

**UNIVERSITY OF KWAZULU-NATAL**

**A MECHATRONIC APPROACH TO DEVELOP THE  
CONCEPT OF A MATERIALS HANDLING SYSTEM  
FOR A RECONFIGURABLE MANUFACTURING  
ENVIRONMENT**

Student:

**Priyen Naidu- 991235508**

BScEng  
School of Mechanical Engineering  
Durban

Naidup1@ukzn.ac.za

Supervisor:

Professor Glen Bright  
Brightg@ukzn.ac.za

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## **Preface**

The author declares that this is his own work except where due acknowledgement has been given. It is being submitted for the degree of Master of Science in Engineering to the University of KwaZulu-Natal, Durban. It has not been submitted for any other degree or examination to any other University.

This thesis describes the work carried out by the author at the department of Mechanical Engineering, University of KwaZulu from February 2005 to January 2007.

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## **Abstract**

People are unique and display a variety of preferences with regard to the products that are available today. It is important to provide customised products to suit the unique needs of different individuals. The ability to manufacture customised products on large scale is an added advantage so long as the production rate is not hindered in the process.

A reconfigurable manufacturing environment is one in which products can be mass customised by changing or reconfiguring the production process in order to vary the parameters of a product. This is achieved by a materials handling system with sufficient intelligence to vary the routing of parts to the various machines within the manufacturing environment.

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## **Chapter 1: Introduction**

A custom product is a variation of a particular product that is manufactured to suit the distinctive needs of individual people. Consumers favour such products, which complements personal preferences and highlights uniqueness. This insight into consumer preferences induces the production of custom products on a large scale by manufacturing business entities. This form of customisation is known as 'mass customisation'.

In order for the manufacturing company to produce the desired customised product, its manufacturing system must be continuously reconfigured according to specific consumer input. This system is known as a 'reconfigurable manufacturing system'.

Materials handling represents the "safe, continuous and unimpeded flow of materials and goods" throughout their production and distribution. The materials handling system must provide the means to "move, store, control and protect material and goods at every stage in their journey through manufacturing and distribution" [1].

The materials handling system for a reconfigurable manufacturing environment must itself be reconfigurable. This is to ensure that the system is able to transport materials, parts or products to various locations within the manufacturing environment. In order to achieve this, the materials handling system must continuously self-adjust to follow a manufacturing schedule that is being constantly updated.

This reconfigurable materials handling system must have the ability to facilitate mass customisation without hindering the rate of production. It becomes necessary for the system to track, schedule and route materials, parts or products through the manufacturing environment. The effect of this is the optimisation of the mass-manufacturing rate.

'Part tracking' refers to the ability of a manufacturing system to locate parts, materials or products at any stage of their production. This capability enables a level of quality control by allowing the system to query the part's history. This particularly relates to parts that were not manufactured to specification. If the materials handling system is aware of the location of a part, suitable measures can be taken to transport the part to the appropriate location.

In order to minimise any inefficiencies in the production rate, the materials handling system must additionally be capable of routing parts such that any delays in the movement of the product through its cycle of production are reduced.

Mechatronics is the integration of “microprocessor systems, mechanical systems and electronic systems” [2]. A Mechatronic approach must be applied to develop and construct the concept of a Reconfigurable Materials Handling System.

### 1.1 Project background and objectives

This Mechatronics project was undertaken at the University of KwaZulu-Natal, more specifically, in the department of mechanical engineering. This endeavour was undertaken through the Mechatronics and Robotics Research Group (MR<sup>2</sup>G).

The Mechatronic approach adopted for this project must facilitate the design of new equipment as well as the integration of existing equipment into the system. The system initially comprised of an Automated Storage and Retrieval System (AS/RS), a Reconfigurable Manufacturing System (RMS) and an Automated Visual Inspection System (AVIS). Parts were transported to these machines via a conveyor system. An Automated Guided Vehicle (AGV) was available as well to transport parts off and onto the conveyor. This system, which is explained in greater detail in the following sections, is illustrated in figure 1-1.

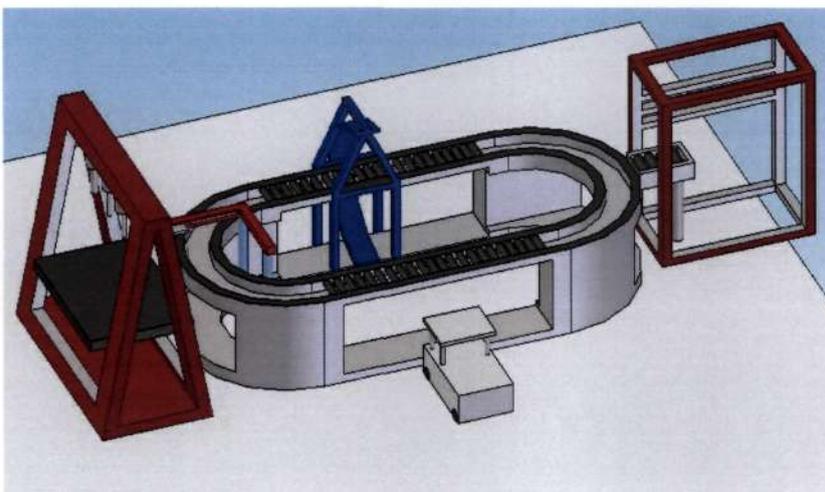


Figure 1-1 An illustration of the existing system

### 1.1.1 The Conveyor

The conveyor, shown in figure 1-2, is a machine used for materials handling. It is used to transport parts from the AS/RS to various other machines such as the RMS and AVIS. It consists of a mild steel frame and system of rollers, wooden and plastic. These rollers are interconnected by rubber O-rings and driven by ten 12V Direct Current (DC) motors. These motors are powered by a 12.6 V DC power source. The Conveyor is broken down into 10 segments, 1 for each motor. This allowed for the independent motion of individual sections. These will be referred to in the chapters that follow.

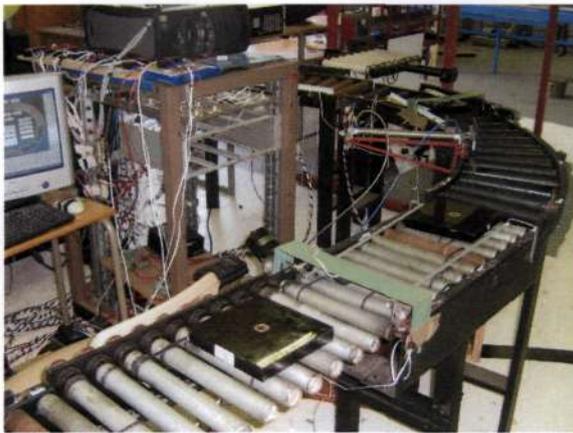


Figure 1-2 The conveyor

### 1.1.2 The Automated Storage and Retrieval System (AS/RS)

The Automated Storage and Retrieval System (AS/RS) is used to store parts/pallets and release them into the manufacturing environment at a predetermined rate. The parts/pallets that are stored have not undergone secondary machining. The AS/RS houses each pallet in a slot. The AS/RS employs the use of a mechanical arm that is actuated by Direct Current (DC) motors to move in three dimensions to retrieve parts from the slots. The control program is equipped with co-ordinates of each slot and is able to guide the locater arm to correct location using encoders.



Figure 1-3 The Automated Storage and Retrieval System (AS/RS)

### 1.1.3 The Automated Guided Vehicle (AGV)

The Automated Guided Vehicle (AGV) is an autonomous materials handling robot that can transport parts from one location to another in a manufacturing environment. The AGV, at present, is responsible for transporting parts in a straight line between the conveyor and an intermediate docking station. The AGV is capable of moving forward as well as laterally to dock with various systems.



Figure 1-4 The Automated Guided Vehicle (AGV)

### 1.1.4 The Reconfigurable Manufacturing System (RMS)

The Reconfigurable Manufacturing System (RMS) consists of a series of modular machines that can be interchanged to perform specific manufacturing operations based on corresponding market changes. The RMS is a multi-tooled machine that can perform drilling, milling and

grinding operations. The RMS is able to move the working tool in 3 dimensions. The RMS has a built-in transfer system able to transfer parts between the RMS and the conveyor.



Figure 1-5 The Reconfigurable Manufacturing System (RMS)

### 1.1.5 The Automated Visual Inspection System (AVIS)

The Automated Visual Inspection System (AVIS) provided a method for quality control of parts in the manufacturing environment. The AVIS was able to capture an image of the part as it passes through it. Image processing was performed on the part in order to ascertain whether or not the part was manufactured to specification. The AVIS was equipped with a high-speed camera that was used to capture images of the part at various angles. The camera was mounted on a motorised guide that moved the camera to different angles with respect to the part. The AVIS was able to provide alerts to the control software when a part does not meet a certain standard of quality.



Figure 1-6 The Automated Visual Inspection System (AVIS)

### 1.1.6 The Segway Human Transporter (HT) i167

The Segway HT i167 is a two-wheeled, self-balancing, electric transportation device. The Segway HT i167 was designed and developed with the vision of creating a highly efficient, zero emission transportation system. The Segway HT was not used in the existing system but was available to the group for modification and integration into a system. The i-version was designed initially for industrial applications where it was ridden on factory floors in manufacturing facilities. The Segway HT is differentially steered and can perform zero radius turns by twisting the steering grip on the handlebar [3]. The Segway HT is agile without becoming unstable as it employs a patented technology called dynamic stabilization that keeps it balanced. That is, the wheels automatically move in the direction of the tilt to prevent the Segway HT from falling over [4].



Figure 1-7 The Segway HT i167

In carrying out this project, the overall aim was identified in the following manner:

- To create an efficient reconfigurable materials handling system that constantly reconfigures on the basis of consumer input, so as to facilitate mass customisation.

In pursuit of this ultimate goal, the following objectives were ascertained at the outset:

- To create part-tracking capabilities to assist the control system in scheduling the part, thereby facilitating mass customisation.
- To route parts efficiently through the manufacturing system, thereby minimising delays in part movement.
- To implement the necessary hardware required for a reconfigurable materials handling system.
- To create a control system for reconfigurable materials handling so that the environment can operate autonomously.

## **Chapter 2: Materials Handling and Mass Customisation**

A reconfigurable manufacturing system (RMS) is a system “designed at the outset for rapid change in its structure, as well as its hardware and software components, in order to quickly adjust its production capacity and functionality within a part family in response to sudden market changes or intrinsic system change” [5].

Manufacturers have been obliged to produce goods of higher quality at lower prices, and shorten their manufacturing lead times. A manufacturer faces strong competition and cannot afford to waste “time, material or production capacity.” Cost, quality and responsiveness are critical requirements for manufacturer that must be continually improved upon [6]. The responsiveness of the manufacturing concern is paramount in order to meet the needs of a wide consumer base. The ability to produce a wide range of products that suit a wide variety of individuals can provide a manufacturer with a competitive edge.

Mass Customisation is the ability of a manufacturing entity to produce customised products for consumers on a large scale. Mass Customisation was defined as a situation wherein “the same large number of consumers can be reached as in mass markets of the industrial economy and simultaneously they can be treated individually as in the customised markets of the pre-industrial economies” [7].

Three elements that are required to facilitate mass customisation are defined as “elicitation (a mechanism for interaction with the customer and obtaining specific information), process flexibility (production technology that fabricates the product according to the information) and logistics (subsequent processing stages and distribution that are able to maintain the identity of each item and to deliver the right one to the right customer)” [8].

Mass Customisation has risen in popularity due to new information technologies that have improved communications between manufacturers and customers. This communication is often on a global scale causing the manufacturer to deal with a very wide variety of customers. The Internet has erased traditional market boundaries and led to increased competition and possibilities for customers to choose from a broader range of products. Companies are obliged to accommodate many consumers of differing wants in order to maintain the volume necessary for competitive production [9].

Mass Customisation is only feasible if it can be achieved without hindering the production rate. A practical mass customisation strategy states that it employs “the use of flexible processes and organizational structures to produce varied and often individually customised products and services at the low cost of a standardised mass-production system” [10].

A flexible manufacturing system generally “consists of a number of CNC machine tools and a materials handling system that is controlled by one or more dedicated executive computers” [6]. A typical flexible manufacturing system “can completely process the members of one or more part families on a continuing basis without human intervention.” FMS is very responsive to market changes and is flexible enough to manufacture a part when the market requires it. This can be achieved without the need to purchase any other equipment [6].

Materials handling represents “the safe, continuous and unimpeded flow of materials and goods throughout the entire supply chain”. The materials handling process must employ methods to “move, store, control and protect material and goods at every stage in their journey through manufacturing and distribution.” The flow of materials through any modern facility must be accompanied by a “concurrent and parallel flow of information” in order to achieve efficient materials handling operations. The co-ordination of different operations becomes much simpler if the valid information is accessible to the facility. The integration of mechanical, electronic and information systems has become necessary to create computer-integrated materials handling systems [1].

Technological development is also providing companies with tools to make a variety of products more easily as well as earlier. Today machines and software systems offer more flexibility in processes and more efficient handling systems to facilitate the production of smaller batch sizes with more variation [9].

Efficient materials handling minimises delays. An efficient materials handling system ensures “continuous, uniform and a maximum working rate”. Automation begins with the materials handling system because materials spend most of their time being moved, inspected and waiting to be processed. Materials handling is an important part of the total procurement/ manufacturing/ marketing system. Therefore any handling problems must be viewed in

relation to the whole system. The events in one stage of the system can have repercussions in the others and should not be dealt with in isolation [11].

Integrated material handling systems enhance production by minimising the time spent on transportation of parts, materials, tools and work-in-process to workstations and various other locations in the manufacturing environment [1].

The automation of a company's materials handling process can facilitate higher savings potential for a higher turnover. A higher turnover would imply that a higher labour cost would be incurred. An automated materials handling system could perform the same task with less expense as long as the materials are dealt with on a conventional basis [12]. This statement indicates that reconfigurable manufacturing and materials handling systems were unavailable during that time. The materials handling systems performed the same repetitive tasks that were programmed into the controller.

Integrated material handling systems must be modular in design and reconfigurable such that the company can meet diverse needs of its customers. The system should be able to adjust to meet large orders from suppliers and distributors but also to accommodate individual customers as well [1].

An integrated materials handling system must provide the flexibility to adapt with frequent setup changes caused by today's short product life cycles. This can only be achieved if there is vertical and horizontal integration across the entire manufacturing process. An order will be received by the company. A production schedule and sequence is formulated and is transmitted to the work areas or cells. This information is also filtered down to the materials handling system to transport parts and materials to the appropriate workstations and manufacturing cells. Simultaneously management information regarding status reports, asset and inventory tracking and monitoring of equipment is acquired by the relevant systems [1].

## **Chapter 3: Part Tracking Technologies**

### **3.1 Types of Technologies**

Part Tracking is the ability to locate parts at any time within manufacturing or warehousing processes with the goal being to increase the manufacturing efficiency. Tracking of parts or products in a manufacturing environment is the primary method of determining the production output and hence establishing a potential income [13].

Part Traceability focuses on documenting the “genealogy of parts assemblies and sub-assemblies that comprise the finished product.” As parts progress through the manufacturing environment and the supply chain they go through many changes. The recording of the changes made in every component of a product throughout its life is known as part traceability [13].

Often, the same “automated data collection (ADC) technologies” can be used for both tracking and traceability. The ADC technologies are categorized as, Optical and Non-Optical Technologies [13].

Optical technologies include Direct Part Marking (DPM), which is “favoured for its permanence”. Permanence is a fairly relative term that is specific to the industry that the part is being manufactured in. DPM is “the act of applying permanent codes and/or human-readable information directly to an individual part or product” [13]. This is carried out using various imprinting techniques that include laser, ink, or physical imprinting. Manufacturers use DPM for parts that function in harsh environments where externally applied labels may be removed [13]. DPM is also practical for very small parts or components where there is not enough surface area available on the part for externally applied labels. The selection of any of these techniques is based on the specific application and objectives regarding the fabrication of the part. If a high-volume production is the manufacturer’s objective then chemical etching would be ruled out as it is a slow process. If parts are used in high-abrasion conditions then the ink-jet imprinting of these parts would not be a suitable method of DPM as the abrasion could remove the markings [13].

Non-Optical Technologies include methods of tracking parts such as Radio Frequency Identification (RFID). RFID is a non-contact technology that permits the transfer of data, by utilising radio waves, from a data-carrying device and its reader. RFID systems are discussed in further detail in section 3.2

### **3.2 Radio Frequency Identification (RFID)**

Radio Frequency Identification (RFID) is a non-contact, data capture technology that does not require a line of sight between the transmitting and receiving device. Radio Frequency (RF) refers to the electromagnetic waves that possess a suitable wavelength for use in radio communication. Radio waves transfer data between the RF tag or transponder and the RF reader or interrogator. RFID is similar to the bar code system. In the bar code system a coded label is adhered to an item being identified. A reader then uses visible symbols and light to transfer the information from the label to the reader. This information could be anything regarding the item such as the description of tagged item and its history [14].

A RFID system is made up of two components, a transponder and a reader. The transponder is located on the object to be identified. The reader or interrogator may be a read or write/read device depending upon the design and the technology used [15]. A reader generally contains a radio frequency module (transmitter and receiver), a control unit and a coupling element to the transponder. The coupling element is used to enable readers to forward the data received to another system such as a computer. Many readers are fitted with an additional interface such as RS 232, RS 485, as well as others. The transponder represents the actual data-carrying device of a RFID system and normally consists of a coupling element and an electronic microchip [15].

The transponder does not normally have a battery. It is completely passive when it is not within the range of a reader. This is because the transponder is only activated when it is within the interrogation zone of the reader. The power required to activate the transponder is supplied to the transponder through the coupling unit as are the timing pulse and data. All power required for the operation of a passive transponder must be extracted from the electrical/magnetic field of the reader. However, active transponders do exist which incorporate a battery. The battery of an active transponder does not provide the power for data transmission between transponder and reader, since it serves entirely to supply the microchip

and for the retention of stored data. The only power used for the data transmission between transponder and reader is the power of the electromagnetic field received from the reader [15].

The operating frequency and the resulting range of the system are one of the most important characteristics of RFID systems. The frequency at which the reader transmits is the operating frequency of an RFID system. The transmission frequency of the transponder is, in most cases, the same as the transmission frequency of the reader. The transponder's 'transmitting power' may be much lower than that of the reader [15].

Transponders are manufactured using different techniques, materials and geometry. The most common construction format is the disk (coin). The disk (coin) is a transponder in a round injection moulded housing, having a diameter ranging from a few millimetres to 10 cm. There is usually a hole for a fastening screw in the centre. Polystyrol or even epoxy resin may be used to achieve a wider operating temperature range as an alternative to injection moulding. Another common package is the plastic housing. The plastic housing was developed for applications relating to high mechanical demands. This construction format is used for electronic immobilisation systems by embedding the tag in car keys [15].

The range required, between the transponder and reader for data transfer, varies for different RFID systems. RFID systems that have a range of up to 1 cm, are referred to as close coupling systems. The transponder must either be inserted into the reader for operation or positioned upon a surface provided for this purpose. Close coupling systems are mainly used in applications that are subject to strict security requirements even though they do not possess a large range. Electronic door locking systems or non-contact smart card systems with payment functions are examples of close coupling systems. Remote coupling systems are systems with write and read ranges up to 1 m. Therefore, these systems are also known as inductive radio systems [15].

RFID systems with ranges extensively above 1 m are known as long range systems. Each long-range system operates by using electromagnetic waves in the Ultra High Frequency (UHF) and microwave range. UHF ranges between 300 MHz and 3 GHz whereas microwave is any frequency above 3 GHz. Through the use of passive long range transponders, typical ranges of 3 m can now be achieved [15]. Read-only transponders with a microchip, also known as low-end systems, have a permanently encoded data in the form of a unique serial number made up of several bytes. The transponder begins to continuously broadcast its own

serial number if a read-only transponder is placed in the transmitting range of a reader. The flow of information is only in one direction and so the reader cannot communicate with the transponder in this case. Also, if two or more transponders transmit at the same time then a data collision would occur. The reader would no longer be able to detect the transponder. There are many applications requiring the identification of items for which this transponder is well suited. Read-only systems are operated at all frequencies available to RFID systems. The achievable ranges are usually very high due to the low power consumption of the microchip. Read-only systems are used where only a small amount of data is required or where they can replace the functionality of barcode systems. Bar coded systems require a line of sight which is not the case with RFID systems [15].

A transponder that is only capable of transmitting two states, that is, 1 or 0 is known as a 1-bit transponder. This system is used specifically for determining if the transponder is in the interrogation zone or not. A typical application of a 1-bit transponder is in electronic anti-theft devices in shops. The most important performance characteristic for this system is the ability to detect when the maximum distance between the transponder and the reader's antenna is exceeded [15]. This could be useful in a factory environment to detect whether a part is being transported to the correct location. It could record a breach each time the part came into range that could trigger a response from the system.

One disadvantage of certain RFID systems is their sensitivity to electromagnetic interference fields. The electromagnetic fields, for example, created by strong electric motors could cause interference in inductive transponders. Microwave systems, which operate in a higher frequency range, do not suffer the same disadvantage. They are more suited to applications involving equipment of this nature [15].

The reader must first enter into communications with a transponder to execute a command from the application software. In relation to the transponder, the reader now plays the role of the master. The transponder is not active independently. It relies on the reader's electromagnetic field to activate it. Once the reader is within range, an electromagnetic force (emf) is induced in the transponder and it now has the power to transmit its signal (transponder data) to the reader [15].

The reader activates the transponder and initiates communication with it so that information transfer can occur. The reader is also responsible for making the connection, and performing anti-collision and authentication procedures [15].

During the development of industrial mass production, the process was continuous but repetitive. The same product was produced with no change in the control parameters. This type of production was known as 'conveyor belt production' where one or more conveyors would transport materials to locations where the same work would be performed on them. The growing competition of today's markets gave rise to manufacturing control systems capable of providing a large range and hence wider variety of products [15].

Centralised and de-centralised control refers to types of control that can produce variants of a product or even different products. With regard to Centralised Control, material flow and object status are constantly monitored during the process and are stored in a database on a central computer. This process is not based on any one technology. Therefore barcodes, optical character recognition, RFID or any other type of information coding and transmission may be employed. The monitoring of the process must be completely reliable. If not, the control of the tracked object will be lost. Centralised control systems based upon a powerful central database are particularly common when it is necessary to access the information from different locations simultaneously. Conventional applications include stores technology of a logistics group or the collection of operating data, apart from production [15]. With regard to Decentralised Control, "the use of readable and writable data carriers widens the possibility of controlling a system locally, which is completely separate of the central process computer." Active tags (those with an on-board power supply) are able to store more data and have read/write functionality. It is possible to read the relevant data from the object at each processing station as well as to change and update this information. Decentralised control can only be achieved with writable RFID transponders that can store and convey relevant part history and future or remaining processes to a local reader [15].

RFID technology is used in a variety of manufacturing entities and materials handling systems. One reason for their popularity is that they eliminate physical contact with the part such that greater handling efficiency can be achieved. This is because the products do not need to be handled to be identified. The product can even be identified if it not directly visible because a line of sight is not necessary with RFID technology [16].

The capability of active transponders to store data is an ideal data collection technology because it stores the entire part/product genealogy. It can store all the historical data of the part/product and serves as a small, portable database that is always attached to the part. This could be useful if the part was not manufactured to specification. The history of the part would reflect this and this could prevent the after sales recall of the parts if the problem is identified early [17].

Maintenance operations can also be carried out more simply using RFID by regularly updating the part/product with service codes, inspection dates and possibly sensor readings. Tagged parts could also be useful in avoiding false warranty claims and these parts are uniquely identified so that look-alike parts are not used. This technology could also prevent the wrong maintenance procedure being performed or even an untimely one from being carried out [18].

RFID systems can also be used in companies that transport or process hazardous materials or other regulated substances. If these materials are found to have caused harm then the company responsible for them originally will have to take responsibility. This is regardless of whether or not they were in possession of it at the time. Using an active transponder with read/write capability, data regarding the life of the product could be stored. This data would identify the time that the company received the product and the time that it was transferred. This information would travel with the product throughout its life. This information, that would be continually updated, could be used to create a chain-of-custody record that could be used to satisfy any regulatory reporting requirements [19].

## **Chapter 4: A Proposed Reconfigurable Materials Handling System**

### **4.1 Background**

Many products may be customised with a reconfigurable system. A dumbbell assembly is a simple example of how, in principle, parts may be customised. This approach can be transposed to other more complicated assemblies that are more likely to be customised on a large scale. Two such examples could be an automotive engine customisation or a personal computer (P.C) customisation. Typically an individual wanting to purchase these products could go online to the manufacturer's website and choose variants of a standard product. If the computer example may be used, an individual could choose computer components based on specific needs and requirements. The individual might choose a computer for gaming purposes. In this case a good graphics card would certainly be selected. Computer games generally use a large amount of Random Access Memory (RAM). Therefore it would be beneficial to select a RAM package with a relatively large capacity. Alternatively, if an individual wanted to use the P.C for word processing, spread sheets and research purposes, then a different package may be selected. A system that is equipped with wireless, high speed data facilities may be selected so that internet access can be achieved remotely. A RAM package with less RAM may even be selected.

This allows the consumer to purchase a product that will be used to its full potential at no unnecessary expense. That is to say, no particular feature will go unused unless the individual's circumstances change.

With regard to an engine assembly, a potential customer of a motor vehicle may customise the car online. The website could possibly have a feature where a number of variations or configurations for engine customisation may be selected. For example if a customer wished to increase the horsepower of the engine then two options, at least, could be presented. To induce more air into the engine, thus increasing the engine's power, an induction kit may be purchased and fitted for the customer upon purchase. The induction kit would be a relatively cheap option and would not result in a dramatic increase in horsepower. Alternatively, one can purchase a turbocharger that fits into the engine which would provide a larger increase in horsepower. This is a more costly option. The consumer will have a choice to weigh up whether it excessive or not.

## 4.2 Customisation of Product: Dumbbell Example

This reconfigurable manufacturing environment or cell was designed specifically for manufacturing dumbbells both standard and customised products. The production of this type of product is more likely to be produced using the available manufacturing cell and was considered to be a way of illustrating the functionality of the proposed system. A dumbbell consisted of a bar, 2 clamps and 2 plates. The manufacturing cell was capable of secondary manufacturing. It was assumed that steel shafts and plates were available for secondary machining. It is also assumed that the weight of a single component will not exceed 1.5 kilograms. The variations of dumbbell parts that are possible with this cell are shown in Figure 4-1.

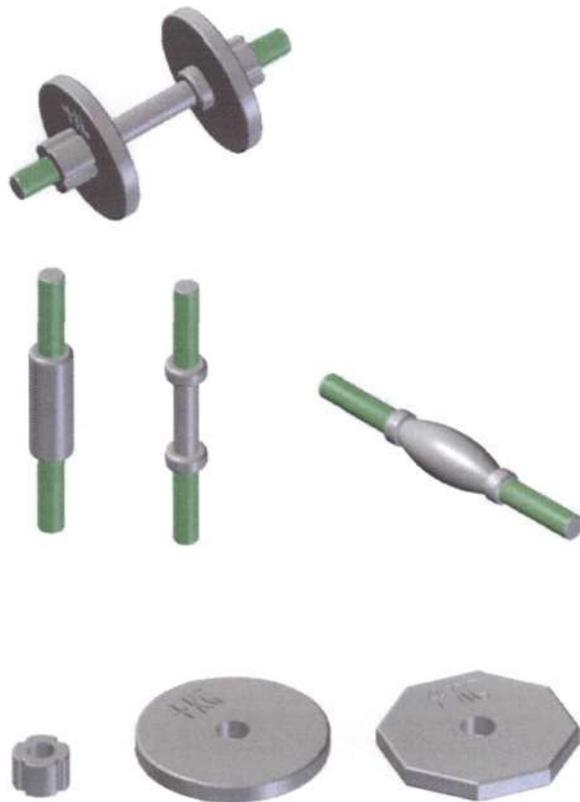


Figure 4-1 Bars, clamps and plates are parts that can be manufactured by the cell

Even though this product was fairly uncomplicated there are many variations of the product that can be achieved. A schedule is devised for each variation of the product. This means that the parts must undergo different manufacturing operations based on different consumer inputs. Tables 4-1 and 4-2 show the variations in the manufacturing processes for a set of dumbbells.

Table 4-1 Schedule of manufacturing processes required to manufacture a single standard dumbbell.

	Saw	Drill	Mill	Grind	Engrave	Tap	Thread	Knurl	Polish
Bar	X			X			X	X	X
Plate		X		X	X				X
Clamp	X	X	X	X		X			X

	Turning		
	Turn 1	Turn 2	Turn 3
Bar	X		
Clamp			
Plate	X		

Table 4-2 Schedule of manufacturing processes required to manufacture a customer-specified dumbbell

	Saw	Drill	Mill	Grind	Engrave	Tap	Thread	Knurl	Polish
Bar	X			X			X		X
Plate		X		X	X	X			X
Clamp	X	X	X	X		X			X

	Turning		
	Turn 1	Turn 2	Turn 3
Bar			X
Plate			
clamp	X		

The shafts are turned on a lathe to suit the customer's specification. There are 3 turning configurations that the customer can choose from. The bars may or may not be knurled depending on the specification. The plates can be circular or octagonal in shape. The customer may also choose for the hole in the plate to be tapped so that it is more securely fastened to the bar when assembled.

A reconfigurable manufacturing cell was conceptualised to mass customise dumbbells. The cell required all the secondary manufacturing machinery to fabricate the parts. Based on what was available in the MR<sup>2</sup>G laboratory, a concept for the manufacturing cell was developed.

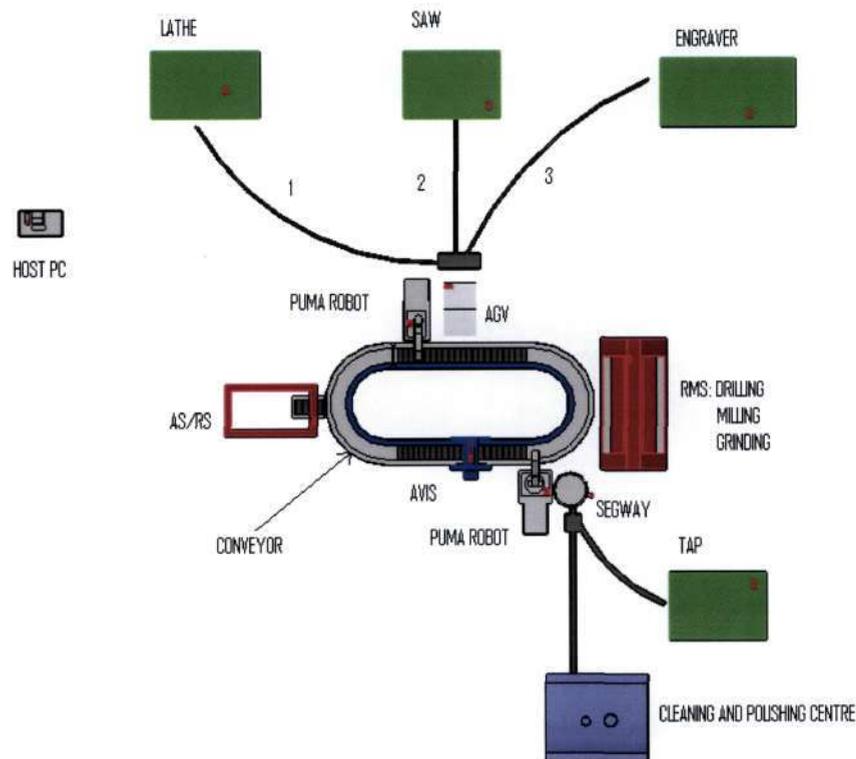


Figure 4-2 Plan view of Agile Manufacturing Cell

The manufacturing cell, shown in Figure 4-2, consists of a conveyor, an Automatic Storage and Retrieval System (AS/RS), a reconfigurable machine system (RMS), an automated visual inspection system (AVIS), an automated guided vehicle (AGV) and 2 pick-and-place robots. The peripheral machines that is the lathe, saw, engraver, tap and polishing centre are hypothetical machining centres.

