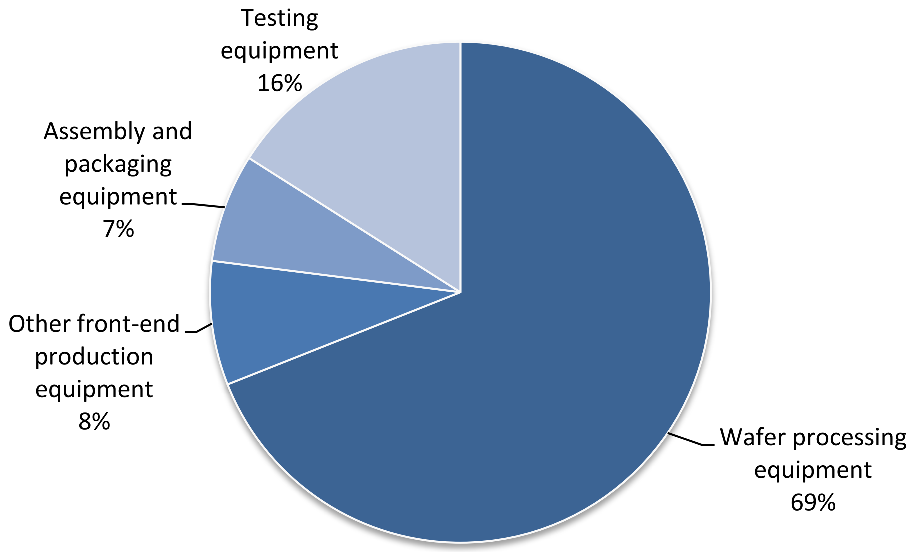


Figure 1.1: Worldwide Semiconductor Manufacturing Equipment Sales in 2005 by Product Type. Source: (USITC, 2006)

The demand for more integrated circuits is driven by the growth of the consumer electronics industry. The global consumer electronics market is expected to grow by 10% from US$873bil in 2010 to US$964bil this year according to the Taiwan Based Industrial Economics and Knowledge Center (IEK) report (Tan, 2011). In an article entitled ‘Semiconductor industry set for highest annual growth in 10 years’, (Ford, 2010) mentioned that “chip sales growth this year will be fuelled by a number of key factors, including continued strong consumer demand for hot electronic products, diligent inventory and capacity management efforts among chip makers and the arrival of innovative technologies at both the component and end-system levels”.

1.2.2 Need for Stable Vision Inspection Systems

The stability of the vision software has to be evaluated before it is sent out to customers. A Suitable method of evaluation is through identifying the GRR value. The current method of measuring GRR is to hold the inspected integrated circuit (IC) package over the top plate opening using a vacuum tip and continuously triggering the vision software to perform the inspection. This leads to a disadvantage where it does not simulate the actual inspection process.

In the actual application, the vision system is a sub module mounted on the IC Test handler. More than 20,000 Units Per Hour (UPH) passes through the vision systems and the ICs are constantly being moved from one inspection station to another (SRM Integration (M) Sdn. Bhd., 2008), (FAS Technology Solution Sdn. Bhd., 2009). Figure 1.2 is an example of a test handler with tube input on the left and tape and reel output on the right. The top centre piece is a high speed rotating turret that moves the IC units from one station to another. Around the turrets are multiple test sites, some of them being vision systems. The monitor to show the vision inspection results are on the left while the machine is controlled via the touch screen monitor on the back.

Figure 1.2: An IC Test Handler with Tube Input and Tape and Reel Output
Source: (SRM Integration (M) Sdn. Bhd., 2008)

The real GRR test is conducted on the IC test handler with the ICs constantly being picked and placed. A method to conduct dynamic GRR is needed to test the MVS system during various phases of design and production.

1.3 Aims and Objectives

The final outcome of the project is to produce a fully functioning automated pick and place machine that can be used to perform GRR on Vision Inspection Modules. The machine should meet the following requirements

- Have a pick and place speed performance of 2000UPH.
- Able to pick and place IC package sizes of 4mm × 4mm to 10mm × 10mm.
- Be able to handle Surface Mount IC Packages Quad Flat No Leads (QFN), Quad Flat Package (QFP), Small Outline Transistor (SOT), Small Outline Integrated Circuit (SOIC), Micro Leadframe Package (MLP) and other similarly shaped IC packages.
- Controlled using an application developed using Microsoft Foundation Class (MFC) C++.

1.4 Report Outline

Chapter 1 presents the background of the topic, the motivation for carrying out the project and the aims and objectives of the project. Then, an outline of the chapters in the report is given.

Chapter 2 is the literature review of the fields related to the project. This includes topics such as the process of manufacturing integrated circuits, various package types, industrial test handlers, pick and place design, linear motion technology and pneumatics control.

Chapter 3 is the methodology used to achieve the design project. The design process is explained and a Gantt chart is presented to monitor the progress of the project.

Chapter 4 covers the mechanical portion of the project whereby a conceptual design is discussed and selected. The mechanical components selection criterion is described followed by the overall mechanical design. Topics regarding alignment considerations, materials and surface finish, stress simulation and pneumatics systems are contained in this section as well.

Chapter 5 presents the electronics. The overall system electronics is displayed in a form of block diagram followed by the component selection. Next, the input and output assignment table is presented.

Chapter 6 is regarding the application development using C++ and MFC library. The graphical user interface is presented in this section.

Chapter 7 summarizes the results obtained from this project. Various pictures of the final product and its functions are shown and discussed here. The performances in terms of pick and place speed and placement repeatability is examined with the support of obtained data. Other suggestions for improvements are included.

Chapter 8 is the conclusion to the entire project and this report.

CHAPTER 2

LITERATURE REVIEW

2.1 Integrated Circuit Manufacturing Process

A simple way to explain the manufacturing of semiconductors and integrated circuits is to take some sand, purify it, add materials to it, cut it into little chips, attach the chips to metal frames, connect wires to them, encase them in plastic and then test them (Siliconfareast.com, 2004). Figure 2.1 shows the simplified diagram of the manufacturing process of semiconductors.

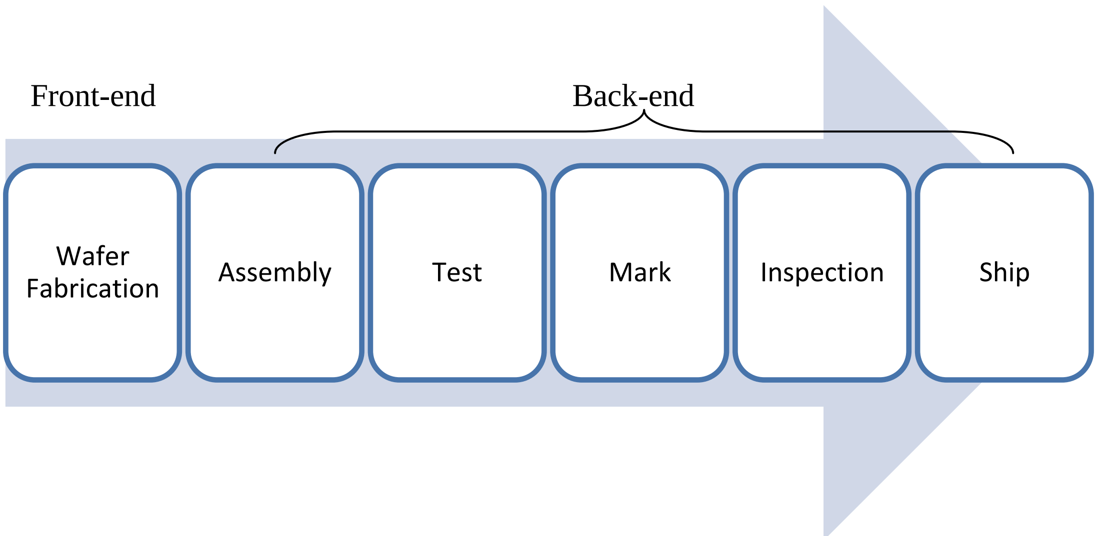


Figure 2.1: Manufacturing Process Diagram of Semiconductors

The final products are ICs that have various functions. The front-end process is where the semiconductor wafer is made and processed. The back-end process is where the silicon chips are assembled and moulded into plastic units, tested, marked, inspected and then shipped. Often the test, mark and inspection parts of the process are done in a single machine. The machine is generally called an IC test handler.

2.2 Integrated Circuit Package Types

Integrated Circuits (IC) are the core of modern digital systems. According to (Wylie, 2009) the first integrated circuits were in fact packaged circuits, where a set of discrete components was assembled into a ‘module’ of some kind that was then used in a larger circuit. The two main advantages of ICs over discrete circuits are due to its cost and performance. In general there are two types of ICs, the pin through hole type (PTH) and Surface Mount Technology (SMT). Figure 2.2 shows the various types of Surface Mount Device (SMD) package types.

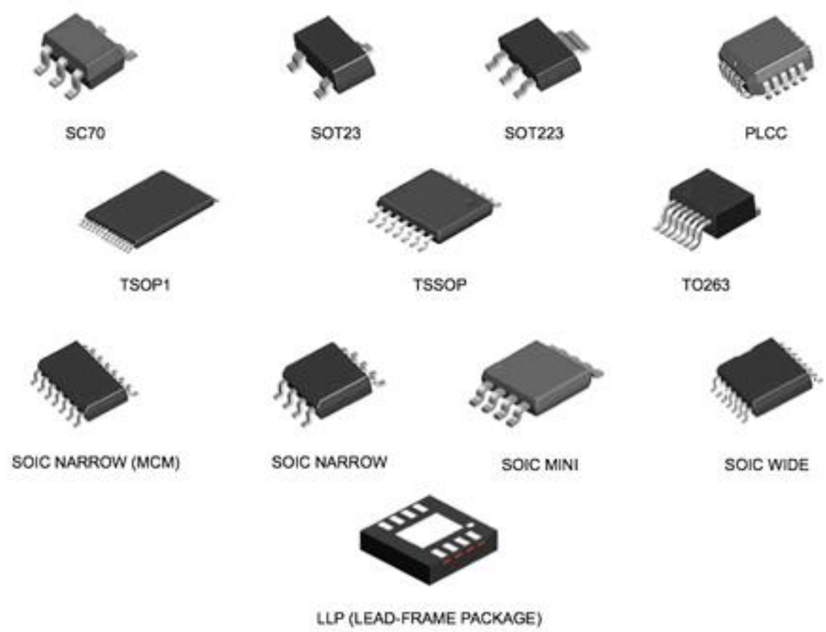


Figure 2.2: Various SMD Package Types. Source: (FAS Technology Solution Sdn. Bhd., 2009)

There are hundreds of different types of SMD packages. The packaging decisions depend on factors such as size, number of pads, circuitry size and manufacturing technology capability (C. Saint & J. Saint, 2002). The SMD mechanical package outlines sizes are determined and standardized by the JEDEC Solid State Technology Association, formerly known as Joint Electron Devices Engineering Council (JEDEC). JEDEC is the global leader in developing open standards for the microelectronics industry and JEDEC publications and standards are accepted throughout the world and are free and open to all (JEDEC, 2011). Package standards and mechanical dimensions can be obtained from the JEDEC website and also from (Intersil Corporation, 2011) website.

2.3 Industrial IC Test Handlers

Testing equipment makes up 16% of the equipment used for semiconductor manufacturing and the percentage is based on 2005 semiconductor manufacturing equipment total market of USD$32.9 billion (USITC, 2006). There are a variety of test handlers and Figure 2.3 shows the distribution of each type that is commonly used in the market.

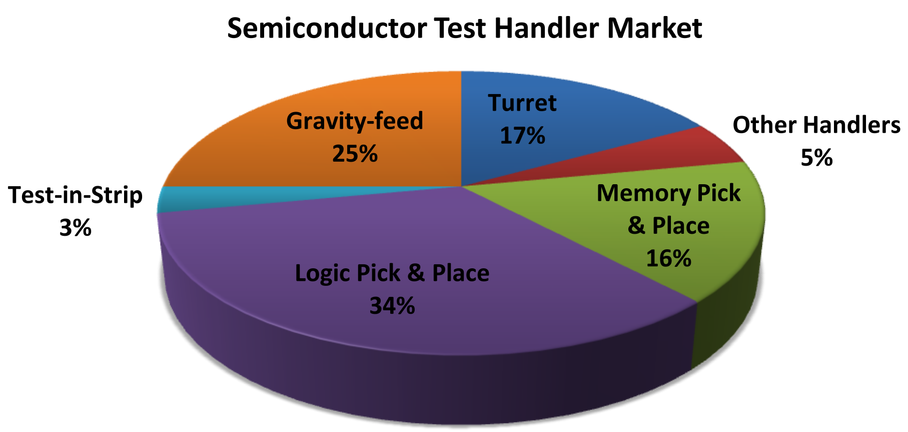


Figure 2.3: Semiconductor Test Handler Market Equipment Type Distribution
Source: (COHU Incorporated, 2011)

Some manufacturers of IC test handlers include Delta Design, Rasco GmbH, FAS Technology, SRM Integration, Chroma ATE, TechWing Inc and Advantest. The different companies focus on the design and development of different types of test handlers like turret, gravity-feed, memory pick and place and logic pick and place. Because this field is so diverse with so many different types of testers available, there are many companies that specialize in different type of handlers. SRM Integration and FAS Technology are Malaysian companies which specialize in the design and development of turret type test handlers.

2.4 Precision Pick and Place Design

Machine set-up and precision is critical to the efficient operation of high speed pick and place machines and requires the evaluation and control of many parameters (Koepp, Allen, Fassett, & Tang, 2008). Proper machine set-up requires highly experienced technicians or engineers. There are various designs to achieve precise pick and place.

In order to optimize the component placement sequences, some SMD placement machines have more than one nozzle per head. Choosing effective nozzles are important since a nozzle change can be time consuming. Ayob & Kendall, 2004, presented a constructive heuristic that aims to minimize the assembly cycle time to address the importance of choosing a proper nozzle group in order to maximize the throughput. Their work was done on a hybrid pick and place machine which has four fixed feeder carriers, a fixed PCB table, two vision cameras, a tool bank, a trash bin and a positioning arm head that is equipped with two pipettes. Each of the pipettes holds a nozzle that is used to pick the components. One tool change takes about two seconds; therefore it is important for their machine to determine the best nozzle pair for the two pipettes to minimize the number of nozzle changes. Overall their developed nozzle selection heuristic was able to increase the throughput of the machine by 2.07% from 2995 chips per hour (CPH) to 3057CPH. . It is also noted that their machine had an on-the-fly mechanical alignment mechanism that does alignment of the component while the robot arm is moving. This saves time as the component packaging type can be recognized and aligned without a vision camera.

In another effort to reduce cycle time of a pick and place machine, (Goede, Verstegen, & Gastel, 2007) designed a component shuttle that carries components with the pick and place head to reduce the travel time. Their reason to doing this is because the total pick and place cycle time increases as the printed circuit board (PCB) size increases since the pick-up arm has to travel further distances. Their research lead to the development of an innovative shuttle design which is able to hold the SMD unit using a passive switching nozzle. The shuttle design proved to be an effective method to carry components around for the pickup head but more improvements are needed to increase the pick and place accuracy. The contents of their research states that the shuttle should carry at least 30 SMD components to have it effectively reduce the cycle time of their machine. The authors experiments yielded a 100% success rate for pick and place process however there was a high deviation of >70µm in one of the axis that is above the limit of 50µm which is unacceptable.

One popular design for pick and place robot is the parallel manipulator design. It is distinguished from the serial manipulator because its end effectors are connected to the body by several linkages usually three, four or six working together to position it. Parallel manipulators have the advantage of high speed and acceleration, high static and dynamic accuracy and low inertia compared to serial manipulators (Merlet, 2006).

A four degree of freedom (DOF) robot has been developed by Nabat, Rodriguez, Company, Krut, & Pierrot (2005). The key difference compared to the current available robots is the symmetrical arrangement of the actuators and the use of articulated travelling plate made of revolute joints. Their prototype was able to achieve very high speeds, up to 13 G acceleration and cycle time of 0.28s. Figure 2.4 shows the prototype parallel robot design developed by Nabat and his team. However there is also research on two DOF parallel manipulators for translational motion. Li, Lou, Li, Yang, & Gao, 2010, proposed a conceptual design and kinematic analysis of a two DOF translational parallel robot that has a simple and symmetrical mechanism.

Their theoretical analysis shows that the inverse kinematics and forward kinematics of the robot have a closed-from solution and the workspace and singularity can be computed by geometric analysis. Two DOF parallel manipulators have reduced parts and a simple mechanism therefore the cost is lower but still retains its high speed and acceleration characteristics.

