A TRAINING MODEL OF AN AUTOMATED STORAGE AND RETRIEVAL SYSTEM (AS/RS) WITH CUSTOMIZED WAREHOUSE MANAGEMENT SYSTEM (WMS)

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PENGESAHAN STATUS LAPORAN PROJEK SARJANA

A Training Model of An Automated Storage and Retrieval System (AS/RS) With Customized Warehouse Management System (WMS)

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A thesis submitted
In fulfillment of the requirements for the adward of the
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"No part of the study was covered by copyright. References of infomation obtained from other source are specially quoted, otherwise the rest of the infomation presented through this study is the sole work and experimentation carried out by the author"

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Author : TEE KIAN SEK

Date : 9 May 2007

For my parents, wife and my newborn daughter.

Life becomes merrier with my baby, Chloe.

Wish all luck and happiness to them!

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ABSTRACT

AS/RS is a key industrial automation system that has drastically reduced the workforce needed to run a warehouse. Via a computer-controlled system, many intensive labour jobs are taken over by the system, including tediously moving and sorting heavy load from the minute of receving until shipping to customers, intensive paperwork to record goods receiving and order receipts. Somehow, in real business, the system is always complex in the perspective of engineering considerations, depending on the nature of the business, tending to upgrading and modification from time to time. It is desirable that the engineering training curve would provide an engineer perspective in industry design concepts and contemporary technologies to the students, not in the operator prospective. This project is intended to develop a training model of AS/RS for the engineering students. The learning curves are provided through three levels in the system integration. The device level illustrates basic input and output devices that are carefully choosen. The controller level processes all input information from the input devices and host computer. The supervisory level implements graphic user interface for system monitoring and control for the operator. The training model also emphasizes in three design concepts, flexibility, expandability and modularity. Flexibility will allow a broad spectrum of application environments and extend application life. Expandability will allow application in areas not yet defined. Modularity will enhance modification and maintenance.

ABSTRAK

AS/RS merupakan satu sistem automasi yang penting dan mengurangkan tenaga pekerja yang ramai untuk beroperasi sebuah gudang. Dengan menggunakan kawalan komputer, banyak kerja buruh telah diambilalih, termasuk kerja-kerja pemindahan barang-barang dari saat penerimaan hingga penghantaran ke pelanggan serta mengurangkan beban kertas kerja penerimaan dan penghantaran. Namun, pada industri yang sebenar, sistem ini adalah rumit pada perpektif kejuruteraan dan amat bergantung kepada fungsi niaga. Dari masa ke masa, ia juga perlu dinaik-taraf dan diubah-suia. Pembelajaran ilmu kejuruteraan perlu dipandang di perspektif jurutera pada konsep-konsep rekabentuk dan teknologi terkini, bukannya di perspektif seorang operator. Di project ini, satu sistem pembelajaran AS/RS dibangunkan untuk pelajar-pelajar aliran kejuruteraan. Pembelajarannya dibentang dalam tiga peringkat. Peringkat peralatan menunjukan kegunaan dan pemilihan alat-alat perangsan dan aktuator. Peringkat kawalan akan memproses semua data daripada alat-alat perangsan dan komputer. Peringkat pengawasan menggunakan perantaraan muka grafik pengguna untuk kegunaan pengawasan dan kawalan di sisi operator. Sistem pembelajaran ini menekankan tiga konsep rekabentuk, iaitu kebolehlenturan, kebolehkembangan dan modulariti. Kebolehlenturan mempelbagaikan aplikasi dan memanjangkan hayat kebolehgunaan applikasi. Kebolehkembangan pula membenarkan aplikasi pada bidang yang belum ditentukan. Modulariti menggalakan pengubahsuaian dan penyenglenggaraan.

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CHAPTER 1

INTRODUCTION

1.0 The Introduction

Computer Integrated Manufacturing (CIM) system is well-known as 1. Group Technology (GT), 2. Computer Aided Design and Manufacturing (CAD/CAM), 3. Flexible Manufacturing System (FMS), 4. Industrial Robot, 5. Automatic Warehouse [4]. Automated Storage and Retrieval System (AS/RS) is a computer-controlled system for depositing and retrieving goods from defined storage locations. AS/RS is importance to improve the efficiency of operation of a warehouse or a distribution centre. Automatic warehouse has drastically reduced the workforce required to run the business. Minimum labor workers are needed for tasks input via a computerized warehouse management system. These tasks include goods receiving, retrieving and dispatch processing. On goods arrival, the automation system is notified and the goods are properly identified using an identity device such as a barcode scanner or a magnetic tag. Thereby, the goods are taken by a material handling system (MHS), sortation system and automated cranes to an assigned storage location. Upon receipt of orders, the automation system is able to re-locate the goods immediately via a computer and retrieve the goods to a pick location. The automation will combine all order information and assign picked goods into dispatch units. By sortation systems and the MHS, these dispatch units are move to outgoing trailers.