Parts must be tracked continuously, in the cell, to facilitate mass customisation. If the location

of the part is known by the control program then the part can be routed by the program to other locations. For example, if the bar is currently at the lathe and its next stop is at the RMS then the conveyor must transport the part to the RMS and stop so that the part can be transferred across to the RMS. Then the conveyor will restart. If the control system did not know where the relevant parts were then it would be impossible for the materials handling machines to transport the parts to the correct locations. Tracking is also a measure for quality control. The list of locations to which a part has been, in the system, was stored in a database for later reference. This was information which can be referenced if the part was not fabricated to specification. If the part has indeed gone to the wrong location, this was seen in the database and the error was rectified.

The parts travelled through the manufacturing cell on a plastic pallet. A passive RF tag was placed on every pallet. Each tag had a unique identification code. RF tag readers were placed at various locations throughout the cell to track the location of the part and pallet. These tags are found on each machine and are depicted in red.

It is assumed that when parts are taken to a machine a process queue begins at that machine where parts are dealt with as they arrive. It is also assumed that the pick-up and drop-off points for parts on each machine are different so that pick-up areas will not be congested and if more than one AGV is used then they will not collide. The RMS has its own transfer system to transfer the part onto or off the conveyor. Similarly the pick-up and drop-off points are not the same to avoid dropping off a part onto another awaiting a pick-up.

#### **4.3 Proposed Part Tracking, Routing and Scheduling System**

The Dumbbell customisation manufacturing cell was chosen to demonstrate the concept of mass-customisation. This concept was chosen because of the existence of certain machines. It also adequately demonstrates the part routing and scheduling systems necessary for mass-customisation.

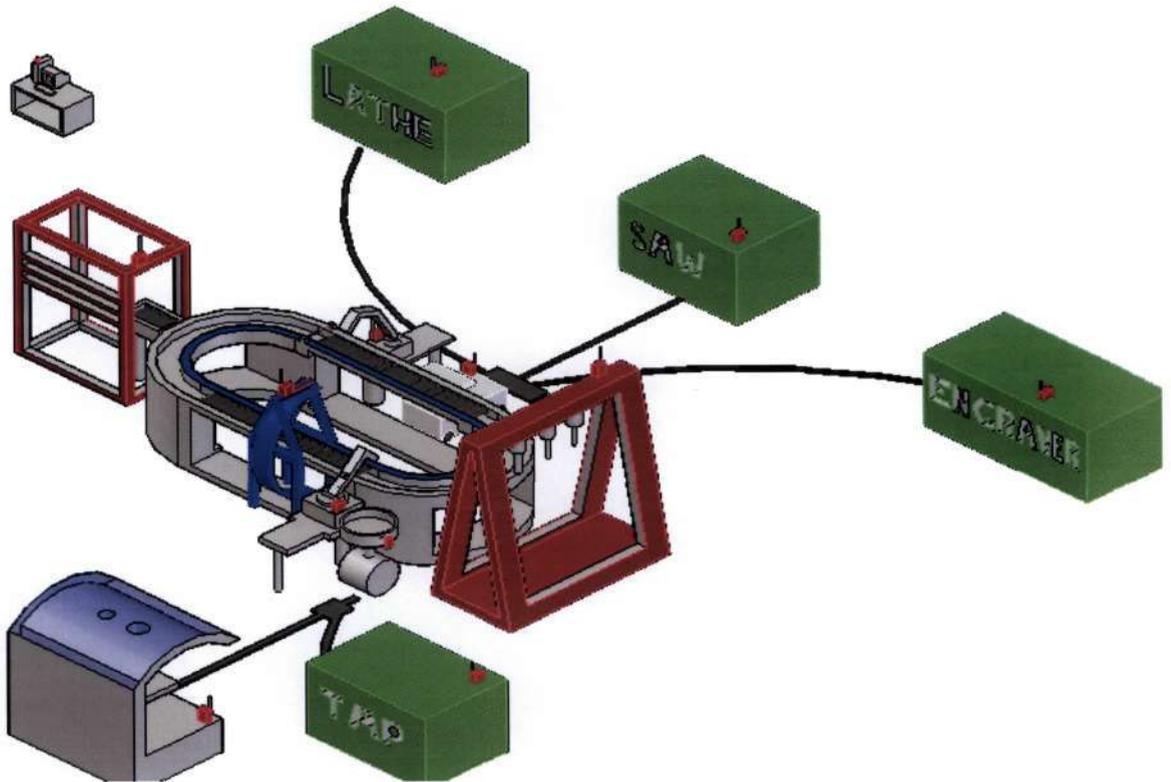


Figure 4-3 Reconfigurable Dumbbell Manufacturing Environment

The components were placed on pallets and stored in the AS/RS prior to manufacturing. The AS/RS released an unknown part with its pallet onto the conveyor. The pallet travelled clockwise around the conveyor until it crossed a laser sensor (transmitter-receiver pair) which caused that section of the conveyor to stop moving such that the pallet was directly in front of the first pick-and-place robot. A reader, located on the robot, read the tag and linked with the database. In this way the part was identified for the first time. The host computer then started a process queue for the part. The host then told the robot to pick up the part and place it on the AGV. The AGV was then told by the host to go to a machining centre such as the lathe. All the machining centres had readers and RF devices so that the parts cannot be confused.

The AGV docked with the lathe which proceeded to machine the part according to its computer numerically controlled (CNC) programming. The peripheral machines were also controlled by the host for the CNC operations. The AGV then returned to the conveyor in the mean time to transport other parts back and forth. When the lathe had completed the operation

on the part it communicated this with the host computer and host then sent the AGV to fetch the part from the lathe. The database was also updated to show that the lathe operations had in fact been performed on that particular part. In similar fashion the part was sent to the saw and the engraver. When those processes were performed and the part was brought to the conveyor, the host then updated the database and told the robot to place the part on the conveyor again.

The part travelled to the next sensor pair which stopped the conveyor such that the part was directly in front of the Reconfigurable Machine System (RMS). The tag was read by the RMS reader and this was communicated to the host which gave instructions to the transfer system to transfer the part into the RMS. The host told the computer to perform the relevant processes on the part. When the processes were performed the RMS informed of this. The host, in turn, instructed the transfer system to transfer the part back onto the conveyor. The database was once again updated.

The part was placed back on the conveyor where it continued to travel until it crossed the next sensor pair where it stopped again opposite another pick-and-place robot. The tag was read and the part was placed on the Segway HT, an autonomous materials handling system, which was then told by the host to travel to either the tap or the polishing centre depending on the part. The tag was read again and the processes were performed using CNC. The host was informed upon completion of the machining processes and the Segway HT fetched the polished parts and the robot placed them back on the conveyor. The database was updated once again.

The part was placed back on the conveyor where it travelled through the AVIS, which had a reader, which checked the parts quality. The database was updated for the last time when it was established that the quality of the part was satisfactory. The completed part is finally returned to the AS/RS via the transfer system.

#### **4.3.1 The Laser Sensor System**

A laser sensor system was constructed from a laser diode, taken from a laser pointer, and a purchased light sensor circuit. The circuit outputted a low or high signal, -12 or 12 volts respectively, to the control program via RS-232 serial communication. Three sensors were constructed and placed at various points on the conveyor. These sensors were only capable of sensing an obstruction when an obstacle disturbed the beam transmitted from the laser diode to the receiver circuit.

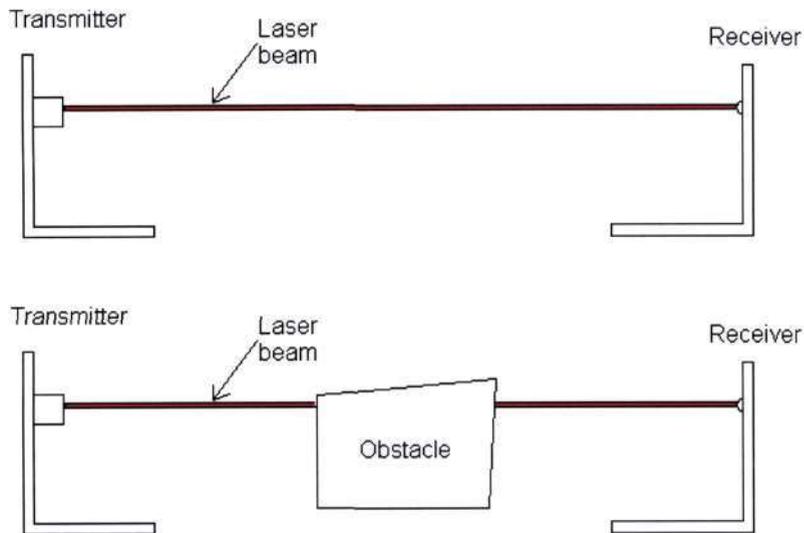


Figure 4-4 Block diagrams representing laser transmitter-receiver sensor

The sensor was incapable of ascertaining the type of part that had breached the beam. Still it was useful in that the presence of any part in a location could be ascertained. For example, if the control program was designed to stop a part whenever it broke a beam at some location. When this occurred, the receiver circuit would output a low signal to the control program indicating that an obstacle was located in between the transmitter and receiver. If this part was taken off the conveyor by the AGV, then the beam would be remade and the receiver circuit would output a high signal. This would indicate that to the control program that the part had been taken off the conveyor, and the conveyor could possibly be restarted again. This is similar to a 1-bit RFID system except that the laser transmitter and receiver had to have a precise line of sight to produce an output. For this reason the transmitter and receiver were well fixed to the frame of the conveyor using a mild steel bracket. The photograph below is of a pallet obstructing the line of sight of a transmitter and receiver, breaking the beam. The red line is drawn to indicate the beam and the red/blue line is drawn to depict its continued path had it not been obstructed.



Figure 4-5 Laser Transmitter used to sense passing pallets

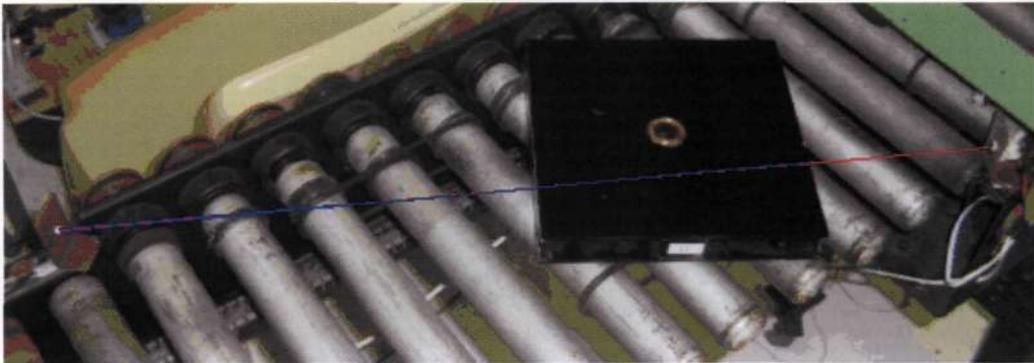


Figure 4-6 Pallet breaking a beam between the laser transmitter and receiver

#### 4.3.2 The Radio Frequency Identification (RFID) system

A Radio Frequency Identification (RFID) system was purchased and implemented to track individual parts/pallets in the manufacturing cell. This tracking hardware was adapted from a home security system that would allow or deny access through doorways. Radio Frequency (RF) readers were placed at certain locations on the conveyor. These locations are section 3 and 6, on the conveyor. At these sections certain parts are transferred off the conveyor. The part must be identified before it can be transferred in case it is not required to leave the conveyor at that point. RF tags were adhered to the parts/pallets. These tags contained a unique numerical identification (ID) number. When the tag was within range of a reader it would power up and continuously transmit its ID number to that reader. The reader, in turn, would communicate this information to the system database via RS-232 communication. The database stored details regarding the read event, namely the ID number of the tag, the ID number of the reader, the time and data of the event. This information has short and long term

uses. The short term use is that the control program can query the database to ascertain the ID number of the tag and the location at which it was read. If this information is known then the control program could choose the best route for the part thereafter.



Figure 4-7 An RF reader reads an RF tag adhered to pallet

The readers were connected to a microcontroller. The microcontroller and the readers were powered by a 12 volt power supply. The microcontroller connected to the serial port of the host P.C and communicated the reader's data to a database. The specifications for these components appear in **Appendix A**



Figure 4-8 Power supply and RS-232 terminals



Figure 4-9 The microcontroller for the RFID system [26]

The range of the RF reader was very low. This poor range could be attributed to the electromagnetic interference of the conveyor's motors or its proximity to metallic surfaces. The reader had to be mounted very close to the passing pallets for a successful read event. The readers were mounted on U-shaped mild steel brackets and mounted such that reader was approximately a centimetre from the passing pallet. The tag also was required to pass directly beneath the reader. The pallet does not always keep a fixed orientation as it moves through the conveyor. For this reason the tag was adhered to the middle of each tag. Also, aluminium guides were constructed such that the tag on the pallet always passed underneath the reader.



Figure 4-10 The range of the RFID system

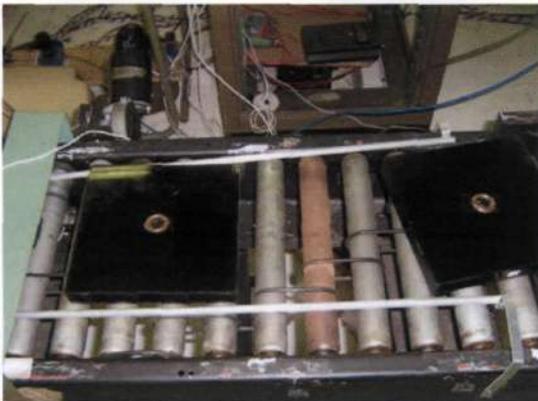


Figure 4-11 The guides pallet orientation and path

### 4.3.3 The Control Program

The control program was developed to manage the materials handling system in terms of part tracking, routing and scheduling. The control program was able to query the RFID system's database in order to track specific parts moving through the manufacturing cell. The information about the location of the part was then used to route the part to the next appropriate location.

The process was modelled on the dumbbell example where Part A represents a bar, Part B represents a plate and Part C represents a clamp. Part A and C need to exit and re-enter the conveyor via the AGV docking point in section 3. Part B travels directly to the RMS to be machined. After Parts A and C are machined and brought back to the conveyor at section 3 they continued through the cycle. Part C was transferred to the RMS at section 6 and Part A continued directly to the AS/RS. In summary, Part A and C exit and re-enter the conveyor at section 3 and Parts B and C exit and re-enter the conveyor at section 6.

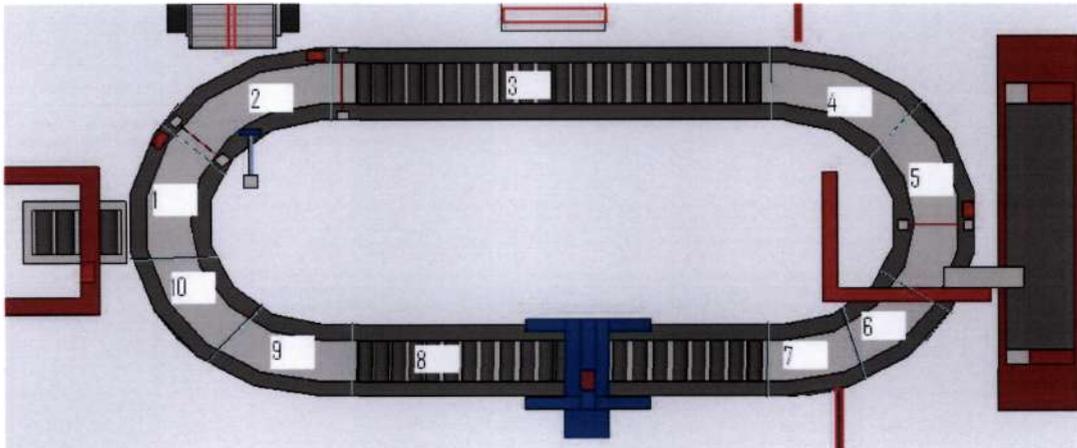


Figure 4-12 The plan view of the conveyor with highlighted segments

The system released a part that was read by a RF reader at the end of section 3. There was a 4 second delay from when the tag is read to when the system could respond. The readers were always placed 4 seconds behind every drop off point. If the reader reads the tag and the ID number matched Part A or C, the conveyor stopped in section 3 and the AGV was call up to transfer the part across for machining. If somehow the part was not transferred to the AGV

then the transfer system would repeat the process until the AGV sensors confirmed that the part was on board. If part B was read then the conveyor continued to transport the part to section 6. Similarly in section 6, if either part B or C was read then the conveyor for section 6 was stopped and the RMS transfer system was called up to transfer the part onto or off the conveyor. If part A was read then it was allowed to proceed. The laser sensors were also incorporated to determine whether a part had left the conveyor or not. If the beam was originally broken and the conveyor had stopped, then when the beam was remade the conveyor would restart. The overall control program for the reconfigurable manufacturing environment is available in **Appendix F**.

The RFID system database, created by Firebird, required a connection to be made before any information was extracted. The programming language used for the control program was Visual Basic 6.0 (VB 6.0). Unfortunately, VB 6.0 could not directly connect to the database. The extraction process was eventually performed indirectly by using VB.Net. Using this language, the connection to the Firebird database was achieved by the locating a Proxette database file that was provided with the RFID database software. This was not hard coded but rather a case of dragging and dropping the Proxette database icon on the form of VB.Net. Once the connection was made, the last entered record in the database was extracted and displayed in text boxes. The data entries have a unique 3-digit sequence number. To extract the last record, the largest value of the sequence number was queried. The information attached to this sequence number, namely the RF tag's ID number and the reader's ID number were transferred to a Microsoft Access database to which VB 6.0 could easily connect. The Microsoft Access database was developed by using the Data Form Wizard in the program and thereafter to follow the prompts. The information was then transferred to text boxes in the VB 6.0 program. Timers were used in VB 6.0 that continuously refreshed the query for the highest sequence number every half a second. This method was an indirect one where the information was transferred from the Firebird database to VB.Net into a Microsoft Access database to VB 6.0. If the connection could have been made using VB 6.0 then VB.Net and Access would have not been included [25].

## **Chapter 5: Performance and Improvements of the Proposed Reconfigurable Materials Handling System**

### **5.1 Tests performed on the Reconfigurable Materials Handling System**

#### Conveyor efficiency test

The systems efficiency is the ratio of the time taken for a part to be processed (without waiting in a queue) to the total time for it to complete its cycle. Part B leaves the AS/RS and must go directly to the RMS located in section 6. A test was performed to move part B from section 1 to section 6 on the conveyor. Part A was released before part B. Thereafter parts were continuously released onto the conveyor from the AS/RS. Part A travelled to section 3 which stopped as soon the part A was at the AGV docking point. The part B follows part A but could not proceed passed section 2 because section 3 was stopped. Other parts reached the end of section during this time. This formed a bottleneck at the section 2-3 border. The AGV when undocked took approximately 41 seconds to reach its docking point on the conveyor and to remove part A. Once part A was lifted off the conveyor, the conveyor started up again and part B continued unimpeded through to section 6. A time was recorded for each leg of the journey for part B. The experiment was repeated 3 times and an average was taken.

Table 5-1 Duration of journey for Part B.

Stages of Journey for Part B	Time taken (seconds)
Section 1	5.5
Section 2	5.5
Delay: Wait for AGV to clear section 3	41.7
Section 3	16.4
Section 4	5.5
Section 5	5.5
Section 6	5.5

The total time calculated for part B to travel from the AS/RS to the RMS via conveyor, that is the sum of the times taken for every stage of the journey, is 85.6 seconds. If no obstruction

was present on section 3 then the time taken for the journey would reduce by 41.7 seconds to 43.9 seconds. That implied that the 48.71% of the time taken to complete the journey was spent waiting for the obstruction to clear. If 43.9 seconds is the ideal time taken then the system is 51.2% efficient. These calculations are shown below.

$$\frac{43.9}{85.6} \times 100 = 51.2\% \dots\dots\dots \text{Efficiency calculation}$$



Figure 5-1 Build up of parts in section 2 due to obstacle in section 3



Figure 5-2 Bottleneck formed on section 2

## **5.2 Improvements to Reconfigurable Materials Handling System**

Section 3 appeared to be the weakest link in the material transfer chain. It was such because the AGV had to pick up parts from the conveyor and transport them to the external machining Centre and return to the conveyor to pick up another part. The AGV could not perform this task at the rate that the parts were being released from the AS/RS. As a result, parts were left waiting at Section 3 to be fetched by the AGV. This delay caused the production rate of parts, which were going for external machining, to be hindered. Using the example of dumbbell manufacture, not enough bars and clamps were being produced in any given time frame. It became necessary to fabricate and implement a second AGV that would be available to pick up parts when the first was unavailable.

The other difficulty that was encountered was the problem of bottlenecks that occurred at Sections 3 and 5. This was because of the delays that occurred when parts were transferred on or off the conveyor at those locations. Other parts that needed to proceed directly through those locations could not do so when certain parts were being lifted off or placed onto the conveyor. This delay caused a ripple effect all the way back to AS/RS.

It became necessary for parts to circumnavigate obstacles on the conveyor in order alleviate the problem of bottlenecks on the conveyor. If the parts were re-routed around the obstacle, effectively "jumping" the queue, then the rate of production could be improved.

Various concepts were generated to solve the problem of re-routing parts. A solution was generated that was both flexible and improved the production rate. These concepts are discussed below.

### **5.3 Concepts Generated**

#### **5.3.1 Concept 1: The Bypass Conveyor**

The simplest solution to move parts around section 3 was to create a Bypass Conveyor that would transport parts, directly, from section 2 to section 4 without the parts passing through section 3. A curved shape conveyor was conceptualised to perform this function whenever a

part in section 2 was delayed by another part waiting to be picked up in section 3. The radius of the Bypass Conveyor would be kept to a minimum in order to minimise the distance travelled by a part. A larger radius of curvature for the Bypass conveyor would mean a longer length for Bypass Conveyor as well. The Bypass conveyor would consist of a mild steel structure, rollers and a belt. The drive roller would be driven by a DC motor. The AGV could freely transport parts underneath the Bypass Conveyor to and from the docking station.

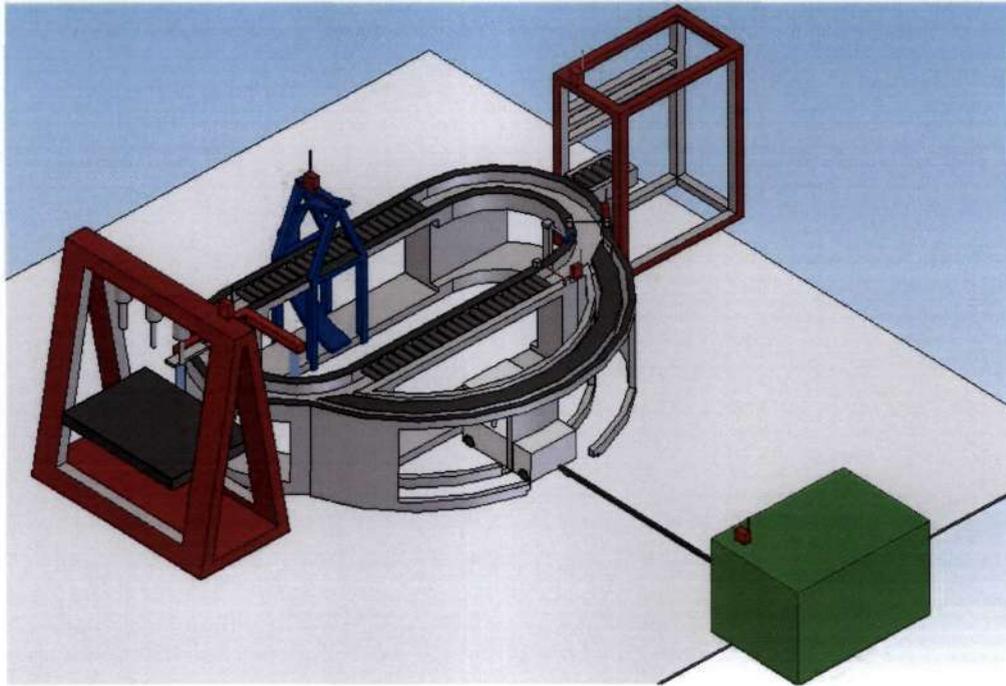


Figure 5-3 Conceptual Manufacturing Environment incorporating a Bypass Conveyor

When the RF reader in section 2 reads a part B then the control system would ascertain whether or not section 3 is in motion. If section 3 is not in motion then it can only mean that a part is waiting to be picked up there. This part is the obstacle that must be avoided by part B that is in section 2. The control system would signal a transfer system to transfer the part B from section 2 to the Bypass Conveyor. The Bypass Conveyor would then transport the part B to Section 4 where it rejoins the main loop. A Bypass Conveyor would be placed wherever a bottleneck zone is located. A sensor, possibly a laser transmitter-receiver pair, may be set up on the Bypass Conveyor that would detect the presence of a part. The sensor would send a signal to the control system. The control system would then, via a relay or switch, set the Bypass Conveyor in motion. The other alternative is to run the Bypass Conveyor continuously.

### 5.3.2 Concept 2: The Overhead Pick and Place System

This concept entailed the design of an overhead system that would transport a part from section 2 to section 4 by travelling over section 3. The overhead system consists of tracks mounted into the ceiling, along which a pneumatic piston cylinder assembly would travel. A fork-like gripper would be fixed to the end of the piston to mate with the part to be transported. The system would travel using a rack and pinion system. The tracks would be long racks that are bolted into the ceiling. A pinion driven by a motor is fixed to the overhead system. The rotational motion of the pinion, due to the motor, is converted to linear motion by the rack and in this way the system travels parallel to the plane of the ceiling. The pneumatic cylinder extends a certain distance when it receives compressed air. Fully extended the gripper would line up with the part/pallet. The system would then move forward so that the gripper could mate with the part/pallet. The compressed air supply flowing to the cylinder would then be stopped and the pneumatic cylinder would be retracted and the part/pallet would be lifted above the conveyor. The system would then transport a part/pallet, via the rack and pinion, from section 2 to section 4 by travelling over section 3. Non-contact sensors would be placed at the beginning and end of the rack to prevent the overhead system from travelling too far. Tracks could be fixed into the ceiling in any path that the overhead system was required to follow.

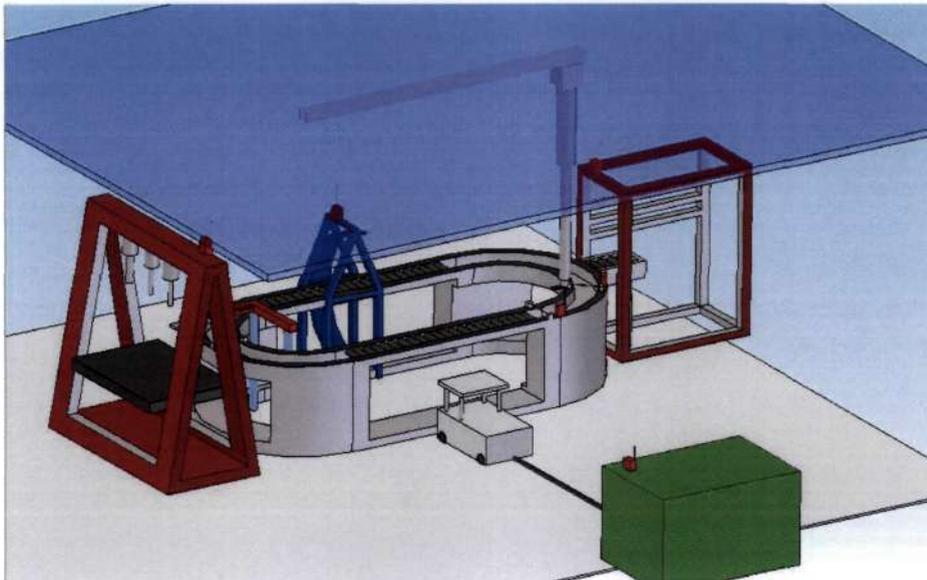


Figure 5-4 Conceptual Manufacturing Environment incorporating an Overhead system

When the RF reader reads a part B in section 2 the control system ascertains whether or not section 3 is stopped. If it is, then a part must be waiting to be picked up in section 3 and an alternate route would be taken by the part B. The control system would send a signal to pneumatic valve to allow compressed air to flow to the cylinder to allow it to extend. A signal would be sent to the motor via a relay to move the system forward to mate the gripper with the part/pallet. A sensor would have to be set up on the gripper to make certain that the gripper has in fact mated with the part/pallet. This sensor would send a signal to the control system informing it of the mate. The control system would then send a signal to the pneumatic valve to remove the air supply that would retract the cylinder that, in turn, would lift up the part. Another signal would be sent to the pinion motor to drive the system forward along the rack. The system would move until a sensor is breached that would stop the system from going further. The cylinder would extend until the part/pallet was back on the conveyor. The system would move backwards to separate the gripper and the part/pallet. The cylinder would then retract and the motor would drive the system backwards parallel to the ceiling until the rack sensor is breached indicating that the system is in its original position.

### **5.3.3 Concept 3: The Automated Guided Vehicle (AGV)**

An Automated Guided Vehicle (AGV) concept was developed as a flexible solution to the bottleneck problem by transporting a part B, directly, from section 2 to section 4 on the conveyor. The AGV would be a wheeled robot that is manoeuvrable enough to navigate through a cluttered manufacturing environment. The AGV would dock with the conveyor at locations where parts/pallets would be picked up or dropped off. The AGV would also have to follow a predetermined path. Line-following sensors in conjunction with a control program could possibly achieve this. These sensors would track a dark line on a light coloured background. The line could be obtained by a drawing it on the floor or sticking down tape in the required path. The AGV, when docked, would require a means to transport the parts onto and off the conveyor. This could be achieved by a set of rollers on top of the AGV that could roll backwards to accept a part being transferred on to the AGV from the conveyor. The rollers could also roll forward to transfer a part off the AGV onto the conveyor. The AGV would require the ability to avoid collisions. Ultrasonic sensors could be used as a non-contact solution to sense objects in the path of the robot. The only obstacle that could cross the path of the AGV is the existing AGV. The AGV would then stop if the existing AGV was sensed.

The AGV could also re-evaluate, after a period of time, in the event of that the obstacle moved out of its way. When the existing AGV did move off the path then the AGV would proceed.