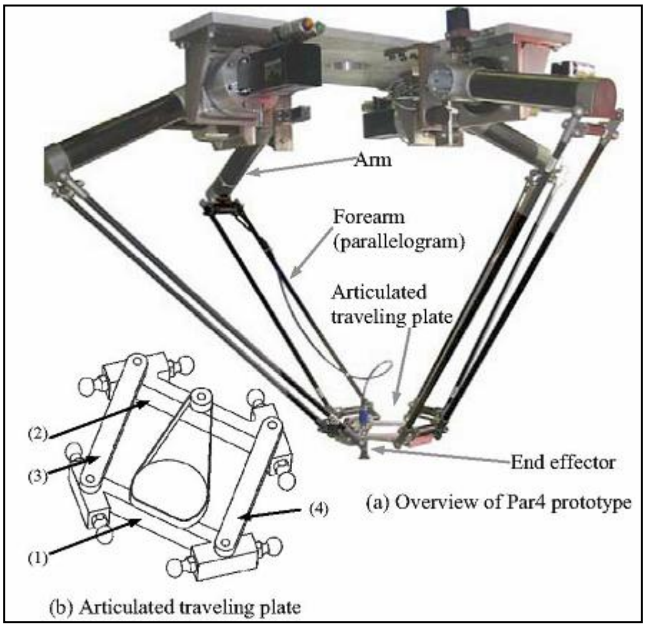


Figure 2.4: Prototype Parallel Robot. Source: (Nabat, Rodriguez, Company, Krut, & Pierrot, 2005)

In gantry type robots, Paulides, et al. 2008 proposed topics for an architectural discussion to accomplish a contactless pick and place robot. The mutiple robot pick and place design incorporates direct-drive linear permanent magnet motor. The contactless concept is aimed at eliminating wear and disturbances due to friction and cables on a single axis. Data is transfered via optical and radio means but optical link was found to be superior due to lower costs, lower data loss and improved bandwidth. The study was able to produce a robot prototype that uses contactless energy and data transfer. However it had the disadvantage of twice as much moving masses from the extra equipment which caused the maximum acceleration to be 50% larger than before**.** Table 2.1 is a summary of the various methods researchers use to achieve high speed pick and place.

Table 2.1: Summary of Methods to Achieve High Speed Component Pick and Place

Researcher and year	Methodology	Results
Ayob, M. & Kendall, G. (2004)	Developed nozzle selection heuristic to optimize hybrid pick and place machine. Machine with on-the-fly component alignment mechanism	Throughput of machine increased by 2.07% from 2995CPH to 3057CPH
Goede, P., Verstegen, P. & Gastel, J. (2007)	Innovative shuttle concept to reduce travel time of pick up arm	Successful pick and place cycles however accuracy needs to be improved.
Nabat, V., Rodriguez, M., Company, O., Krut, S., & Pierrot, F. (2005)	Four degree of freedom (DOF) parallel robot	Achieved high speeds of up to 13G acceleration and cycle time of 0.28s
Li, Z., Lou, Y., Li, Z., Yang, G., & Gao J. (2010)	Two degree of freedom translational parallel robot	Presented inverse kinematics, forward kinematics, singularity and workspace analysis.
Paulides, J. et al. (2008)	Contactless pick and place robot aimed at eliminating wear due to friction and cables on single axis	Successful prototype however had twice more moving masses which resulted in 50% larger acceleration than previous prototype.

From the review conducted, it can be summarized that researchers attempt to achieve higher pick and place speeds by two methods. Firstly is by optimizing the software that determines the movement of the pickup head and secondly by adding mechanical parts or use a new design altogether. Parallel robots is found to be a promising type of design compared to serial robots as it allows for extremely high speeds however it takes up a lot of space and complex control algorithms are required. Many serial robots will require optimization on the software side for further speed enhancements and this includes the possible incorporation of Artificial Intelligence.

2.5 Linear Motion Technology

There are various ways to achieve linear motion and the selection of components depends on factors such as speed requirements, repeatability, positioning accuracy, and load. Vendors supply linear guides, linear bushings and shafts and also pre-assembled drive units that may utilize ball screws, belt and pulley or rod-less pneumatic actuators.

Lead screw and ball screw mechanisms are the most widely used precision motion conversion mechanisms which transfer rotary motion to linear motion (Cetinkunt, 2007). The screw is not allowed to travel and the nut on it is not allowed to rotate. Therefore the rotary motion of the motor connected to it moves the nut in a translational motion. Cetinkunt also mentioned that ball screw design uses precision ground spherical balls in the groove between the screw and nut threads to reduce backlash and friction in motion transmission mechanism. Comparing ball screws and lead screws, Centinkunt mentioned that the load carrying capacity of ball screws are less than that of the leadscrews since the contact between the moving parts (lead and nut) is provided by point contacts of balls. However ball screw has less friction than a lead screw. (Ugural, 2003) state that efficiencies of 90% or greater are possible with ball screws over a wide range of helix angles when converting rotary to axial motion.

Another method of achieving linear motion is by using timing belts or synchronous belts. This mechanism is widely used in low inertia, low load force and high bandwidth applications such as coil winding machines (Cetinkunt, 2007). A timing belt does not stretch or slip due to the toothed side being in contact with the sprockets and hence transmits power at a constant angular velocity and ratio. The efficiency of a toothed belt drive ranges from about 97 to 99% (Ugural, 2003). Precision linear guides and shafts are commonly used together with ball/lead screws and synchronous belts to maintain a precise linear motion and increase load carrying capability. Figure 2.5 shows examples of ball screw, linear guide with guide blocks and linear shaft with its bushing.

Figure 2.5: Ball Screw, Linear Guide, Linear Shaft and Bushing. Source: (Bosch Rexroth, 2011)

Some other methods of converting rotary motion to linear motion include the use of rack and pinion, linkages and cams. However, rack and pinions are mostly used for heavy load applications while linkages and cams provide only a small range of repetitive movement. Pneumatics mechanisms also provide good linear actuators and will be discussed in the following sub chapter.

2.6 Pneumatics System Design and Technology

According to (Majumdar, 1995), pneumatics control is a cheap but very effective method of automation technique and hence found to be used extensively all over the world in robotics and pick and place devices. In order to achieve high speed actuation, pneumatic cylinders can be used. Some other advantages of pneumatic actuators include high reliability of work, explosion and fire safety, reduced sophisticated transfer mechanisms and simpler realization of small back and forth motions (Ponomareva, 2006).

All pneumatic systems require a stable supply of compressed air. However, the air that is taken in by the air compressor is evidently not clean because of the presence of various types of contaminants in the atmosphere (Majumdar, 1995). Usually a Filter, Regulator and Lubricator (FRL) is used to clean, stabilize and lubricate the supplied air. However, (About Air Compressors, 2011) mentioned that many air valves and air cylinders come from the factory well lubricated for the life of that item. It is only in really high cycles that lubricant need to be added. Therefore, it is not necessary for a small machine to have the lubricator component in the FRL unit.

The major problem with pneumatic devices is that air is compressible, and thus, it compresses and deforms under load (Niku, 2001). Niku also stated that controlling the exact position of pneumatic cylinders is very difficult if the actuator is not used for all the way forward or all the way backward motions. Ponomareva (2006) also states the disadvantages of pneumatic actuators due to the compressibility of air, difficulties in performance at slow speed and requirement of good preparation for compressed air.

However, multiple authors have proposed solutions for pneumatic actuators position control. To achieve position control, 5/3-way solenoid valves can be used to stop the pneumatic actuator in the desired position. Another method is to use four 2/2-way valves where the valves are usually mounted on the cylinder covers. According to (Krivts & Krejnin, 2006), valves mounted on cylinder covers allows for decrease in energy loss in the pneumatic line between the control valves and the actuator. Krivts & Krejnin also mentioned that besides the decrease in energy loss, one can also achieve minimum lag in the control of the signal (the response time of a 2/2-way valve is shorter than that of a 5/3 way-valve), which is very important for the actuator’s dynamic behavior. However, there are obvious disadvantages to using four 2/2-way valves where four control signals are needed as opposed to two for a 5/3-way valve.

Nurtac & Kuzucu (2009), presented three low-cost control technologies for accurate position control of pneumatic cylinder. These include bang-bang control with velocity feedback, sliding mode control and pulse width modulation (PWM) control using 3/2 way directional solenoid valves. The authors used modular programming in LabVIEW to achieve 0.05mm precision and very high repeatability in sliding mode control and claims that the control algorithm can replace expensive servo cylinders and step motor cylinders in the industry.

In a seperate study, (Foldi, Beres, & Sarkozi, 2011) presented a method to realize fast and accurate position control of a pneumatic actuator using inexpensive on/off solenoid valves. A closed-loop circuit is constructed using a double acting cylinder, a pair of 5/3 way valves and an analogue displacement encoder. Their experiment results on various settings produced a steady-state error ranging between 0.003mm and 0.02mm with settling times ranging from 0.6s to 3s. This proves that although the settling time is slow, the accuracy that can be obtained is in an acceptable range with their low cost set-up.

2.7 Vacuum Suction End Effectors

Suction cups are most commonly used to as the end effectors for pick and place mechanisms. Suction cups (also known as vacuum pads) come in a wide range of diameters from 2mm to 125mm and various materials such as Nitrile Butadiene Rubber (NBR), Silicon Rubber, Urethane Rubber, Fluoro Rubber and Conductive NBR. It also available in various pad shapes and types including flat, ribbed, bellows and elliptical along with varied mounting configurations (SMC Pneumatics, 2008). A range of vacuum pads is shown in Figure 2.6.

Figure 2.6: Various types of Vacuum Pads. Source: (Korea International Trade Association, 2011)

CHAPTER 3

METHODOLOGY

3.1 Project Design Overview

The project will be accomplished in a series of continuous stages. These stages are defined in a step-by-step manner. The stages include various phases such as mechanical design, assembly and wiring, application development and performance optimization. Figure 3.1 summarizes the various stages of the design process in a flowchart.

The first stage is to define the detailed requirements of the machine according to the user's specifications. This is the most important step that will determine the final outcome and process of developing the machine. After the specifications are determined, technical research and literature review is conducted to familiarise with the required knowledge needed to execute the project. Several conceptual designs are then drawn up. Each design's advantages and disadvantages are considered. The main criteria in evaluating the designs are cost and performance.

Subsequently, the components that will be used to achieve the design requirements are selected. During the selection of the components, different brands are considered and the quotations are obtained from various companies. Cost and performance are compared and the utilization of used automation components is also considered to reduce the overall cost. Technical calculations are done manually when necessary.

Next, the detailed mechanical design of the machine is completed using SolidWorks computer aided design (CAD) software. From the CAD file, the overall size, weight and potential problems can be identified. Motion of the actuators used can also be simulated using the CAD software to verify the design and ensure there are sufficient clearances to avoid any collisions.

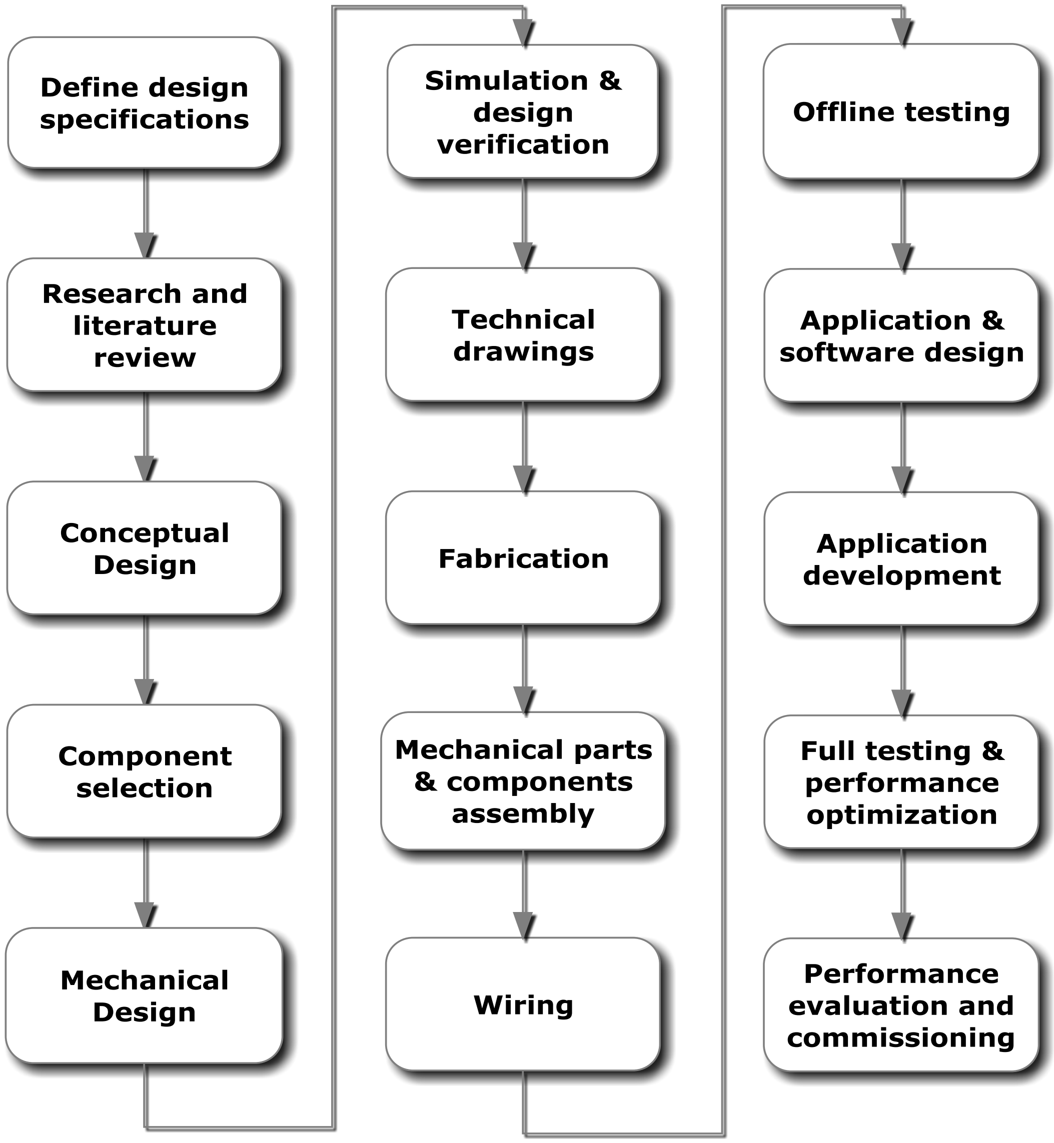


Figure 3.1: Flowchart of Overall Design Process

Once the design is verified to be problem-free, technical drawings can be produced before it is sent for fabrication. Before the fabrication process begins, it is important to communicate with the vendor and iron out any ambiguity about the design. Any doubts should be addressed. Otherwise unacceptable parts will be produced. While the fabrication is being done, offline testing can be performed on various parts. Some components such as the stepper motor can be controlled with the available stepper driver and data acquisition card (DAQ). The pneumatic system can also be tested in advance.

The next stage would be the assembly of parts and components. Once the fabricated parts are received from the vendor, they will be checked to ensure that they are within the drawing specifications. Then, the assembly of the parts is carried out. This step is followed by wiring. Once all these are completed, offline testing can be done using the power supply. Manual firing of inputs and outputs (IO) via the DAQ card can be used to test the components. If there are no problems in this stage, the application can then be developed to control the machine.

The application will be developed using Microsoft Foundation Class (MFC) in Visual Studio using the C++ programming language. The needed functions of the software are drafted. The required graphical user interface (GUI) is also defined and drawn out. Then, coding can begin and it must be able to communicate with the DAQ. Finally, the machine can be controlled via the GUI created and must be able to function accordingly.

The final stage is testing and performance optimization. The volume of the pneumatic airflow has to be controlled and IO signal timing must be optimized for the machine to function properly. It is calibrated to function without error and then tuned to optimize the throughput, measured in units per hour (UPH). The response time of various components is evaluated and improvements are made wherever necessary. The machine should then be run through a series of continuous tests to check for any possible failures. If it passes this final test and all possible improvements are done, the final performance and specifications are evaluated and the machine can then be commissioned for use.

3.2 Project Gantt Chart

The Gantt chart splits the tasks of the project into more detailed parts unlike the design process flowchart. The design process is a general procedure for the project but the Gantt chart is the actual breakdown of the tasks that need to be done.

The work is divided into five main phases. The first phase is research and literature review. When the project title and specifications are decided, the technical knowledge required to complete the task is first studied. Basic concepts like pneumatics, electrical design and computer control using DAQ has to be understood. The types of components that can be used to achieve the requirements are also researched and compared. Work completed by other people on similar projects is reviewed. The design process is then listed out as a guideline.

The following phase is system hardware design. All the hardware is done in this stage. The design of the entire system including the mechanical parts, pneumatics and electrical connections is prepared. Simulation is conducted to verify the design before CAD drawings are produced and sent to the vendor for fabrication. All the components are then assembled together and the electrical wiring and pneumatic connections are connected to integrate all components. Once some of the components are obtained, offline testing can already begin without all the parts fabricated. The components can be tested individually or connected to a system and tested. Once the hardware design phase is completed, full offline testing can conducted. At this stage any flaws in the design should be corrected before proceeding to the software design.