Typical AS/RS involve in goods receiving together with goods identifying process, storing and retrieving, sortation system, dispatching, a warehouse management system and personnel [1]. Technically, it can be seen that the system is an integration of multiple computer-controlled automations. Each automation serves for an assigned purpose, which may vary depending on the goods and the business. In general, it is a complex design involving modular system designs and integration system designs. The technologies applied for the system will evolve as new devices are invented, such as radio frequency identification (RFID). Consequently, for engineering instructors and students, AS/RS is too complex and too business nature dependant for teaching and learning purpose.

The engineering students are not supposed to learn in operator perspective but an engineer perspective in industry design concepts and contemporary technologies. The design concepts - Flexibility, Expandability and Modularity, are stressed in this paper. Via an automatic warehouse which integrates both a supervisory level and controller level via the PLC and computer network, this system demonstrates the design concepts and technologies applied in the integration. By inventory policies and the user friendly WMS software, the integration gives the user various information on the stored/retrieved items, the item searching mode and the status of the system. The integration highlights the concept of the supervisory level , the controller level and the device level. The supervisory level provides large amount of information meaningful to human, through an user-friendly graphic interface program. Whereas the controller level defines large information critical to the controllers themselves, both the logic and the communication amongst the controllers. The device level states the bottom level of the integration on variious types of input and output devices.

1.1 Objective

This project is intended to develop a training model for the engineering students. The training model is equipped with these objectives for learning.

1 To learn design concepts that apply flexibility, expandability and modularity in the integration;

2 To understand the supervisory level that implements an industry communication protocol for networking PLCs and a host computer with a customized application software.

3 To understand the controller level that enhance systematical sequential programming methods;

4 To understand the device level that tells the students to choose a sensory device for input and an actuator for output based on the application;

1.2 Research Scope

The scope of the project includes:

1. Design network connection between the supervisory level and the controller level using Omron Compolet, Omron CX-Programmer
2. Customized Storage and Retrieval Management software using Microsoft VB.net
3. Create monitoring and control, database of WMS.
4. Programming the controller level consisting of Omron PLC, including the SRM, the material handling, the receiving station, the picking and sorting station, the labeling and packaging station.
5. Specifying the devices used in the system.

CHAPTER 2

LITERATURE REVIEW

2.0 Literature Review

In real industry world, the development of automation is fast and the technology in system evolves as new solutions are recommended in the market from time to time. Engineering education must match with the high-speed automatic development of the factory, so it may not be fall behind in manpower training [6]. The training system is designed to contain all of the automation mechanic part, the control system, and in open structure. Somehow the overall design philosophy is based on three interrelated objectives, namely flexibility, modularity and expandability. We-Min Chow [9] had stated in his paper that flexibility will not only allow a broad spectrum of application environments but is also a major contribution factor in extending application life; expandability is closely coupled with flexibility and will allow application in areas not yet defined. Finally, modification and maintenance are greatly enhanced if the system is modularized in a meaning manner. As new technologies emerge, these three objectives are still valid for all automation applications.

There are some constraints in manpower training. Firstly, the system does not reflect the technologies used in industry or the technologies lagged behind. Secondly, the system does not review the real application in industry. Thirdly, real industry application is too complex.

Computer Integrated Manufacturing (CIM) system is well known as follows: [5] [6]

1. Group Technology (GT)
2. Computer Aided Design and Manufacturing (CAD/CAM)
3. Flexible Manufacturing System (FMS)
4. Industrial Robot
5. Automatic Warehouse

Automatic warehouse is one of the major applications of the CIM. An Auto Storage and Retrieval System (AS/RS) can be defined as an automatic warehouse.AS/RS has been an essential business operation system since the introduction of CIM In general, the automatic warehouse has the functions such as receiving, material handling, storage, picking and sortation, shipping, labeling and packing, the warehouse management and personnel [1]. In real industry application, Dotoli, M.; Fanti, M.P.; Iacobellis, G. (2004) [2], have stated that:

"A typical AS/RS comprises several aisles with storage racks on either side, each serviced by an automated stacker crane, operating storage and retrieval of the parts.Cranes move in three directions: along the aisle to perform transfers, sideways between the aisle and the racks, and vertically to reach the Storage/Retrieval (S/R) location. Each aisle is also serviced by a storage and by a retrieval conveyor. Moreover, the AS/RS may include Rail Guided Vehicles (RGVs), transporting parts. Finally, several input (storage) and output (retrieval) buffer stations, where the RGVs load or deposit pallets, are located in the system."

Graphically, the definition of a large scale AS/RS [2] is shown in Figure 2.1.