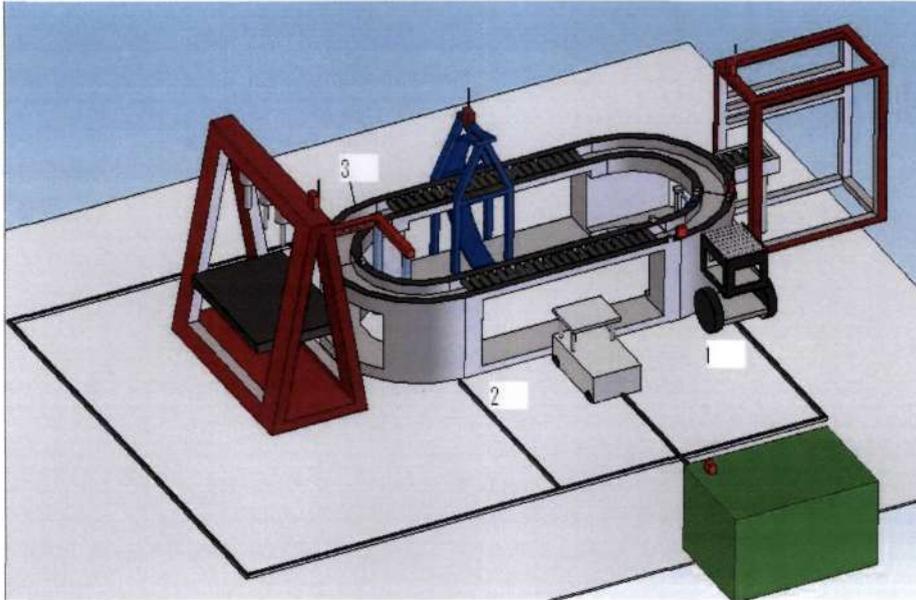


Figure 5-5 The Additional AGV incorporated into the system

The RF system would read a part B in section 2 and then ascertain whether or not section 3 was in motion. If not, then that would imply that an obstacle is on section 3 and must be avoided. The control system would then command a transfer system that would transfer the part onto the AGV. A separate control system would be required to control the AGV. As the part/pallet is transferred across, the rollers on the AGV would roll backwards to draw the part/pallet on board. A sensor would be required to verify that the part is on board. The AGV would then disengage from section 2 on the conveyor and proceed to section 4. The line-following sensors would constantly feedback to the control program for the duration of the robots journey. The control program would, in turn, constantly adjust the AGV's position based on the inputs from the line-following sensors. The AGV would finally dock with section 4 of the conveyor. The AGV's rollers would then roll forward and the part would be transferred to the conveyor. The AGV's sensor would verify that it no longer had the part and then disengage from section 4. The laser system on the conveyor would also have to verify that the part had re-entered the conveyor loop. Only if these two controls were satisfied could the system be allowed to proceed, without transfer errors. It would then follow the same path back to section 2 where it would dock with section 2 again to wait for the next run.

### 5.3.4 Concept Selection

Concept 1 appeared the simplest but also the most rigid of the 3 concepts. It seemed cumbersome to build Bypass Conveyors around every bottleneck zone because of cost and spatial constraints in the manufacturing environment. The existing AGV travels under the Bypass Conveyor to the Docking Station transporting parts between the conveyor and the Docking Station. The size of the parts that are carried on the existing AGV is also limited because of this. If very large parts were carried then it is possible that it could crash into the Bypass Conveyor. A possible improvement may have been to automate the Bypass conveyor further by providing motorised wheels to move the conveyor to the locations where bottlenecks arose. This too was not feasible because there was a fair chance that the moveable Bypass Conveyor would, at times, collide with the existing AGV. Concept 1 was not selected.

Concept 2 was an improvement to concept 1 in that it solved the problem of space on the floor of the manufacturing environment. The Overhead system could transport parts to any point on the conveyor as long as its tracks ran to those locations. The tracks are mounted in the ceiling in a path that the Overhead system would follow. This concept was also rejected because it was an inflexible solution. New tracks would have to be fixed into the ceiling based on the bottlenecks formed during the daily running of the manufacturing environment. This concept is considered rigid because the path for the Overhead system cannot be easily altered which hinders reconfigurable manufacturing.

Concept 3 was selected for the final design. The additional AGV was chosen because it was a flexible solution to the bottleneck problem that arose in section 3 due to stagnating parts in that location. The AGV would be able to pick up parts from section 2 and transport them, at an efficient rate, to section 4 to bypass obstacles on section 3. This additional AGV could be utilised wherever a bottleneck arose. Extra AGV's were not required as the one would be agile and manoeuvrable enough to help wherever it is needed. Spatially it is a more efficient solution, as there would be more room for other systems in the manufacturing environment. In addition the AGV could assist the existing AGV by transporting parts to and from the Docking Station whenever the existing AGV was unavailable. This concept facilitates reconfigurable manufacturing in that it is manoeuvrable and flexible, in terms of path following, to adjust its routes based on the bottlenecks that may form in the manufacturing environment.

## **Chapter 6: Bottleneck Solution: The Automated Guided Vehicle**

The AGV's primary function was to alleviate bottlenecks that occurred at specific locations on the conveyor. This was achieved by transporting pallets, which were prevented from progressing through a point on the conveyor, around the obstacle. This minimised the build up of parts in any location on the conveyor.

The AGV had to be flexible in that the path that it followed could be easily reconfigured to suit new scenarios. The AGV also had to proceed at a fair speed through the manufacturing environment as well as perform very sharp turns at certain places. It also had to have a mechanism of transferring parts/pallets onto the conveyor after transporting them.

The design of the AGV entailed the integration of mechanical, electrical and software engineering principles and ideas to produce a structurally sound, intelligent and autonomous materials handling machine. The design of the AGV is discussed in the following sections.

### **6.1 The Segway, Human Transporter (HT)**

The choice of platform for an AGV entails the consideration of many factors. These factors include the operational environment, payload, mission period, cost and control simplicity. Moreover an AGV operating in an indoor environment the ability to navigate around sharp turns and through tight spaces is favourable [28]. In light of this, the Segway HT appeared an appropriate platform upon which the mobile robot could be constructed. However the use of the Segway HT entailed careful manipulation to simulate rider conditions. The Segway has 4 pressure switches on its base underneath the rubber diaphragm. When a rider stands on them then the Segway HT is aware of the rider's presence and it becomes dynamically stable. Also the Segway HT, being an inverted pendulum, is constantly adjusting its drive motors back and forth to keep the Segway HT in balance. When the rider leans forward, instead of falling over, the Segway HT's moves forward to maintain a vertical position and so provides stability. This is known as dynamic stability [4]. This occurs because of balance sensors that feedback to a control system that, in turn, instruct the drive motors to turn the wheels back, forth or in opposing directions (in the case of turns). In this way, the rider can lean forward on the Segway HT and is immediately propelled forward. When the rider stabilises, The Segway HT

stops accelerating. Similarly when the rider leans back, the Segway accelerates in that direction. The steering grip on Segway HT's handlebar could rotate in a clockwise and anticlockwise direction. The clockwise (forward) twist of steering grip turned the Segway left and an anticlockwise twist turned the Segway HT right. These controls, designed for a human rider, were manipulated to create an autonomous Automated Guided Vehicle.



Figure 6-1 A labelled diagram of the Segway HT [20]

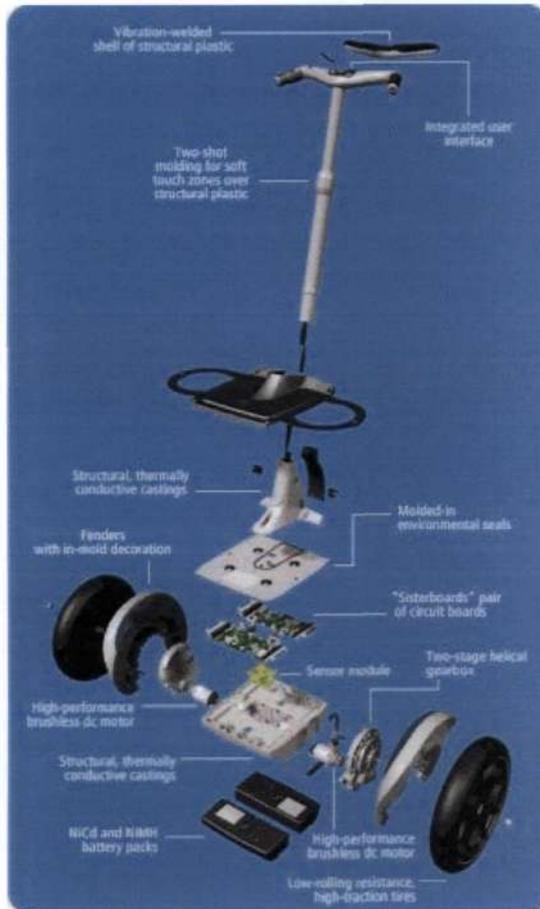


Figure 6-2 Exploded view of a Segway HT [27]

Undoing a single bolt dismantled the Segway HT's handlebar and control shaft. There are two cords connecting the handlebar to the base of the Segway HT that run through the control shaft. These cords were unplugged and the control shaft was sawn off the handlebar in order to liberate the cords. The control electronics in the handlebar was responsible for the steering on the Segway, the starter, the display and for the off button. The keys for the Segway are shown in figure 6-4. They are the yellow and black plastic objects resting on the handlebar. They are encrypted and limit the Segway at different speeds. The yellow key was used to test the Segway. The cut-off speed when using the yellow key is approximately 15 km/hour.

The Segway HT still demonstrated its ability to remain dynamically stable even though its handlebar and control shaft were detached. The specifications for the Segway HT appear in **Appendix B**.



Figure 6-3 The base of the Segway



Figure 6-4 The Segway handlebar and control shaft with the key

The agility of the Segway, its low power consumption and availability made it the ideal platform for a mobile robot which was relied on for a fast response to changes in the manufacturing cell. The following sections detail the modification of the Segway into the AGV used for improving system efficiency.

## 6.2 Mechanical System

### 6.2.1 Mechanical Structure

#### 6.2.1.1 The Base Plate

It was decided that a set of motorised rollers would be used to transfer the part off the AGV and onto the conveyor. This was achieved by fabricating housing for the rollers. The roller housing had to be mounted on a base plate that remained parallel to the Segway HT's base. In this way, the rollers would be parallel with the ground when the Segway was dynamically

stable. A flat surface was required to be fixed onto the Segway HT base upon which the roller housing could be attached. A mild steel base plate was fabricated to fit onto the base of the Segway HT. This was a modular design as the base plate could be removed and the original control shaft and handlebar could be reassembled onto the Segway HT. A mild steel cylinder was welded onto the base plate at an angle of approximately 70 degrees. This cylinder could fit into the stem of the Segway HT's base, which previously mated with the control shaft. Two other cylinders were welded to the base plate to form supports so that the base plate was parallel to the Segway HT's base. Six 10mm boltholes were drilled into the base plate so that the roller housing could be bolted on. Mild steel, 3 mm thick, was chosen because the load on the Segway HT was not a critical factor as it can support a human being weighing over 100 kilograms. Mild steel is relatively cheap, easily available and strong enough to perform the function of bearing the rest of the mechanical structure. The assembly of the base plate with the base of the Segway is shown in figure 6-5. The technical drawings for the base plate appear in **Appendix D**.



Figure 6-5 The Base Plate

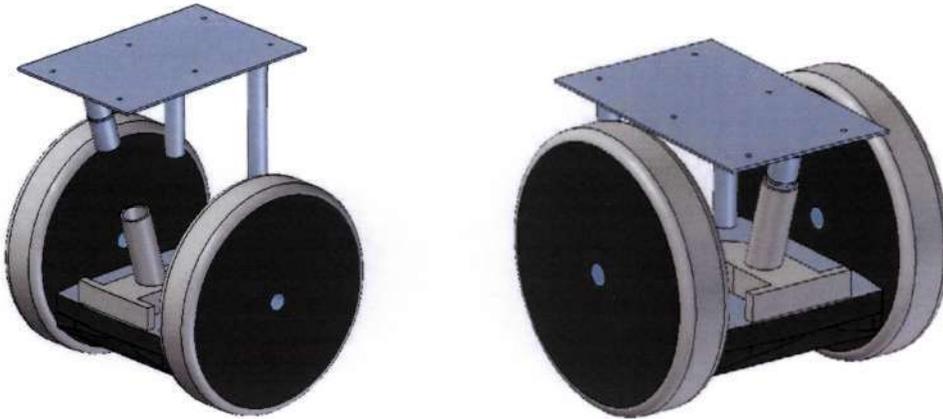


Figure 6-6 Assembly of Segway and Base Plate

#### 6.2.1.2 The Roller Housing

The roller housing was a 3mm mild steel frame that would house motorised rollers that are used to transfer the part onto the conveyor. The housing also contained the control electronics that was removed from the Segway HT. A hole was cut in the roller housing and in the base plate to allow the control electronics to connect to the base of the Segway HT. Nine, 10mm holes were drilled in the side-walls of the roller housing for the rollers. Rectangular holes were cut out of the roller housing to permit easy access to the electronics inside.

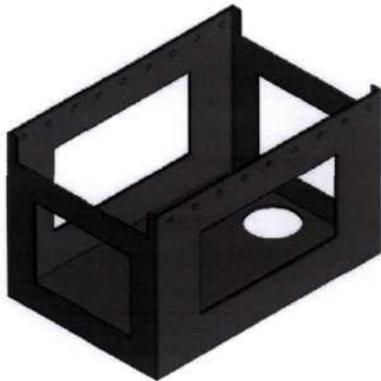


Figure 6-7 The Roller Housing

The roller housing was bolted on to the base plate using six M10 bolts. The Segway HT, because of its dynamic stabilisation is constantly tilting back and forth. The inertia of the roller housing causes a large shear stress, approximately 0.5 MPa, on the fasteners and that is why the M10 bolts were selected. In the event that the Segway HT did become unstable, the

roller housing, which would also house the control electronics, would not be thrown off. The assembly of the roller housing to the base of the Segway is shown in figure 6-8. The technical drawings for the roller housing appear in **Appendix D**.

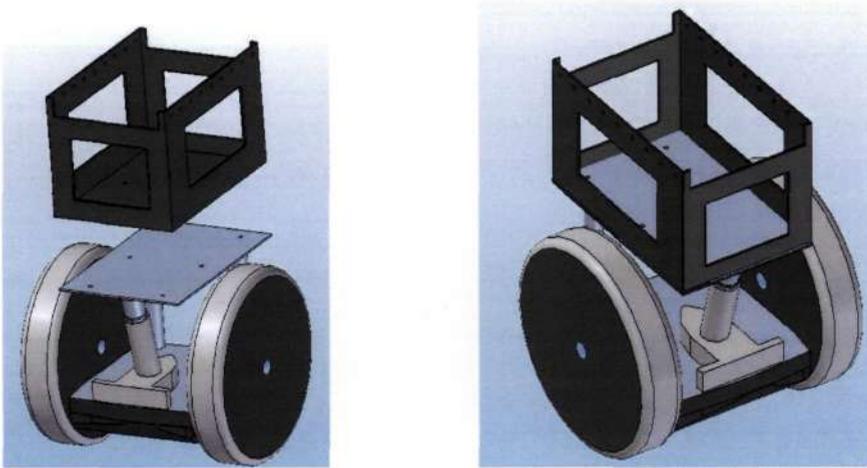


Figure 6-8 The Roller Housing Assembled

### 6.2.2 Steering Mechanism

The Segway HT has its steering mechanism on the handlebar. The steering mechanism is twisted clockwise and anticlockwise for left and right turns respectively. A servo was used to twist the steering grip in either direction. The HS-422 servo was removed from a model aeroplane.



Figure 6-9 The HS-422 Servo [21]

The servo was mounted in the roller housing using a mild steel bracket perpendicular to the Segway HT's steering grip. A plastic gear was mounted on the steering grip. A stainless steel pinion that meshed with gear was mounted on the servo. The servo was able to turn the

steering grip based on inputs from the control program. The technical specifications of the servo are in **Appendix C**.



Figure 6-10 The Turning Throttle Gear meshed with the Servo Pinion

### 6.2.3 The Slider System

The Segway HT was able to balance on two wheels by the concept of dynamic stabilisation. Balance sensors were able to sense a tilt on the Segway HT and send a signal to the drive motors. These motors propelled the Segway HT forward or backward such that balance was restored. In practice, when the Segway HT was tilted forward it accelerated forward and if it was tilted backward then it accelerated backward as well. The forward and reverse acceleration was achieved by actuating a weight on the base of the Segway HT that provided the tilt required for motion.

### 6.2.4 Rack and Pinion

The Segway, if perfectly balanced, will stand still. A net weight (which will cause a torque) is required to unbalance it. A 1,5 Kilogram weight was placed at the centre of the Segway HT's base to keep it balanced. When the weight was moved to the front edge of the base the Segway HT accelerated forward. A means for transporting the weight to the front, middle and back position of the Segway HT was formulated. A rack and a pinion were purchased and the 1.5 kg weight was welded onto the rack.



Figure 6-11 The Rack and Pinion used to in the slider assembly

A Ryobi cordless drill was purchased and its motor and battery pack were removed. The motor was partially stripped of its housing and a gear was keyed onto the motor shaft. A linear way slider was purchased that was bolted to the underside of the base plate as shown in figure 6-12. The slider consisted of a length of tool steel and a saddle. The saddle contained bearings and was able to slide along the length of the tool steel. The saddle had 4mm holes onto which the object that was being slid was bolted. The length of tool steel was bolted to the underside of the base plate. The bolts used were M6 and pass through the roller housing and the base plate.



Figure 6-12 The slider assembly incorporating the motor, rack, pinion and weight

The pinion was meshed with the rack and the 1.5 kilogram weight (slider weight) was bolted to the saddle of the slider. This weight was selected to match the maximum weight of any of the dumbbell components to counteract any net torque caused by the payload. These components were assumed to be 1.5 kilograms each. Increasing the weight of the components (the payload) would require an equal increase in the slider weight as well. The rack and pinion

system converts rotational motion into linear motion. The rotational motion provided by the drill motor rotated the gear and propelled the rack forward. The weight, having been welded to the rack was also propelled forward while being supported by the saddle of the slider. When the drill motor turned in either direction the weight moved to a certain distance from its neutral position to cause either forward or backward tilt of the AGV. This tilt resulted in a forward or reverse acceleration of the AGV. An optimum distance from the neutral position was found such that the AGV could achieve a certain speed for a certain distance.

The slider weight had three positions with respect to the base of the AGV. These positions were the front, neutral and back positions. The slider weight was stopped in these positions by the use of limit switches. A limit switch was placed in the front position. When the weight was moved forward and struck the limit switch the control program would stop the motor so that the weight did not move past the front position. The AGV would accelerate forward. When the weight was moved to the back the same thing would happen. The slider weight was never allowed to go passed the limit switches because the switch can only be depressed in one direction. It would damage the reed on the limit switch to strike it from the other direction. Also, it was found that the slider weight was striking the reed too hard and deforming it every time. The weight was moved too fast and the system took too long to respond when the limit switch was clicked causing it to sometimes go passed. Introducing a spring-loaded plastic shaft on either side of the slider weight solved this problem. When the slider weight moved forward the plastic shaft would make first contact with the limit switch, depressing it. The plastic shaft did not strike too hard because it was spring loaded and there was enough time for the system to stop the weight before it passed the limit switch.



Figure 6-13 Plastic spring-loaded shafts on either end of slider weight

The AGV was neutral when the slider weight was in the middle/neutral position. The weight had to the sensor from either side in this case. The reed of a limit switch was bent into a curved shaped and placed in an orientation such that the slider weight could pass from either side without damaging it. This orientation is illustrated in figure 6-14

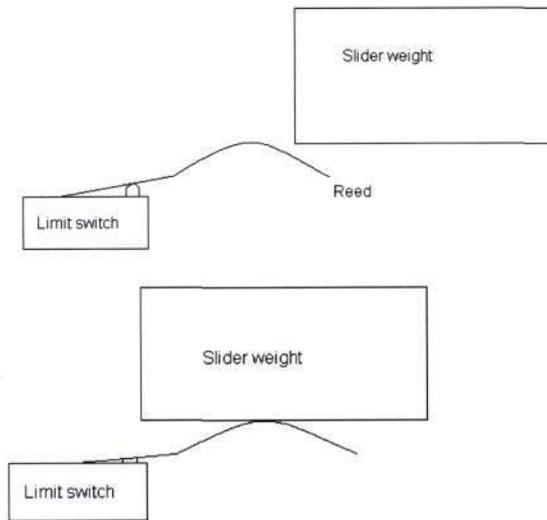


Figure 6-14 Modified Limit Switch before and after impact

The modified limit switch, when depressed, signalled the control software. The control made decisions regarding whether or not to stop the slider weight. The modified limit switch is shown in Figure 6-15



Figure 6-15 Modified Limit Switch about to be struck by weight

### 6.2.5 The Rollers

The rollers were fabricated by press fitting a set of roller bearings on a mild steel rod. A plastic tube, with diameter 40 mm was press fitted onto the bearings. A groove, 5 mm wide, was machined on each end of the plastic tube. Each roller would be linked to the next by rubber O-rings that would sit in the grooves of the plastic tube. The ends of the mild steel rod were threaded so that nuts could be used to fasten the rollers to the roller housing. The technical drawings for the rollers appear in **Appendix D**.



Figure 6-16 The Roller Assembly

Nine rollers were fabricated. The rollers were inserted into the holes (provided in the roller housing) and the ends were fastened using nuts. A Ryobi drill motor was used to drive the rollers in a clockwise or anticlockwise direction. The motor was fixed inside the roller housing using a bracket. An Aluminium pulley was designed and fabricated to fit on the shaft of the drill motor. An O-ring connected the pulley, which was held on the shaft using a grub screw, to the first roller.

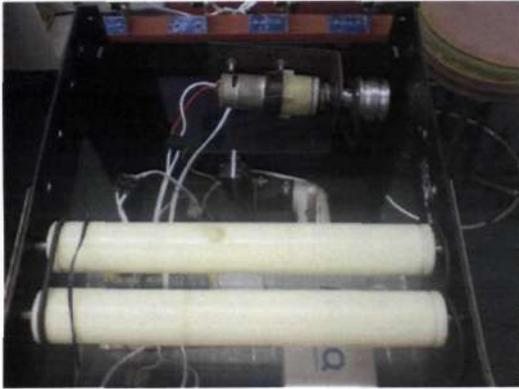


Figure 6-17 The drill motor and two rollers connected with an O-ring

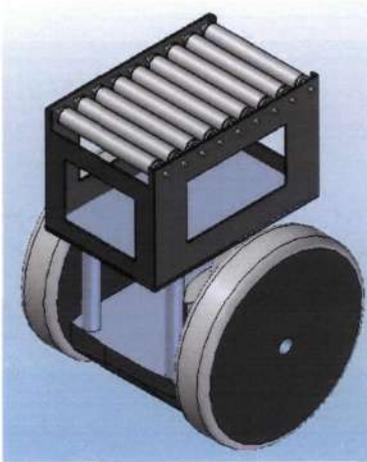


Figure 6-18 The Rollers assembled with the Roller Housing

### 6.2.6 The Docking System

The AGV would dock with the conveyor to either pick up or drop off a part. A docking interface was designed and fabricated that would allow the AGV some tolerance when docking. A male/female docking mechanism was implemented whereby the AGV would mate with the conveyor's docking interface. The conveyor was made aware of whether or not the AGV was docked by a limit switch. Another limit switch also made the AGV aware that it had docked. This system is discussed in the later sections.

### 6.2.6.1 The Conveyor Docking structures

There were two points on the conveyor where the AGV docked, namely section 2 and section 4. The docking structures that were fabricated were placed at these locations. The docking structure comprised of a wooden frame, a base plate and a female docking mechanism. The wooden frame was the approximate height of the AGV to ensure a mate each time.

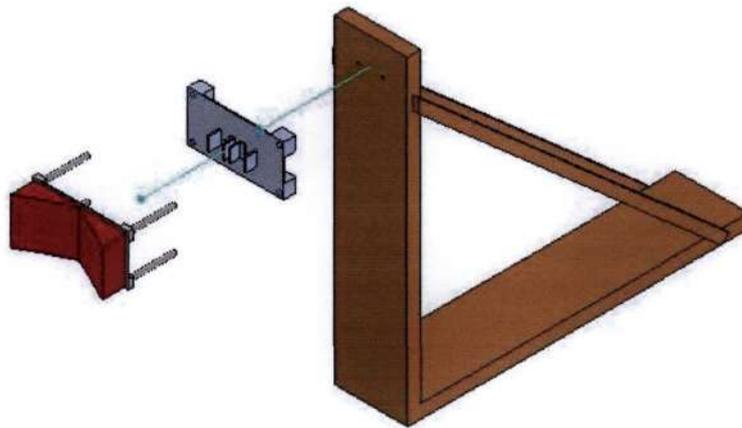


Figure 6-19 An exploded view of the docking structure

A limit switch was fixed between the 2 L-shaped brackets that are welded to the plate. The docking mechanism was a wooden, wedged-shaped block that was adhered to a thin mild steel plate. Four mild steel rods are welded to the mild steel plate. Four springs were placed over each of the four rods. Four holes were drilled into the base plate so that the rods could fit in. The docking mechanism fitted into the base plate.

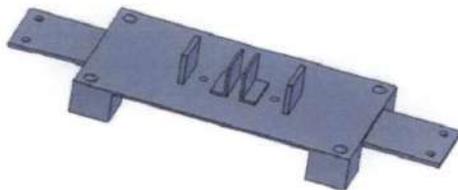


Figure 6-20 The Docking Base Plate

The AGV docked with the docking structure and the docking mechanism was pushed into the base plate, clicking the limit switch. The limit switch alerted the conveyor's control program that the AGV had in fact docked. The spring on each of the four rods absorbed the energy of

the AGV's dock and thus limited the impact. The springs compressed just enough such that the docking mechanism could click the limit switch. When the AGV undocked again, the springs pushed the docking mechanism out again and the limit switch button was no longer depressed. This indicated to the control program that the AGV had undocked and to wait for the next dock. The 2 plates were welded perpendicularly to the base plate. These plates acted as a stopper if the impact of the dock overcame the spring force.

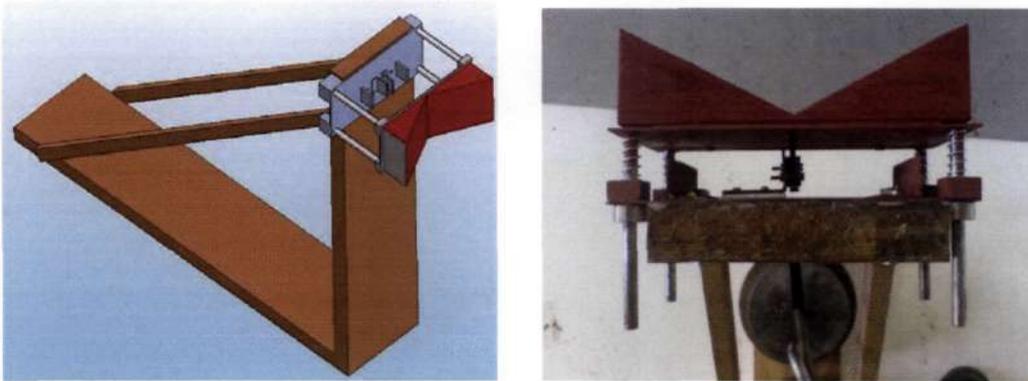


Figure 6-21 The Conveyor's Docking Structure

#### 6.2.6.2 The Docking Structure for the AGV

A docking mechanism and base plate was attached to the AGV. The docking mechanism was wooden, triangular-shaped and adhered to a mild steel plate with four mild steel rods. The base plate was attached to the AGV. A spring was placed on each of the rods. The AGV docked with the conveyor's docking structure and pushed the docking mechanism into the base plate such that the springs compressed and the limit switch was depressed. This sent a signal to the control program for the AGV that it had docked. When the control program received this signal the slider weight was moved to the centre point such that the AGV was no longer tilted. This meant that it came to a stop since it no longer had any acceleration. When the AGV undocked the springs decompressed and pushed out the docking structure. This left the limit switch open and indicated to the control program that the AGV had undocked.

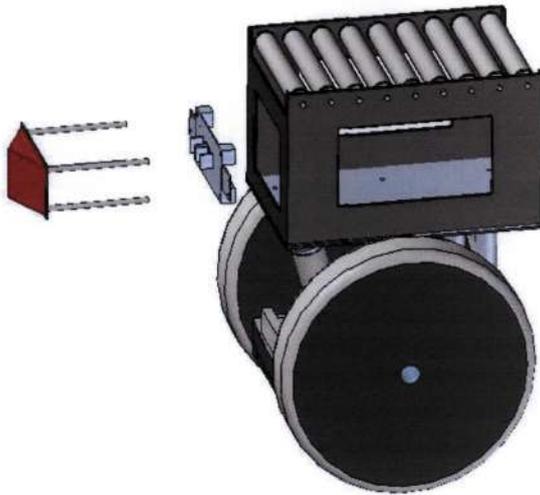


Figure 6-22 An exploded view of the docking structure

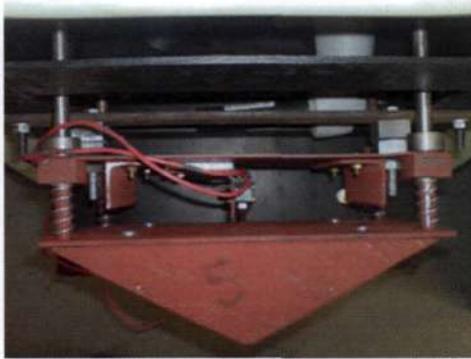


Figure 6-23 The AGV Docking Mechanism

The force of the AGV on the docking structure was obtained by the product of the mass of the AGV and largest acceleration measured on the AGV in the manufacturing environment. This is given by equation 6-2. The mass of the AGV was measured to be 68 kilograms. The AGV covered 3 metres in 6.11 seconds from its initial position at rest. Using Equation 6-1, the AGV was found to have an acceleration of  $0.161 \text{ m/s}^2$ .

$$s = u \cdot t + 0.5 \cdot a \cdot t^2 \dots \dots \dots \text{equation 6-1}$$

Where  $u$  = initial velocity of the AGV (m/s)

$a$  = acceleration of AGV ( $\text{m/s}^2$ )

t = time taken for the AGV to cross a given distance (s)

s = displacement covered by AGV (m)

$F = m \cdot a$  .....equation 6-2

Where m= mass (kg)

a= acceleration ( $m/s^2$ )

F= force (N)

The force of the AGV on the docking structure was 10.948 N and the displacement allowed was measured to be 30mm. The formula for the design of a spring is given by equation 6-3.

The diameters and material choice was evaluated until an appropriate spring was found.

$$\delta = \frac{8NFD^3}{Gd^4} \text{ .....equation 6-3}$$

Where  $\delta$  = displacement of the spring (m)

F= force (N)

D= mean coil diameter (m)

d= diameter of the wire

N= number of coil turns

G= torsional modulus

The mechanical structure was the first aspect that was completed. The robot was expected to perform autonomously. This required control electronics as well as a control program.

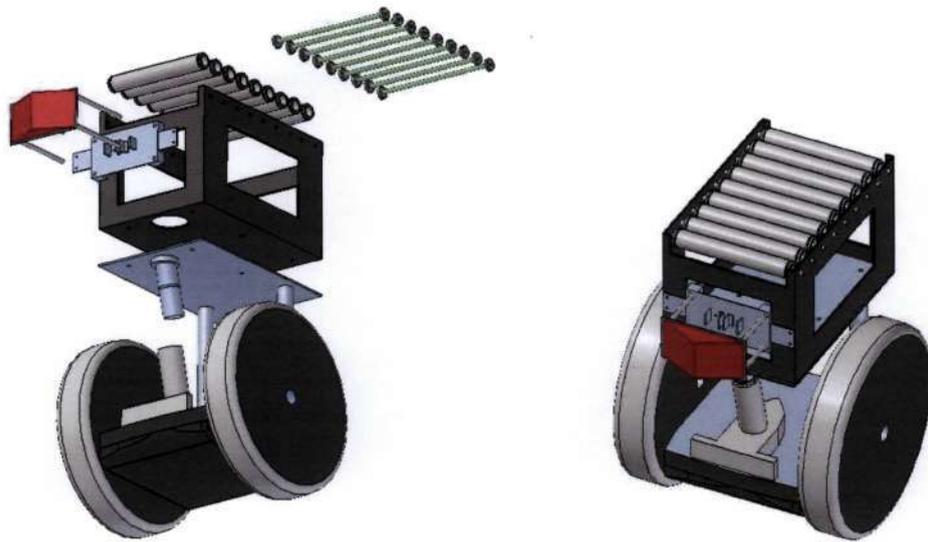


Figure 6-24 The Exploded and unexploded Illustration of the AGV

### 6.3 The Electronic System

The electronic system consisted of sensors and control units that worked with a control program to allow the AGV to perform autonomously. The control system for the AGV worked independently of the control program for the conveyor.