With all the hardware functioning properly, the application to control the machine can be developed. The application will then be tested to ensure that it is bug-free and finally the performance of the machine can be optimized and evaluated. More time is allocated to fine-tune the machine so that it will be in the best configuration for optimal performance. The final specifications are evaluated and compared with the goals before it can be commissioned for use. The Gantt chart is shown in Figure 3.2 for the May 2011 semester and Figure 3.3 for the January 2012 semester. Milestones are marked in diamond shapes.

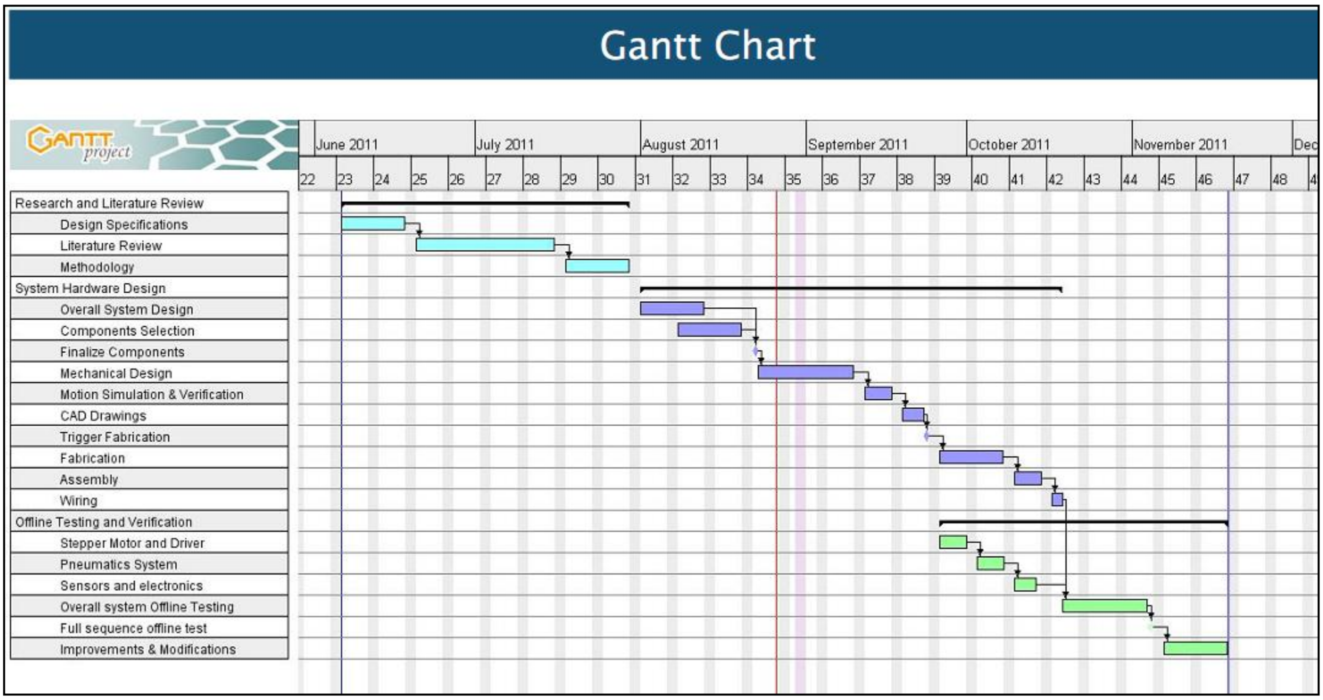


Figure 3.2: Gantt Chart May 2011 Semester

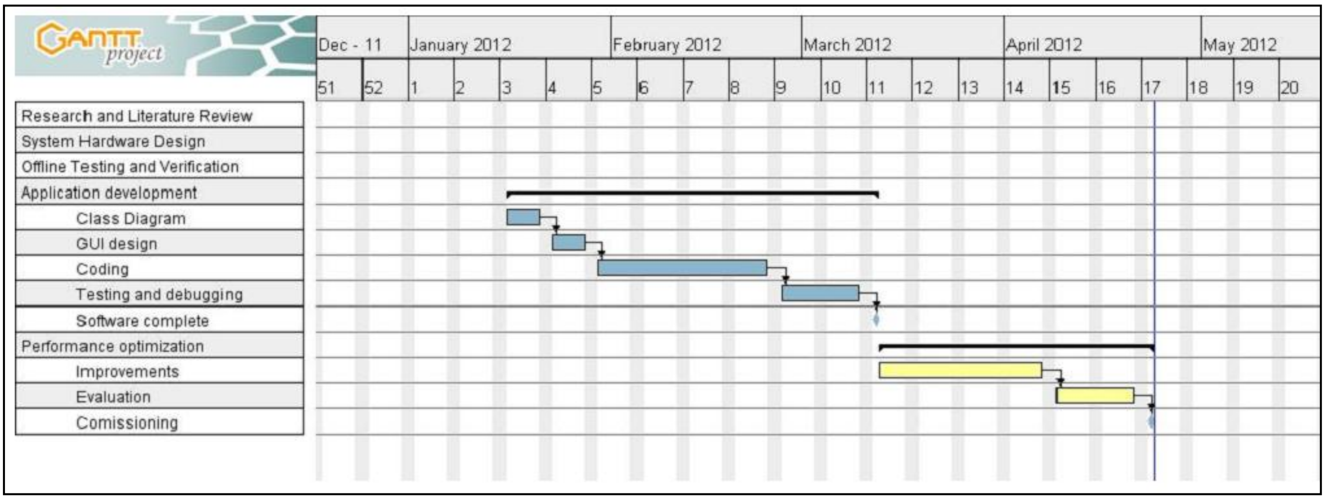


Figure 3.3: Gantt Chart January 2012 Semester

Even with the creation of the Gantt Chart, it is important to allow flexibility within the schedule. Tasks should always be completed ahead of time. However, there are times when unforeseen circumstances may occur therefore the schedule is always subject to constant change. Therefore, this tool is important for managing the time and tasks within a project.

CHAPTER 4

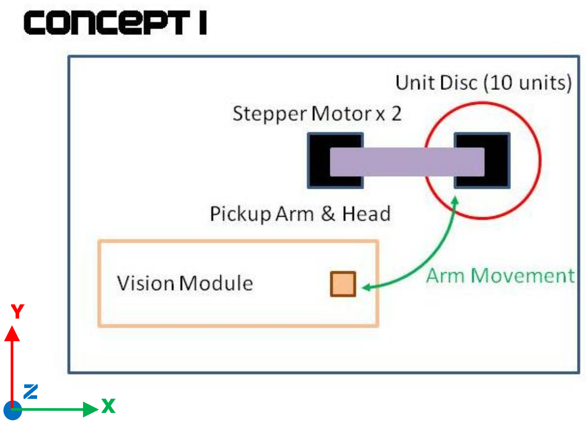
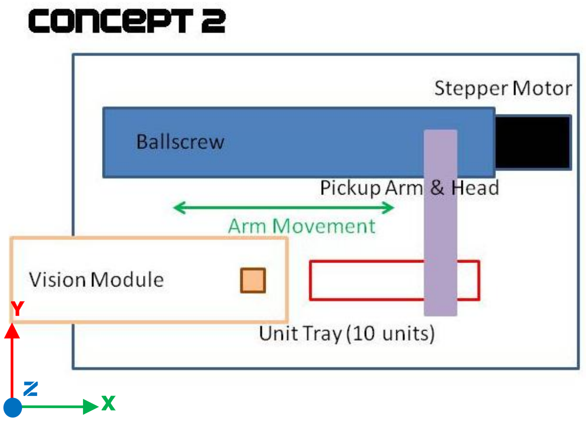
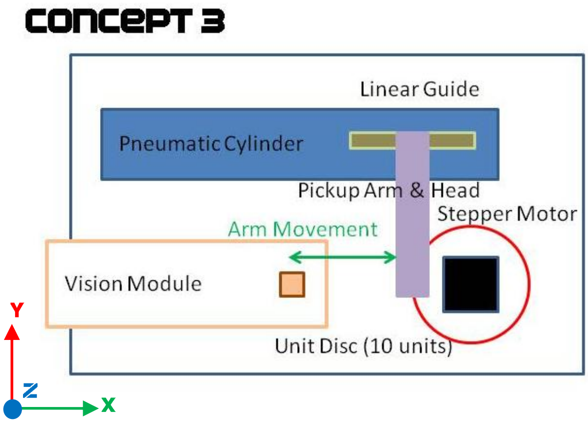
MECHANICAL DESIGN

4.1 Conceptual Design

Before the design phase is begun, a few conceptual designs are drafted according to the requirements as stated earlier in the objectives. Each of these designs are physically drawn out to easily get an understanding of how each will work and what components will be required to achieve the design. The advantages and disadvantages of the different designs are considered and compared. Some other important factors such as cost, ease of assembly, ease of control, overall size and weight and component availability is also considered. Table 4.1 shows the summary of conceptual designs and advantages and disadvantages of each design.

Concept one (C1) utilizes two stepper motors as driving actuators. The pickup arm moves 90 degrees from one point to another and the units are placed in an indexer disc. The arm will pick and bring the unit to the vision system and after done inspection rotates back to the indexer and places the unit. The indexer then rotated 36 degrees to the next unit and the process is repeated. This concept yields the smallest footprint. However, two stepper driver cards are required to drive the two motors. The stepper drivers need to be programmed separately using COM port via RS-232 communication. The motors require five inputs to control therefore a total of ten outputs will be taken up out of the 16 that is available. The stepper motors also require a lot of current to operate which will lead to the machine to consume more power.

Table 4.1: Conceptual Design - Comparison of Advantages and Disadvantages

<table>
<tr><th>Concept Sketch</th><th>+ Advantage / – Disadvantage</th></tr>
<tr><td>
</td><td>+ Smallest footprint
+ Less parts required
– Two stepper motors require two motor drivers
– Many digital outputs required to control (five for each motor)
– High power consumption due to two motors
– Arm inertia may cause jerk when stepper moves and stops</td></tr>
<tr><td>
</td><td>+ Require minimal alignment (only X,Y and Z axis)
+ Less control requirements (stepper controls movement of pickup arm)
– Many sequences needed for stepper motor since units horizontally placed
– Largest footprint due to ballscrew
– Slower speed as ballscrew require high torque</td></tr>
<tr><td>
</td><td>+ Half the footprint of Concept 2
+ Faster speed since movement is for two fixed ends
+ Lower power consumption since movement utilizes pneumatics
– Alignment between linear guide and cylinder critical
– End to end cylinder impact may cause vibrations</td></tr>
</table>

Concept two (C2) utilizes a ballscrew to achieve X-axis movement. The units are placed in a linear fashion since the ballscrew can position the pickup head to move and stop at various positions. A stepper motor is used to drive the ballscrew. The speed of the ballscrew depends on the manufacturers rating and also on the torque and speed characteristics of the stepper motor. This concept will produce the largest footprint since the ballscrew is larger and also much heavier.

Concept three (C3) is almost same as C1 since the units are placed on an indexing plate and rotated for the pickup arm to sequentially pick each unit. However, the X-axis movement is achieved by using one pneumatic cylinder instead of a ballscrew in concept two. A linear guide is also needed to assist in withstanding the moment due to the pickup arm and ensure stability when the cylinder is fully extended. It consumes the least power since the motor is only used to turn the index disc and only small currents are need to trigger the pneumatic valves.

All the concepts utilize a small pneumatic cylinder to pick and place the units whereby the movement is in the Z- axis. Other alternatives include a stepper motor and linear motor. Stepper motor requires a small belt drive and other parts to hold the pickup head. And both types of motors will add to the overall mass on the pickup arm which leads to higher moments acting on the arm which is undesirable. One disadvantage of using a cylinder is it is hard to implement position control. However when compared with other alternatives it gives the best performance in terms of speed, ease of control and weight.

Stepper motors are generally selected because of its lower cost and simple control control using the stepper driver. It is also readily available in standard forms. Servo motors are much more expensive and more complicated to control therefore it is not considered in this application.

4.2 Selected Conceptual Design

After the various designs are drafted and considered, a decision was made to choose concept three (C3) as the final design. C3 combines the advantages of both C1 and C2.

C3 requires the least power to drive since the stepper motor will draw less current when turning only the indexer disc. C1 requires turning of the entire pick up arm, the inertia of the arm and the components on it may cause a transient response before it arrives to a full stop at the desired position. On the other hand, C2 requires the stepper to drive the ballscrew. High torque is needed to rotate the ballscrew which will cause the motor to draw high currents.

In terms of size, C3 is acceptable and not as bulky as C2. C1 on the other hand is compact however the requirement of 2 stepper driver cards will take up more space. C3 also conveniently allows the control components to be placed at the back of the machine away from the area where the operator will usually interact and clear of all the moving parts.

C3 also allows for the simplest control program. The cylinder movement is end to end and no instructions are required for the pickup head to stop at different positions unlike C2. C1 has the same advantage. However more output signals is required from the IO card to control the stepper motor.

A three dimensional (3D) sketch of the concept is then produced before components are selected and the other parts are designed. Figure 4.1 shows the 3D sketch of the design in comparison with the 2D drawing for better understanding.

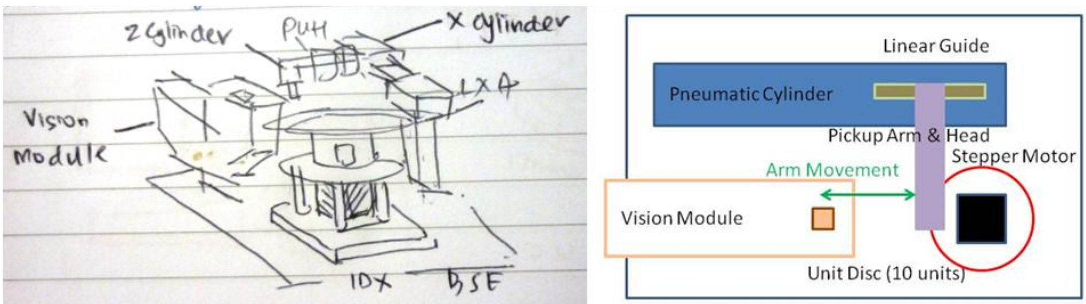


Figure 4.1: 3D Sketch and 2D Top View Drawing

From Figure 4.1 it can be seen that the various components need to be selected first before the design for the parts can be fabricated to assemble the components together.

4.3 Component Selection

A number of components are already available on hand so it is priority to use the components instead of purchasing new ones to save cost. The following chapters show the selected components and some considerations in the selection.

4.3.1 Motor

The stepper motor chosen is a 2-phase step motor by Tamagawa. The model number is TS3653N94E5 which is equivalent to TS3653N2E5 in the datasheet attached in the appendix. The N94 number stands for a customized wiring connection however the other specifications are the same. Figure 4.2 shows the image of the motor. It is a 1.8˚ angle step motor with a rated voltage of 3.6V/phase, rated current of 2.0A/phase, holding torque of 0.9N.m and 0.7kg in mass. Refer to Appendix A for further specifications.

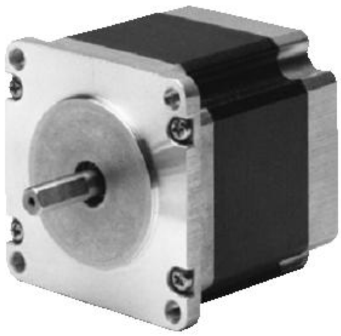


Figure 4.2: TS3653N94E5 Tamagawa Step Motor. Source: (Tamagawa Motor)

This step motor is chosen for the following reasons:

- Old part available for reuse
- Available stepper driver and controller
- Simple control and high speed actuation
- Compact design (56.4mm×56.4mm×54.0mm)
- Easy mounting

4.3.2 Pneumatic Cylinders

There are two main cylinders that are used for the actuation in the X-axis and the Z-axis. The first cylinder in the X-axis have to be able to push a larger load than the Z-axis cylinder which is only required to pick and place relatively light SMD components.

For the X-axis cylinder, the CXSJ series by SMC is chosen since it is compact type dual cylinder which allows for higher actuation forces to move the pick up arm. The model chosen is CXSJL10-70 which has a 10mm bore size, 6mm rod size (standard for 10mm bore) and 70mm stroke. The force for the away and return stroke can be calculated with equation 4.1 and 4.2 respectively. For the case of this cylinder, the piston area is doubled since there are 2 cylinders therefore the force is calculated to be approximately 78.5N when the operating pressure is 0.5MPa.

$$\boldsymbol{F_{away} = p\,\frac{\pi d_1^2}{4}} \tag{4.1}$$

$$\boldsymbol{F_{return} = p\,\frac{\pi d_1^2 - d_2^2}{4}} \tag{4.2}$$

where
F = force, N
p = pressure, Mpa
d_1 = bore diameter, m
d_2 = rod diameter, m

The CXSJL series also allows for a non-rotating accuracy of ±0.1 as it utilizes ball bushing bearing. This leads to another advantage as it can share the load of the linear guide that will be used. More information of the cylinder can be found in Appendix B for the CXSJ datasheet.