#### 6.3.1 Sensors

Limit Switches were used in the many different aspects of the system because they were a cheap and simple solution and were readily available. In some areas a non-contact sensor may have been used.

A Hall Effect sensor may have been used in place of the modified limit. The Hall Effect sensor is a non-contact sensor that can be used as position, displacement and proximity sensors. The object that is being sensed must have a permanent magnet attached to it. The result is a Hall voltage output that is a measure of the distance from the magnet to the sensor. The sensor is often used as a switch that can operate up to 100 Kilohertz (Khz) repetition rate. They cost less than electromechanical switches and do not suffer from contact bounce. [2]

A strip of magnetic tape would have been adhered to the slider weight. The Hall Effect sensor would have been mounted at a point on the AGV. A minimum Hall voltage output would have been configured on the control system to indicate that the slider weight was within range. This means that whenever the slider weight was a certain distance from the sensor, a certain Hall voltage would be set up that would be fed back to the control program.

Four limit switches were placed at the end of the rollers on the AGV. When the AGV docked at section 2 the transfer system would push the part on the AGV. Simultaneously the AGV turned its rollers backwards such that the part was transferred all the way to the back. The part would strike one of the four limit switches. The limit switches were connected in parallel such that if any one was breached, a signal was still sent to the control system to confirm that the part was on board.

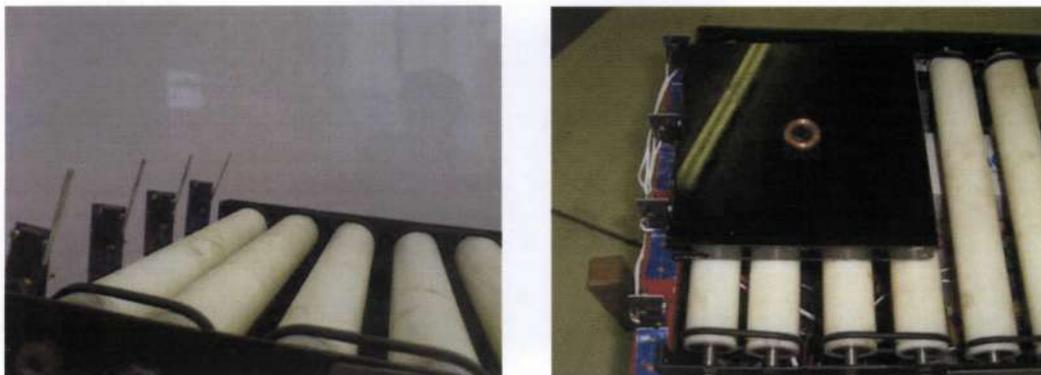


Figure 6-25 The roller limit switches

### 6.3.2 Interfacing: The Wireless Data Acquisition hardware (MicroDAQ)

The wireless Data Acquisition (DAQ) is a portable interface for Analogue to Digital (A/D) and Digital to Analogue (D/A) conversion. The wireless DAQ was used to control the motors of the slider system and the rollers of the AGV. One channel of the wireless DAQ was used. It used Bluetooth communication to send signals wirelessly to a Personal Computer (P.C) within a 10-metre range.

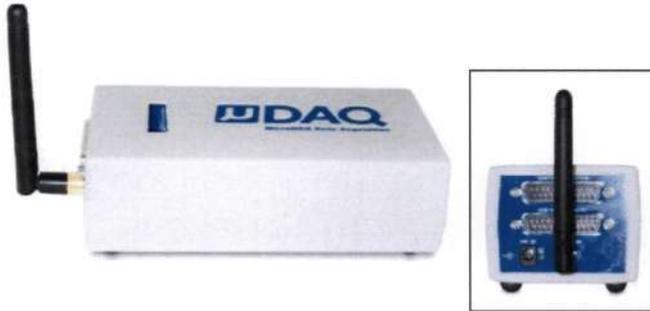


Figure 6-26 The wireless data acquisition interface [22]

It provides agreement between devices at the physical level. Bluetooth is a radio-frequency standard. Bluetooth communicates on a frequency of 2.45 GHz, which is set aside by an international agreement for the use of industrial, scientific and medical devices.

There is always a danger in any system using many wireless devices that one device interferes with another that it is not supposed to. One of the ways that Bluetooth devices avoid interfering with other devices in the same frequency range is by sending out only very weak signals of about 1mW. The low power limits the range of a Bluetooth device to about 10m, (for class 2 devices), thus reducing the chances for interference between devices.

Bluetooth also uses a technique called spread-spectrum frequency hopping to avoid devices interfering with each other by decreasing the likelihood of devices being on the same frequency. In this technique, a device will use 79 individual, randomly chosen frequencies within a designated range, changing from one to another on regular basis. In the case of Bluetooth, the transmitters change frequencies 1600 times every second [23].

A class 2 Bluetooth adapter was plugged into the host P.C and a search was performed for any Bluetooth device within range. Once the adapter recognised the wireless DAQ, four digit code had to be chosen so that the two devices could synchronise. Once synchronisation had occurred, signals were transmitted from the P.C to the DAQ, thereby controlling the mobile robot wirelessly.

A relay was used to switch the voltage on or off based on the signal received from the wireless DAQ. The switching signal for the relay was 12 Volts. The relay circuit had outputs for 2 motors. Both the slider and the roller motors were controlled via the relay circuit.

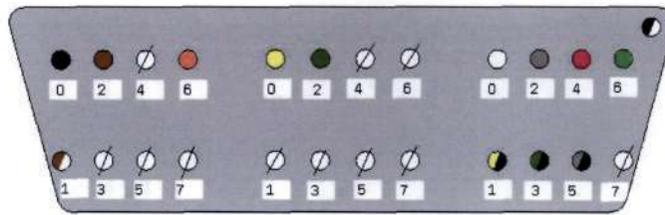


Figure 6-27 The pin connections for the wireless DAQ

The wireless DAQ has 3 ports per channel. Each port comprises of 8 Input / Output (I/O) pins. Each pin is used to control different components. The key for the wireless DAQ is given below.

Black = slider motor	green = miscellaneous	yellow and black = dock limit
Brown = roller motor	white = roller limit	green and black = Miscellaneous
white =start pin	grey = front limit	grey and black = miscellaneous
orange = lost line pin	pink = neutral limit	black and white = ground
yellow = found line pin	bright green = back limit	

The use of these pins will be discussed in the coming sections.

### 6.3.3 The Guidance System

The AGV needed to proceed on a path between section 2 and section 4. A line following approach was used. A line-tracking mouse was purchased and assembled. The mouse consists of a control circuit and three transmit/receive light sensors. These sensors output a high signal (5 volts or more) when they detect a dark surface. They output a low signal when they detect a white surface. The mouse was able to follow a black line on a white surface using these light sensors. The outputs from these sensors are fed into the Brainstem module which is the servo's interface. The servo constantly adjusts to turn the steering grip to ensure that the AGV turns quickly and evenly enough not to lose the line.



Figure 6-28 The Line Tracking Mouse

Brainstem GP 1.0 is an interface technology that is made up of both hardware and software that enables the manipulation of physical quantities using high-level programming languages. The Brainstem GP 1.0 module can be operated in up to three modes at the same time. The slave mode facilitates the host computers read/write capability directly from I/O. The second mode is the reflex mode where the module can automatically respond to inputs with a predetermined output. The module can also run several tiny embedded applications (TEA) at the same time to achieve simple tasks. [24]

For the application of the servo control, a TEA was written to ensure that the servo turned based on the input from the line following mouse circuit. The program stipulated that the middle and right light sensors did not see the line then the servo must turn the AGV toward the line. Similarly if the left and middle sensor were unable to see the line then the program would turn the AGV such that the middle sensor saw the line again.

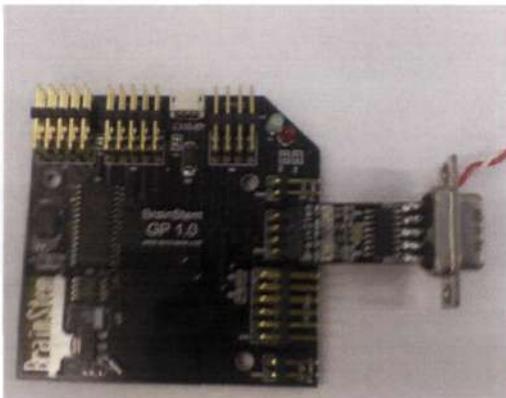


Figure 6-29 The BrainStem General Purpose Module 1.0

The line-tracking mouse was fixed to the underneath of the base of the AGV. The range of the light sensors was extremely small. They had to be approximately 2 mm from the ground in order to sense the light and dark. A spring-loaded bracket was fabricated to press the mouse onto the floor. No matter what angle the AGV made with the ground, the spring kept the mouse's sensors firmly pressed down onto the floor. The Perspex end of the bracket was adhered to the underneath of the AGV. The bracket end was cable tied to the line-tracking mouse.



Figure 6-30 The Guidance System Housing

#### 6.4 The Software System

The control System required software to control travel on a straight path and curved path. The Brainstem circuit was used to program the AGV such that it would follow a dark line on a light coloured surface. This was achieved from feedback obtained by the Line-Tracking Mouse that was placed underneath the AGV. The Line-Tracking Mouse comprised of 3 light sensors placed in a straight line parallel to the axel of the Mouse. Black insulation tape was adhered to the white floor of the manufacturing environment in the form of the desired path that the AGV would follow. The software was designed such that the AGV would adjust to maintain its position on the black line such that the light sensor in the middle would be on the line and the outer 2 would be on either side of the line. For example, if the AGV moved too far left, then the right light sensor would go high and the control program would force the AGV to move to the right until the right light sensor went low.

The program also contained a section for DC motor control of the AGV. There are two DC motors on the AGV. One is used to turn the rollers in either direction. The other is used to

move the slider weight to the back, middle or front of the AGV. A slider weight in the front position would cause forward motion of the AGV. A signal was sent from the program to control the slider weight direction.

The program was designed to control the following sequence of events. The AGV was called into action to alleviate a bottleneck (build up of parts) in section 2. The AGV docked (if it was not docked initially) with the conveyor. The limit switch on the docking mechanism of the AGV closed and sent a signal to the program. The program, in turn, sent a signal to move the slider weight to the middle position such that the AGV stopped accelerating forward. Simultaneously, a signal was sent to the roller motor to start the rollers in the backward direction. The conveyor and manufacturing systems were also aware of the dock due to the limit switch in the conveyor docking structure. The control program sent a signal to the transfer system to transfer the part off the conveyor and onto the AGV. The part was rolled backwards on the roller system until it struck one of four roller limit switches that were connected in series. A closed roller limit switch indicated that the part was definitely on board the AGV. The control program sent a signal to move the slider weight to the back of the AGV such that the AGV reversed and in so doing, undocked. The limit switch behind the docking mechanism that was previously closed now opened which indicated that the AGV had undocked. A signal was sent up move the slider weight to the neutral position so that the AGV was stationary. The AGV then switched off its navigational light sensors for a split second and performed 180 degree turn. When the line was seen again, the AGV lined up and a signal was sent to the slider weight to move forward. The AGV moved forward, continuously adjusting to follow the black tape path.

The AGV finally docked with conveyor at section 2. The docking limit was closed and this time the rollers turned in the forward direction. The part was rolled out onto section 4 of the now moving conveyor. The part was transferred from section 4 to section 6 where the RMS transfer system transported it to the RMS.

### 6.5 The Transfer System

A pneumatic cylinder and solenoid valve were purchased and fixed onto the conveyor to transfer the part from section 2 to the AGV. The valve was activated by a 12 volt power source. A 12 volt relay circuit was used to open and close the valve. When the valve opened, compressed air caused the cylinder to actuate and push the part off the conveyor and onto the AGV. When the relay removed power from the valve, it closed and the cylinder retracted. A signal was sent from the control program via the wireless DAQ to switch the relay between open and closed states. The specifications for the cylinder and the valve appear in **Appendix H**.



Figure 6-31 Transfer system pushing a part onto AGV

## **Chapter 7: Testing, Performance and Improvements of the AGV**

### **7.1 AGV Docking Test**

The AGV was tested to investigate its response to docking with the conveyor. The docking structures were placed under the conveyor at section 2 and 4. A limit switch was situated behind the AGV's docking mechanism. When the AGV docked with the conveyor its spring loaded docking mechanism was pushed back onto the limit switch. The limit switch was closed and a signal was sent to the control software that, in turn, stopped the AGV by moving its slider weight to the neutral position. The system response was satisfactory and the end result was that the AGV did, in fact, stop when docked. The test would have failed if the AGV had crashed through the docking structure.



Figure 7-1 AGV about to dock with docking structure.



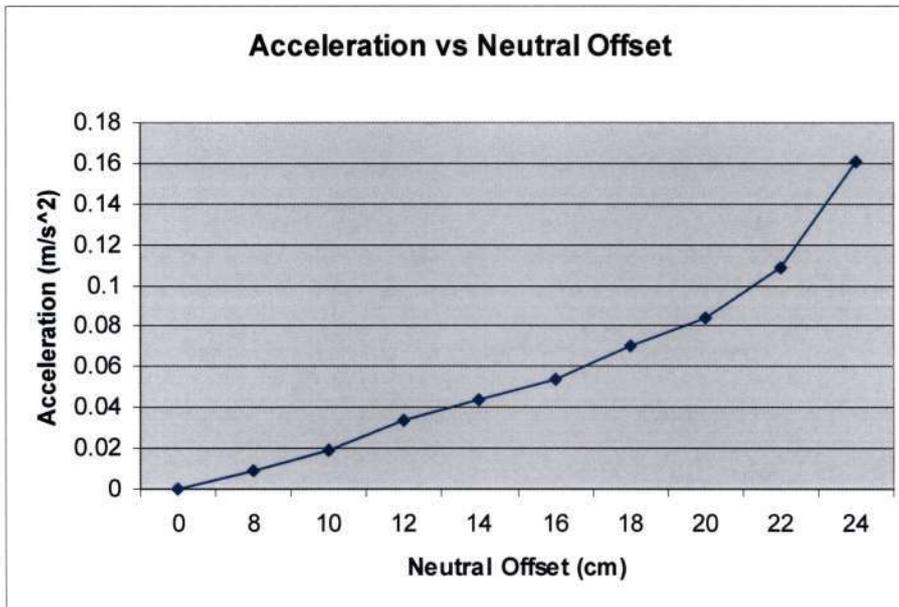
Figure 7-2 The AGV docks with the docking structure

## 7.2 Speed versus Slider Position

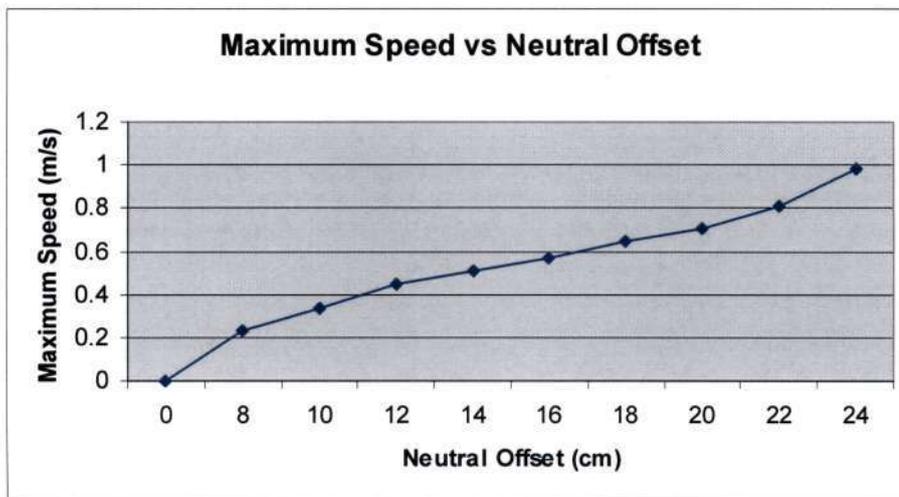
The position of the slider weight of the AGV determined whether or not it would move forward, backward or stop moving. Due to the dynamic stabilisation of the Segway HT, when the AGV experienced a net weight in the forward direction, it tilted forward and then accelerated in the forward direction. The tilt sensors were aware of the unbalanced AGV and hence move the wheels forward so as to regain the balance to the system. The neutral position is the slider weight position where the AGV does not move because it is already balanced. The neutral offset is any distance from the neutral position. A neutral offset that was greater than seven centimetres resulted in an acceleration of the AGV. The AGV was held at rest with the neutral offset at 0. The offset was then increased, in two centimetre intervals, and the AGV was allowed to travel a distance of three metres. The time taken for the AGV to traverse three metres was recorded and used to generate the speed and acceleration of the AGV at the end of three metres. Table 7-1 is a table of corresponding speeds and accelerations for a different neutral offsets. Graphs were generated to develop a relationship between velocity and neutral offset.

Table 7-1 Quantities obtained from the AGV as a function of slider weight position

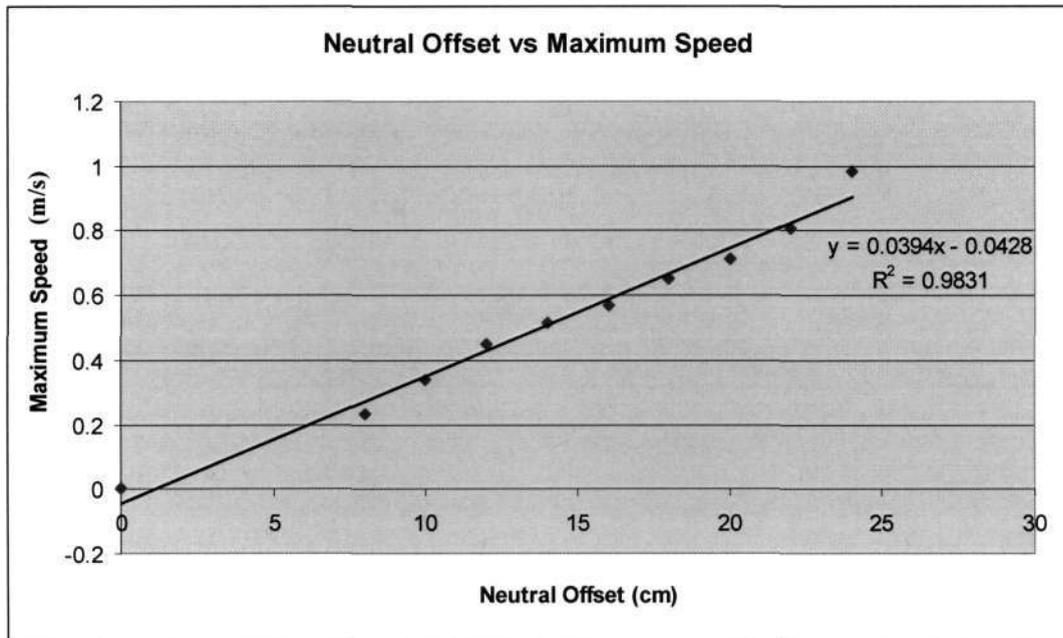
Neutral Offset (cm)	Time (seconds)	Acceleration ( $m/s^2$ )	Maximum Speed (m/s)
0	0	0	0
8	25.92	0.008930613	0.231481481
10	17.81	0.018915743	0.336889388
12	13.33	0.033766881	0.450112528
14	11.71	0.043755985	0.512382579
16	10.59	0.053500683	0.566572238
18	9.21	0.070734614	0.651465798
20	8.45	0.084030671	0.710059172
22	7.43	0.108686004	0.807537012
24	6.11	0.160719595	0.981996727



Graph 7-1 Neutral Offset versus Acceleration of AGV



Graph 7-2 Neutral Offset versus Maximum Speed of AGV



Graph 7-3 Trend line illustrating relationship between Neutral Offset and Maximum Speed

The gradient of the Graph 3 is  $0.0394 \frac{m/s}{cm}$ . The line follows the straight line relationship

of  $y = mx + c$ .

If  $c$  is taken to be 0 then the relationship is:

$$\text{Maximum Speed} = 0.0394 * (\text{Neutral Offset}).$$

Therefore to calculate any speed, all that is required is the offset distance of the slider weight from the neutral position.

### 7.3 Line Following Capability

The light sensors underneath the AGV output a five volt signal when a dark colour is seen and zero volts when a light colour is seen. These voltages are approximate. The AGV was able to follow a black strip of tape in a path leading it from section 2 to section 4 on the conveyor.

The servo originally turned to either 0, 90 or 180 degrees. The angle for the neutral position was 90 degrees. These angles generated sharp turning response of the AGV and the line was easily lost. This occurred on every run. The servo angle was modified to turn to 25, 70 and 165. The servo was neutral at 70 degrees. The AGV did not exhibit excessively sharp turns after the modification and was able to successfully follow the path from section 2 to section 4.



Figure 7-3 AGV following a dark line

#### 7.4 AGV Efficiency Test

The AGV was constructed to minimise the bottleneck problem at section 2 to make the rate of production more efficient. The experiment was performed in the same way as the first time test. Part A was released. The part B was released and more parts were randomly released thereafter. Part A travelled to the existing AGV docking point at which time section 3 was stopped. Again, Part B could not follow into section 3 from section 2 because section 3 was not moving. At this point the control program initiated a sub-program to enable the additional AGV that docked in section 2. When the AGV docked, the transfer system shifted part B onto it. The AGV transported the part using an indirect route to section 4. The AGV docked with section 4 and transferred the part across onto the conveyor. Part B continued its journey to section 6 via the conveyor. The times taken for this journey appear in table 7-2.

Table 7-2: Times recorded for stages of journey for Part B

Stages of Journey for Part B	Time taken (seconds)
Section 1	5.5
Section 2	5.5
Delay: Wait for AGV to clear section 3	9.7
Mobile robot indirect routing	22
Section 4	5.5
Section 5	5.5
Section 6	5.5

The time taken for part B to complete its journey from the AS/RS to the RMS was 59.2 seconds. When compared to the time taken without the incorporation of the AGV, the efficiency has increased by 22.9%. The efficiency of the system that incorporated the AGV was 74.2%. This calculation is shown below.

$$\frac{43.9}{59.2} \times 100\% = 74.2\% \dots\dots\dots \text{Efficiency calculation}$$

## **Chapter 8: Discussion**

The materials handling system was able to self adjust to the extent that the responsiveness of the manufacturing system was such that mass customisation was possible. Mass customisation is only feasible if the production rate remains unhindered. The routing of parts needed to be revised such that parts followed the most efficient path. The reconfigurable materials handling system was essentially divided into three sections. These sections are part tracking, routing and scheduling.

Part tracking is the ability to locate parts at any stage of their production. The part tracking technique employed was Radio Frequency Identification (RFID). Radio Frequency (RF) tags were adhered to the pallets. RF readers were placed at sections of the conveyor where parts entered and exited. The RF readers read the tags on the pallets and conveyed the information serially to the RFID database via RS-232. The control program was written to schedule the path of production for three different parts A, B and C. Part A was scheduled to go to the Docking Station. Part B was scheduled to go to the Reconfigurable Manufacturing System (RMS). Part C was scheduled to go to both the Docking Station and the RMS. The RF readers were placed at the AGV docking point on the conveyor section 3 and at RMS on the conveyor section 6. If part A is read in section 3 then the AGV transports the part to the docking station. If part B is read in section 3 then the conveyor continues and the part is transferred to section 6. Part C is transferred via the AGV to the Docking Station. After some time has passed the AGV picks up the part from the Docking station and reintroduces it back onto the conveyor in section 3. The conveyor transports part C to section 6 where it is read again. Having been identified as a part that is scheduled for the RMS, the control program stopped the conveyor part C was transferred across. Another aspect of the tracking system was the laser sensors that were used to sense the presence of an obstacle between an emitter and receiver pair. The part was stopped, either in section 3 or section 6 at the transfer locations. This caused the laser sensors, which were also placed at those locations to be obstructed. This indicated that a pallet was at that location. The laser sensors provided a means for the control program to ascertain that the part had left the conveyor so that it could start moving again. When the part was transferred off the conveyor, the laser beam was remade and this then meant that the conveyor no longer had a part waiting at that location. The information stored in the RFID database was tag and reader ID numbers as well as the date and time of the read event. This information was extracted from the database and used in a control program. The database information was also useful in keeping a record of a part's history.

The one difficulty of the system was that when a part was waiting to be picked up off the conveyor in section 3, all the parts in section 2 had to wait for the path to become clear. The delay was unacceptable as it consisted almost half the time of the entire transfer. The customisation process is only feasible if the rate of product remains unchanged. In light of this a number of concepts were generated to overcome this problem. All of the concepts involved a method of transporting the obstructed part around section 3 and directly onto section 4. The main concept proved to be the most flexible and was selected for this reason. The concept entailed the construction of an additional AGV that would transport parts from section 2 directly to section 4. The mobile robot was constructed on the platform of a human transporter known as the Segway HT.

The Segway HT is a two wheel differentially steered transport machine. It was selected for its agility and speed. The Segway was dismantled and the base was used as the platform for the mobile robot. A mechanical structure was design and implemented onto the Segway HT's base. The structure consisted of a base plate, set of rollers that were built into a roller housing. The housing rested on base plate. The rollers were interconnected via rubber O-rings. The drive roller was connected to a drill motor via an O-ring as well. The Segway balances by dynamic stabilisation, that is, it senses its own tilt and moves forward or backward automatically to regain its balance. This concept was adapter to move the AGV back and forward. A slider assembly that consisted of a rack, pinion and 1.5 kilogram weight was assembled under the roller housing. The 1, 5 kilogram weight was bolted to the saddle of a linear way. The linear way was bolted to the underside of the roller housing. The pinion was keyed into the shaft of the drill motor. The rack was fastened to the weight such that when the motor turned the pinion actuated the rack and the weight was slid either backwards or forwards. An experiment was performed to ascertain if a relationship existed between slider weight position and the overall speed of the AGV for a given distance. The slider weight, when moved to the front of the AGV caused a cantilevered loading that caused the AGV to tilt forward. As a result the AGV accelerated forward to regain balance. The relationship found between slider position and the speed of the AGV over a three metre distance was found to be linear. This could be used in the future to model higher speeds.

The AGV utilised a wireless data acquisition interface card to send and receive signals wirelessly from the control program that ran on a P.C. The wireless DAQ was connected to motors and limit switches on the AGV. The limit switches sensed whether or not the AGV had docked/undocked from the conveyor, if a part was on board and the slider weight position.

The AGV followed a dark lined path on a light coloured surface. This was achieved by using light sensors sensitive to light colours. The turning of the AGV was controlled with a servo. The servo turned to maintain its path on the line based on inputs received from the light sensors. Initially the servo turned through very large angles and as a result the AGV turned excessively often losing the line. This was overcome by re-calibrating the servo to turn through smaller angles causing the AGV to turn less sharply until it was capable of following the line.

The docking mechanism in the front of the AGV was spring loaded and designed to push in when an external force caused the springs to compress. A limit switch was mounted behind the docking mechanism. The limit switch was closed when the docking mechanism was pushed in. The control program was written such that the AGV would stop if it docked or impacted on another obstacle. This was successfully demonstrated when it was guided into a conveyor docking structure and stopped after the limit switch was closed.

The performance of the AGV indicates that the Segway HT was a good selection for a platform. It is fast and able to manoeuvre through cluttered environments. Furthermore the AGV improved the time of the delay caused by a bottleneck in section 2. This alone proves that it is an efficient addition to materials handling system. The AGV could be used in many other areas of the manufacturing environment in the future.

The Reconfigurable Materials Handling System is feasible in that it is able to successfully track, route and schedule parts throughout the manufacturing environment.

The possible future work for the manufacturing environment may be to design and implement a Palletiser / depalletiser system that places and removes parts from pallets. Active RF tags are able to store data onboard. These tags could work as portable databases that are able to store the history of their production. These tags can even work independently as a subsystem. The performance of the system could also be measured against known benchmarks in the future.

## **Chapter 9: Conclusion**

In order to achieve the production of custom products on a large scale in a manufacturing environment, a reconfigurable manufacturing system required continuous adjustment. This autonomous adjustment was found to be integral to the process of mass customisation.

By applying a Mechatronic approach, that is, by integrating mechanical, electrical and software engineering principles, the concept of a Reconfigurable Materials Handling System was developed and constructed.

The implementation of the Reconfigurable Materials Handling System required the formulation of a part tracking, scheduling and routing system as well as the mechanical, electronic and software implementation required to construct it. Part-tracking was achieved by the application of a Radio Frequency Identification (RFID) system. Part routing was achieved by interrogating the tracking database by the manufacturing control system with the result that parts were routed to the appropriate locations. The scheduling system for various manufacturing configurations was successfully programmed into the control system.

The development of the AGV was an integral component of the materials handling system in that it minimised bottlenecks and so increased the efficiency of the overall production rate. The AGV was found to be an essential component of the materials handling system.

### **References**

1. Kulwie, R., (2003), 'The Essentials of Materials Handling: Considerations for Planning and Implementing Integrated Material Handling Systems', An ISC/MHIA Publication, pp 1-10.
2. Bolton, W.,(2003), 'Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering, 3<sup>rd</sup> Edition' England, Pearson Education Ltd, pp 32.
3. <http://www.msu.edu/~luckie/segway/i167/i167.html>
4. <http://www.segway.co.za/humanhowitworks.asp>
5. [http://en.wikipedia.org/wiki/Reconfigurable\\_manufacturing\\_system](http://en.wikipedia.org/wiki/Reconfigurable_manufacturing_system)
6. <http://www.advancedmanufacturing.com/December03/colExploring.htm>
7. Davis, S., (1987), 'Future Perfect', Addison-Wesley, Reading, MA, pp.1-15.
8. Zipkin, P., (2001), "The Limits of Mass Customisation", MIT Sloan Management Review, Vol. 42, no.3, pp. 81-87.
9. Skjelstad, L., Hagen, I., Alfnes, E., (2001), 'Guidelines for Achieving a Proper Mass Customisation System' SINTEF Technology and Society, Economics and Logistics pp. 1556.
10. Hart, C., (1995), 'Mass Customisation: Conceptual Underpinnings, Opportunities and Limits', International Journal of Service Industry Management, Vol. 6, no.2, pp. 36-45.
11. Department of Industry, Committee for Materials Handling, (1978), 'Materials Handling: An Introduction', London, Crown Copyright, pp 1-25.
12. Hulett, F M., (1970), 'Unit Load Handling', London, Gower Press, pp 5-35.
13. [http://epsfiles.intermec.com/eps\\_files/eps\\_wp/PartsTraceProdGenology\\_wp\\_web.pdf](http://epsfiles.intermec.com/eps_files/eps_wp/PartsTraceProdGenology_wp_web.pdf)

14. <http://www.abetech.com/pdfs/AbeTech%20-%20RFID%20RPC.pdf>
15. Finkenzerler, K., (2004), 'RFID Handbook: Fundamentals and Applications in Smart Cards and Identification. Second Edition' England, John Wiley and Sons, pp. 2-36.
16. Karkkainen, M and Holmstrom, J., (2002), 'Wireless product identification: enabler for handling efficiency, customisation and information sharing', Supply Chain Management: An International Journal, Vol. 7, No. 4, pp. 242-252.
17. [http://epsfiles.intermec.com/eps\\_files/eps\\_wp/PracticalRFID\\_wp\\_web.pdf](http://epsfiles.intermec.com/eps_files/eps_wp/PracticalRFID_wp_web.pdf)
18. [http://epsfiles.intermec.com/eps\\_files/eps\\_wp/beyondthetag\\_wp\\_web.pdf](http://epsfiles.intermec.com/eps_files/eps_wp/beyondthetag_wp_web.pdf)
19. [http://epsfiles.intermec.com/eps\\_files/eps\\_wp/RFIDread\\_write\\_wp\\_web.pdf](http://epsfiles.intermec.com/eps_files/eps_wp/RFIDread_write_wp_web.pdf)
20. <http://www.mobilewhack.com/images/segway.jpg>
21. <http://www.imagesco.com/catalog/motors/HS-422.html>
22. [http://www.hitechtools.com/news/produit/carte\\_acquisition/Wireless/BT-120A\\_fichiers/image001.jpg](http://www.hitechtools.com/news/produit/carte_acquisition/Wireless/BT-120A_fichiers/image001.jpg)
23. Diegel O., Bright G., Potgieter J., (2005), 'Bluetooth ubiquitous networks: seamlessly integrating humans and machines', Assembly Automation, volume 24, no. 2, pp. 168-176.
24. <http://www.acroname.com>
25. <http://home.pacbell.net/cetta/workingwithdatabases.html>
26. <http://www.impro.net>
27. <http://www.arngren.net/Segway-assembly.untitled.gif>
28. <http://www.araa.asn.au/acra/acra2004/papers/jarvis.pdf>

## **Appendix A**

### Radio Frequency Hardware

Section 1 – System Overview

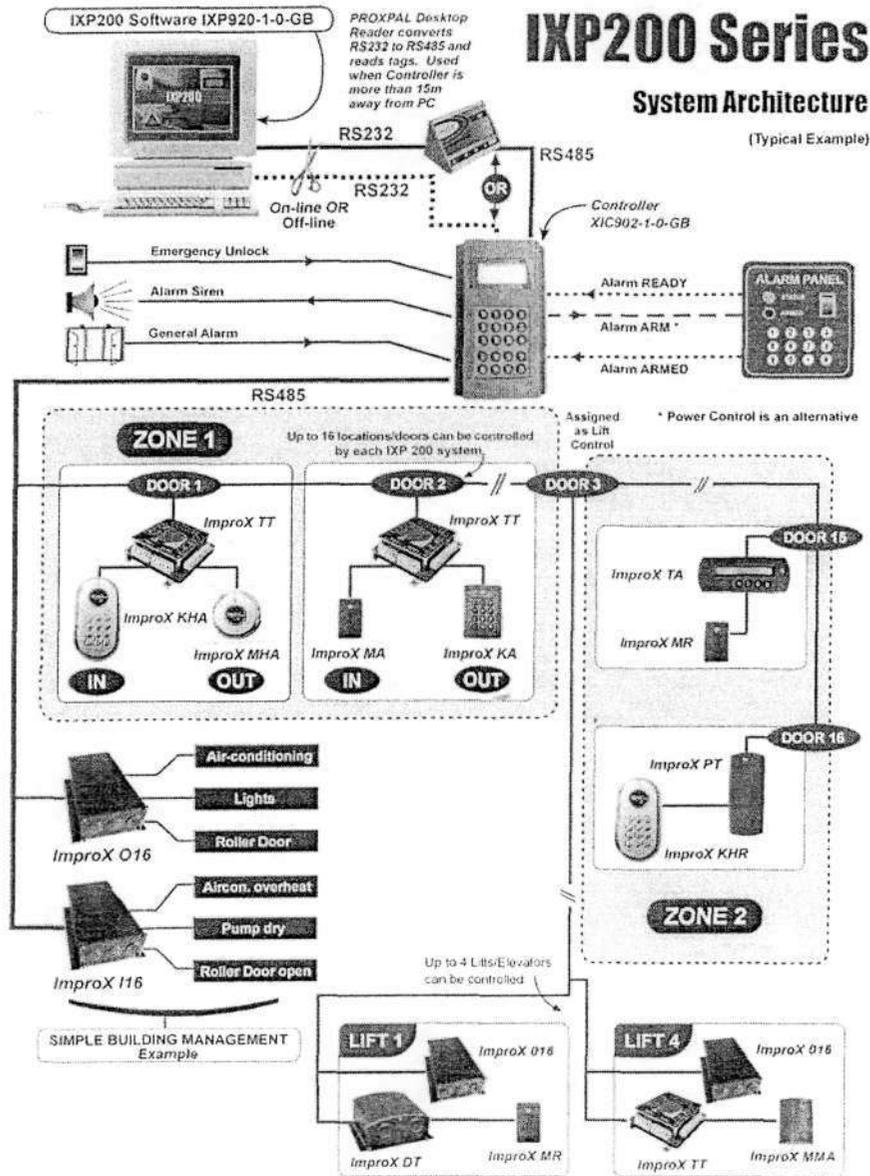


Figure 1 : Block diagram of a typical IXP200 System



impro<sup>®</sup>

MODEL NUMBER: XIC902-1-0-GB-XX

# IXP200 CONTROLLER

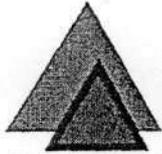
## IXP200 LCD Keypad Controller INSTALLATION MANUAL

### SPECIFICATIONS

<b>Working Environment</b>	:	Designed to work in an indoor (dry) environment similar to IP40. The Controller is, therefore, NOT sealed against water.
<b>Input Voltage</b>	:	10 V DC to 30 V DC.
<b>Power Requirements</b>		<b>Current (mA)</b> <b>Power (W)</b>
Supply Voltage 10 V DC Relays all OFF	:	175                                      1.75
Supply Voltage 10 V DC Relays all ON	:	270                                      2.70
Supply Voltage 30 V DC Relays all OFF	:	65                                        1.95
Supply Voltage 30 V DC Relays all ON	:	90                                        2.70
<b>Relays</b>		
Relay Output	:	2 x Relays, each with NO, COM and NC contacts.
Relay Contact Ratings	:	10 A at 28 V DC, 5 A at 220 V AC.
<b>Digital Inputs</b>		
Type	:	4 x Dry-contact inputs.
Protection Range	:	+15 V and -15 V continuous.
<b>Memory</b>		
RAM (Non-volatile)	:	512 KBytes.
Flash ROM	:	128 KBytes.
Battery Backup (for RAM)		
Battery Type	:	1 x 3.6 V, size 1/2 AA.
Battery Life	:	5 Years (with power OFF).

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impro<sup>®</sup>

MODEL NUMBER: XTT901-1-0-GB-XX

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# IMPROX MMA

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## ImproX (MMA) Mullion Antenna Reader INSTALLATION MANUAL

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### SPECIFICATIONS

<b>Working Environment</b>	:	Designed to work in an indoor or outdoor environment similar to IP66. The ImproX MMA is, therefore, sealed (potted) against water.
<b>Buzzer</b>	:	
Volume and Tone	:	No Buzzer.
<b>Status Indicators</b>	:	
Status LED	:	Bi-coloured Red or Green.

### INSTALLATION INFORMATION

#### Accessories

Find the following when unpacking the Antenna Reader:

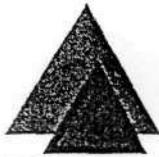
- An ImproX MMA Antenna Reader housed in a Dark Grey, ABS Plastic housing. The ImproX MMA consists of a Front Cover and a Backing Plate. The Front Cover (including the potted electronic components) assembly includes 8 m (26 ft) of 4-core, 0.5 mm solid strand Communications Cable.
- Four countersunk, Brass Wood Screws (3.5 mm x 25 mm).
- Four Wall Plugs (7 mm).
- An extra Serial Number Label.

#### General

Remember the following when installing the Antenna Reader:

#### Maximum Data Communications Distance

The ideal cable distance between the ImproX TT or IXP121 Controller and its Antenna Reader ranges between 2 m to 16 m (7 ft to 53 ft). Achieve this by using a good quality shielded multi-strand 3-pair twisted cable. The cross-sectional area of the cable must not be less than 0.2 mm<sup>2</sup> (0.0003 in<sup>2</sup>).



impro®

MODEL NUMBER: XTT900-1-0-GB-XX  
XTT910-1-0-GB-XX  
XTT911-0-0-NN-XX

# IMPROX TT

## ImproX (TT) Twin Antenna Terminal INSTALLATION MANUAL

### SPECIFICATIONS

<b>Read/Write Capability</b>	:	Impro Tags: Slim Tags (Read Only), Omega Tags (Read Only), WriTag 128 (Read/Write), and WriTag 2048 (Read/Write). Third-party Tags (selected): (Read Only).
<b>Working Environment</b>	:	
XTT900-1-0-GB-XX (Open Frame Construction)	:	Designed to work in an indoor (dry) environment. The Terminal is not sealed against water.
XTT910-1-0-GB-XX (Aluminium Extruded Cabinet)	:	Designed to work in an indoor (dry) environment, similar to IP40. The Terminal is not sealed against water.
<b>Input Voltage</b>	:	10 V DC to 30 V DC, polarity sensitive.
<b>Power Requirements</b>		
Input Voltage 10 V DC	:	<b>Current (mA)</b> <b>Power (W)</b> 180                                      1.8
Input Voltage 30 V DC	:	60                                        1.8
<b>Relays</b>	:	
Relay Output	:	2 Relays, each with NO, COM and NC contacts.
Relay Contact Ratings	:	3 A at 24 V DC or 125 V AC. 1.5 A at 220 V AC.
<b>Digital Inputs</b>	:	
Type	:	4 Dry-contact inputs.
Protection Range	:	+50 V to -50 V continuous, +80 V to -80 V surge.

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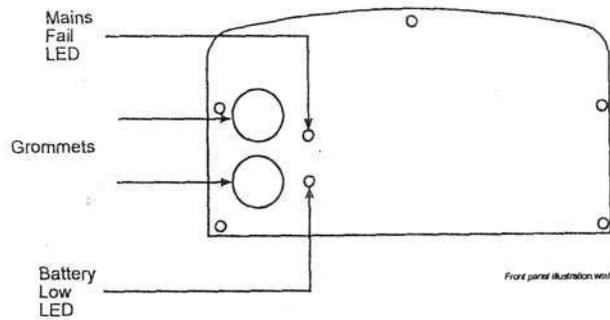


Figure 1 : Front panel illustration

### PHYSICAL SPECIFICATIONS

<b>DIMENSIONS</b>	:	L=171 mm (6.7 in). W=197 mm (7.7 in). H=88 mm (3.5 in).
<b>WEIGHT</b>	:	1.7 Kg (3.75 lb) (excluding battery).
<b>HOUSING MATERIAL</b>	:	Aluminium.
<b>COLOUR</b>	:	Black.

### ENVIRONMENTAL SPECIFICATIONS

<b>TEMPERATURE</b>	
• <b>Operating</b>	: -25°C to +60°C (-13°F to +140°F).
• <b>Storage</b>	: -40°C to +80°C (-40°F to +176°F).
<b>HUMIDITY RANGE</b>	: 0 to 95% relative humidity at +40°C (+104°F) non-condensing.
<b>EMC</b>	: EN 55022.
<b>EMC</b>	: EN 55024.
<b>ELECTROSTATIC DISCHARGE</b>	: EN6 1000-4-2.
<b>ELECTRICAL FAST TRANSIENTS</b>	: EN6 1000-4-4.
<b>SURGE IMMUNITY</b>	: EN6 1000-4-5.
<b>VOLTAGE DIPS AND INTERRUPTIONS</b>	: EN6 1000-4-11.
<b>RADIATED SUSCEPTIBILITY</b>	: EN6 1000-4-3.

<b>CONDUCTED SUSCEPTIBILITY</b>	:	EN6 1000-4-6.
<b>DUST AND SPLASH RESISTANCE</b>	:	This unit is manufactured in accordance with a dust and splash environment similar to that of IP 40.
<b>DROP ENDURANCE</b>	:	1 m (3.28 ft) drop (in packaging).

### ELECTRICAL SPECIFICATIONS

#### INPUT

<b>Input Voltage</b>	:	115 V AC or 230 V AC ± 5%. 50/60 Hz.
<b>Mains Input Fuse</b>	:	0.25 A 250 V (fuse mounted under the mains protection cover of the UPS).
<b>Mains Input Power Cord</b>	:	15 A, 3-core power cable. Brown – Live. Green – Earth. Blue – Neutral.

#### UNSWITCHED OUTPUTS

<b>Output Voltage</b>	:	Maximum 13,7 V DC +2%/-5% (fully charged battery).
<b>Output Current</b>	:	2 A surge or 1 A continuous (with fully charged battery).
<b>Output Fuses</b>	:	2 A 250V slow-blow (mounted below terminal blocks).
<b>Ripple Voltage</b>	:	< 1 Vpp at 50 Hz.

#### SWITCHED OUTPUTS

<b>Output Voltage</b>	:	Maximum 13.7 V DC +2%/-5% (fully charged battery).
<b>Output Current</b>	:	2 A surge or 1 A continuous (with fully charged battery).
<b>Output Fuse</b>	:	2 A 250 V slow-blow (mounted below terminal blocks).
<b>Ripple Voltage</b>	:	< 1 Vpp at 50 Hz.

**NOTE :** The total continuous output current on the switched, unswitched and battery charging outputs must not exceed 1.25 A.

#### BATTERY

<b>Type</b>	:	The enclosure accepts a 12 V 6.5 Ah Lead Acid Battery.
-------------	---	--

## **Appendix B**

### Automated Guided Vehicle Specifications

### Rider Detection

The Segway HT Platform contains four Rider Detect sensors (beneath the Mat), which detect the presence or absence of a rider while the Segway HT is powered on. When a rider (weighing 100 lbs. / 45 kg or more) is aboard with feet properly positioned on the Platform, these Rider Detect sensors are depressed, and allow the Segway HT to operate normally in Balance Mode. If fewer than three Rider Detect sensors are depressed while riding, the Segway HT will reduce the top speed limit while moving forward, regardless of the Key used.

If the Segway HT is in Balance Mode, but none of the Rider Detect sensors are depressed, and the Segway HT is moved too quickly, the Segway HT will give the Stick Shake Warning after moving some distance, and will switch to Power Assist Mode. This is intended to prevent a riderless Segway HT from traveling on its own. You should never let go of your Segway HT while it is in Balance Mode.

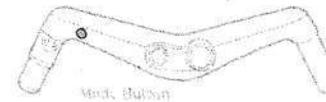
#### WARNING!

You should never place anything on the Platform. Doing so could defeat this safety feature and allow the Segway HT to travel on its own, and run into a person or property and cause injury or damage.

### Mode Button

There is only one button on the Segway HT Handlebar. It is called the Mode Button and has three distinct functions:

1. Change from Power Assist Mode to Balance Mode.
2. Change from Balance Mode to Power Assist Mode.
3. Power off from either Power Assist Mode or Balance Mode.



See the Riders' Guide for more information regarding the Mode Button.

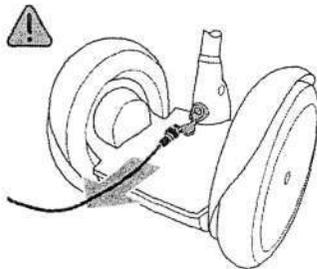


When you are riding the Segway HT, the Mode Button is disabled. This is to prevent accidentally powering off or accidentally switching to Power Assist Mode while riding.

## chapter 3: batteries

### Safety Guidelines

Your Segway HT is powered by two rechargeable Battery Packs. Take some time to read these guidelines for your own safety and to extend the life of the Battery Packs.



**WARNING!**  
Unplug and disconnect your Segway HT from AC power before removing or installing Battery Packs. It is hazardous to work on any part of your Segway HT when it is plugged into AC power. You risk serious bodily injury from electric shock as well as damage to your Segway HT.

The cells within the Battery Packs contain toxic substances. Do not attempt to open Battery Packs. Do not insert any object into the Battery Packs or use any device to pry at the Battery Pack casing. If you insert an object into any of the Battery Packs' ports or openings you could suffer electric shock, injury, burns, or cause a fire. Attempting to open the Battery Pack casing will damage the casing and could release toxic and harmful substances.

Use care when handling the Battery Packs. If you are transporting your Segway HT, be sure to protect the Battery Packs to avoid damage during shipment. If the casing of a Battery Pack should

break open, leak any substance, become excessively hot, or if you detect an unusual odor, do not use the Battery Pack. Do not handle a damaged or leaking Battery Pack unless you are wearing disposable rubber gloves. Dispose of the rubber gloves and damaged Battery Pack properly in accordance with regulations governing disposal of toxic materials.

Keep Battery Packs out of reach of children and pets. Ingesting toxic substances and exposure to battery voltage could result in death or serious injury.

### Charging

To maximize battery life and performance, follow this procedure to charge your new Segway HT Battery Packs before the first use and after the first five uses:

1. As soon as possible and before your first use, charge the Battery Packs for at least 12 hours. Charging is best performed at room temperature.

## chapter 5: service

### General Information

Segway Customer Operations can answer your questions about your Segway HT via the web, email, or phone. If you have a question on parts or replacements, please contact us using the information below:

#### Hours of Support Operation

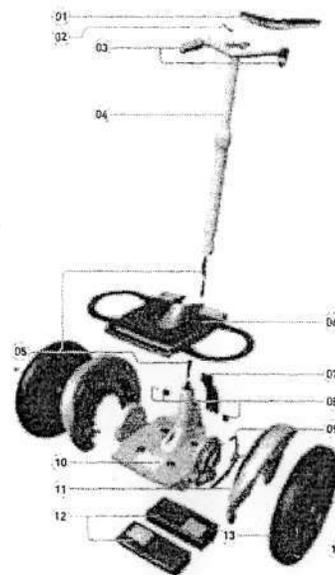
8:00 am - 8:00 pm Eastern Time

Monday - Friday (except Segway observed holidays)

Phone: 1-866-4SEGWAY (1-866-473-4929)

Fax: (603) 222-6001

Email: [technicalsupport@segway.com](mailto:technicalsupport@segway.com)



i Series shown

### Parts Diagram

1. Handlebar Trim
2. Key
3. Grips
4. Handlebar/Control Shaft Assembly
5. Control Shaft Cords
6. Mat
7. Front Trim
8. Control Shaft Clamp Bolt and Clamps (2)
9. Parking Stand (i Series models only)
10. Platform with Control Shaft Base and Gearboxes
11. Fender
12. Battery Packs
13. Tire/Wheel Assembly
14. Wheel Nut



## **Appendix C**

Servo Specifications

D.C Motor Specifications

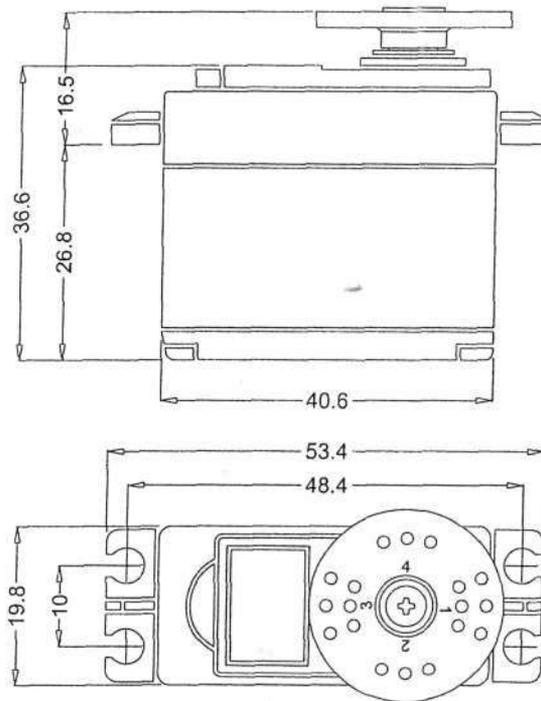
Relay Card Wiring Diagram

MicroDAQ specifications

# ANNOUNCED SPECIFICATION OF HS-422 STANDARD DELUXE SERVO

## 1. TECHNICAL VALUES

CONTROL SYSTEM	: +PULSE WIDTH CONTROL 1500usec NEUTRAL	
OPERATING VOLTAGE RANGE	: 4.8V TO 6.0V	
OPERATING TEMPERATURE RANGE	: -20 TO +60°C	
TEST VOLTAGE	: AT 4.8V	AT 6.0V
OPERATING SPEED	: 0.21sec/60° AT NO LOAD	0.16sec/60° AT NO LOAD
STALL TORQUE	: 3.3kg.cm(45.82oz.in)	4,1kg.cm(56.93oz.in)
OPERATING ANGLE	: 45° ONE SIDE PULSE TRAVELING 400usec	
DIRECTION	: CLOCK WISE/PULSE TRAVELING 1500 TO 1900usec	
CURRENT DRAIN	: 8mA/IDLE AND 150mA/NO LOAD RUNNING	
DEAD BAND WIDTH	: 8usec	
CONNECTOR WIRE LENGTH	: 300mm(11.81in)	
DIMENSIONS	: 40.6x19.8x36.6mm(1.59x0.77x1.44in)	
WEIGHT	: 45.5g(1.6oz)	



## 2. FEATURES

- 3-POLE FERRITE MOTOR
- LONG LIFE POTENTIOMETER
- DUAL OILITE BUSHING
- INDIRECT POTENTIOMETER DRIVE

## 3. APPLICATIONS

- AIRCRAFT 20-60 SIZE
- 30 SIZE HELICOPTERS
- STEERING AND THROTTLE SERVO FOR CARS
- TRUCK AND BOATS

# RYOBI.

## OWNER'S OPERATING MANUAL 12V CORDLESS DRILL MODEL HCD12VR

### SPECIFICATIONS:

Power .....	12 Volt DC
No Load Speed .....	0 - 550r/min
Drill Chuck.....	10 mm keyless
Drilling Capacity	
Wood.....	13 mm
Steel .....	10 mm
Clutch Settings .....	16
Weight .....	1.5 kg
Battery Charger.....	3-5hour



### THANK YOU FOR BUYING A RYOBI CORDLESS DRILL

Your new Drill has been engineered and manufactured to Ryobi's high standard for dependability, ease of operation, and operator safety. Properly cared for, it will give you years of rugged, trouble free performance.



**CAUTION: Carefully read through this entire owner's manual before using your Drill.**

Pay close attention to the Rules for Safe Operation, Warnings, and Cautions.

If you use your Drill properly and only for what it is intended, you will enjoy years of safe, reliable service.

Thank you again for buying Ryobi tools.

**SAVE THIS MANUAL FOR FUTURE REFERENCE.**

5A FUSE

RELAY02

4120-C-S

A K

\*\*

BATT+

MOTOR

MOTOR

BATT-

4K7

337

\*\*

+12

DIR

R1

R2

0V

4K7

4120-C-S

A K

NC

NO

COM

337

\*\*

4K7

4120-C-S

A

NC

NO

COM

4K7

337

4K7

4K7

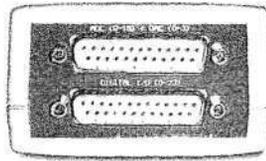
4120-C-S

A K

# USB-26/30

USB 250/400KHz 14 Bit A/D Unit with 4x D/A  
& 24DIO

Ideal for Desktop/Laptop use



USB-30 Front



USB-30 Back



## DESCRIPTION

The MicroDAQ USB-26/30 is a multi function data acquisition device for the USB bus. The unit has a 14-bit resolution and is the perfect measurement device for portable, laboratory or classroom use.

The MicroDAQ USB-26/30 has two interface options and sample speeds. The A variant is a USB 1.1 device with a sampling rate of 250kHz. The B variant is one of our first data acquisition products featuring the high speed USB 2.0 interface. The 480Mbps bandwidth which USB 2.0 offers allows this unit to have an analog sampling rate of 400kHz across the analog input channels\*. This speed is unprecedented in external USB data acquisition products.

Featuring 16 or 32\*\* analog inputs, the unit can be used to measure voltage signals from sensors, transducers, accelerometers and much more. It also features four analog outputs (USB-30 model) which can be used as reference voltages and many other applications. The digital I/O is available in 3 sets of 8 channels which can be programmed as inputs or outputs.

## FEATURES

- USB Interface
- 16 / 32 Single Ended or 8/16 Differential Analog Input Channels
- 250kHz / 400kHz (model dependent) Total Sampling speed across 16 channels\*\*
- 4 x 14-bit Analog Outputs (USB-30 Model)
- Onboard 16K FIFO
- 4x Analog Outputs (14-bit)
- 24x DIO lines (3x 8-bit ports)
- I/O Connector: 2x DB25 Male (1 for A/D & 1 for DIO)
- LED indication for power & USB connection
- Ideal for Portable/Laptop Use
- Housing: Plastic ABS with rubber feet
- Operating Temp: 0 to 70°C
- O/S Support for Windows 98/ME/XP/2000 & Linux
- Includes EDRE SDK, EDRE-Labview, EDRE-Testpoint and WaveView for Windows
- Power: Supplied with a 1A 9VDC external PSU
- Power Consumption: 500mA typ @ 9VDC
- Dimensions: 45(H) x 80(W) x 148(L) mm

## Specifications

### Analog Inputs (A/D)

#### Input Characteristics

Input Channels:	16 / 32** Single Ended (Model Dependent)
Input Ranges:	± 2.5V ± 5V ± 10V 0-5V 0-10V
Gain Scale:	1 / 10 / 100
Resolution:	14-bit
Input Coupling:	DC
Max Sampling Rate:	250kHz / 400kHz* (Model Dependent)
Clock Source:	Internal 10MHz External - Convert (EXT_CLK)
Gate Source:	External - Convert (EXT_GATE)
Input Impedance:	1M Ohm
System Noise:	±1 LSB

### Analog Outputs (D/A)

#### Output Characteristics

Output Channels:	None / 4 / 8 (Model Dependent)
Output Range:	± 10V
Resolution:	14-bit
Full Scale Error:	± 2 LSB
Settling Time:	1mS to 0.1% of full scale
Output Drive	+/-10V @ 5mA
Power-On State:	0V

### Digital I/O (DIO)

No. of TTL Lines: 24

#### Logic Levels:

Input Low Voltage:	-0.5V to 0.8V
Input High Voltage:	2.0V to 5.0V
Output High Voltage Min:	2.4V
Output Low Voltage Max:	0.45V
Maximum Output Current:	2mA

## Ordering Information

Supplied with EDR Enhanced Software, 1.8 Mtr. USB Cable & Universal Switch Mode 9V PSU

USB-26A16	USB 16(SE) or 8(DIFF) Channel 250KHz 14-bit A/D, 24 DIO
USB-26B16	USB2.0 16(SE) or 8(DIFF) Channel 400KHz 14-bit A/D, 24 DIO
USB-26A32	USB 32(SE) or 16(DIFF) Channel 250KHz 14-bit A/D, 24 DIO
USB-26B32	USB2.0 16(SE) or 8(DIFF) Channel 400KHz 14-bit A/D, 24 DIO
USB-30A16	USB 16(SE) or 8(DIFF) Channel 250KHz 14-bit A/D, 4 x 14-bit DACs, 24 DIO
USB-30B16	USB2.0 16(SE) or 8(DIFF) Channel 400KHz 14-bit A/D, 4 x 14-bit DACs, 24 DIO
USB-30A32	USB 32(SE) or 16(DIFF) Channel 250KHz 14-bit A/D, 8 x 14-bit DACs, 24 DIO
USB-30B32	USB2.0 32(SE) or 16(DIFF) Channel 400KHz 14-bit A/D, 8 x 14-bit DACs, 24 DIO

Please Note:

\* Please note that a PC with a USB 2.0 compliant interface is required to achieve these speeds.

\*\* On models with 32 inputs, the channels can only be sampled in banks of 16. If you are sampling from the lower bank (0 - 15), you will not be able to sample from the upper

USB MicroDAQ

### DB-25M

PA1	14	1	PA0
PA3	15	2	PA2
PA5	16	3	PA4
PA7	17	4	PA6
PB1	18	5	PB0
PB3	19	6	PB2
PB5	20	7	PB4
PB7	21	8	PB6
PC1	22	9	PC0
PC3	23	10	PC2
PC5	24	11	PC4
PC7	25	12	PC6
		13	DGND

Digital I/O

### DB-25 (M)

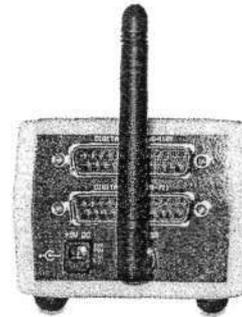
ACH1	14	1	ACH0
ACH3	15	2	ACH2
ACH5	16	3	ACH4
ACH7	17	4	ACH6
ACH9	18	5	ACH8
ACH11	19	6	ACH10
ACH13	20	7	ACH12
ACH15	21	8	ACH14
DAC0	22	9	AGND
DAC2	23	10	DAC1
NC	24	11	DAC3
EXT_TRIG	25	12	NC
		13	EXT_CLK

Analog

# BT-24A/72A/120A

Wireless 24, 72, 120 Line Digital I/O Uni

Ideal for Desktop/Laptop/PDA use



BT-120A-Back



## DESCRIPTION

The **MicroDAQ BT-24A, BT-72A and BT-120A** are general purpose digital I/O products which communicate to the host PC via a Wireless connection. Based on the industry standard 82C55 PPI device. They Feature 24, 72 or 120 TTL level digital I/O lines (depending on model). The I/O can be programmed in banks of 8 as inputs or outputs.

The units come supplied with a USB Wireless dongle which plugs into the PC to offer wireless communication. You can achieve a range of up to 10 metres depending on circumstances.

Drivers are provided for the most popular operating systems, as well as for the WindowsCE® family of products including PocketPC2002 and PocketPC2003. This support allows the wireless MicroDAQ range to be controlled directly from a Wireless enabled palm held PC. Each unit is supplied with a WindowsCE API and control panel which is downloaded from a PC to the handheld device. Embedded Visual C++ and embedded Visual Basic examples are supplied.

These digital I/O products are ideal for use in the connection between a computer and the outside world. Allowing computer programs not only to sense real world events, but control them as well. Applications include man-machine interfacing, driving high power loads, sensing switch contact closures and much more.