For the Z-axis actuation, the force required is not an important parameter since the units are relatively light, less than 100grams. However it is critical that the cylinder rod is guided as well to keep its straightness when it picks and places the unit. The rod must also be non-rotating in order to avoid the units from rotating out of orientation. The cylinder CDUK6-15D by SMC is selected to for this purpose (equivalent to CUK series where the D stands for a built-in magnet for operation with sensors). Figure 4.3 is an image of the cylinder. It contains a stainless steel block at the end and a linear guide rod to avoid the rod from rotating.

Figure 4.3: CDUK6-15D Double Acting Cylinder. Source: (SMC Pneumatics Distributor)

After looking through different cylinders, this is found to be ideal as a vacuum block can be mounted directly to the end of the cylinder. It is also a free mount type cylinder where five faces of the cylinder can be used for mounting, allowing for more flexibility when designing the pickup arm. More specifications can be found in Appendix C.

4.3.3 Pneumatic Valves

To achieve high speed actuation, quick response is required. The valves play an important role in channelling the air to the cylinders. It acts as a switching mechanism to control the movement of the cylinders. A vacuum generator switch is also required to generate the vacuum for unit pick and place.

The valves chosen for this project are standard 5/2 way valves which stands for five ports for airflow and two positions which can be switched depending on the requirement. The SY3000 series by SMC is chosen due to its compact size, ultra fast response time (15ms or less) and low power consumption (0.45W). The specific model part name is SY3120-5MZD. It is a two position single actuation means only one signal of 24V is required to change the position. The ports are a standard M5 × 0.8 thread sizes as with all other pneumatic components and fittings since it is easy to come by. The valve also has a push-turn locking type button as a manual override so the valves can be tested even without a 24V signal. More details can be found in Appendix D.

A vacuum module is selected which contains all the required components to generate vacuum, ejector (low pressure blow of air to ensure unit is not stuck to the pickup head), valve and a filter to avoid the valve from being contaminated. Figure 4.4 below shows the complete unit selected which has the part number ZX1071-K15LZ with a digital pressure switch ZSE3-0X-23CN. It has two valve switches to turn on and off the vacuum and purge, an ejector unit, digital vacuum pressure readout switch and suction filter unit.

Figure 4.4: ZX Series Vacuum Module. Source: (SMC Pneumatics Distributor)

The vacuum module is made to pick electronic components up to 100g in mass. It also allows for additional functions such as error detection for clogged filter and output to identify unit is picked when there is a change in vacuum pressure. This is a big advantage to avoid triggering a false vision. When no unit is detected, the software can stop immediately and skip to the next unit instead of triggering the vision system when there is no unit present. More specifications of the module can be found in Appendix E.

4.3.4 Air Regulator

A simple filter-regulator unit (FR) unit is implemented at the front end of the system to regulate the pressure to a suitable working pressure of 0.5MPa. The unit chosen for this is the AW10-M5C by SMC as it is the most compact in its class regulator and allows for a set pressure of 0.05MPa to 0.07MPa.

4.3.5 Linear Guide

Linear guide is used to hold the pickup arm in place. It also ensures that most of the moment caused by the pickup arm is supported by the guide instead of the pneumatic cylinder. In this project a stainless steel linear guide is chosen with 1 block for the mounting of the pickup arm. The part number is SSEBL-N8-119 and is sold by Misumi. Figure 5.4 shows the table of load rating for the selected guide and the allowable static moment of the applicable axis.

kgf=Nx0.101972

H	Basic Load Rating		Allowable Static Moment			Mass	
	C (Dynamic) kN	Co (Static) kN	M_A N·m	M_B N·m	M_C N·m	Blocks kg	Guide Rails kg/m
6	0.3	0.6	0.8	0.8	1.5	0.004	0.13
8	0.9	1.5	4.1	4.1	5.2	0.01	0.19
10	1.5	2.5	5.1	5.1	10.2	0.02	0.31
13	2.2	3.3	8.8	9.5	16.1	0.04	0.61
16	3.6	5.4	21.6	23.4	39.6	0.06	1.02
20	5.2	8.5	48.4	48.4	86.4	0.12	1.65

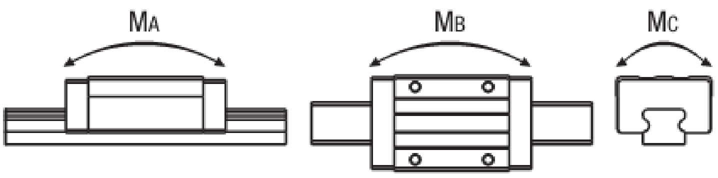


Figure 4.5: Load rating and allowable static moment on guide blocks. Source: (Misumi Catalogue)

Verification of the moment can only be done after the pickup arm design is finalized however due to the compact size required, we can assume that this is a suitable guide since the pickup arm and pickup head will not exceed a moment of 5.2N.m which is equivalent to suspending a 0.5kg load 1meter away. More specifications are available in Appendix F.

4.4 Overall Layout and Mechanical Design

Once the components are selected, their dimensions can be obtained from the respective datasheets while the CAD files can be obtained online. The entire design is then done in SolidWorks before technical drawings are produced. The entire project is divided into several modules to allow for a naming standard so that files can easily be looked up and identified. It is also easier to design a machine separately by its modules since each module's problems can be solved individually before it is all combined. Table 4.2 shows a list of modules and their abbreviation. The abbreviations are used in naming of CAD files for parts that are custom fabricated.

Table 4.2: Modules Abbreviation and Full Name

Abbreviation	Full Name
BSE	Base Module
IDX	Indexer Module
LXA	Linear X-axis Module
ECU	Electronics Control Unit

The overall design is a combination of the various modules. Figure 4.6 shows the base, indexer and linear x-axis module together with the vision module. The vision module is not a part of this project and it is only used as an illustration and dimension references for the other parts. The figure shows a top view, side view front view and Isometric view of the project. Other components such as the valves, stepper board and power supply are not included for simplicity purposes. The parts shown are important for design verification before fabrication.

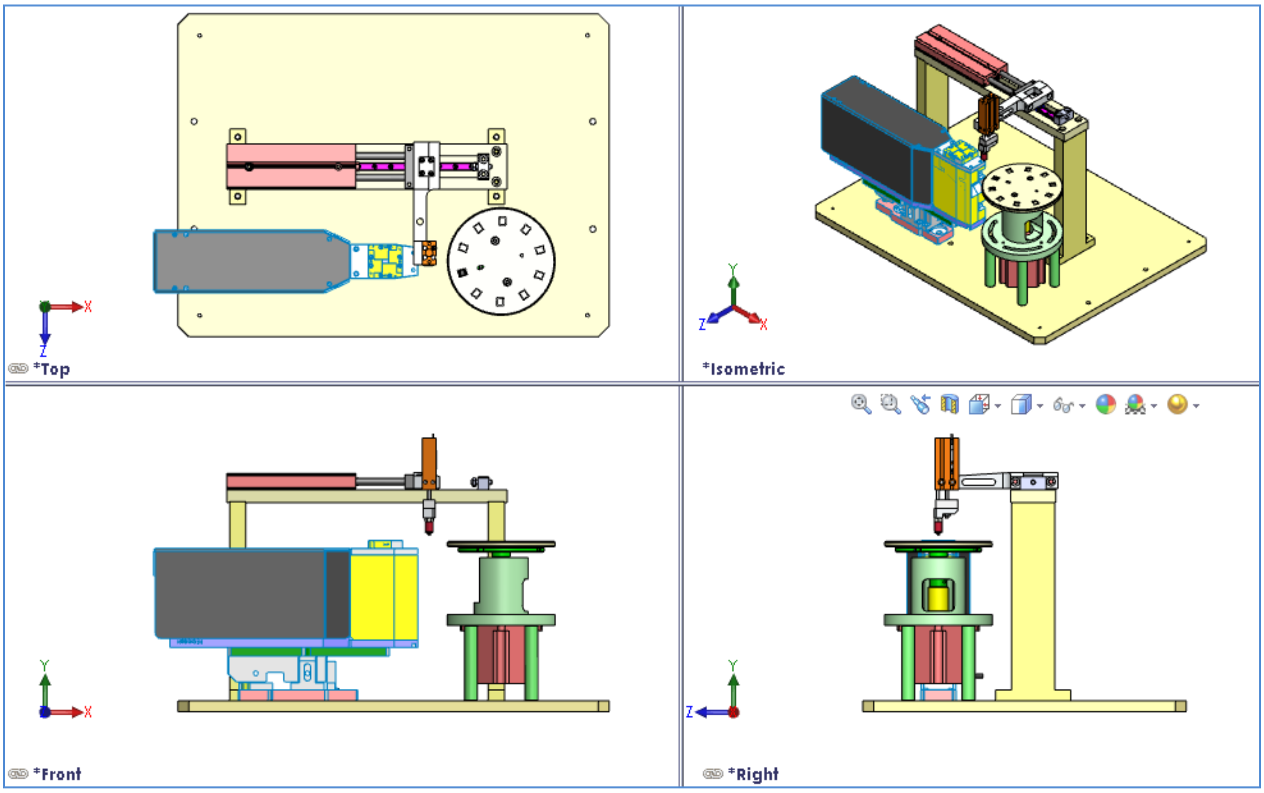


Figure 4.6: 3D Design - Top, Front, Right and Isometric View

The design allows for some room at the back of the machine for the mounting of the control components and electronic parts such as the power supply, motor driver board and pneumatic valves. The design also omits pneumatic fittings, tubing and sensors. All these will be visible in the final product later on. By reducing unnecessary CAD files, the access time of the assembly is reduced especially if the computer used to design does not have capable hardware to support complex assemblies.

In the design, consideration has to be done for the assembly of the parts and the tolerances of fabrication. Lower tolerances mean higher cost therefore some alignment tolerances has to be designed into every part that will allow the assembler to manually fix alignment problems without re-fabricating the part. Moreover, manual alignment is needed at certain areas to compensate for different sizes of inspected unit and different types of vision modules. Detailed drawings for the parts can be found in the Appendix G.

4.4.1 Alignment Considerations

In several places of the design, additional tolerances are added to allow for alignment. There are certain considerations that go into the design which will allow time saving during assembly and calibration. From experience, there are a few general rules that should be followed when considering where to provide additional tolerance for alignment:

- Not all parts should be free for alignment as it introduces too much uncertainty in the assembly process. The more fixed parts, the better.
- The additional tolerance for alignment should be allocated as near as possible to the section where the alignment is critical for it to function properly.
- The alignment should only be allowed along or around one axis in each position where extra tolerance is given.

In Figure 4.7 the places where alignment is allowed for the X, Y and Z axis is drawn in red. These places are the nearest to the pickup head as it is critical for these adjustments to be made depending on the type of unit and vision module used.

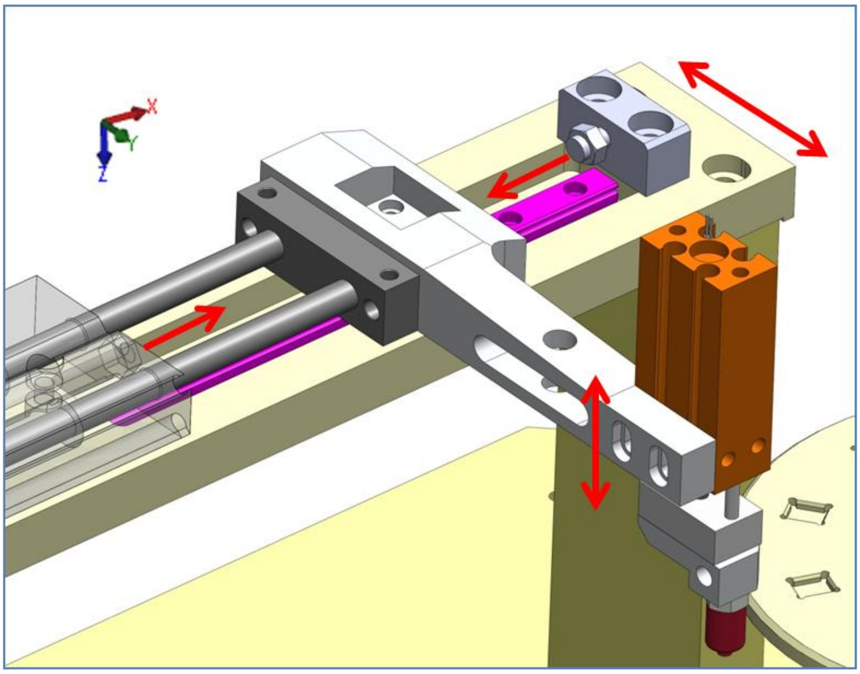


Figure 4.7: Locations for Alignment of Pickup Head

Grooves and specific cut-outs are also designed into the fabricated parts to constraint the movement of components. These help reduce overall alignment time. In Figure 4.8, the pickup arm is designed specifically to allow the cylinder to only move in the Z-axis for alignment purposes as the outer edge will be flush to the end of the arm. If there was no specific cut-out designed here, the cylinder can rotate around the X-axis when trying to fix a proper alignment along the Z-axis.

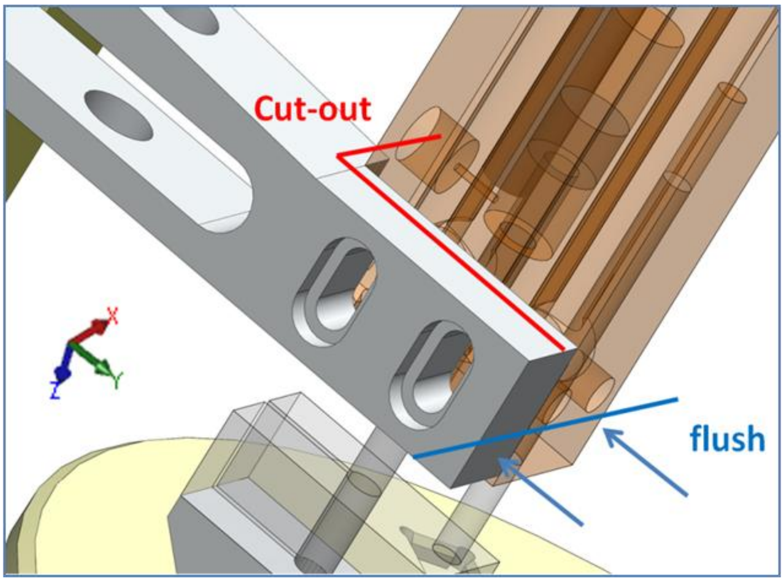


Figure 4.8: Cut-out and Flush to Edge Design for Pickup Arm

4.4.2 Materials and Surface Finish

The main materials used for this project include aluminium, stainless steel and nylon. Aluminium (ALU 6061) is generally used for most of the parts as it is lightweight and low cost. Stainless Steel is used in certain areas of the design where a harder material is required due to continuous adjustments.

For example, the poles of the indexer module and the body are made of stainless steel. This is because constant tightening and loosening to do alignments may deform the material if aluminium is used. The tapping threads are also one of the weakest points and may easily break free if the size of the tapping is too small. All bolts used are stainless steel bolts since it is an industry standard for machines. It also does not rust and has a high tensile strength. Nylon is used as a stopper for the pickup arm to reduce the impact and create less noise. Figure 4.9 shows the fabricated parts before assembly.

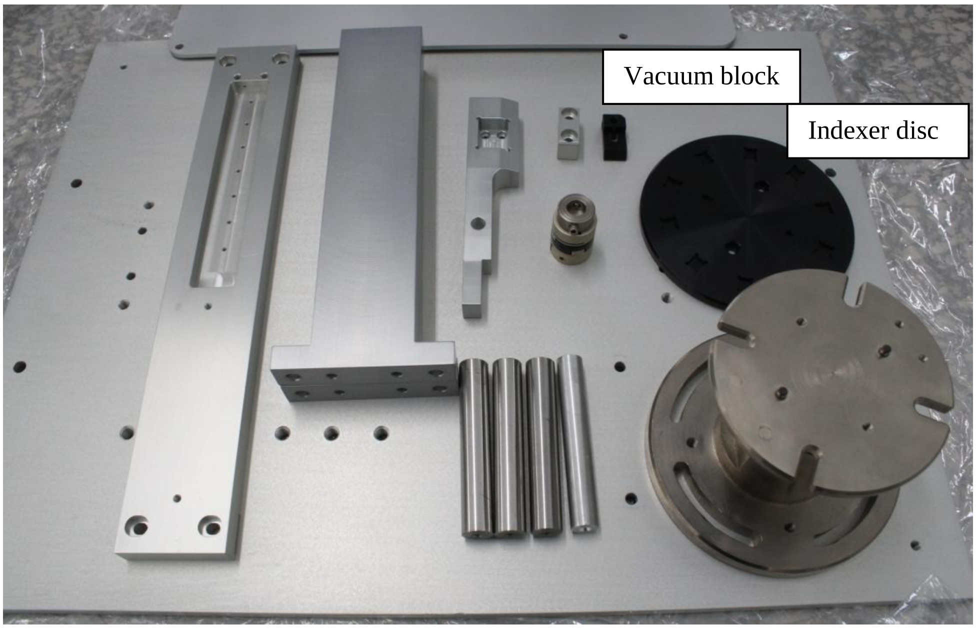


Figure 4.9: Custom Fabricated Parts before Assembly

All of the aluminium parts are finished with a form of coating. In general, clear anodizing is used. This coating removes the conductivity of the aluminium surface and gives it a clean look. The probability of electrical short circuit is reduced when the part is anodized. For some parts, black anodized finish is used. Black anodized coating is important in areas that will likely come into close contact with the vision system. The black colour reduces stray reflections caused by the vision system's lighting. Stray reflections introduce more noise into the images taken by the vision system. In Figure 4.9 the vacuum block is black anodized because it operates very near to the vision light source.

The indexer disc may be used to conduct 2D vision inspection where the camera is oriented from the top directly facing the indexer. Therefore, it is finished with black anodize as well. The dimensions of the pockets for the indexer are based on the dimension specification of the units in Appendix H.

4.4.3 Stress Simulation on Pickup Arm

The pickup arm is an important component in the design of this machine. Because it has a one side overhang and a small load (pneumatic cylinder and fittings) on it, it tends to generate a bending moment and inertia due to its weight. To reduce the moment and inertia, the arm is tapered to be smaller at the far end. The middle of the arm is also designed to be hollow to reduce the overall mass. Before executing the design, simple stress simulation is done to ensure that the remaining material on the arm can withstand the stress without fracturing if any mishap were to occur. One possible scenario is when the Z-axis cylinder extends and hits the vision system or indexer disc because it is not aligned properly. The suction head can be replaced easily however damage to the structure may be more costly to repair.

From a bore diameter of 6mm, the away stroke of the cylinder can put out a force of approximately 15N at 0.5Mpa. Assuming worst case conditions, a force of five times the static force (75N) is exerted by the cylinder on the arm during impact. The simulation result is shown in Figure 4.10. The highest stress areas are marked in red. It can be observed that the yield strength of the material is still almost double the red areas, therefore it can be concluded that the design will not fail under this situation.

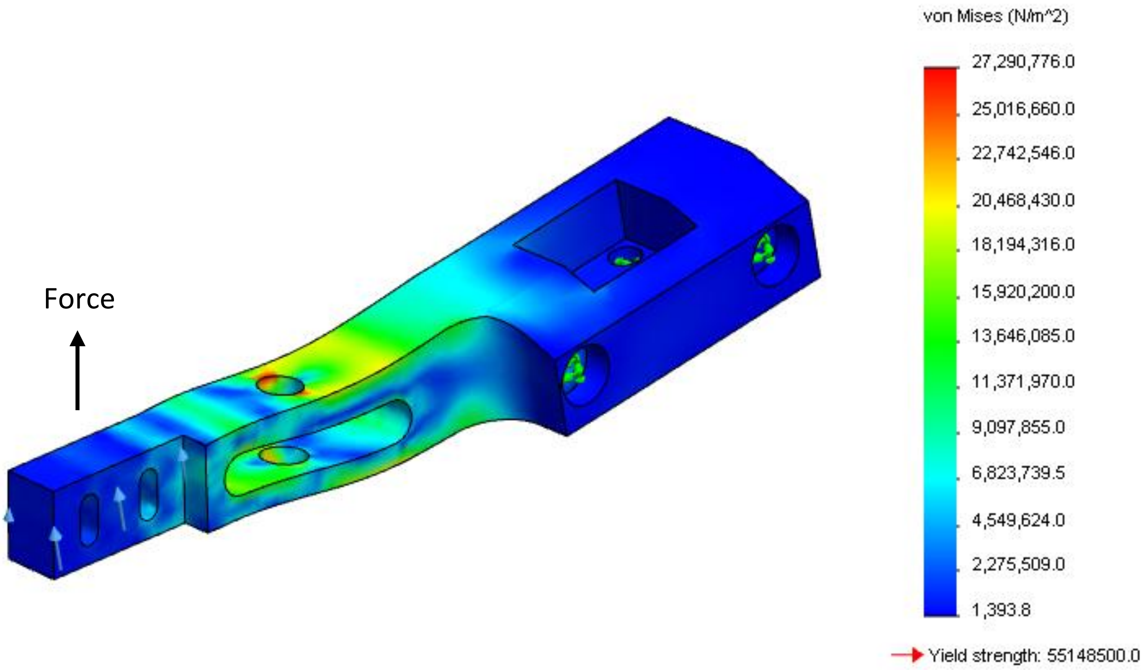


Figure 4.10: Stress Simulation on Pickup Arm

4.4.4 Pneumatics System

Two cylinders two valves, one regulator and one vacuum module make up the total pneumatic components for this machine. Other parts include the elbow type speed controller, M5 fittings, Y and T junction fittings and tubing.

The connection of all the components are done in Festo FluidSim and simulated before the actual connections are made. Figure 4.11 shows the pneumatic schematics using standard symbols.

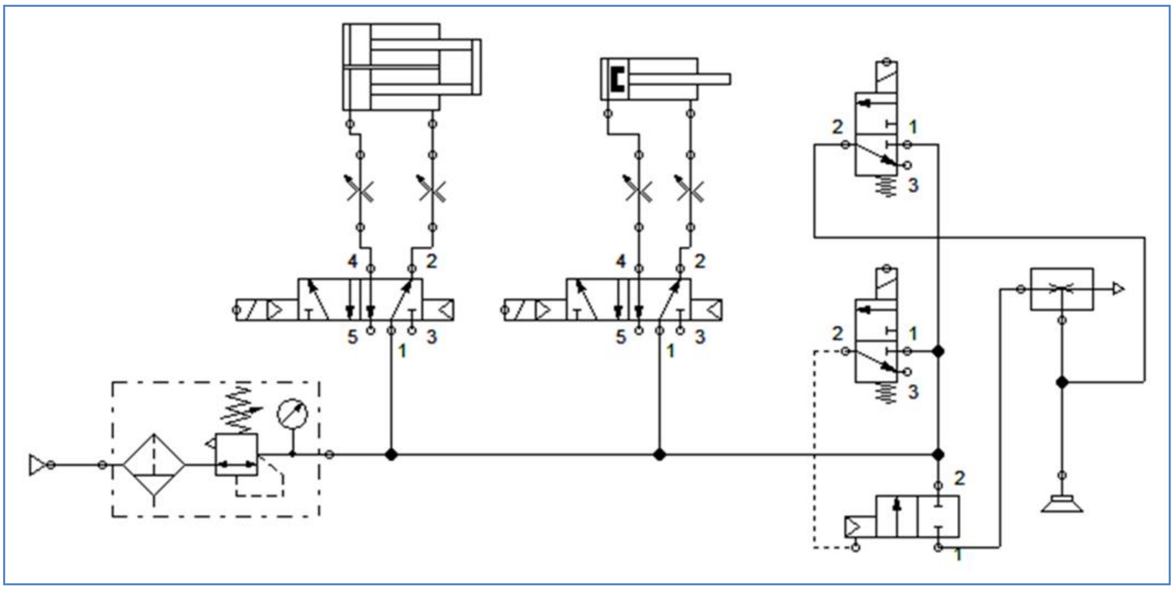


Figure 4.11: Pneumatic Diagram

The parts on the far right form the vacuum module where two inputs are required to switch on or off the vacuum and purge (blow air to remove unit). The symbol on the far left is the air regulator while the components in the middle are the valves and cylinders. Overall, this simple pneumatic system is able to achieve most of the functions required by the machine.

CHAPTER 5

ELECTRONICS AND CONTROL DESIGN

5.1 Overall Electronics

The power supply input to the machine is 240V AC via a standard three pin plug. A step down transformer and a switching supply is used to step down the high voltage. 24V DC is the operating voltage of all the components used except for the motor driver which requires a 12-0-12V two phase AC. The machine logic also operates on a 24V DC voltage and a compatible Data Acquisition Unit (DAQ) is used for Input and Output (IO). The overall connection block diagram is shown in Figure 5.1

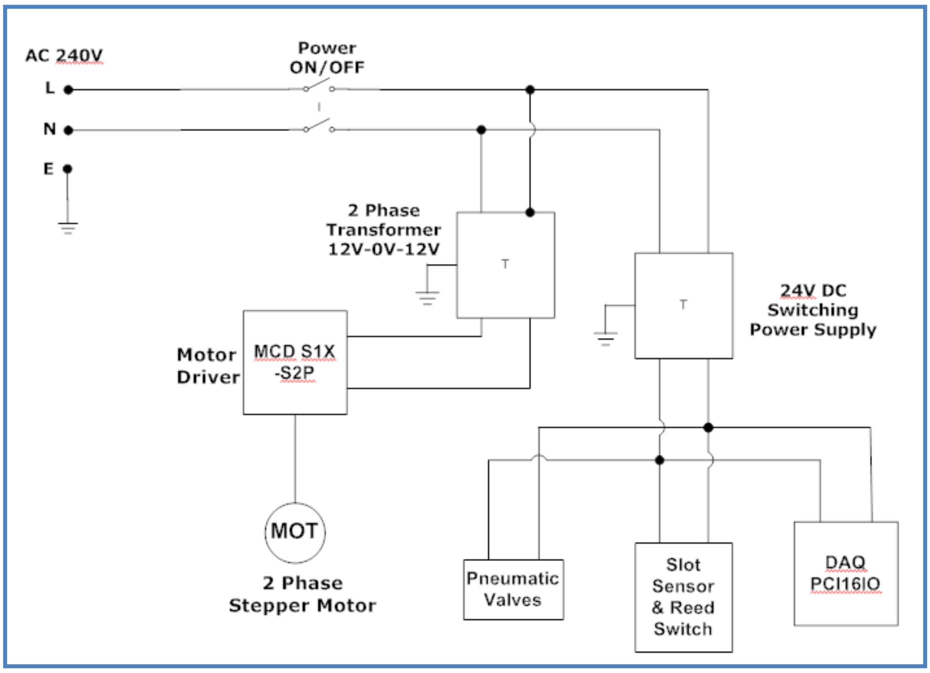


Figure 5.1: Electronic Connection Block Diagram

5.2 Component Selection

The electronic components are selected based on their voltage and current rating. The response time of the units also considered as it is an important criteria to achieve high speed in the design requirements.

5.2.1 Power Supply

Once the overall voltage requirement is set, the current requirements are estimated to determine the type of power supply that needs to be used.

The selected transformer is a 240V to 12-0-12V transformer by E.K.K rated at 3A/ 36VA. It is an ideal size because the stepper motor runs at about 2A. Higher current rating transformers are much bigger and add to the overall weight. To supply the 24V DC, the switching power supply used is NES-15-24 by Meanwell which has a current rating of 0.7A. This is found to be sufficient as most of the 24V devices consume very little power. Switching power supply is chosen as it is more efficient and compact in size compared to conventional voltage transformers. It also supplies a more stable current with minimal ripple (15mVp-p).

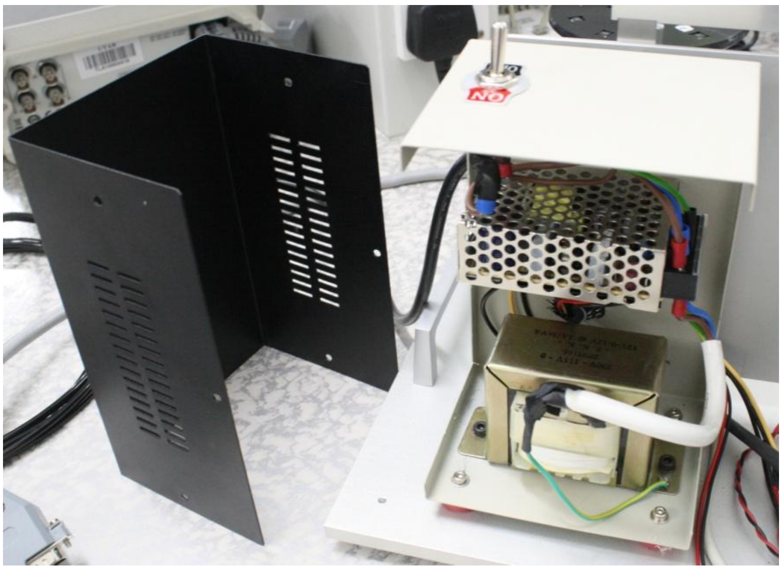


Figure 5.2: Power Supply Box Enclosure and Components

Figure 5.2 is an image of the power supply with the components inside an insulated sheet metal casing. The switching power supply is located at the top while the transformer is on the bottom of the box. An industrial grade switch with 250V AC with 15A rating is used to turn on and off the main power to the transformer and switching power supply.. Cable mesh is wrapped around certain portions of the wire to protect it from friction between the wire and the metal casing. Heat shrink tubing and insulation tape is also used where applicable to insulate exposed wires and avoid accidental short circuit. The datasheet of the switching power supply is in Appendix I.

5.2.2 Motor Driver

The motor driver selected is the MCD S1X-S2P by Vie Technologies. Its input voltage is 12-0-12V and its driving voltage is about 34V to 36V with maximum current output of up to 4A. This driver suite the requirements of the Stepper Motor used. It can store a maximum of 16 motion sequences. When the motion sequences are called upon and the stepper driver will drive the motor accordingly.

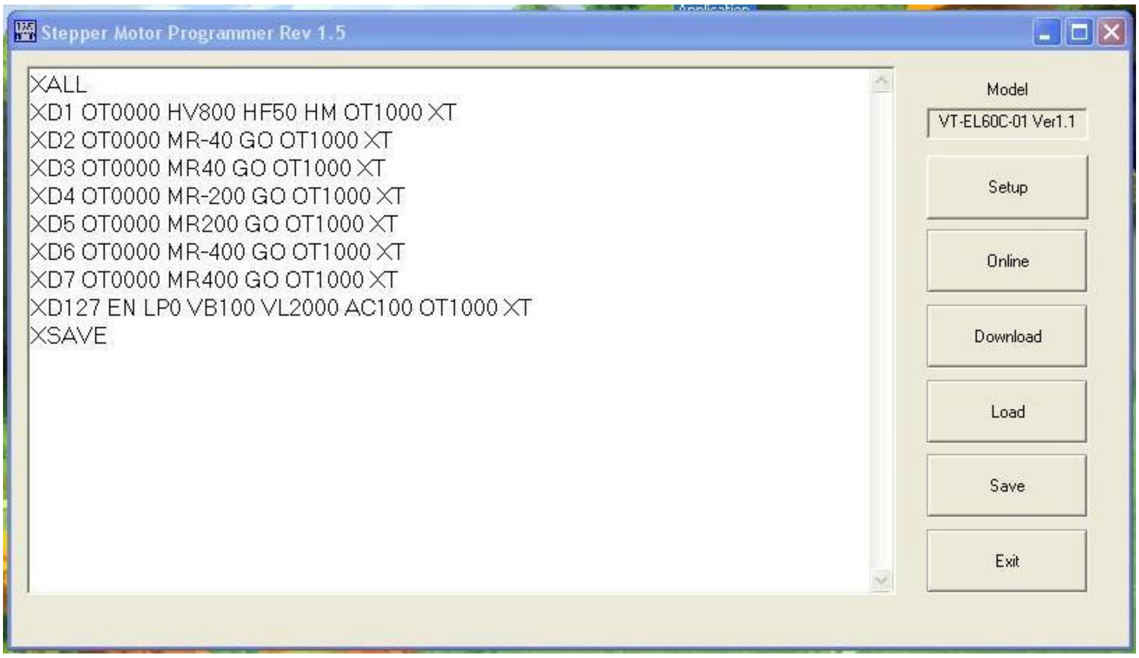


Figure 5.3: Stepper Motor Programmer Application

Figure 5.3 shows the stepper motor programmer application and the program sequence that is programmed in it. The software application will fire the IO where five bits are required to communicate with the stepper driver. The first column in the commands is the sequence definition. Here seven definitions are stated and the 127th definition is the default settings. 'OT' is the handshake signals which can be used to communicate with the IO when the stepper has completed its sequence. 'MR' stands for move relative and the value that follows is 40 pulses. The settings selected is a half step, therefore 1 pulse is equivalent to 0.9˚ rotation. 'HV' and 'HF' are the home velocity and home final speeds.

5.2.3 Input Output Card and Terminal

The input output card or also known as the Data Acquisition Unit (DAQ) is an important component in the machine. It allows for communication between the hardware and personal computer (PC) where the software is written. The selected card is the DAQ-PCI16IO by Vie Technologies. It has 32 channel isolated digital IO (16 digital inputs, 16 digital outputs).