## FEATURES

- Connects via Wireless connection
- 24, 72 or 120 DIO lines (model dependent)
- TTL level I/O
- I/O Connector: 1x DB25 (-24A); 3x DB25(-72A); 5x DB25(-120A) Male
- LED indication for power connection
- Ideal for portable/laptop applications
- Housing: Plastic ABS with rubber feet
- Operating Temp: 0° to 70°C
- Power: 100mA (BT-24A); 260mA (BT-72A); 360mA (BT-120A) max
- O/S Support for Windows 98/ME/XP/2000 & WinCE (PocketPC2002 & PocketPC2003)
- Includes EDRE SDK, EDRE-Labview, EDRE-Testpoint and WaveView for Windows
- Dimensions (BT-24A; BT-72A): 45(H) x 80(W) x 148(L) mm
- Dimensions (BT-120A): 65(H) x 80(W) x 148(L) mm

## Specifications

Digital I/O (DIO)

No. of TTL Lines: 24 / 72 / 120 (Model Dependent)

Logic Levels:

Input Low Voltage: -0.5V to 0.8V

Input High Voltage: 2.0V to 5.0V

Output High Voltage Min: 2.4V

Output Low Voltage Max: 0.45V

Maximum Output Current: 2mA

## DB-25M

PA1	14	1	PA0
PA3	15	2	PA2
PA5	16	3	PA4
PA7	17	4	PA6
PB1	18	5	PB0
PB3	19	6	PB2
PB5	20	7	PB4
PB7	21	8	PB6
PC1	22	9	PC0
PC3	23	10	PC2
PC5	24	11	PC4
PC7	25	12	PC6
		13	DGND

Digital I/O



## Ordering Information

Supplied with EDR Enhanced Software & Universal Switch Mode 9V PSU

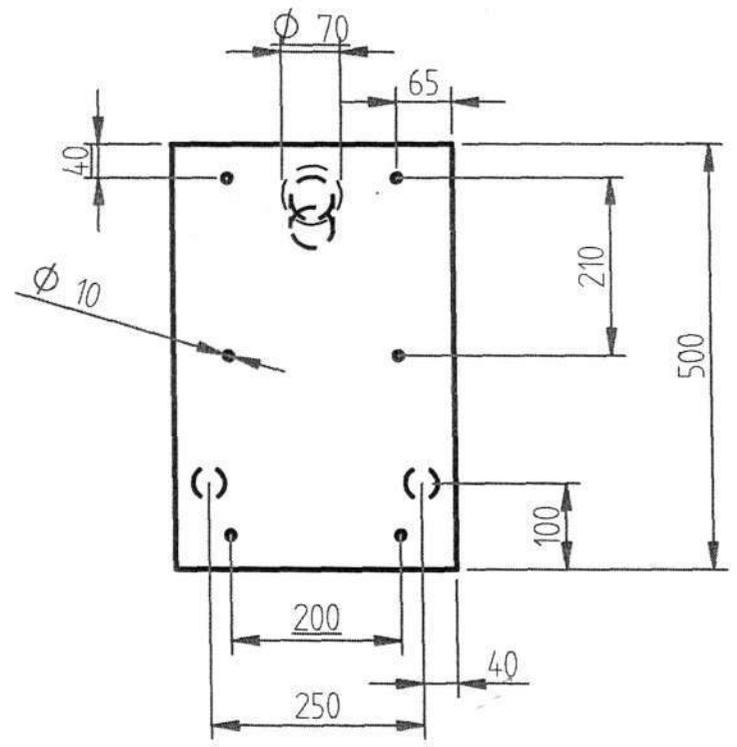
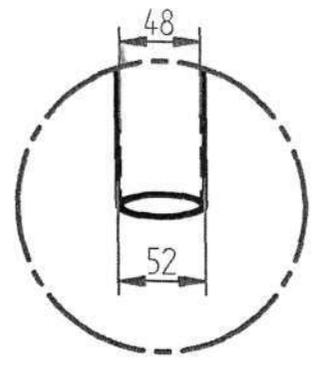
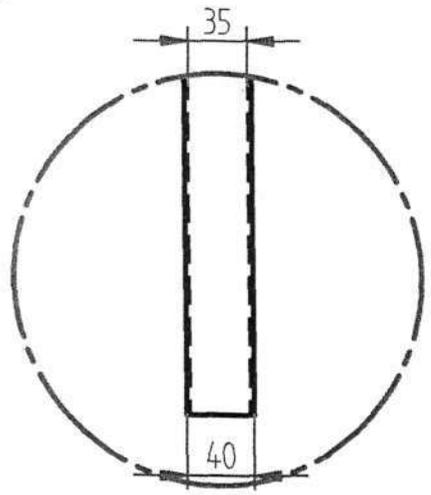
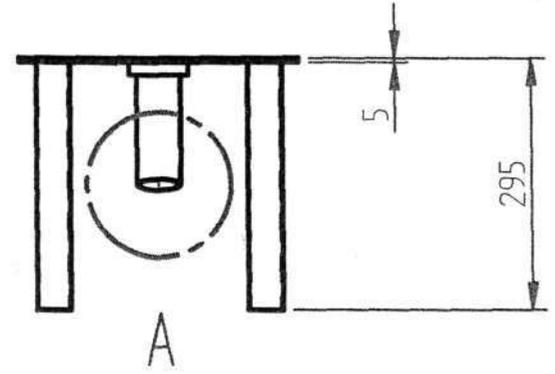
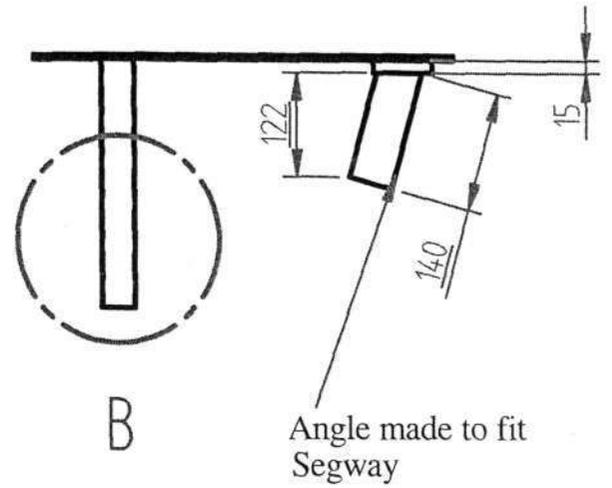
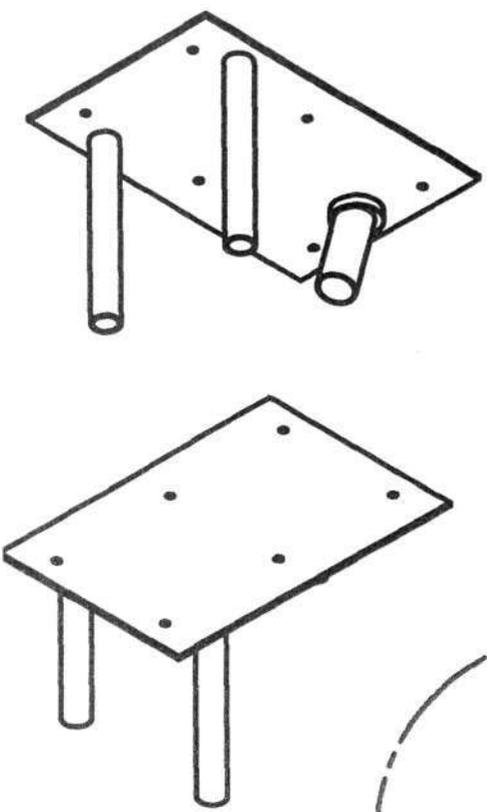
BT-24A Wireless 24 Channel DIO Unit, USB Wireless Dongle & 2.4 GHz Antenna

BT-72A Wireless 72 Channel DIO Unit, USB Wireless Dongle & 2.4 GHz Antenna

BT-120A Wireless 120 Channel DIO Unit, USB Wireless Dongle & 2.4 GHz Antenna

## **Appendix D**

### Automated Guided Vehicle Technical Drawings

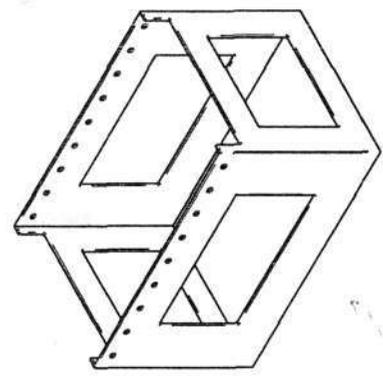
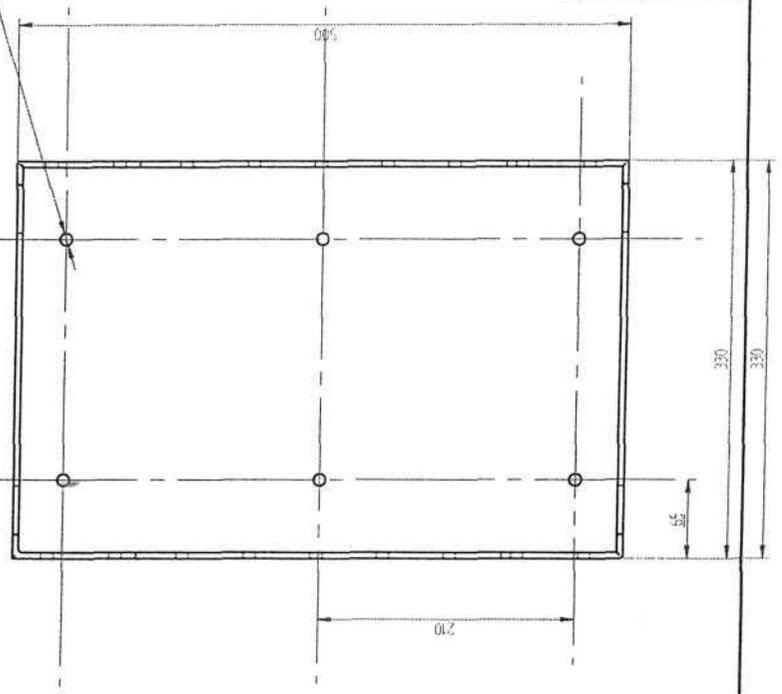
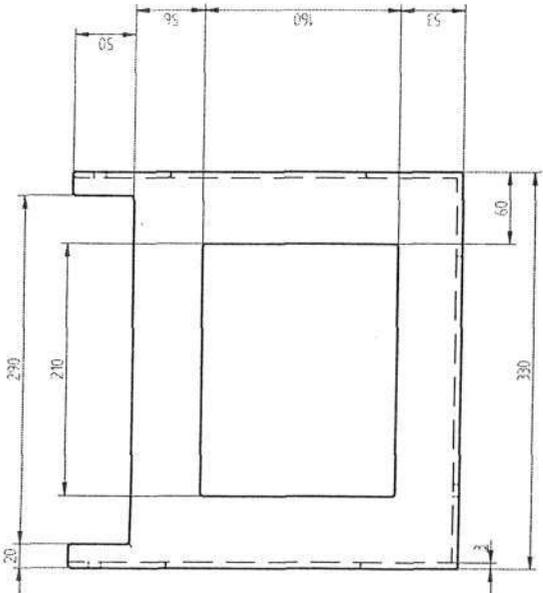
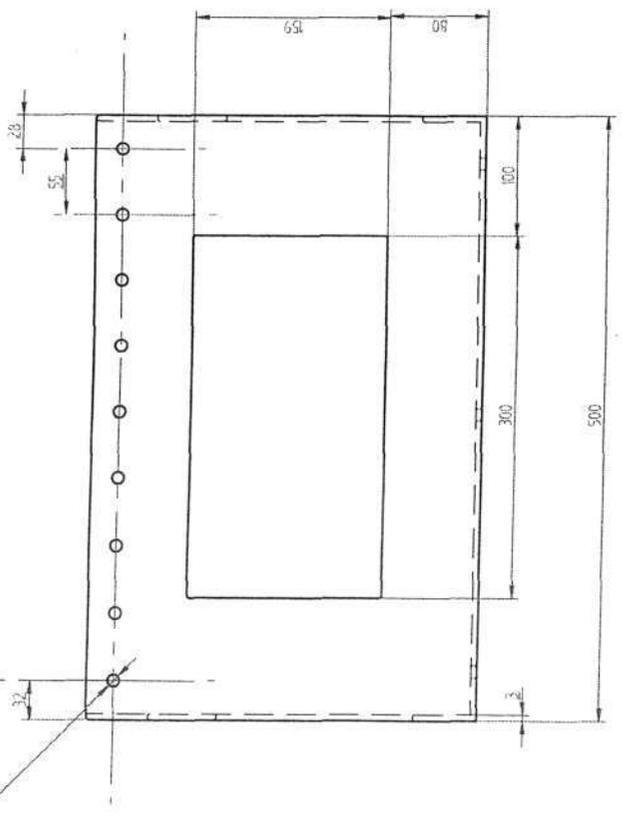


DETAIL B

DETAIL A

UNIVERSITY OF KWAZULU-NATAL School of Mechanical Engineering		DATE	CHECKED	SCALE 1: NTS	UNITS: mm	TITLE: Base plate	No.
	W'Shop Technician			MATERIAL: Steel	NOTES:		
	Draftsperson			STUDENT NAME: Priyen Naidu		TEL No.: 031 260 1227	
	Project Supervisor			Project: Mechatronics		E-MAIL: narupri@ukzn.ac.za	

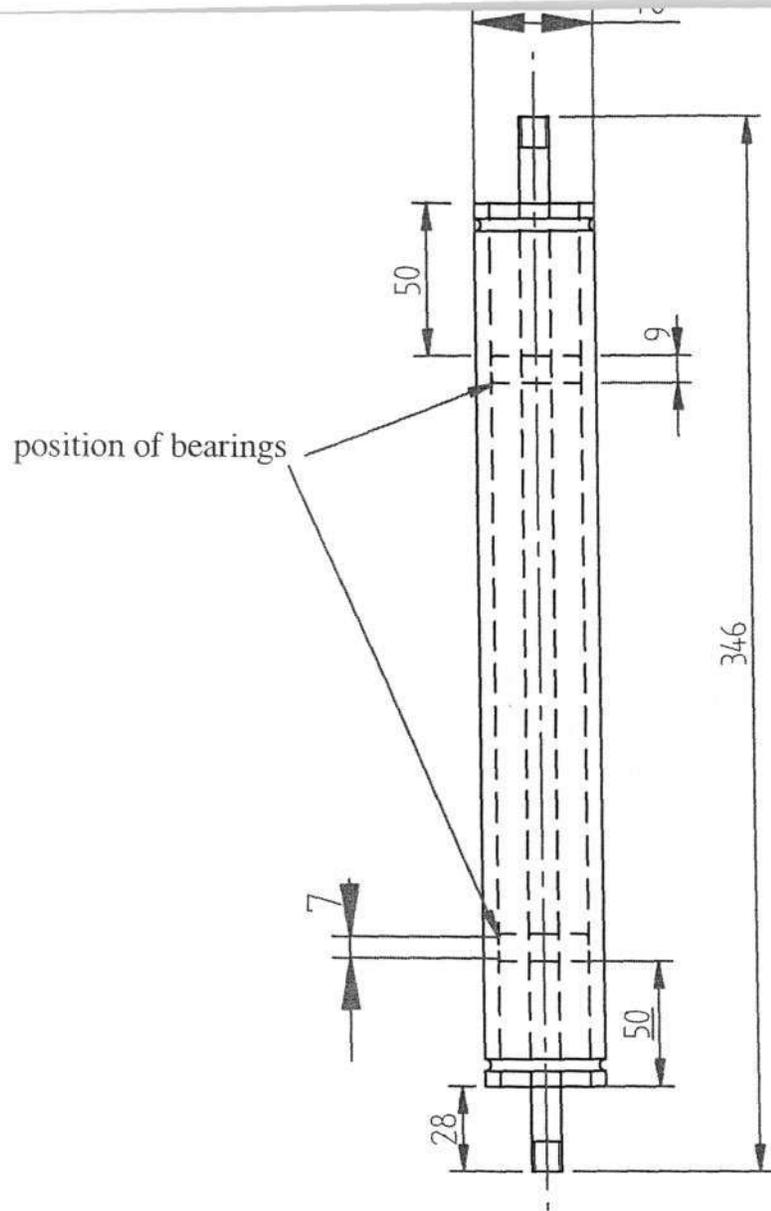




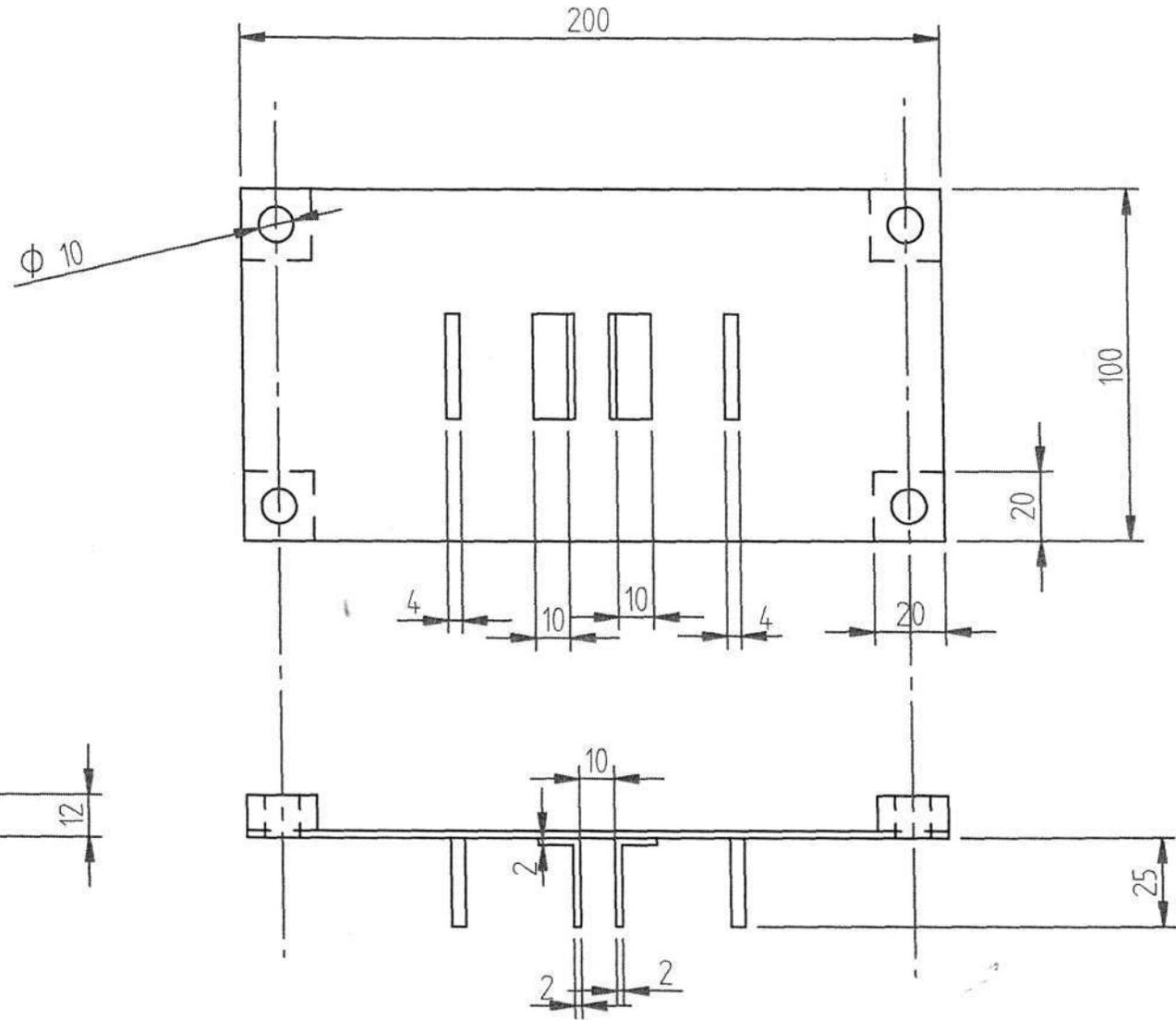
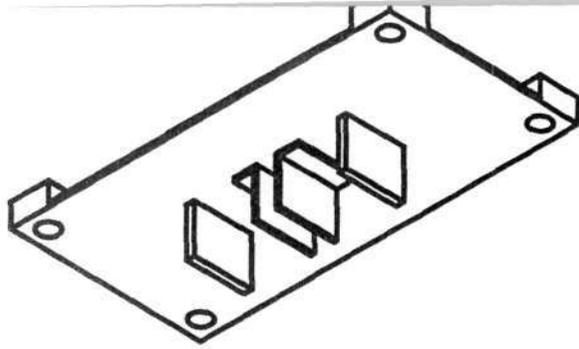
Wall thickness is 3mm throughout

DRAWN		NAME	DATE
CHECKED		Administrative	15/05/2016
ENG APPR			
MGR APPR			
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS ANGLES ±XX°			
2 PL ±XXX 3 PL ±XXXX			
TITLE		Roller Housing	
SIZE	DWG NO	SCALE	WEIGHT
A2			
REV			
	FILL NAME	PROJECT NUMBER	SHEET NO
			1

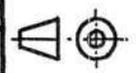
**SOLID EDGE**  
UGS - The PLM Company

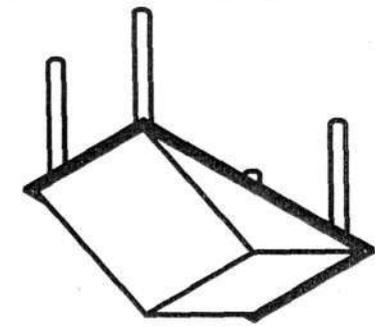
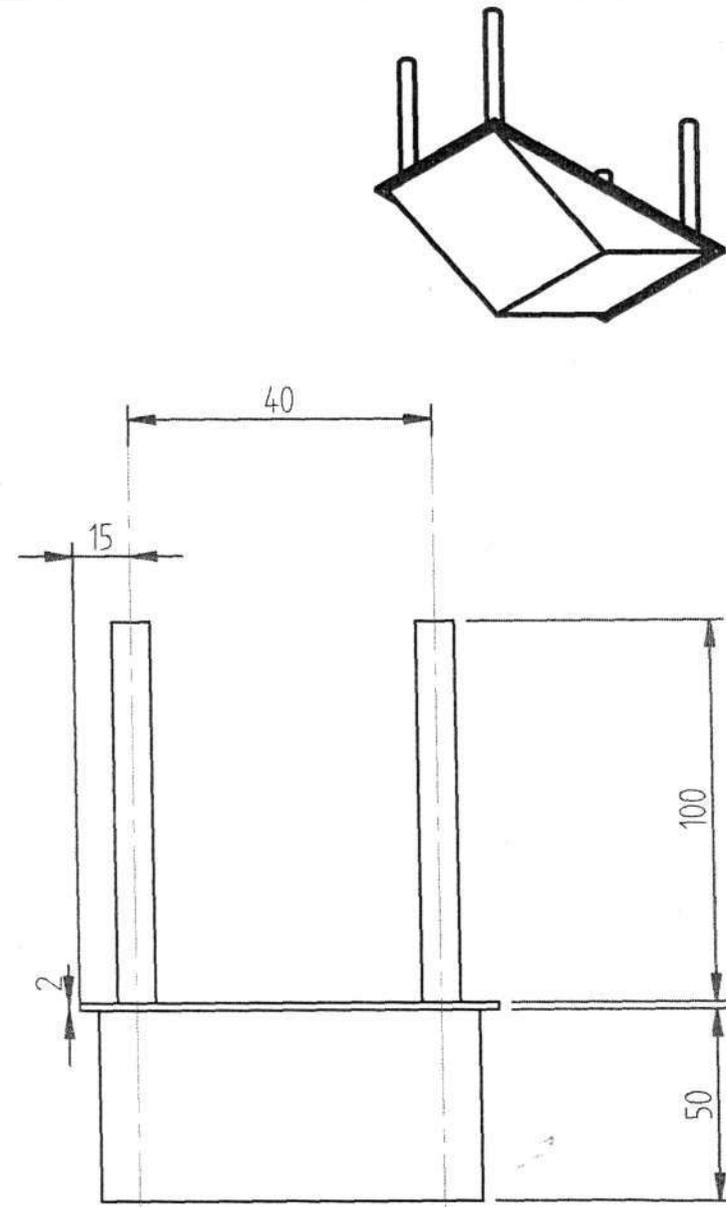
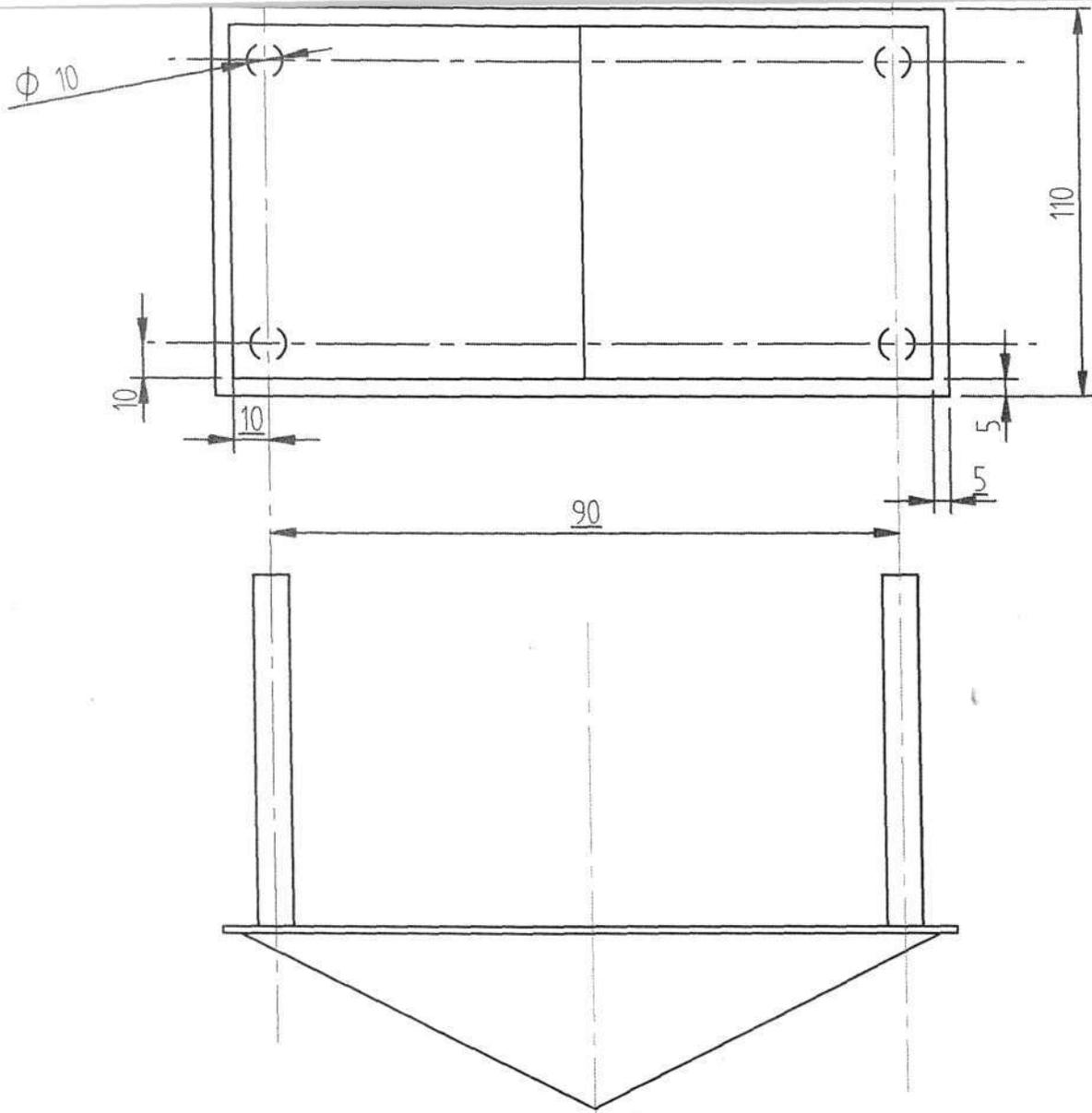


UNIVERSITY OF KWAZULU-NATAL School of Mechanical Engineering	DATE	CHECKED	SCALE 1: NTS	UNITS: mm	TITLE: Roller assembly	No.
	W'Shop Technician		MATERIAL:	NOTES:	TEL No.: ext 1227	
	Draftsperson		STUDENT NAME: P Naidu		E-MAIL: natdup1@ukzn.ac.za	
	Project Supervisor		Project: Mechatronics			



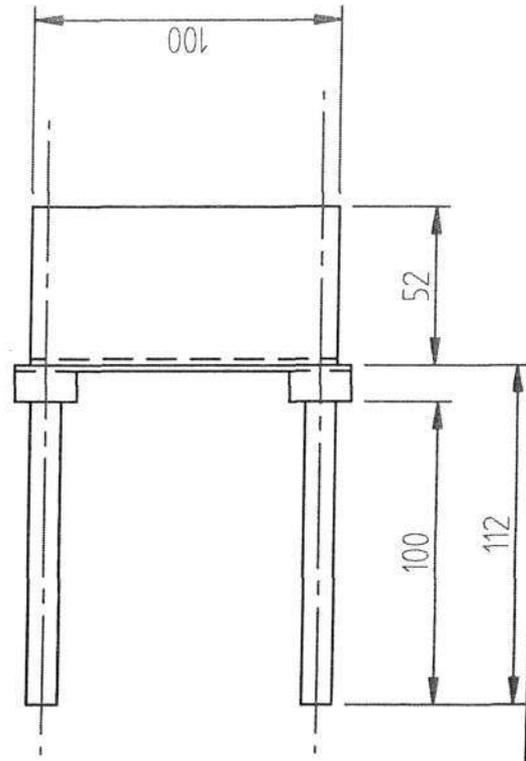
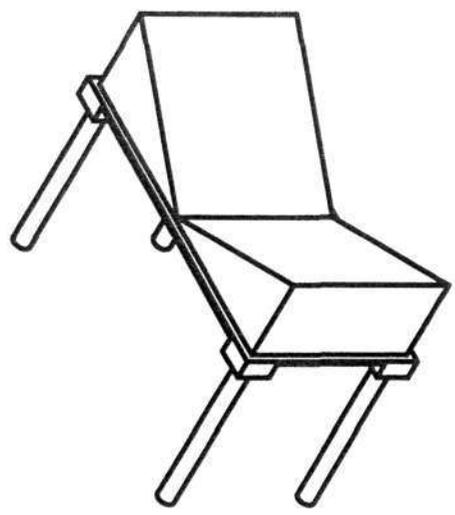
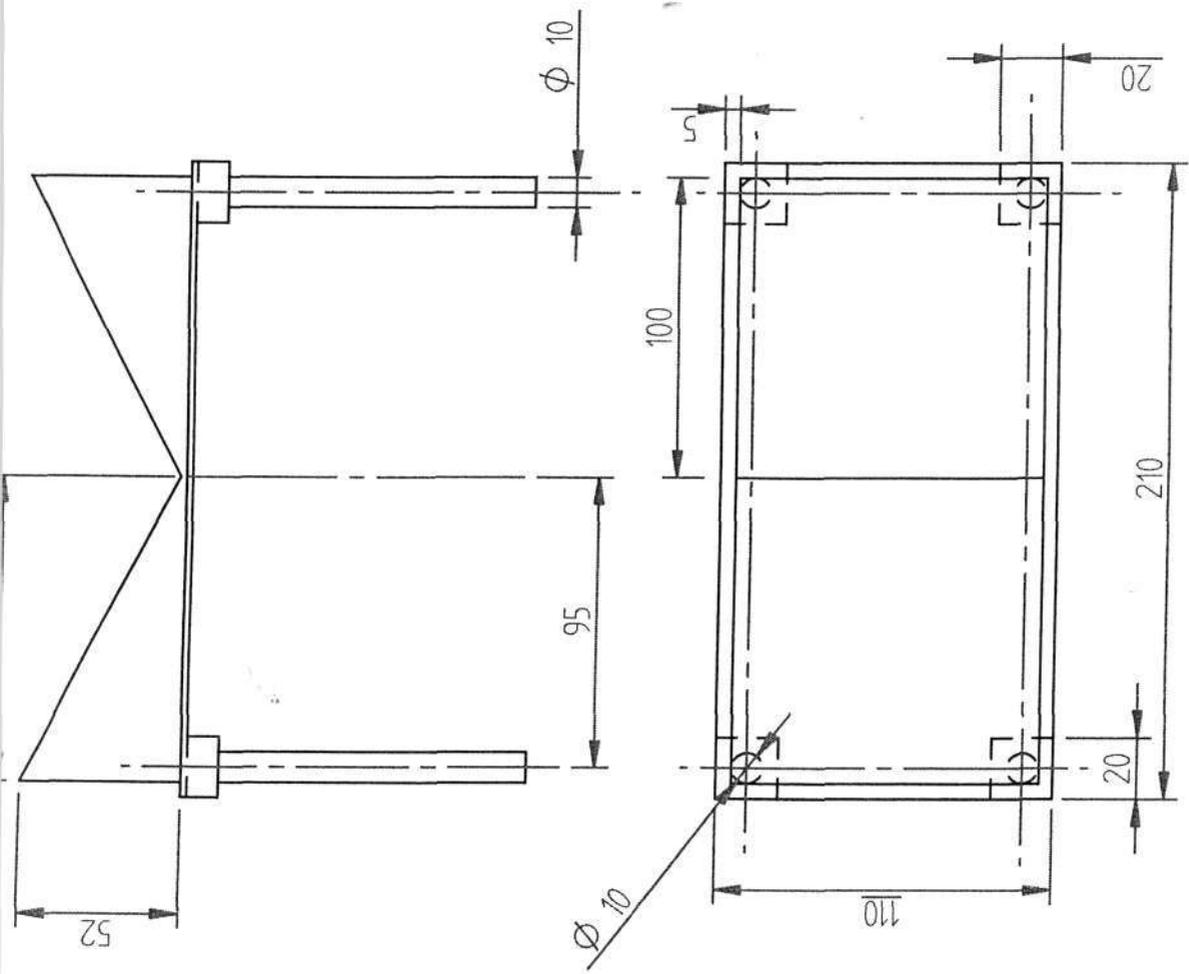
UNIVERSITY OF KWA-ZULU NATAL School of Mechanical Engineering	DATE	CHECKED	SCALE 1: 2	UNITS: mm	TITLE: Leadscrew	No. 2
	W'Shop Technician		MATERIAL: mild steel	NOTES:	TEL No.: ext 1227	
	Draftsperson		STUDENT NAME: Priyen Naidu		E-MAIL: naidup1@ukzn.ac.za	
	Project Supervisor		Project: Mechatronics			





UNIVERSITY OF KWA-ZULU NATAL School of Mechanical Engineering		DATE	CHECKED	SCALE 1: NTS	UNITS: mm	TITLE: Docking mechanism	No. 2
	W'Shop Technician			MATERIAL:	NOTES:		
	Draftsperson			STUDENT NAME: Priyen Naidu		TEL No.: ext 1227	
	Project Supervisor			Project: Mechatronics		E-MAIL: naidup1@ukzn.ac.za	





UNIVERSITY OF KWA-ZULU NATAL School of Mechanical Engineering	W/Shop Technician	DATE	CHECKED	SCALE 1: NTS	UNITS : mm	TITLE: Dock point	No. 2
	Draftsperson			MATERIAL:	NOTES:	TEL No. : ext 1227	
	Project Supervisor			STUDENT NAME : Priyen Naidu		E-MAIL : naidup1@ukzn.ac.za	
				Project : Mechatronics			



## **Appendix E**

### **Linear Way Specifications (LWH 15B)**

# Linear Way H

LWH...B/LWHT...B/LWHD...B/LWHS...B/LWHY

**IKO** Linear Way H incorporates two rows of large diameter steel balls in four point contact with the raceways and provides stable high accuracy and rigidity in operations even under fluctuating loads with changing direction and magnitude or complex loads. This series features the largest load ratings and rigidity among all ball types. A wide range of variations in shapes and sizes are available for selecting a model suitable for each application.