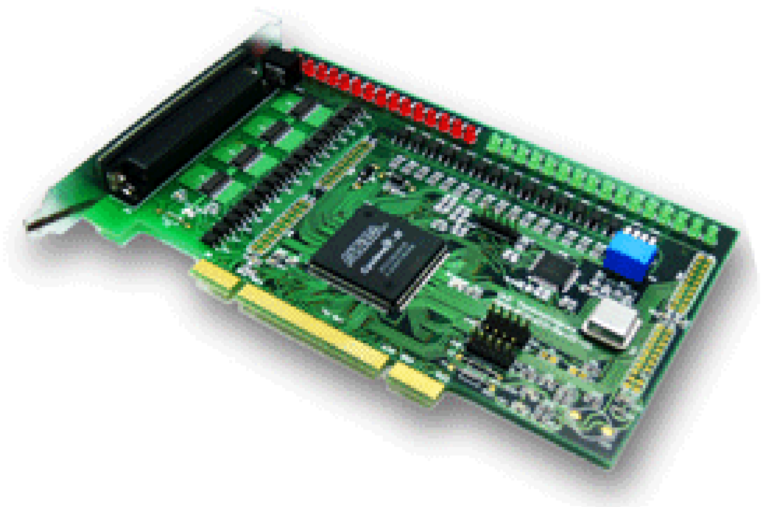


Figure 5.4: DAQ-PCI16IO. Source: (Vie Technologies, 2012)

Figure 5.4 is an image of the IO card. One advantage of using this card includes; it has a high isolation voltage (3750V DC) which can protect the PC against high external voltage. The output is an open collector type (current sinking). Each output is connected parallel to the common supply pin with a fly-back diode to protect the driver from inductive loads such as relay, motors and solenoids. The input and outputs have a response time of 10kHz which is equivalent to a time response of 0.1ms.

The IO card and machine is connected via a DB37 connector head. Since not all the inputs and outputs will be used for this application, a 25core wire is used between the two connectors. 25 core wire costs less and is more readily available compared to 37 core wires. Each core is soldered individually and protected with heat shrink tube. Figure 5.5 shows the wire connection to the connector without the casing.

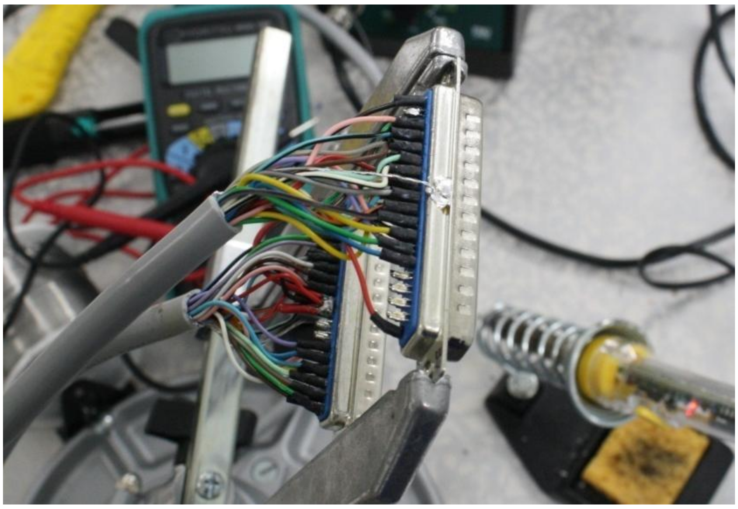


Figure 5.5: 25 Core Wire Soldered to DB37 Connector Head

The other end of the connector is attached to a 16IO termination board, DB16IO. This termination terminal allows for more convenient connections between the components and the DAQ. Figure 5.6 shows the connector and the termination board. The usable IOs are lighted up in red and green. The LEDs on the board also provides convenience when troubleshooting IO problems.

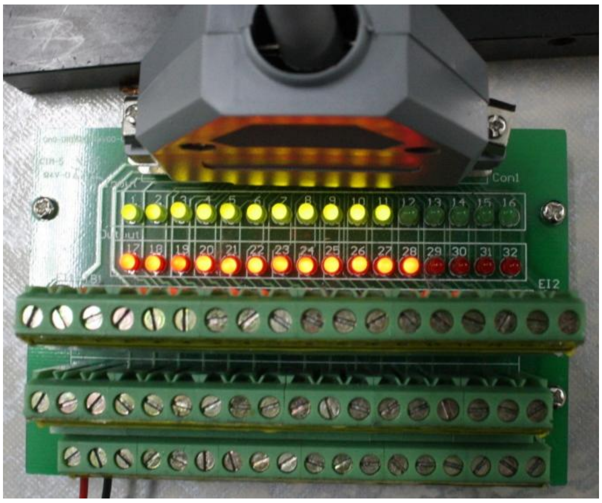


Figure 5.6: DB16IO Termination Board with All Connected IO Turned On

5.2.4 Sensors

There are two types of sensors used in this machine. The photoelectric slot sensor and reed switch.

The photoelectric slot sensor is used in many industrial machines. It is mainly used for position indication and overrun avoidance. The sensor PM-T54 by Sun-X is chosen due to its footprint which makes it suitable for the IDX module. It has a response time of 100μs under light interrupted condition and a repeatability of 0.03mm.

The reed switch is used to detect the positions of the pneumatic cylinders. Most cylinders have built in magnets for this purpose. The sensor used for this machine is the D-A93 model by SMC. It is a two wire type connection that forms a closed circuit when magnet is present. The response time for this switch is 12ms.

5.3 Input Output Assignment

Before proceeding with the connection and wiring of all the components, the IO table is created as a reference. Table 5.1 is the table of inputs and outputs. A total of 10inputs and 11 outputs are available. TB1 Label number corresponds to the numbering on the termination board while DAQ IO corresponds to the numbering on the IO card. TB1 numbering is referred to when doing the wiring while DAQ IO is referred to when writing the program.

Table 5.1: IO Table

TB1 Label	DAQ Input / Output	Description
INPUT		
1	IDI 0	Motor Controller Handshake
2	IDI 1	IDX Home
3	IDI 2	X Cylinder Home
4	IDI 3	Z Cylinder Home
5	IDI 4	-
6	IDI 5	-
7	IDI 6	Unit picked
8	IDI 7	Vacuum Error (Check Filter)
9	IDI 8	-
10	IDI 9	-
11	IDI 10	VC (Vision Complete)
OUTPUT		
17	IDO 0	-
18	IDO 1	Strobe IN5 (orange)
19	IDO 2	IN1 (yellow)
20	IDO 3	IN2 (green)
21	IDO 4	IN3 (dblue)
22	IDO 5	IN4 (purple)
23	IDO 6	X Cylinder Away
24	IDO 7	Z Cylinder Away
25	IDO 8	Vacuum On
26	IDO 9	Purge
27	IDO 10	-
28	IDO 11	VT (Vision Trigger)

CHAPTER 6

APPLICATION DESIGN

6.1 Software Development

Before the software is developed, the requirements are listed out. For this machine, the main requirement is to automatically perform pick and place of ten units and each unit is picked for inspection nine times. Besides, other functions are added that includes manual control of each cylinder, vacuum and stepper motor.

The Microsoft Foundation Class Library (MFC) is chosen as the library to create the application. It is a library that wraps portions of the Windows Application Programming Interface in C++ classes. It is easy to include functionality that enables a user to use the default application framework. The application framework is all the basic functions that allow us to run an application in Windows. One disadvantage of MFC is it is only Windows compatible and is not supported by other operating systems.

However, the main advantage of using MFC is because of its extremely efficient coding. MFC applications are applied in situations where is speed critical. It is common practice for fields like machine vision and electronic share trading to use MFC because of its speed and stability.

6.2 Graphical User Interface

The application Graphical User Interface (GUI) is drawn and developed in Microsoft Visual Studio 2008 using MFC library and the C++ programming language.

Figure 6.1 shows the developed GUI that is used to control the GRR Auto Module. The top most part shows the number of IO Cards detected, Base Address and Slot Number the card is found in. It also allows the user to select the board that is connected to the machine.

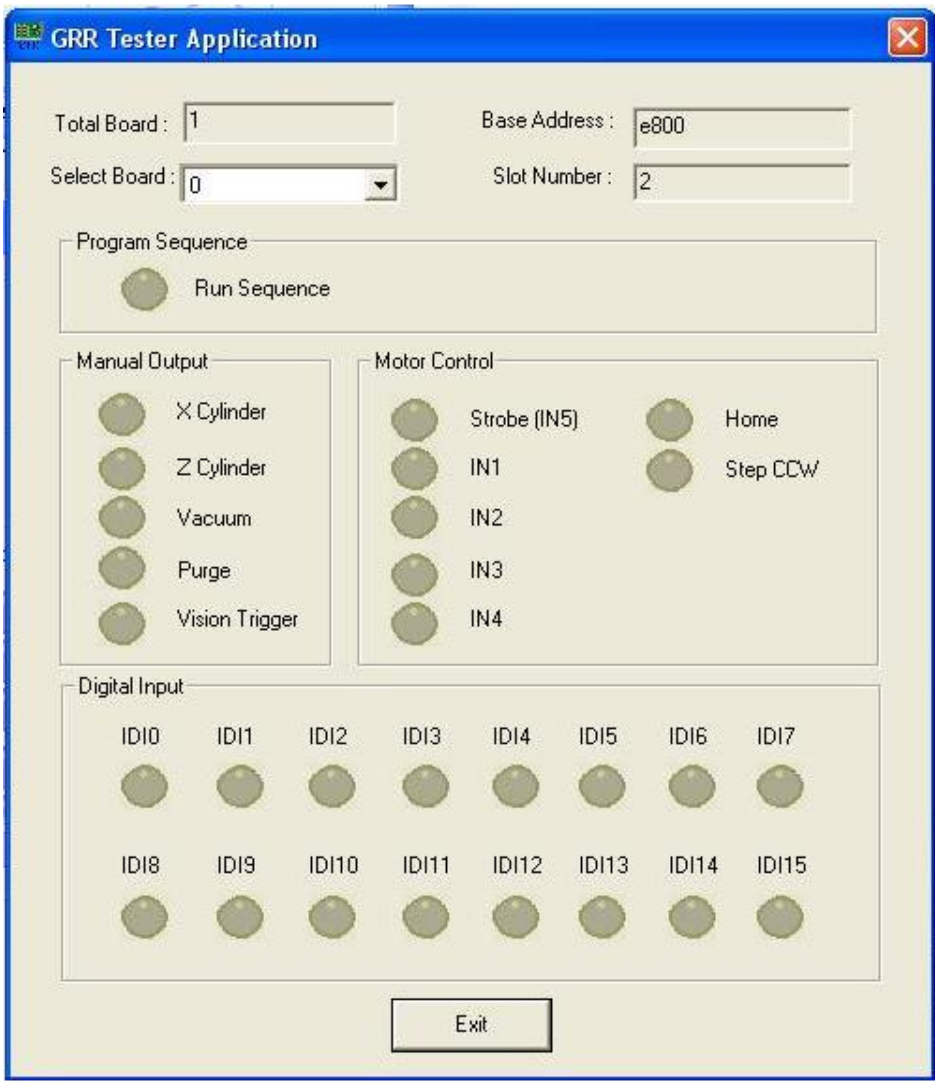


Figure 6.1: GRR Tester Application Graphical User Interface

The application is divided into four different group boxes. The first group box is to run the program sequence. This is an automatic sequence and runs according to the program. The C++ program code snippet for this function can be found in Appendix J. The next two boxes allow the user to manually control certain outputs. The manual output box can be used to control the cylinder movements, vacuum, purge and trigger the vision signal. These buttons can allow the user to manually pick and hold a unit static in a desired position.

The motor control allows for the user to home the indexer and step the indexer plate. The five outputs to manually control the motor is also available. However, knowledge of the sequence in the stepper controller is needed to use these buttons. This is mainly used for troubleshooting motor errors.

The final group box shows the digital input. It is also used for troubleshooting and gives the user awareness on the response of the various outputs from the machine. By using the GUI and referencing the IO table in section 5.3, the user can know the state of the machine from the application without a physical view of the machine.

CHAPTER 7

RESULTS AND DISCUSSION

7.1 Final Product

After the completion of the mechanical, electronics and software, testing is done to ensure all the components integrate seamlessly to form the entire system.

The Final product is a fully functional pick and place machine that is controlled by an application run on windows. Table 7.1 below shows the general specifications of the machine. This model of the machine is called the ‘GRR Auto Module’.

Table 7.1: GRR Auto Module Specifications

Overall Dimensions	400mm(L) × 340mm(W) × 340mm(H)
Overall Mass	9kg
Input Voltage	240V AC
Operating Voltage	24V & 12-0-12V
Operating Pressure	0.5Mpa
Maximum Vacuum Pressure	-91kPa
Rated Speed	1500 UPH

Figure 7.1 is the image of the final product. The isometric view shows the pickup arm and the pickup head at the home position. The tube extending out from

the left is the input for the compressed air supply, the black cable on the right is the power cable while the grey cable is connected to the DAQ card. The idea was to keep the front as simple and clutter-free as possible as this is where the operator will conduct most of his/ her work.

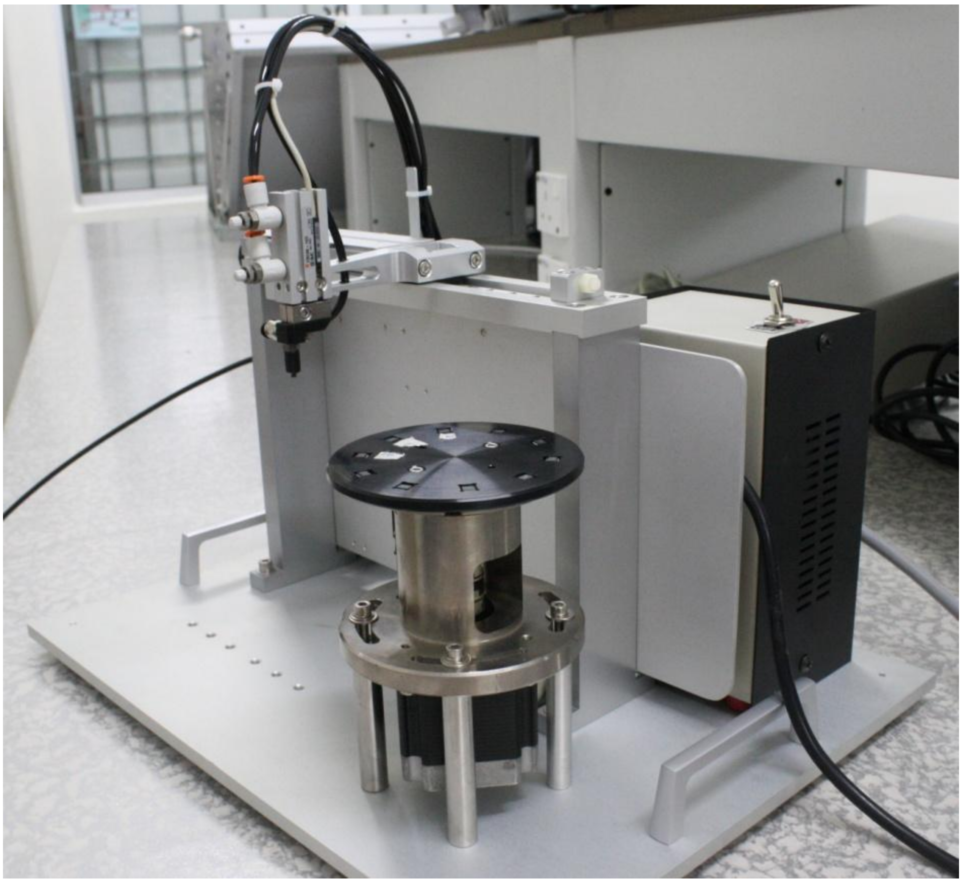


Figure 7.1: Isometric-Front View of GRR Auto Module

Figure 7.2 is a top-back image of the final product. The power supply box, motor stepper and driver, IO termination board, valves, air regulator and vacuum module are visible in this image. All of the control components are placed at the back of the machine because the general operator need not use any of the controls here. Only during machine assembly and set up this section will be used.