## Interchangeable

Linear Way H includes interchangeable specification products.

The dimensions of slide units and track rails of this specification are individually controlled, so that the slide units and track rails can be combined, added or exchanged freely.

## Flange type and block type

Slide units are available in five different sectional shapes: two flange types for different mounting directions and three narrow block types that are different in height and mounting directions.

## Length of slide unit

A standard type slide unit and a high rigidity long type slide unit both having the same sectional dimensions are available.

## Stainless steel type

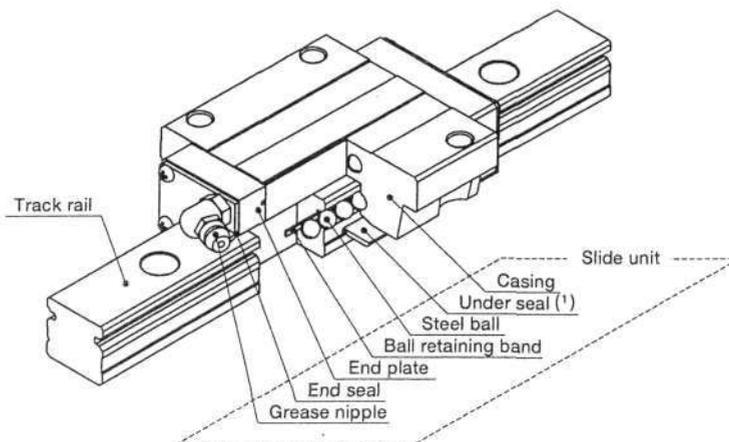
The stainless steel type has excellent corrosion resistance and is most suitable for machines and equipment used in clean environments, for example, medical equipment, disk read devices and semiconductor manufacturing equipment.

## Ultra sealed specification

The track rail of this specification is ground on all surfaces, and is combined with a slide unit with specially designed end seals and under seals. Excellent dust protection performance is provided.

## Miniature size

Miniature size models with track rail widths of 8 mm, 10 mm and 12 mm are available for use in the extended application range of Linear Way H.

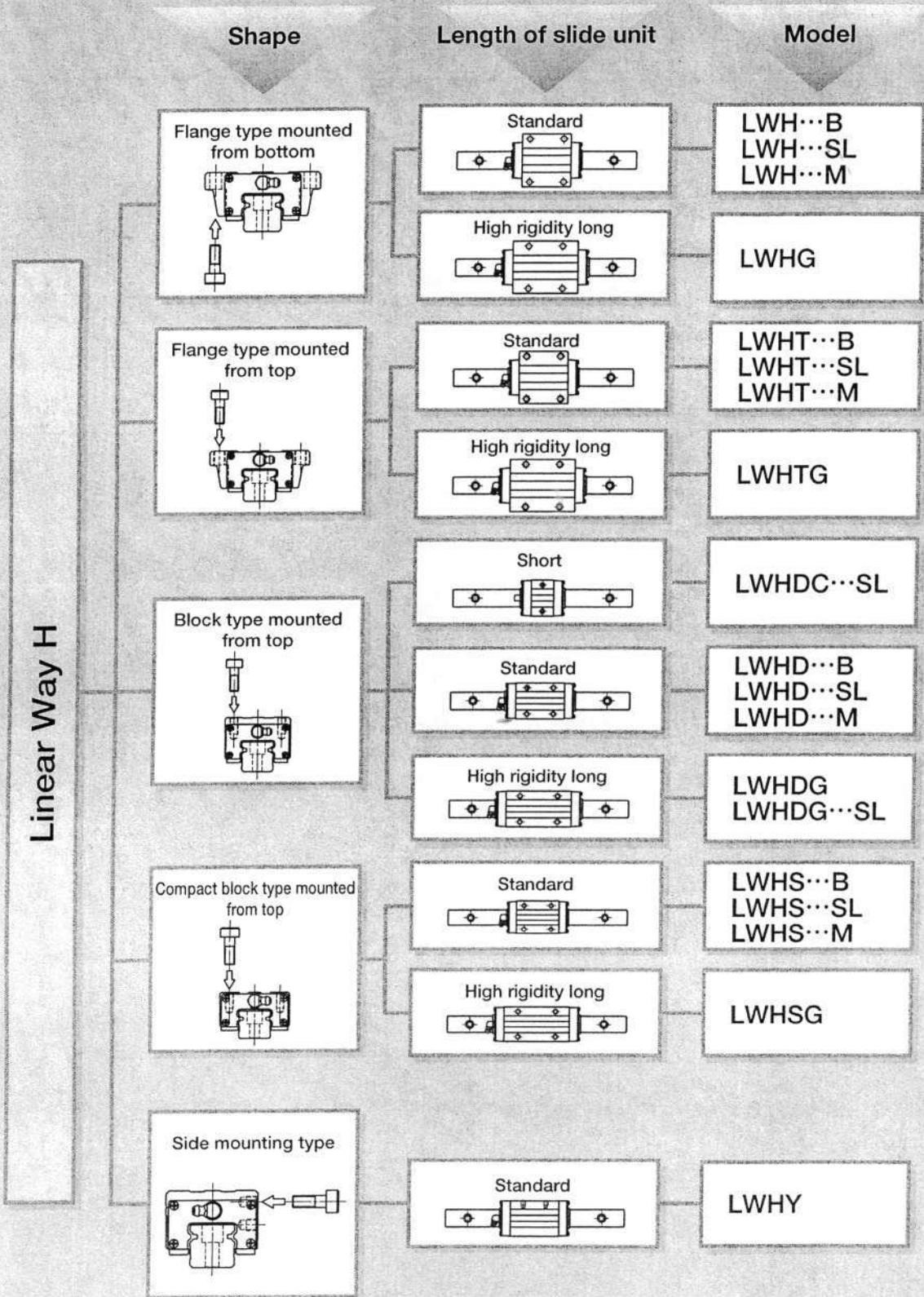


Structure of Linear Way H

U.S. PATENT No. 6,176,617  
 No. 5,967,667  
 No. 5,289,779  
 No. 5,250,126  
 No. 4,652,147  
 No. 4,610,488  
 No. 4,505,522

Note<sup>(1)</sup>: Size 8, 10 and 12 models with under seals are special specification products.

# Linear Way H series

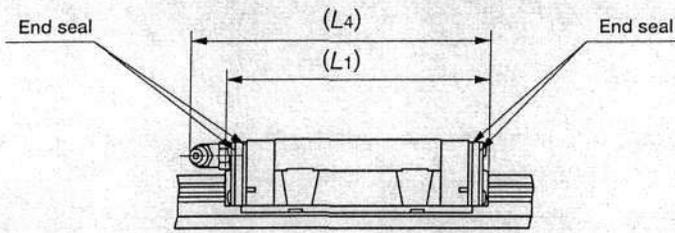


B

LWH, LWHT, LWHD, LWHS, LWHY

Remark 1 : Models with "SL" are stainless steel type.  
 2 : Models with "M" are ultra sealed specification products.

Table 9 Slide unit with double end seals (Supplemental code /V, /VV)



unit : mm

Model number	L1	L4
LWH 15...B	72	77
LWH 15...SL		
LWH 15...M	71	76
LWH 20...B	91	104
LWH 20...SL		
LWH 20...M	90	103
LWHG 20	119	133
LWH 25...B	104	116
LWH 25...SL		
LWH 25...M	103	115
LWHG 25	127	139
LWH 30...B	122	134
LWH 30...SL		
LWH 30...M	121	133
LWHG 30	148	160

Model number	L1	L4
LWH 35...B	133	146
LWH 35...M		
LWHG 35	161	173
LWH 45...B	159	170
LWH 45...M	158	
LWHG 45	202	213
LWH 55...B	196	206
LWHG 55	247	258
LWH 65...B	241	251
LWHG 65	316	326

Remark 1 : The above table shows representative model numbers but is applicable to all models of the same size.  
 2 : The values are for the slide unit with double end seals at both ends.

## ● Track rail length

Standard and maximum lengths of track rails are shown in Tables 11.1, 11.2 and 11.3. Track rails of any length are also available. Simply indicate the required length of track rail in mm in the identification number. For the tolerances of  $E$  dimension and track rail length, consult **IKO** for further information.

- For track rails of non-interchangeable specification longer than the maximum length shown in Tables 11.1, 11.2 and 11.3, butt-jointing track rails are available upon request. In this case, indicate "/A" in the identification number.
- $E$  dimensions at both ends are the same and are within the standard range of  $E$  unless otherwise specified. To change these dimensions, specify the specified rail mounting hole positions "/E" of special specification. For details, see page 89.

Table 11.1 Standard and maximum lengths of high carbon steel track rails

$n$  (Number of mounting holes)

Model number		LWH 12	LWH 15...B	LWH 20...B	LWH 25...B	LWH 30...B
Standard length $L(n)$	Item	80( 2)	180( 3)	240( 4)	240( 4)	480( 6)
		160( 4)	240( 4)	480( 8)	480( 8)	640( 8)
		240( 6)	360( 6)	660(11)	660(11)	800(10)
		320( 8)	480( 8)	840(14)	840(14)	1 040(13)
		400(10)	660(11)	1 020(17)	1 020(17)	1 200(15)
		480(12)	900(15)	1 200(20)	1 200(20)	1 520(19)
		560(14)	1 200(20)	1 500(25)	1 500(25)	2 000(25)
		640(16)			1 980(33)	
		720(18)				
		Pitch of mounting holes $F$	40	60	60	60
	$E$	20	30	30	30	40
	Standard range of $E^{(1)}$	incl. 5.5	7	8	9	10
		under 25.5	37	38	39	50
	Maximum length <sup>(2)</sup>	1 480	1 500 (3 000)	1 980 (3 000)	3 000 (3 960)	2 960 (4 000)

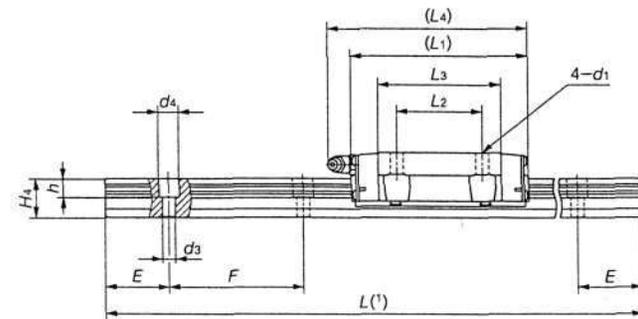
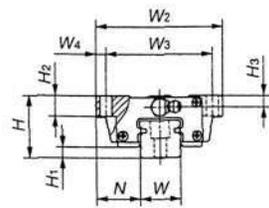
Model number		LWH 35...B	LWH 45...B	LWH 55...B	LWH 65...B
Standard length $L(n)$	Item	480( 6)	840( 8)	840( 7)	1 500(10)
		640( 8)	1 050(10)	1 200(10)	1 950(13)
		800(10)	1 260(12)	1 560(13)	3 000(20)
		1 040(13)	1 470(14)	1 920(16)	
		1 200(15)	1 995(19)	3 000(25)	
		1 520(19)			
	Pitch of mounting holes $F$	80	105	120	150
	$E$	40	52.5	60	75
	Standard range of $E^{(1)}$	incl. 10	12.5	15	17
		under 50	65	75	92
	Maximum length <sup>(2)</sup>	2 960 (4 000)	2 940 (3 990)	3 000 (3 960)	3 000 (3 900)

Note<sup>(1)</sup>: Not applicable to the track rail with female threads for bellows (supplemental code "/J").

<sup>(2)</sup>: Track rails with the maximum lengths in parentheses can be manufactured. Consult **IKO** for further information.

Remark: The above table shows representative model numbers but is applicable to all models of the same size. For the ultra sealed specification, see Table 11.3 on page B-90.

Flange type mounted from bottom  
 LWH ...B  
 LWHG  
 LWH ...SL (Stainless steel made)  
 LWH ...M (Ultra sealed type)

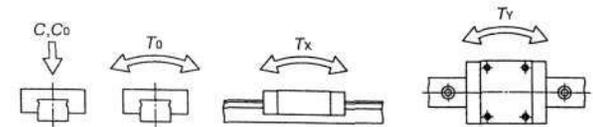
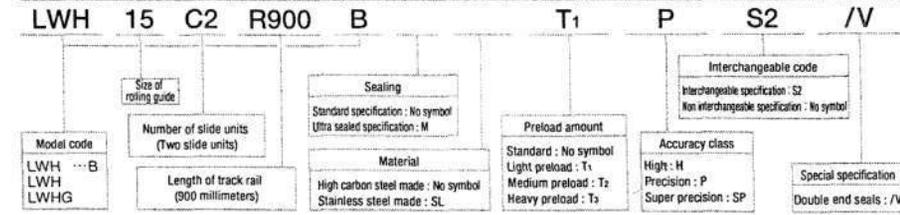


Model number	Interchangeable	Mass (Ref.)		Dimensions of assembly mm			Dimensions of slide unit mm							
		Slide unit kg	Track rail kg/m	H	H <sub>1</sub>	N	W <sub>2</sub>	W <sub>3</sub>	W <sub>4</sub>	L <sub>1</sub>	L <sub>2</sub>	L <sub>3</sub>	L <sub>4</sub>	d <sub>1</sub>
LWH 15...B	☆													
LWH 15...SL	☆	0.22	1.47	24	4.5	16	47	38	4.5	66	30	44.6	69	4.5
LWH 15...M														
LWH 20...B	☆													
LWH 20...SL	☆	0.48	2.56	30	5	21.5	63	53	5	83	40	57.2	95	6
LWH 20...M														
LWHG 20	☆	0.71								112		86	124	
LWH 25...B	☆													
LWH 25...SL	☆	0.70	3.50	36	6.5	23.5	70	57	6.5	95	45	64.7	106	7
LWH 25...M														
LWHG 25	☆	0.93								118		87.4	129	

		Dimensions of track rail mm							Mounting bolt for track rail mm	Basic dynamic load rating(?)	Basic static load rating(?)	Static moment rating(?)		
H <sub>2</sub>	H <sub>3</sub>	W	H <sub>4</sub>	d <sub>3</sub>	d <sub>4</sub>	h	E	F	Bolt size x length	C N	C <sub>0</sub> N	T <sub>0</sub> N·m	T <sub>x</sub> N·m	T <sub>y</sub> N·m
7	4.5	15	15	4.5	8	6	30	60	M4×16	11 600	13 400	112	95.6 556	95.6 556
10	5.5	20	18	6	9.5	8.5	30	60	M5×18	18 100	21 100	232	195 1 090	195 1 090
										24 100	31 700	349	421 2 140	421 2 140
10	6.5	23	22	7	11	9	30	60	M6×22	25 200	28 800	362	309 1 690	309 1 690
										30 800	38 300	483	533 2 740	533 2 740

Note(1) : Track rail lengths are shown in Table 11.1 on page B-86, Table 11.2 on page B-89 and Table 11.3 on page B-90.  
 (2) : The directions of basic dynamic load rating (C), basic static load rating (C<sub>0</sub>) and static moment rating (T<sub>0</sub>, T<sub>x</sub>, T<sub>y</sub>) are shown in the sketches below. The upper values in the T<sub>x</sub> and T<sub>y</sub> columns apply to one slide unit, and the lower values apply to two slide units in close contact.  
 Remark 1 : The mark ☆ indicates that interchangeable specification products are available.  
 2 : The appended track rail mounting bolts are hexagon socket head bolts of JIS B 1176 or equivalent.  
 For stainless steel type Linear Way H, stainless steel bolts are appended.  
 3 : For grease nipple specifications, see page 97.

Example of identification number of assembled set (For details, see "Identification number and specification".)



LWH, LWHT, LWHD, LWHS, LWHY

## **Appendix F**

Final Control Program- Compiled by Priyen Naidu and Emeka Udo-Chijoke

emeka's final program

```
Dim SerialNo As Long
Dim Major As Long
Dim Minor As Long
Dim bld As Long
Dim opsys As Long
Dim nd As Long
Dim counter As Integer
Dim counter2 As Integer, decimal_string As Integer
Dim databyte(1) As Double
Dim code As String
Dim wait As Boolean
Dim Connection As Boolean
Dim timer As Boolean
Dim timervalue As Integer
Dim textdatabyte(1) As String
Dim readernumber1 As String
Dim readernumber2 As String
Dim readernumber3 As String
Dim taga1 As String
Dim taga2 As String
Dim tagb1 As String
Dim tagb2 As String
Dim tagc1 As String
Dim tagc2 As String
Dim dummyvariable As Integer
Dim dummycounter As Integer
Dim limitswitch As Integer
Dim limitswitchtosegway As Integer
Dim counterr As Integer
Dim counterx As Integer
Dim countery As Integer
Dim counterz As Integer
Dim dummylimitswitch As Integer
```

```
Private Sub btn_clr_Click()
    Text1.Text = ""
    pic_container.Cls

    For counter = 0 To 1
        txt_databyte1(counter).Text = ""
    Next counter

    counter = 0
End Sub
```

```
Private Sub btn_decrement_Click()

    MSComm1.Output = Chr$(75)
    txt_timervalue.Text = " "
    If timervalue >= 1 Then
        txt_timervalue.Text = " "
        timervalue = timervalue - 1
        txt_timervalue.Text = timervalue
    End If

End Sub
```

```
Private Sub btn_increment_Click()

    MSComm1.Output = Chr$(73)
    If timervalue <= 47 Then
        txt_timervalue.Text = " "
        timervalue = timervalue + 1
        txt_timervalue.Text = timervalue
    End If

End Sub
```

emeka's final program

End Sub

```
Private Sub comm_timer_Timer()  
    comm_timer.Enabled = False  
    wait = False  
End Sub
```

```
Private Sub Command17_Click()
```

```
    'Define the three objects that we need,  
    ' A Connection Object - connects to our data source  
    ' A Command Object - defines what data to get from the data source  
    ' A RecordSet Object - stores the data we get from our data source
```

```
    Dim conConnection As New ADODB.Connection  
    Dim cmdCommand As New ADODB.Command  
    Dim rstRecordSet As New ADODB.Recordset
```

```
    'Defines the connection string for the Connection. Here we have used fields  
    'Provider, Data Source and Mode to assign values to the properties  
    ' conConnection.Provider and conConnection.Mode
```

```
    conConnection.ConnectionString = "Provider=Microsoft.Jet.OLEDB.4.0;Data  
Source=C:\Documents and Settings\Administrator\My  
Documents\IPX200.mdb;Mode=Read"
```

```
    'Define the location of the cursor engine, in this case we are opening an  
Access database  
    'and adUseClient is our only choice.
```

```
    conConnection.CursorLocation = adUseClient
```

```
    'Opens our connection using the password "Admin" to access the database. If  
there was no password  
    'protection on the database this field could be left out.
```

```
    conConnection.Open
```

```
    'Defines our command object
```

```
    ' .ActiveConnection tells the command to use our newly created command object.  
    ' .CommandText tells the command how to get the data, in this case the command  
    ' will evaluate the text as an SQL string and we will return all  
    ' records from a table called tabTestTable  
    ' .CommandType tells the command to evaluate the .CommandText property as an  
SQL string.
```

```
    with cmdCommand  
        .ActiveConnection = conConnection  
        .CommandText = "SELECT * FROM transack where seq = (select max(seq) from  
transack)"  
        .CommandType = adCmdText  
    End with
```

```
    'Defines our RecordSet object.
```

```
    ' .CursorType sets a static cursor, the only choice for a client side cursor  
    ' .CursorLocation sets a client side cursor, the only choice for an Access  
database  
    ' .LockType sets an optimistic lock type  
    ' .Open executes the cmdCommand object against the data source and stores the  
    ' returned records in our RecordSet object.
```

emeka's final program

```
With rstRecordSet
    .CursorType = adOpenStatic
    .CursorLocation = adUseClient
    .LockType = adLockOptimistic
    .Open cmdCommand
End With
```

'Firstly test to see if any records have been returned, if some have been returned then  
'the .EOF property of the RecordSet will be false, if none have been returned then the  
'property will be true.

```
If rstRecordSet.EOF = False Then
```

'Move to the first record

```
rstRecordSet.MoveFirst
```

'Lets move through the records one at a time until we reach the last record  
'and print out the values of each field

```
Do
```

'Access the field values using the fields collection and print them to a message box.

'In this case I do not know what you might call the columns in your database so this

'is the safest way to do it. If I did know the names of the columns in your table

'and they were called "Column1" and "Column2" I could reference their values using:

```
' rstRecordSet!Column1
' rstRecordSet!Column2
```

```
'MsgBox "Record " & rstRecordSet.AbsolutePosition & " " &
readerNumber.Text = rstRecordSet.Fields(2)
```

```
tagNumber.Text = rstRecordSet.Fields(1)
```

```
'rstRecordSet.Fields(2).Name & "=" & rstRecordSet.Fields(2)
```

'Move to the next record

```
rstRecordSet.MoveNext
```

```
Loop Until rstRecordSet.EOF = True
```

'Add a new record

```
With rstRecordSet
```

```
    .AddNew
```

```
    .Fields(0) = "New"
```

```
    .Fields(1) = "Record"
```

```
    .Update
```

```
End With
```

'Move back to the first record and delete it

```
'rstRecordSet.MoveFirst
```

```
' rstRecordSet.Delete
```

```
' rstRecordSet.Update
```

'Close the recordset

```
rstRecordSet.Close
```

```
Else
```

```
MsgBox "No records were returned using the query " & cmdCommand.CommandText
```

emeka's final program

```
End If
'close the connection
conConnection.Close
'Release your variable references
Set conConnection = Nothing
Set cmdCommand = Nothing
Set rstRecordSet = Nothing
'rs.Close
Set rs = Nothing
End Sub
```

```
Private Sub Connect_Click()
    lbl_conn_status.Caption = " "
    If Connection = False Then
        Connection = True
        Connect.Caption = "Disconnect"
        If MSComm1.PortOpen = False Then
            MSComm1.PortOpen = True
        End If
        Connect.Enabled = False ' button
        For counter = 0 To 15
            ' Sends Activation signal a maximum of 10 times, acknowledge
            ' activation must be read within this time for succesful
            ' connection !!!!
            lbl_conn_status.Caption = "Connection Attempt No: " & counter
            MSComm1.Output = Chr$(65) ' A Activate signal
            Delay
            If code = Chr$(67) Then ' C Acknowledge Activation
                counter = 16 ' effectively ends for loop, connection is
successful
                Connect.Caption = "Disconnect"
                lbl_conn_status.Caption = "Connection Successful!"
                pic_container.Cls
                ' Enable Controller Timer Button
                button_enable (True)
            End If
        Next counter
    End If
End Sub
```

```

emeka's final program
Connect.Enabled = True ' button

power!"
If (code <> Chr$(67) And counter = 16) Then
    lbl_conn_status.Caption = "Connection Failed, check hardware,
    Connection = False
    Connect.Caption = "Connect"
End If

ElseIf Connection = True Then
    If MSComm1.PortOpen = True Then
        ' Stop chip timer if its running
        If timer = True Then
            timer = False
            MSComm1.Output = Chr$(71) 'G
            Delay
            controller_timer.Caption = "Start Controller Timer"
        End If

        MSComm1.PortOpen = False

    End If

    pic_container.Cls
    ' Disable controller timer button
    button_enable (False)

    Connection = False
    Connect.Caption = "Connect"

End If

End Sub

Private Sub controller_timer_Click()
    If timer = False Then
        timer = True
        MSComm1.Output = Chr$(69) 'E
        Delay
        controller_timer.Caption = "Stop Controller Timer"
    ElseIf timer = True Then
        timer = False
        MSComm1.Output = Chr$(71) 'G
        Delay
        controller_timer.Caption = "Start Controller Timer"
    End If

End Sub

Private Sub Form_Load()
    SerialNo = EDREut1X1.SelectDialog
    EDREDioX1.SerialNumber = SerialNo
    CheckBoard

    Connection = False
    timer = False
    timervalue = 1
    txt_timervalue.Text = timervalue
    code = 0

    For counter = 0 To 1

```

```

emeka's final program
    textdatabyte(counter) = ""
Next counter

counter = 0
counter2 = 0

' Drawing variables
pic_container.Scale (0, 0)-(96, 24)

End Sub

Private Sub CheckBoard()
    If EDREUT1X1.DIOPorts = 0 Then
        MsgBox "This board has got no Digital I/O ports", vbExclamation
        Unload Me
    End If
End Sub

Private Sub Form_Unload(Cancel As Integer)

    If MSComm1.PortOpen = True Then
        MSComm1.PortOpen = False
    End If

    If comm_timer.Enabled = True Then
        comm_timer.Enabled = False
    End If

End Sub

Private Sub MSComm1_OnComm()

    code = MSComm1.Input

    If (code = Chr$(65) Or code = Chr$(90)) Then

        Connect.Enabled = False
        button_enable (False)
        ok.Enabled = True
        ok.Visible = True

        If code = Chr$(65) Then ' request for activation, checking to see if
user connected to controller

            lbl_controller_request = " Request from controller for activation, a
hardware reset has occured, check your power supply/connections! "

            ' Must reset counter 2 so that datatbytes are in sync
            counter2 = 0

        ElseIf code = Chr$(90) Then

            lbl_controller_request = " Controller claims unknown instruction
received, try sending the instruction again or reset the hardware and click on
connect! "

        End If

        ElseIf code = Chr$(67) Then

            lbl_controller_request = " A Connect Acknowledge has been received
from the Controller! "

        ElseIf code = Chr$(88) Then

            ' Converts string to decimal value

```

```

emeka's final program
databyte(counter2) = Val(textdatabyte(counter2))
Text1.Text = Text1.Text & "

' Clear strings
textdatabyte(counter2) = ""
'Display values of databytes
txt_databyte1(counter2).Text = databyte(counter2)

If counter2 >= 0 And counter2 < 1 Then
    counter2 = counter2 + 1
Else
    counter2 = 0
    ' can draw sensor grid as we have all the databytes
    Call draw_sensorgrid

End If

Else

Text1.Text = Text1.Text & code
textdatabyte(counter2) = textdatabyte(counter2) & code

End If

End Sub

Private Sub ok_Click()

    lbl_controller_request = " "

    Connect.Enabled = True
    button_enable (True)

    ok.Enabled = False
    ok.Visible = False

End Sub

Private Sub Delay()

    wait = True
    comm_timer.Enabled = True
    while wait = True
        ' Stay in loop until timer overflows
        DoEvents
    wend

End Sub

Private Sub stop_Click()

End Sub

Private Sub startconfig1_Click()
configuration1.Enabled = True
counterr = 1
End Sub

Private Sub startconfig2_Click()
configuration2.Enabled = True
counterrx = 1
End Sub

Private Sub startconfig3_Click()
configuration3.Enabled = True
countery = 1

```

emeka's final program

End Sub

```
Private Sub startconfig4_Click()
configuration4.Enabled = True
counterz = 1
End Sub
```

```
Private Sub Stopconveyor_Click()
EDREDioX1.Write 0, 0
EDREDioX1.Write 1, 0
EDREDioX1.Write 2, 0
```

```
configuration1.Enabled = False
configuration2.Enabled = False
configuration3.Enabled = False
configuration4.Enabled = False
```

End Sub

```
Private Sub Test_Click()
MSComm1.Output = "M"
End Sub
```

```
Private Sub button_enable(t As Boolean)
```

```
fme_timer_container.Enabled = t
controller_timer.Enabled = t
Test.Enabled = t
txt_timervalue.Enabled = t
btn_increment.Enabled = t
btn_decrement.Enabled = t
```

```
fme_datareceived.Enabled = t
```

```
For counter2 = 0 To 1
txt_databyte1(counter2).Enabled = t
lbl_databyte1(counter2).Enabled = t
Next counter2
counter2 = 0
```

End Sub

```
Private Sub draw_sensorgrid()
```

```
' Draw the sensor grid
```

```
x = 6
y = 6
```

```
For column_number = 1 To 0 Step -1
```

```
For row_number = 7 To 0 Step -1
```

```
' This routine finds which sensor was stimulated in the databytes
' each databyte corresponds to a column on the sensor grid
```

```
If (databyte(column_number) >= (2 ^ row_number)) Then
databyte(column_number) = databyte(column_number) - (2 ^
```

```
row_number)
```

```
'sensor not stimulated
pic_container.FillColor = &HFF8080 ' blue
```

```
Else
```

```
'sensor stimulated
pic_container.FillColor = &HFF& 'red
```

```
End If
```

emeka's final program

' have to select fill colour and determine which sensor has been stimulated before we can draw the sensor grid

```
pic_container.Circle (x, y), 4  
x = x + 12
```

```
Next row_number
```

```
x = 6  
y = y + 12
```

```
Next column_number  
y = 6
```

```
End Sub
```

```
''CONFIGURATTION 1.0
```

```
-----  
Private Sub configuration1_Timer() 'timer mimics a safe and slow looping
```

```
readernumber4 = "01010104"  
readernumber1 = "01010101"  
readernumber3 = "01010103"  
taga1 = "208040969623"  
taga2 = "208040987508"  
tagb1 = "208040987514"  
tagb2 = "208040971272"  
tagc1 = "208040389082"  
tagc2 = "208040987859"  
limitswitch = EDREDioX2.Read(2) 'limit switch  
limitswitchtosegway = EDREDioX3.Read(2)  
dummylimitswitch = EDREDioX4.Read(0)
```

```
'If (column_number = 0) And (row_number = 0) Then 'default: conveyor starts  
'once laser 1 is broken
```

```
'If counterr = 1 Then
```

```
If readernumber <> "01010101" And readernumber <> "01010104" And  
readernumber <> "01010103" Then  
    EDREDioX1.write 0, 77 'start motors 1 to 7  
    EDREDioX1.write 2, 1  
    EDREDioX1.write 1, 0 'stop port 1 (why do you want to stop port
```

```
ElseIf readernumber = "01010101" And (tagnumber = taga1 Or tagnumber = taga2  
Or tagnumber = tagc1 Or tagnumber = tagc2) Then  
    EDREDioX1.write 0, 77  
    EDREDioX1.write 2, 0 'run all except motor 3 at docking point
```

```
ElseIf (column_number = 0 Or column_number = 1) And row_number <> 4 Then  
    EDREDioX1.write 0, 77  
    EDREDioX1.write 1, 0 'if there is no obstruction at docking point then  
run 1, 2, 3, 4, 5  
    EDREDioX1.write 2, 1
```

emeka's final program

```
ElseIf readernumber = "01010103" And (tagnumber = tagb1 Or tagnumber = tagb2) And column_number = 0 And row_number = 4 Then
    EDREDioX1.write 0, 72
    EDREDioX1.write 2, 0

    'call segwayprogram()---let anthony do this from his c++ program
    'please once conveyor pickup section halts please start the segway
```

```
ElseIf limitswitch >= 2 And column_number = 0 And row_number = 4 Then
    'limitswitch at segway pickup-port1, pin 3
    EDREDioX1.write 1, 32 'Jared's plunger-port 1, pin 5
    EDREDioX1.write 2, 0
    EDREDioX1.write 0, 71 'if the limitswitch is on and there is a blockade
at docking
                                'point then motors 1,2,and 3 will stop
```

```
ElseIf limitswitch < 2 And (column_number = 0 Or column_number = 1) And
row_number <> 4 Then
    EDREDioX1.write 0, 77 'Priyen please include controls to retract
plunger if
    EDREDioX1.write 2, 1 'needed
```

```
ElseIf limitswitch < 2 And column_number = 0 And row_number = 4 Then
    EDREDioX1.write 0, 77
    EDREDioX1.write 2, 0
```

```
ElseIf readernumber = readernumber1 And (tagnumber = tagb1 Or
tagnumber = tagb2) Then
    EDREDioX1.write 0, 77
    EDREDioX1.write 2, 1
```

```
'ElseIf limitswitchtosegway >= 8 Then
'EDREDioX1.write 2, 0 'collision avoidance
'EDREDioX1.write 0, 72
```

End If

End Sub

'CONFIGURATTION 2.0

-----  
Private Sub configuration2\_Timer() 'timer mimics a safe and slow looping  
scheme

```
readernumber4 = "01010104"  
readernumber1 = "01010101"  
readernumber3 = "01010103"  
taga1 = "208040969623"
```

emeka's final program

```
taga2 = "208040987508"
tagb1 = "208040987514"
tagb2 = "208040971272"
tagc1 = "208040389082"
tagc2 = "208040987859"
limitswitch = EDREDioX2.Read(2) 'limit switch
limitswitchtosegway = EDREDioX3.Read(2)
dummylimitswitch = EDREDioX4.Read(0)

dummyvariable = 1

'If (column_number = 0) And (row_number = 0) Then 'default: conveyor starts
'once laser 1 is broken

  'If counterr = 1 Then

If readernumber <> "01010101" And readernumber <> "01010104" And
readernumber <> "01010103" Then
  EDREDioX1.write 0, 77 'start motors 1 to 7
  EDREDioX1.write 2, 1
  EDREDioX1.write 1, 0 'stop port 1 (why do you want to stop port
1?)

ElseIf readernumber = "01010101" And (tagnumber = tagb1 Or tagnumber = tagb2
Or tagnumber = tagc1 Or tagnumber = tagc2) Then
  EDREDioX1.write 0, 77
  EDREDioX1.write 2, 0 'run all except motor 3 at docking point

ElseIf (column_number = 0 Or column_number = 1) And row_number <> 4 Then
  EDREDioX1.write 0, 77
  EDREDioX1.write 2, 1 'if there is no obstruction at docking point then
run 1, 2, 3, 4, 5

ElseIf readernumber = "01010103" And (tagnumber = taga1 Or tagnumber =
taga2) And column_number = 0 And row_number = 4 Then
  EDREDioX1.write 0, 72
  EDREDioX1.write 2, 0

  'call segwayprogram()---let anthony do this from his c++ program
  'please once conveyor pickup section halts please start the segway

ElseIf limitswitch >= 2 And column_number = 0 And row_number = 4 Then
'limitswitch at segway pickup-port1, pin 3
  EDREDioX1.write 1, 32 'Jared's plunger-port 1, pin 5
  EDREDioX1.write 2, 0
  EDREDioX1.write 0, 71 'if the limitswitch is on and there is a blockade
'at docking
  EDREDioX1.write 1, 32 'point then motors 1,2,and 3 will stop

  ElseIf limitswitch < 2 And (column_number = 0 Or column_number = 1) And
row_number <> 4 Then
  EDREDioX1.write 0, 77 'Priyen please include controls to retract
'plunger if
  EDREDioX1.write 2, 1 'needed
```

```

emeka's final program
ElseIf limitswitch < 2 And column_number = 0 And row_number = 4 Then
    EDREDioX1.write 0, 77
    EDREDioX1.write 2, 0

```

```

ElseIf readernumber = readernumber1 And (tagnumber = taga1 Or
tagnumber = taga2) Then
    EDREDioX1.write 0, 77
    EDREDioX1.write 2, 1

```

```

'ElseIf limitswitchtosegway >= 8 Then
'EDREDioX1.write 2, 0      'collision avoidance
'EDREDioX1.write 0, 72

```

End If

End Sub

'CONFIGURATTION 3.0

-----  
Private Sub configuration3\_Timer() 'timer mimics a safe and slow looping scheme

```

readernumber4 = "01010104"
readernumber1 = "01010101"
readernumber3 = "01010103"
taga1 = "208040969623"
taga2 = "208040987508"
tagb1 = "208040987514"
tagb2 = "208040971272"
tagc1 = "208040389082"
tagc2 = "208040987859"
limitswitch = EDREDioX2.Read(2) 'limit switch
limitswitchtosegway = EDREDioX3.Read(2)
dummylimitswitch = EDREDioX4.Read(0)

```

```

dummyvariable = 1
'If (column_number = 0) And (row_number = 0) Then 'default: conveyor starts

```

```

'If counterr = 1 Then

```

```

If readernumber <> "01010101" And readernumber <> "01010104" And
readernumber <> "01010103" Then
    EDREDioX1.write 0, 77 'start motors 1 to 7
    EDREDioX1.write 2, 1
    EDREDioX1.write 1, 0 'stop port 1 (why do you want to stop port
1?)

```

```

emeka's final program
ElseIf readernumber = "01010101" And (tagnumber = tagb1 Or tagnumber = tagb2
Or tagnumber = taga1 Or tagnumber = taga2) Then
    EDREDioX1.write 0, 77
    'run all except motor 3 at docking point
    EDREDioX1.write 2, 0

ElseIf (column_number = 0 Or column_number = 1) And row_number <> 4 Then
    EDREDioX1.write 0, 77
    'if there is no obstruction at docking point then
run 1, 2, 3, 4, 5
    EDREDioX1.write 2, 1

ElseIf readernumber = "01010103" And (tagnumber = tagc1 Or tagnumber =
tagc2) And column_number = 0 And row_number = 4 Then
    EDREDioX1.write 0, 72
    EDREDioX1.write 2, 0

    'call segwayprogram()---let anthony do this from his c++ program
    'please once conveyor pickup section halts please start the segway

ElseIf limitswitch >= 2 And column_number = 0 And row_number = 4 Then
'limitswitch at segway pickup-port1, pin 3
    EDREDioX1.write 1, 32 'Jared's plunger-port 1, pin 5
    EDREDioX1.write 2, 0
    EDREDioX1.write 0, 71 'if the limitswitch is on and there is a blockade
at docking
    'point then motors 1,2,and 3 will stop

    ElseIf limitswitch < 2 And (column_number = 0 Or column_number = 1) And
row_number <> 4 Then
    EDREDioX1.write 0, 77 'Priyen please include controls to retract
plunger if
    EDREDioX1.write 2, 1 'needed

    ElseIf limitswitch < 2 And column_number = 0 And row_number = 4 Then
    EDREDioX1.write 0, 77
    EDREDioX1.write 2, 0

    ElseIf readernumber = readernumber1 And (tagnumber = tagc1 Or
tagnumber = tagc2) Then
    EDREDioX1.write 0, 77
    EDREDioX1.write 2, 1

'ElseIf limitswitchtosegway >= 8 Then
'EDREDioX1.write 2, 0 'collision avoidance (will mess up my
'EDREDioX1.write 0, 72

End If

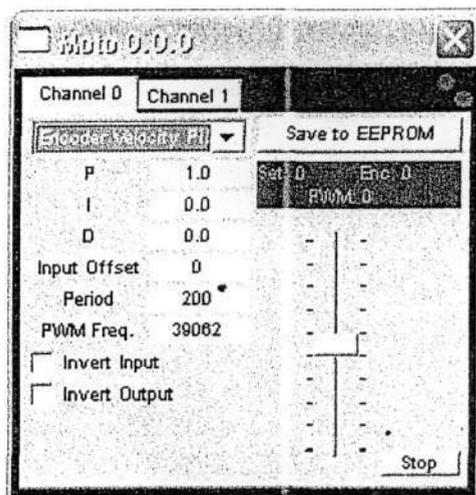
```

## **Appendix G**

Tiny Embedded Applications for Automated Guided Vehicle Program

Automated Guided Vehicle D.C Motor Control Program

## Software:



Sample Moto 1.0 Configuration and Control Application

## Notes:

The module does not include the interface cable/connector which is specific for each supported platform. If you already own a cable for your BrainStem GP 1.0 module, you can use that cable. These are the current interface cables:

- [RS-232 Serial Interface Connector](#)
- [USB Serial Interface Connector](#)
- [RS-232 Interface Connector Assembly](#)
- [USB Interface Connector Assembly](#)
  - [PalmIII Handhelds](#)

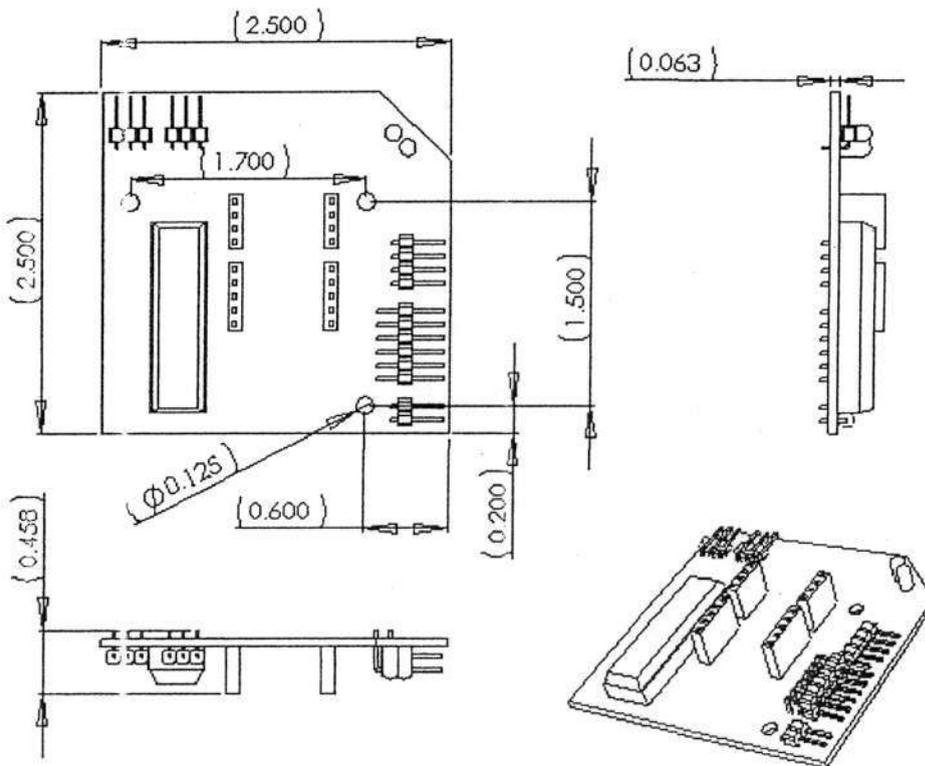
The software is downloadable from our site, and not packaged with the module. You can find the BrainStem software and more at the [Acroname Download Center](#).

Moto 1.0 Module features:

- 40 MHz RISC processor
- 2 motion control channels with PWM frequencies from 2.5kHz - 5MHz
  - 1 dedicated 10-bit A/D
  - 1 dedicated digital I/O lines
    - 1 MBit IIC port
      - IIC routing
      - status LED
- 11 1k TEA file slots and 1 16k TEA file slot
  - 368 bytes of RAM available to user
    - RS-232 serial port
    - reflex architecture
- ability to run 3 concurrent TEA processes
  - hardware EEPROM lock option
  - small size (2.5" square, 0.5" high)

Currently Supported On:

- Windows
- WinCE
- MacOS X
- Linux (access libraries)



Refer to components view of the main PCB as below drawing, the parts identification for each component has been printed on the PCB. This is the side of the board where you will mount parts.

Step 1: Start from the low-key components first such as the resistors.

Part I.D.	Description	Color Code	Qty
R5/6/11/12	1/4W 220Ω	red red brown gold	4
R7/8/9	1/4W 330Ω	orange orange brown gold	3
R10	1/4W 3.3K	orange orange red gold	1
R2	1/4W 10K	brown black orange gold	1
R4	1/4W 56K	brown blue orange gold	1
R13	1/4W 100K	brown black yellow gold	1
R3	1/4W 3.3M	orange orange green gold	1
R1	1/4W 560Ω	green blue brown gold	1

Step 2: Mount other components as below.

Part I.D.	Description	Qty
U1	18 pin IC	1
MIC	Microphone unit	1
C1/2	Ceramic capacitor 104P	2
C3	Ceramic capacitor 22P	1
EC1	Elec capacitor 100uf	1
Q1/2/3	Transistor 1815	3
Q4/5	Transistor 8050	2
D2/3/4	LED red	3
D5/6	LED green	2
IR	5P pin header 180°	1
L/R (+ -)	 ø 1.3mm pin	8
BAT (+ -)		
SW		
D1	IN 4004	1

Please note the direction of 5 pins header must be as drawing.

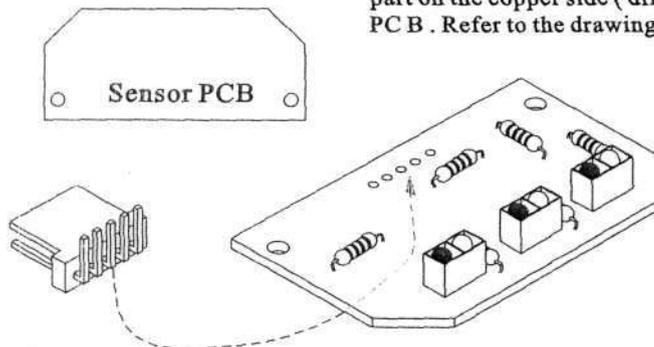
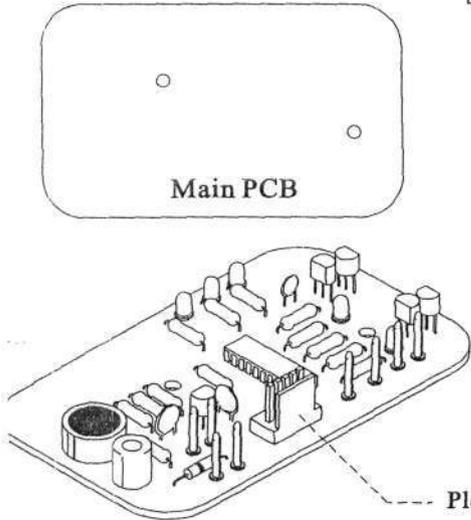
Sensor PCB Assembly:

Refer to the components view of the sensor PCB as below drawing, the parts identification for each component has been printed on the PCB. This is the side of the board where you will mount parts.

Step 1: Mount the resistors, photo interrupters:

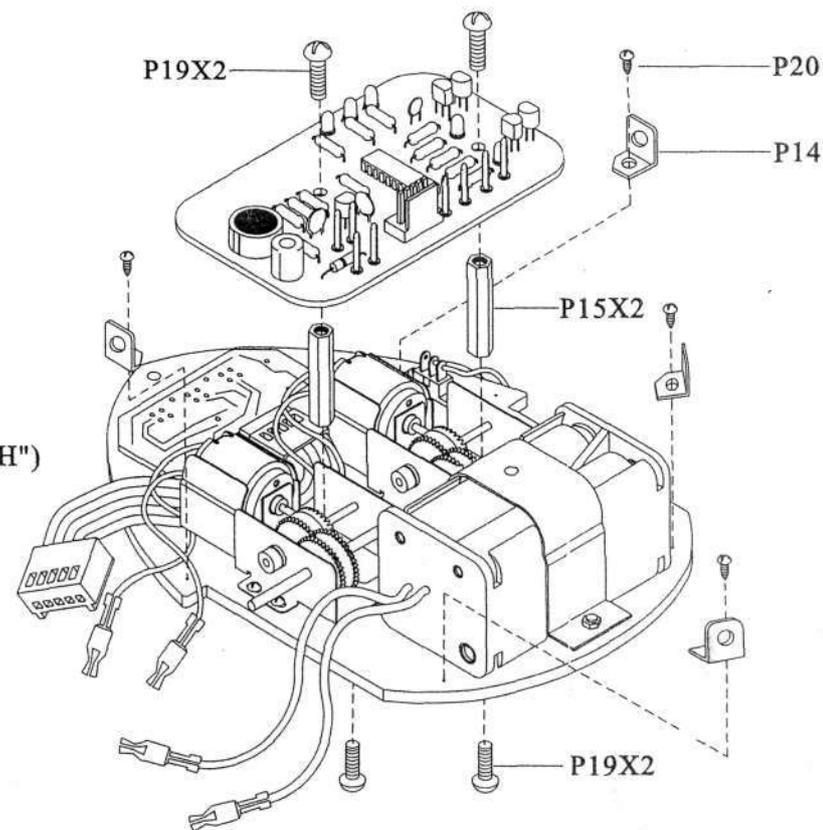
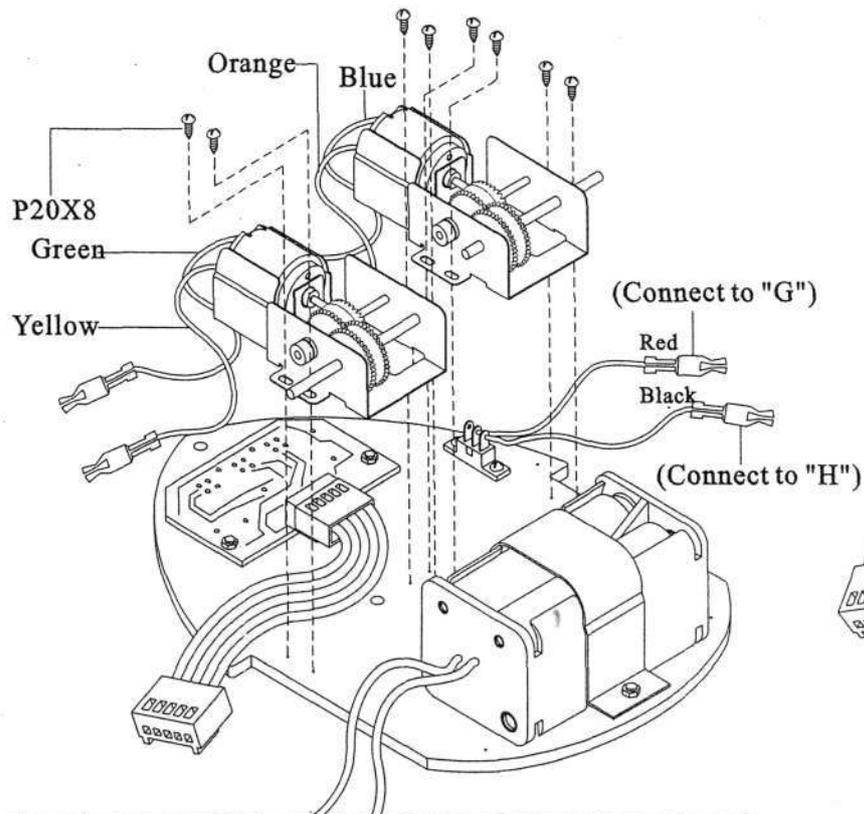
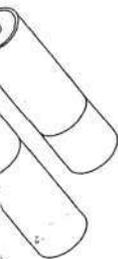
Part I.D.	Description	Color Code	Qty
R17/18/19	1/8W 33K	orange orange orange gold	3
R14/15/16	1/8W 220Ω	red red brown gold	3
U5/6/7	Photo interrupter		3

Step 2: Mount 5p 90° pin header, please note to mount this part on the copper side (different with all other parts) of the PCB. Refer to the drawing below.



## 4 Mounting of Gear box

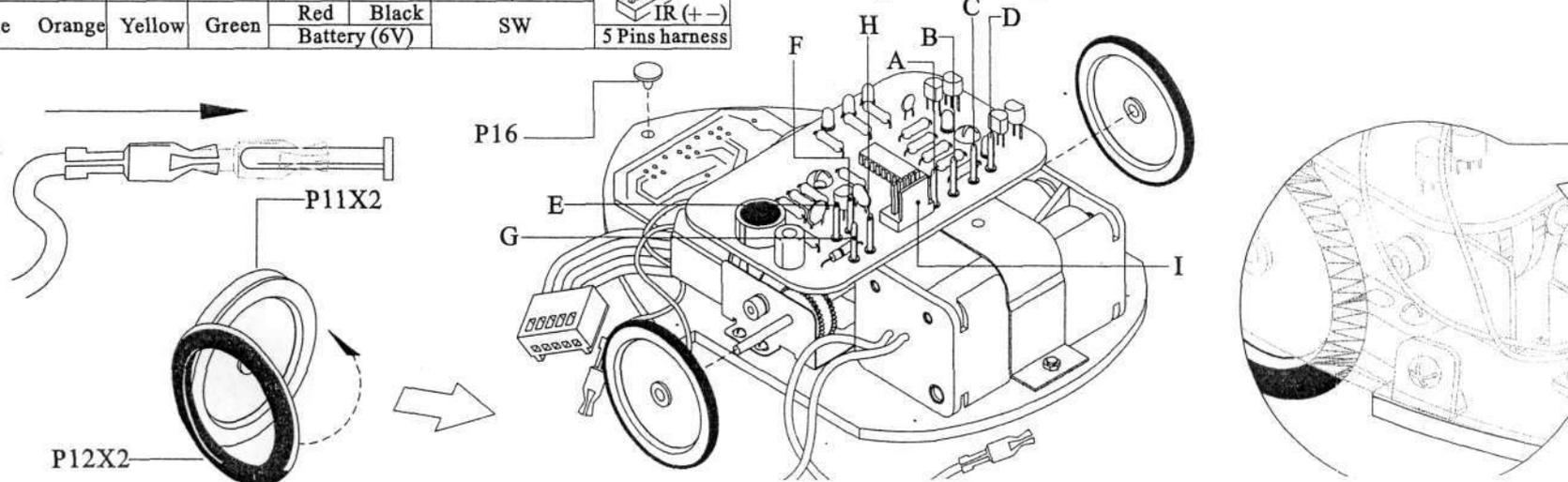
## 5 Main PCB Assembly



assembly

	A	B	C	D	E	F	G	H	I
	L(+)	L(-)	R(+)	R(-)	BAT (+)	BAT (-)	Red	Black	
	Blue	Orange	Yellow	Green	Red	Black	SW		IR (+-)
					Battery (6V)				5 Pins harness

## 6 Wiring



```

// tea program to enable line following on the Segway mobile platform

#include <aCore.tea>
#include <aServo.tea>
#include <aA2D.tea>
#include <aDig.tea>

int main()
{
    // Global Variables

    int AD0 = 0;
    int AD1 = 0;
    int AD2 = 0;

    //Set the digital pins to poll and initiate reflex on 0-1 transition
    from the microDaq
    //as well as set up dig output pin 2 to enable slight reverse movement
    before 90 turn

    aDig_Config(0, ADIG_INPUT | ADIG_POLLENA | ADIG_POLLHI);
    aDig_Config(1, ADIG_INPUT | ADIG_POLLENA | ADIG_POLLHI);
    aDig_Config(2, ADIG_OUTPUT);

    // loop
    while(1)
    {

        // Read the A2D input pins 0 - 2
        // AD1 is the middle sensor and should maintain its High state
        // AD0/AD2 are the outer sensors and should also maintain there
        high states

        AD0 = aA2D_ReadInt(0);
        AD1 = aA2D_ReadInt(1);
        AD2 = aA2D_ReadInt(2);

        if(AD0<80)
        {
            aServo_SetAbsolute(0, 50);
        }

        else if(AD2<80)
        {
            aServo_SetAbsolute(0, (char)204);
        }

        else
        {
            aServo_SetAbsolute(0, 127);
        }

        if((AD0<100)&&(AD1<100)&&(AD2<100))
        {
            break;
        }
    }
}

```

```
#include <aCore.tea>
#include <aServo.tea>
#include <aDig.tea>
#include <aA2d.tea>
#include <aMulti.tea>

void main(char callingProcID)
{
    // A2D read allocations...
    int AD0 = 100;
    int AD1 = 100;
    int AD2 = 100;

    while((AD0 < 50)&&(AD1 < 50)&&(AD2 < 50))
    {
        // Set the servo to default turning location
        aServo_SetAbsolute(0, (char)150);

        // Read the analog pins
        AD0 = aA2D_ReadInt(0);
        AD1 = aA2D_ReadInt(1);
        AD2 = aA2D_ReadInt(2);
    }
    aServo_SetAbsolute(0, 127);
    aMulti_Halt(callingProcID, 0);
}
```

```
    }  
}  
// Set digital pin 2 high to communicate with the microdaq and inform  
of line escape  
  
    aServo_SetAbsolute(0, 127);  
    aCore_Outportc(0x0509, 0b00000001);  
    aCore_Sleep(1000);  
    aCore_Outportc(0x0509, 0b00000000);  
  
    return 0;  
}
```

## Segway Motor Control Program

```
Dim dockinglimit As Integer
Dim Rollerlimit As Integer
Dim forwardlimit As Integer
Dim backwardlimit As Integer
Dim centerlimit As Integer
Dim findlostline As Integer
Dim Start As Integer
```

```
Private Sub limitswitches_Timer()
Start = EDREDioX1.Read(0)
dockinglimit = EDREDioX1.Read(2)
Rollerlimit = EDREDioX1.Read(2)
findlostline = EDREDioX1.Read(2)
frontlimit = EDREDioX1.Read(2)
centerlimit = EDREDioX1.Read(2)
```

```
If Start = 2 And dockinglimit = 2 Then
```

```
EDREDioX2.Write 0, 1 'rollers going backwards
EDREDioX2.Write 1, 1
```

```
If Start = 2 And dockinglimit = 2 And Rollerlimit = 4 Then
```

```
EDREDioX2.Write 0, 0
EDREDioX2.Write 1, 0
EDREDioX2.Write 0, 4 'slider motor in reverse
EDREDioX2.Write 1, 1 'reverse criterion
```

```
If findlostline = 0 Then
```

```
EDREDioX2.Write 0, 0
EDREDioX2.Write 1, 0
EDREDioX2.Write 0, 4
```

```
If frontlimit = 32 Then
```

```
EDREDioX2.Write 0, 0
```

```
If findlostline >= 1 And centerlimit < 16 Then
```

```
EDREDioX2.Write 0, 4
```

```
EDREDioX2.Write 1, 1
```

```
If centerlimit >= 16 And findlostline >= 1 Then
```

```
EDREDioX2.Write 0, 0
```

```
EDREDioX2.Write 1, 0
```

```
End If
```

```
'at this point please turn left for God's sake.
```

```
End If
```

```
End Sub
```

```
Private Sub Timer2_Timer()
```

```
End Sub
```

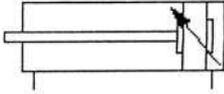
```
Private Sub limitswitches2_Timer()
```

```
End Sub
```

## **Appendix H**

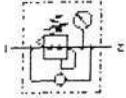
Transfer System Cylinder

Transfer System Valve



**DSN-25-300-PPV**  
**Standard cylinder**

Feature	Data/description
Mode of operation	double-acting
Variants	Single-ended piston rod
Design structure	Piston Piston rod
Piston diameter	25 mm
Stroke	300,000 mm
Ambient temperature	-20 - 80 °C
Pneumatic connection	G1/8
Conforms to standard	ISO 6432
Position detection	none
Cushioning	Pneumatic cushioning, adjustable at both ends (PPV)
Cushioning length	17,000 mm
Operating pressure	1,000 - 10,000 bar
Theoretical force at 6 bar, advance stroke	294,500 N
Theoretical force at 6 bar, return stroke	247,400 N
Operating medium	Dried compressed air, lubricated or unlubricated
Corrosion resistance classification CRC	2
Materials information for cover	Wrought Aluminium alloy neutral anodisation
Materials information for piston rod	High alloy steel, non-corrosive
Materials information, housing	High alloy steel, non-corrosive
Materials information for seals	NBR TPE-U(PU)



## LR-1-D-7-DI-MAXI Pressure regulator

Feature	Data/description
Design structure	directly-controlled diaphragm regulator
Ambient temperature	-10 - 60 °C
Mounting type	Front panel installation Line installation with accessories
Assembly position	Any
Medium temperature	-10,0 - 60,0 °C
Product weight	1.400,000 g
Operating medium	Filtered, unlubricated compressed air, 40 µm filtration Filtered, lubricated compressed air, 40 µm filtration
Pneumatic connection, port 1	G1
Pneumatic connection, port 2	G1
Standard nominal flow rate	8.400,00 l/min
Size	Maxi
Actuator lock	Rotary knob with lock
Pressure gauge	with pressure gauge
Inlet pressure 1	1,000 - 16,000 bar
Controller function	Output pressure constant with return flow with secondary exhaust with initial pressure compensation
Pressure control range	0,500 - 7,000 bar
Max. pressure hysteresis	0,400 bar
Series	D
Materials information, housing	Zinc die-casting
Materials information for seals	NBR

FESTO

Data sheet

Part no.: 4526

Page:1

**MSFG-12DC**  
**Solenoid coil**

Feature	Data/description
Characteristic coil data	12V DC