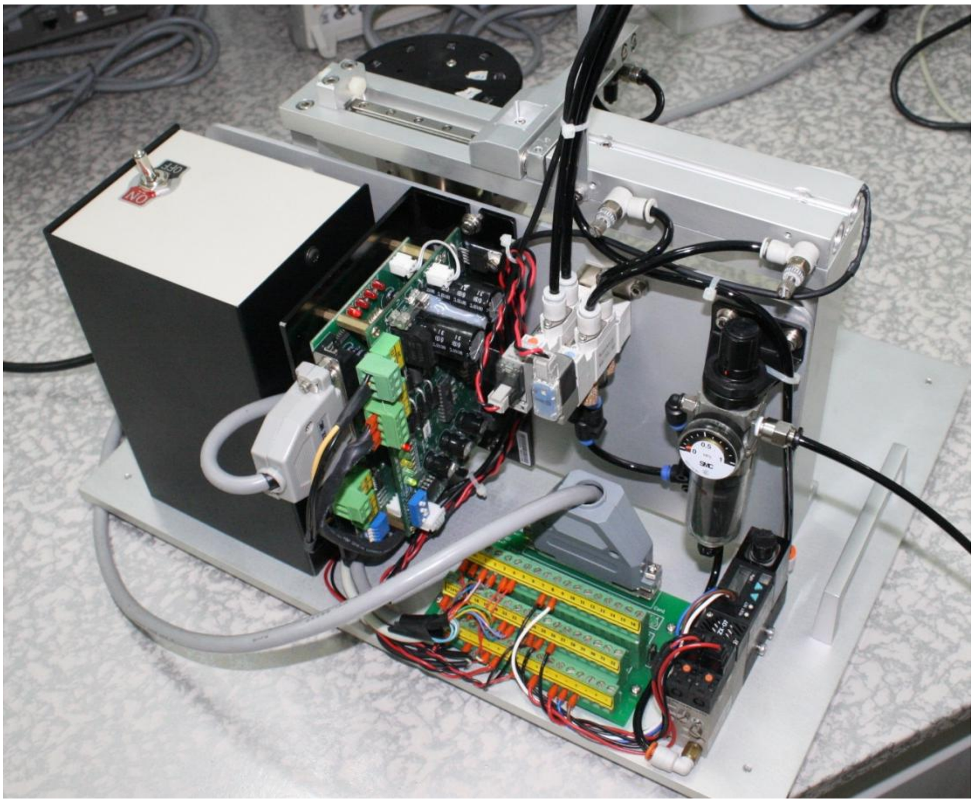


Figure 7.2: Top-Back View of GRR Auto Module

The vision module is mounted on the six holes that are located in front of the pickup arm. Figure 7.3 is an image of the machine with a vision module in place.

Figure 7.3: Machine with Vision Module in Place.

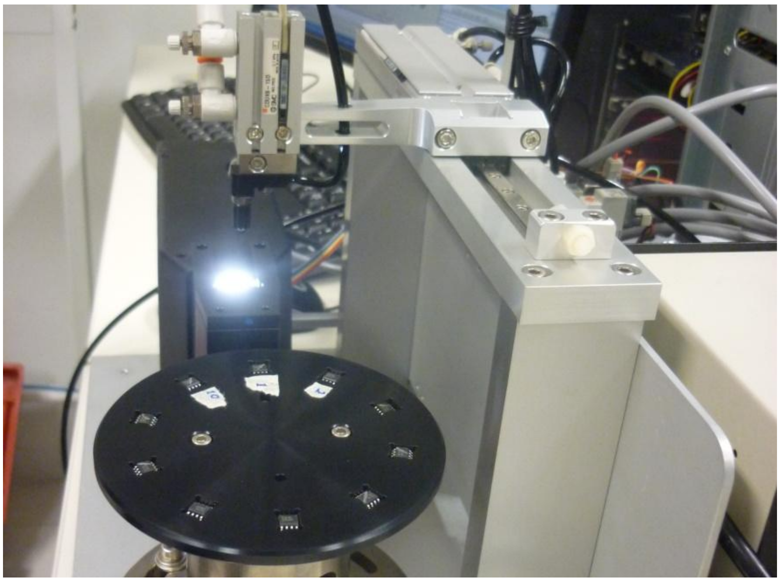


Figure 7.3: Lighting Emitted by Vision System

In Figure 7.3, the lighting effects of the vision system can be observed. The light is a high intensity flash and can be in various colours, depending on the unit inspected. Therefore, components that are anywhere near to the vision system needs to be black in colour to absorb stray reflections. Figure 7.4 shows the pickup head and arm where alignment can be done to adjust the height. The arm is also hollow in the middle to decrease the overall inertia. The indexer is in its home position where the dog is slightly beside the photoelectric slot sensor.

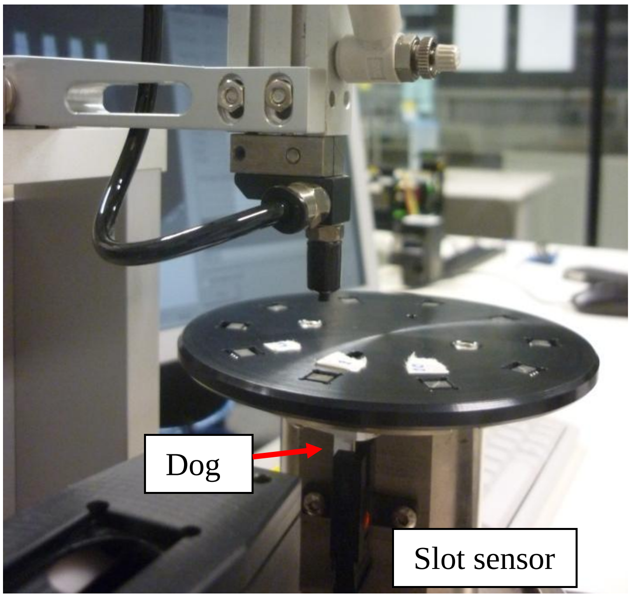


Figure 7.4: Pickup Head and Indexer Disc with Photoelectric Slot Sensor

The LXA module is a critical part to ensure the rigidity of the pickup arm when it is motion. Figure 7.5 shows the top view of the pickup arm which is attached to the linear guide below it. The X-axis cylinder is located on the right of the image and is also connected to the pickup arm at the end of the cylinder.

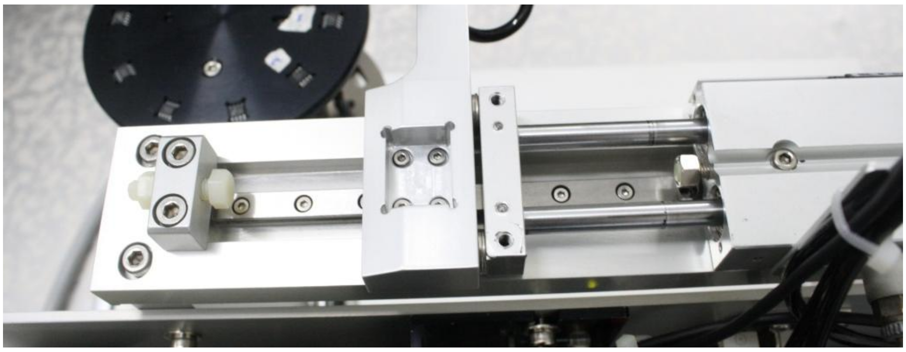


Figure 7.5: Top View of LXA Module

The image capture and image processing of the unit is beyond the scope of this report. However Figure 7.6 illustrates how a typical image looks like when captured and measurements are conducted. The unit is held in place by the GRR Auto Module.

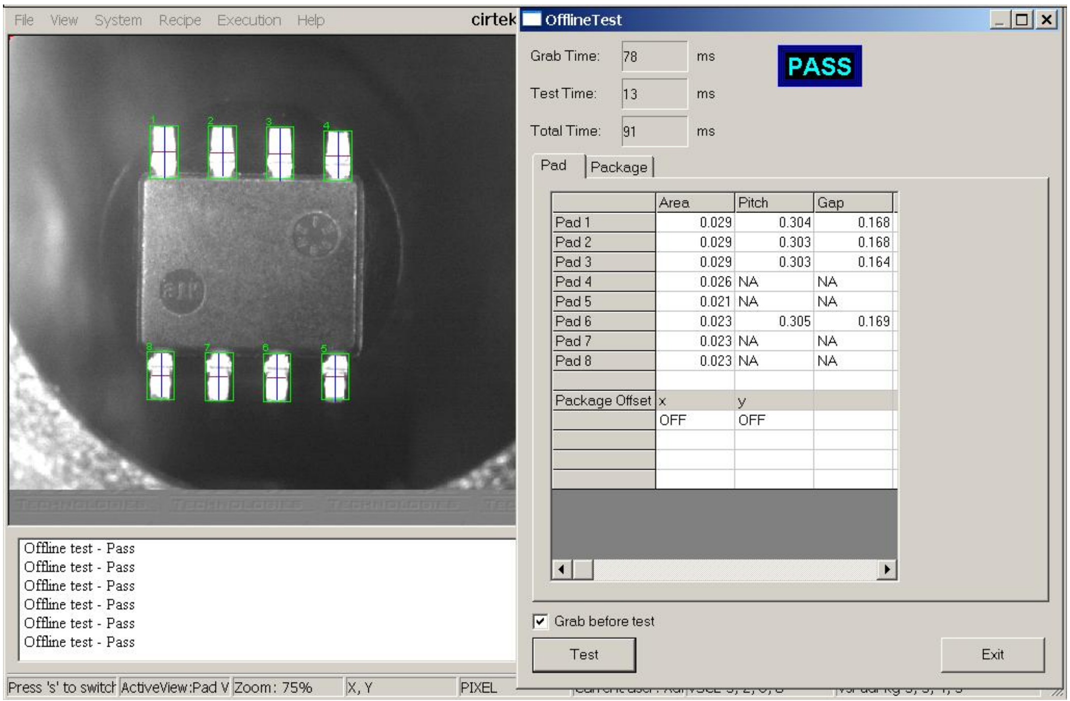


Figure 7.6: Screenshot of Vision Inspection Software when Unit is in Position

7.2 Overall Performance

The capabilities of the machine is judged on two main criteria, the speed or cycle time to pick, inspect and place one unit and the repeatability in which it places the units. There are other functions that add value to the machines which will be discussed in the later sub-chapters.

7.2.1 Pick and Place Speed

For standard evaluation of GRR, a total of ten similar IC units are used and each unit is inspected nine times. This brings a total of 90 times to be considered as one full cycle. The speed of the machine is measured using a sport timer watch from the click of "Run Sequence" button until the X-cylinder returns to its home position. The vision cycle time is assumed to be 100ms for each unit. Table 7.2 shows the results of 3 separate timings recorded by the machine to pick and place 90 units.

Table 7.2: Pick and Place Time for 90 units

Trial number	Recorded Time (s)
1	215.33
2	215.41
3	215.25
Average	215.33

The number of units / second (UPS) and units / hour (UPH) can be calculated using equations 7.1 and 7.2 respectively.

$$\boldsymbol{UPS = \frac{n}{t}} \tag{7.1}$$

where

UPS = Speed, units/s

n = Number of units

t = time taken, s

$$UPH = UPS \times 3600 \tag{7.2}$$

where

UPH = Speed, units/h

Using the average time to complete 90 units, the UPS is calculated to be 0.4180 units/s. And the UPH is calculated to be 1504 units/h. The trial is run was conducted more than 20 times and the recorded time was found to be within ±0.1% of the average time.

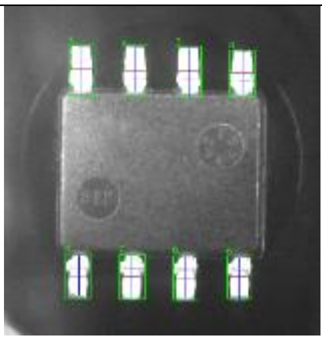
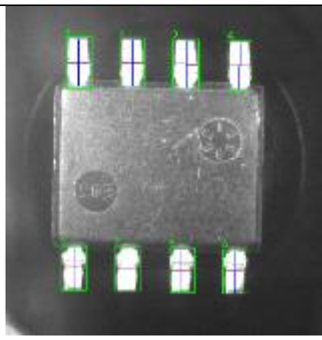
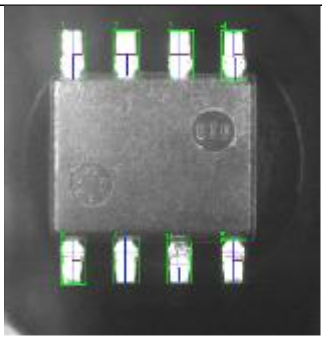
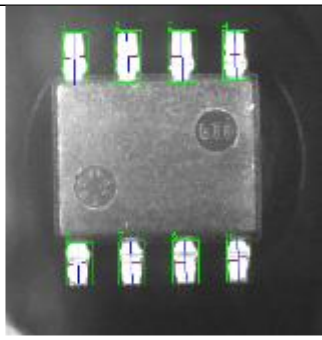
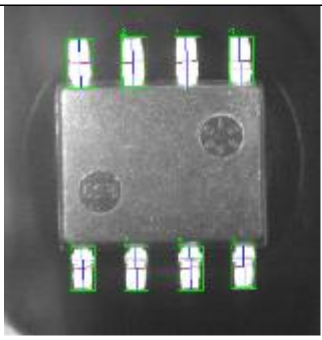
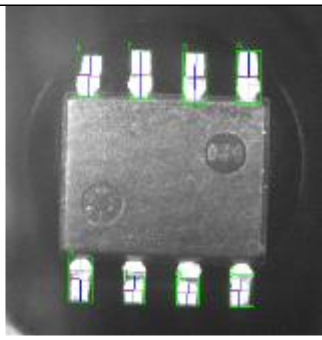
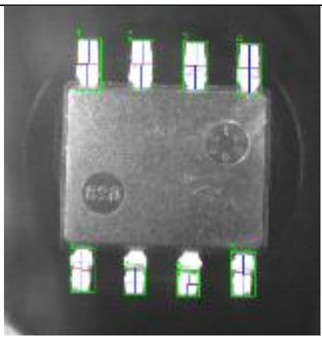
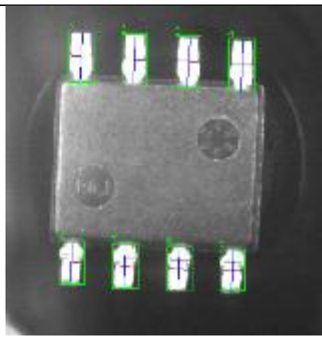
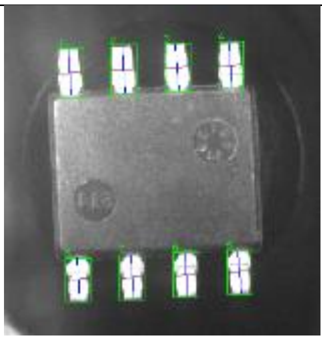
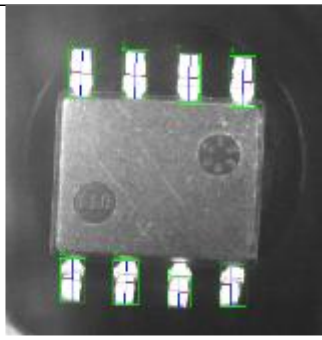
The speed did not achieve the expected 2000UPH due to several reasons. Firstly is there is a defective cylinder which leaks air in one direction, causing the return stroke to be slower that it should be. The speed controller also reduces the speed of all the cylinders by about 50% because higher speeds will cause high machine vibration due to the impact of stopping the cylinders. The high impact forces may reduce the lifespan of the machine. This problem can be reduced by introducing shock absorbers instead of the current nylon bolt that is used as a stopper.

Secondly the software for the machine is not fully optimized. The software functions based on a delay therefore extra time may be wasted waiting for the delay to elapse. There are also not enough sensors for the software to be fully aware of the state of the machine before proceeding to the next step. Having a sufficient delay is a safer alternative in this condition rather than moving the cylinder to soon which may cause the pickup head to collide with the vision module.

7.2.2 Placement Repeatability

In order to visually see the placement repeatability of the machine, aid of a vision system is used to capture the image of the unit in inspection position. A series of 10 units is used and each unit's image is captured and presented in Table 7.3.

Table 7.3: Unit Image Captured by Bottom Pad Vision System

1		2	
3		4	
5		6	
7		8	
9		10	

In Table 7.3 the first and third columns are the unit number while the second and fourth columns are the image of the unit. The images are captured using the Bottom-Pad Vision set up where only the bottom side and leads of the package are of interest. In can be observed from the ten images, the unit’s position slightly moves around and rotates either a little to the left or right side. The position of the suction pad can be seen in the image (the round circle behind the unit). The lighting of the vision slightly illuminates the vacuum pad. In real application this is undesirable as it may affect the image processing.

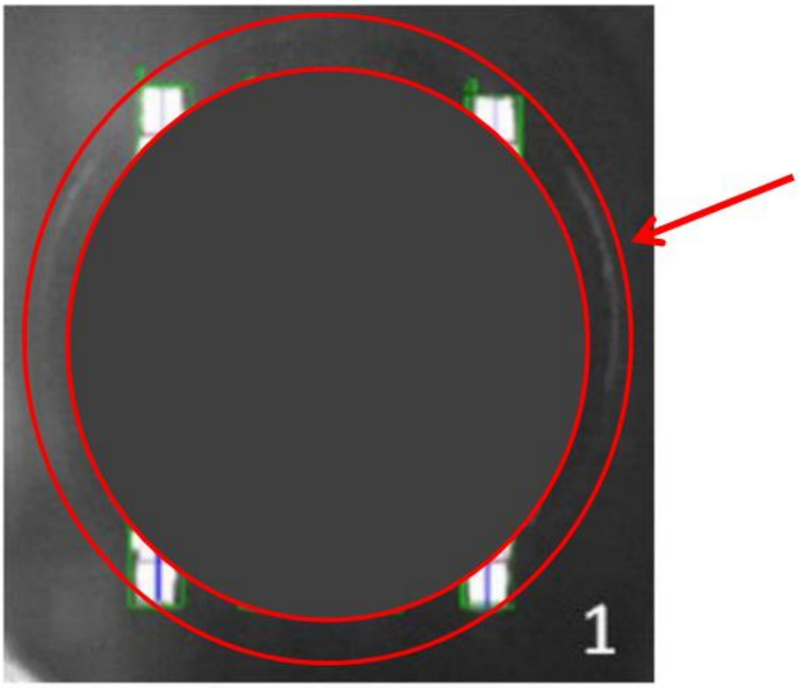


Figure 7.7: Pickup Head Position in Between Red Circles

However, for this case the priority is the positioning capability of the machine. It can be observed in Figure 7.7 that in every image the vacuum pad is exactly at the same position. Since the vacuum pad is directly attached to the Z-axis cylinder and the pickup arm, it can be inferred that the position of the vacuum pad indicates the position repeatability of the machine. Now that the position of the head is confirmed to be repeatable, the root cause of the unit’s misalignment needs to be examined. But before that is done, the repeatability is quantified with the following method.

The image is zoomed to 400% size and measured using pixel ruler (Figure7.8), then the mm/pixel value and error is calculated in Table7.4.

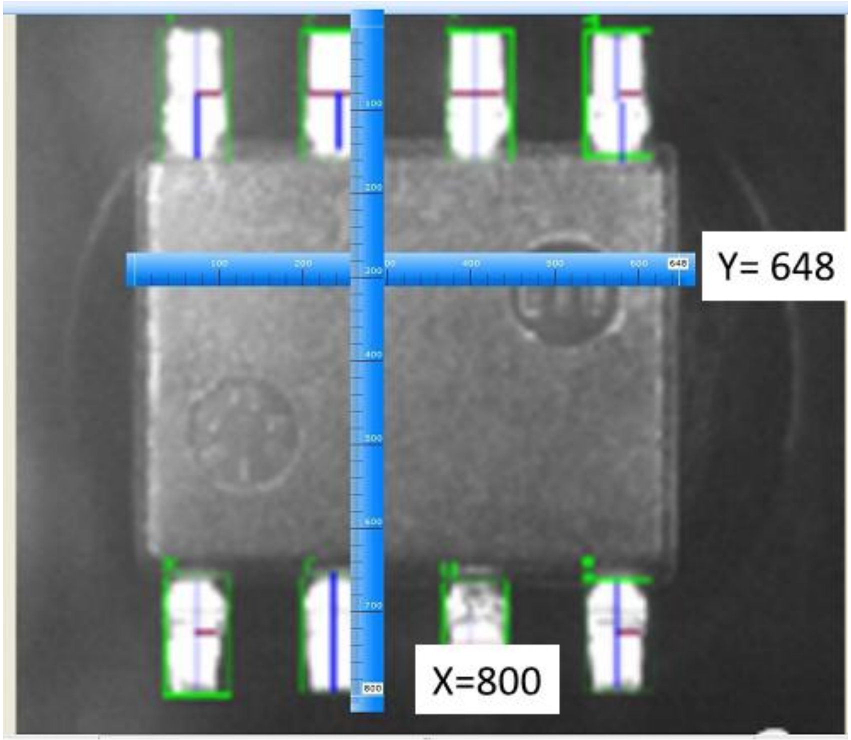


Figure 7.8: Image at 400% Size Measured Using Pixel Ruler

Table 7.4: Calculated mm/pixel Value and Error

Length/ Width	Unit Dimension L (mm)	Standard Length Po (pixels)	Maximum Length Pm (pixels)	Difference ΔP=Po-Pm (pixels)	mm / pixel $\eta = \frac{L}{Po}$	Error $\frac{\Delta P \times \eta}{2}$
X	6.20	200	217	17	0.031	±0.26mm
Y	5.00	162	176	14	0.031	±0.22mm

The standard length is measured when the unit is perfectly aligned and the maximum length is measured from comparing two images with the furthest misalignment out of the ten images obtained. This difference is then multiplied with the mm/pixel ratio and divided by two to obtain the error. The error is the possible misalignment in terms of position in the X and Y axis which can be visualized in Figure 7.9

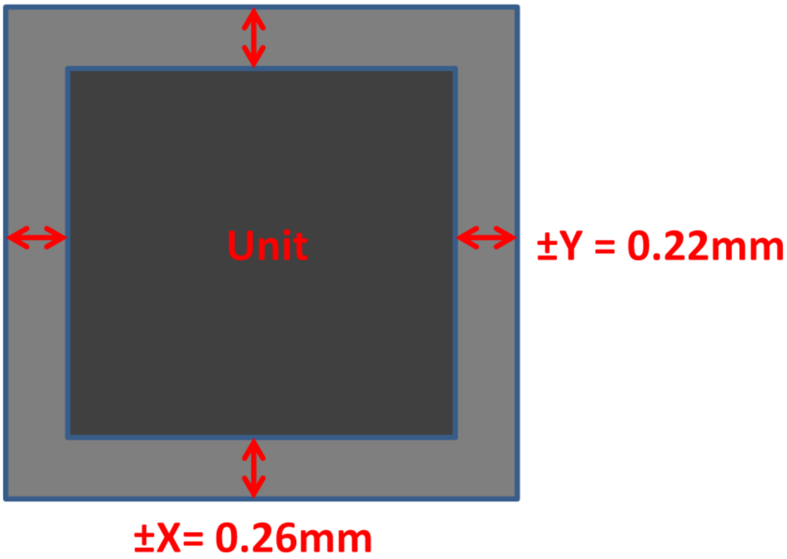


Figure 7.9: Misalignment Error in X and Y axis.

There are two possible factors that can cause the unit to misalign. First, the unit moves while on the pickup head due to the vibration generated by the stopping of the cylinders. Second, the unit was picked up when the position is already misaligned. The first factor is very unlikely since the unit used (SOP8) is very light, approximately 0.080g – 0.153g according the datasheets obtained from various manufacturers (Datasheets Org). Assume a maximum unit mass of 0.2g, the required force to lift is only 1.962×10^{-3}N. The lifting force can be calculated with equation 7.3.

$$\boldsymbol{W} = \boldsymbol{P} \times \boldsymbol{S} \times \boldsymbol{0.1} \times \frac{\boldsymbol{1}}{\boldsymbol{t}} \tag{7.3}$$

where

W= lifting force, N

P = vacuum pressure, kPa

S= pad area, cm^2

t= safety factor (Horizontal lifting, 4 or more)

The calculated lifting force is 0.0329N when P is -85kPa, S is 0.031cm^2 (pad diameter of 2mm) and a safety factor of 8 is used. The lifting force is greater than the required force of 1.962×10^{-3}N, by almost 16 times more. This can be verified as the specification of the vacuum module is to lift units up to 100g in mass. So it is unlikely with such a strong holding force the units will move due to the impact of the pickup arm abruptly stopping.

Therefore, the only possible cause to the problem is that the units are already misaligned when the pickup head approaches to pick the units. From the trials, it can be observed that the units tremble and shake in its pocket every time the stepper motor rotates to the next position. This is due to too much tolerance allowed in the design of the indexer disc. Figure 7.10 shows the layout and space between the unit and the walls of the disc pocket. On the left, a 2D drawing and dimension difference between the unit and pocket is shown and on the right a 3D visualization is shown.

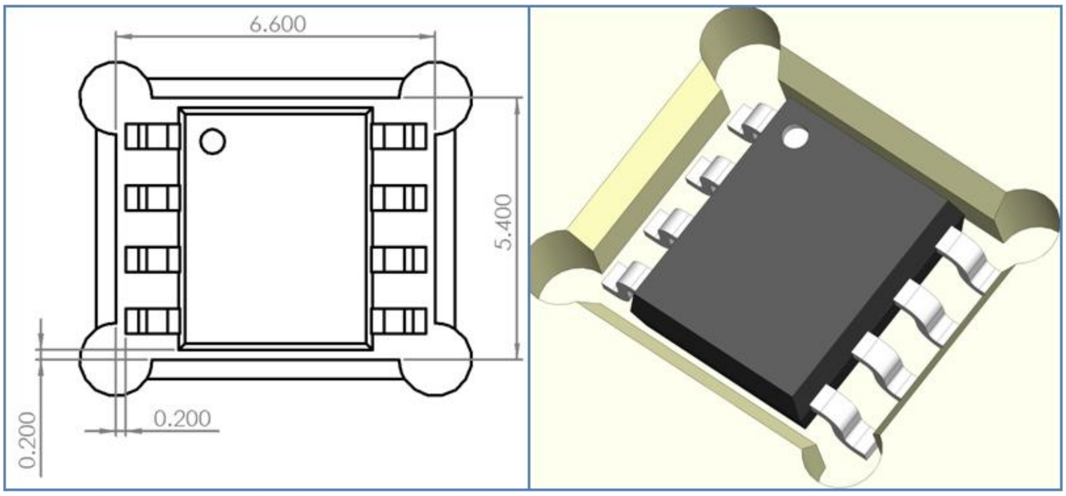


Figure 7.10: 2D and 3D Image of Available Tolerance between Unit and Pocket

From the given specifications (Appendix H), the minimum and maximum dimensions from lead to lead (left side to right side) of the unit is from 5.80mm to 6.20mm. The minimum and maximum dimensions from top to bottom of the package are 4.80mm to 5.00mm. From the current results it shows that ±0.2mm tolerance for both sides (left/ right and top/ bottom) is too wide and allows for too much movement when the indexer rotates. A suggested tolerance of ±0.05mm each side should be sufficient to reduce the misalignment. Table 7.5 shows the expected improvements after the new pocket design is implemented.

Table 7.5: Expected Improvements after Implementation of New Pocket Design

Length/ Width	**Initial Error (mm)**	**After change in indexer pocket dimensions**	**Expected Improved Error**	
X	0.26		≈ ±0.065mm	**65 microns**
Y	0.22		≈ ±0.055mm	**55 microns**

7.3 Possible Areas of Improvement

There are still a few aspects of the machine that can be improved. Besides the placement repeatability as mentioned earlier, the performance speed can be further increased and more software functions can be introduced.

7.3.1 Software optimization

Currently the firing of the output is based on delay timing. The ideal method is to fire the output when an input is received. However in this design, only a limited number of inputs are available since a limited number of sensors are used. If the inputs from the sensors are taken, the program can instantly proceed to the next step without waiting for the delay time to elapse.

7.3.2 Communication with Vision System

When the unit is sent for inspection, the machine sends a signal (Vision Trigger) to indicate to that the vision system can start its inspection. The vision system will send a Vision Complete (VC) signal when it has done its processing. This is done over a period of 70ms to 100ms. The unit actually needs to be at the vision inspection area only when the camera is conducting its image 'grab.' Once the vision has done its grabbing of the required images, it will start the image processing. During this period, the machine can actually go back to return the unit and pick up another unit. Therefore, time can be saved by receiving another signal from the vision system when the grab cycle is complete. Figure 7.11 illustrates an example of the processing time that can be saved if the end of grab signal is accepted as input.

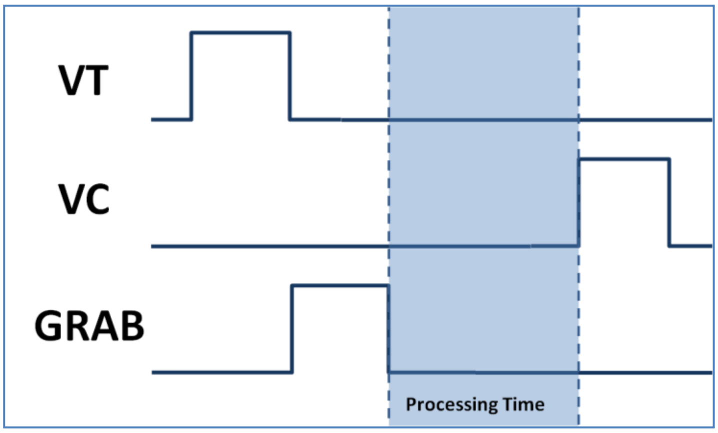


Figure 7.11: VT, VC and Grab Pulse

7.3.3 Additional Features

The software can be made to allow more flexibility in the controls and also have more built-in automation functions.

Currently the vacuum module has a function whereby if the vacuum pressure fails to reach a certain pressure (for three times) when the units are picked; the red LED on the pressure switch will light up. If the vacuum pressure starts to reduce, it may indicate that the filter is getting clogged and some maintenance is needed. Figure 7.12 shows the set points when the error LED will light up after three consecutive occurrences.

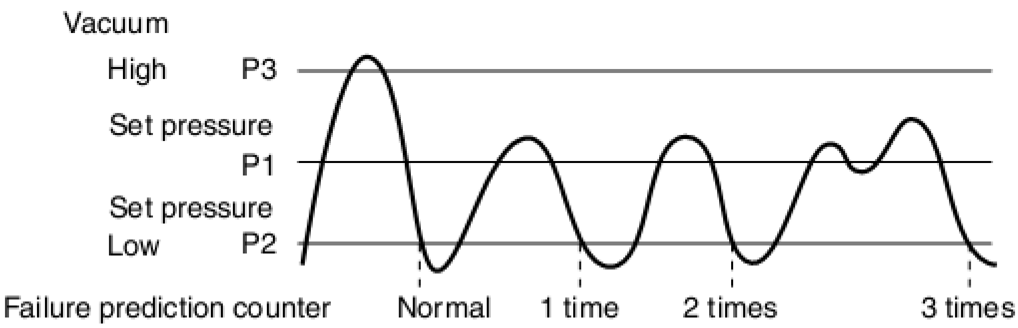


Figure 7.12: Failure Prediction Counter Function

When no unit is present, the vacuum pressure is at -38kPa and when unit is present the pressure is -90kPa. Therefore the value for P1, P2 and P3 is set to -45,-40, -85kPa respectively to allow for tolerances in pressure fluctuation during machine operation. When error occurs (failure prediction counter=3), the LED not only lights up but an output is sent to IDI7. This input to the DAQ can be used as a flag to pop-up a warning window in the software to tell the user that the filter may be clogged and needs maintenance.

The vacuum module also outputs a signal to IDI6 when a unit is picked. It detects the difference in pressure in the vacuum chamber when a unit is blocking the suction head pathway. This characteristic and input signal from the vacuum module can be used to automatically detect the number of units placed on the indexer disc and the program can run accordingly by skipping the empty pockets. The pickup head will check each pocket to see if a unit is present before starting the pick and place sequence.

Moreover, the function of “QueryPerformanceCounter” in C++ can be used to calculate the time between each cycle and have it displayed to the user. The different time intervals can be used to analyze which areas of the machine or the program takes too long can be optimized to reduce the overall cycle time. This function is a more accurate measure of time since it is based on the speed of the processor instead of using a stopwatch or any other physical methods to calculate time.

CHAPTER 8

CONCLUSION

8.1 Project Conclusion

In conclusion, this project has produced an automated pick and place machine that can be used to perform GRR for Vision Inspection Modules. On a click of a button, the machine can automatically pick the units placed on the indexer disc and move it to the required location for inspection then place it back in its original position. It has a capacity of 10 units and can also be re-programmed to pick and place fewer than 10 units.

The machine achieves a speed of 1500UPH. This speed falls short of the initial target of 2000UPH. This is due to several mechanical limitations. The speeds of the pneumatic cylinders are limited to about 50% of their actual speed. If the impact from the cylinder stopping can be reduced, the speed can be greatly increased by cutting down the overall cycle time for cylinder movement. More sensors and further software optimization can still be done to increase the speed. Additional time invested in the algorithm of the machine will allow for unnecessary instructions and wasted delays to be reduced.

The machine is also able to pick and place various IC package sizes ranging from 4mm × 4mm up to 10mm × 10mm. The suction head and indexer disc needs to be changed as the size of the units increase. But there need not be any changes in other parts of the hardware. The vacuum module generates more than enough vacuum pressure to lift larger units. To be able to cater to different surface mount package types, different indexer discs may have to be fabricated depending on the overall dimensions of the package. But generally, all the package types listed are square or rectangular in shape therefore any indexer disc with similar pocket dimensions can be used.

The final objective which is to control the machine using an application developed using MFC in C++ programming language is also achieved. The developed application has basic functionalities to run the sequence and also to manually trigger each output for pneumatics and the stepper motor. All the machine output signals can also be observed from the application interface.

On the whole, by using this machine, GRR need not be performed manually anymore. The traditional method of holding a single unit using a static vacuum head and continuously triggering the vision to test the repeatability of the vision can now be replaced by using this GRR Auto Module. The human factor of handling the units by hand is removed since the machine takes over the task.

Finally, the GRR Auto Module allows for a more actual simulation of the testing conditions that MVS face since the units are constantly picked and placed. The automatic sequence of the machine allows users to work on something else while the machine does the work. Thus, with the implementation of this GRR Auto Module, producers of vision systems can have a more convenient method to verify the GRR of their systems.

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APPENDICES