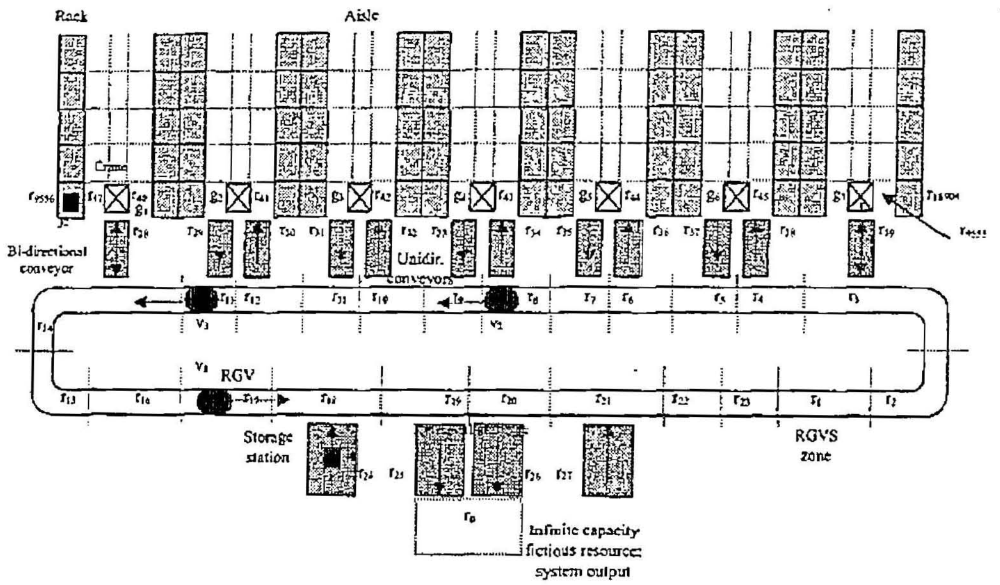

Figure 2.1: Plan layout of a multi-product AS/RS serviced by RGVs [2]

Automated warehouses represent a tremendous financial investment and play a critical role in the manufacturing and distribution process [10]. Especially in logistic business and distribution store, an AS/RS is so essential to automatically handling large amount of different items, flowing in and out according to the order, with minimum labor and human error.

According to Frazelle, E [10], to design an AS/RS, three physical configurations are to be considered carefully during design. Firstly, what is the appropriate size and shape of the warehouse? The question involves of minimizing total system cost with constraints such as storage requirement throughput. Secondly, how many input/output (IO) points should be designed into the system? The question involves the physical size of the system, which would affect the performance. The performance might be evaluated via simulation, queuing theory and statistical analysis. Thirdly, what is the appropriate material handling system to interface with the warehouse? The question involves the layout of the conveyor in a loop where trays can be delivered to workstations along the loop. The performance is affected as the length of the loop increases as the trays traverse along. Besides, the inherent loop control become complex. He did highlighted four major operation strategy design problems which need to be balanced. There are:

1. item classification
2. system balancing
3. storage location assignment
4. man-machine balancing

Beside Frazelle, E [10], there are few papers viewing AS/RS design in a whole picture rather most papers review on certain facets of the AS/RS issues. Suesut, T. and his research team [4] had investigated the purpose of inventory management to reduce the total cost of material stocks.

Serafini, P. and Ukovich, W [8], had recommended an optimum algorithm for the shortest storage and retrieval cycle time. The algorithm depends on the structure and scale of an AS/RS, and the nature of the items. Somehow, Ya-Hong Hu and his team [3] recommend pre-sorts the loads to specified locations to minimize the response time of retrieval, with a new type of AS/RS namely split-platform AS/RS. Soeman Takakuwa [7] had introduced a method of modeling large-scale AS/RS on examining storing/retrieving policy from the efficient standpoint. Seng-Yuh Liou and his team [6] had introduced an education AS/RS. The education model does not incorporate industrial package in integrating the supervisory level (computer) with the controller level (PLC) with graphical user interface (GUI). In his study, design philosophy objectives such as flexibility, expandability and modularity, are not emphasized throughout the design.

Thus, the design of an AS/RS is very business nature dependant and complex for a real industry application. Hence, it would be sensory overload if it is to teach or introduce engineering students a complex industry AS/RS in all design aspects.

There are few papers highlight the education model of AS/RS on:

- System design philosophy on flexibility, expandability and modularity
- The basic techniques in driving two axis servo motor for storing/retrieving

- The product identity data (ID) scheme which are crucial for data searching and matching purposes
- The PLC program method, namely function block programming method which increase repeatability in program and ease for debugging
- Communication protocol between a computer and a PLC, between PLCs, a PLC with a robot.
- the powerful computing capability of the PLC for the algorithms on the Storage and Retrieval Machine (SRM) using servo drives control, storage and retrieval decision scheme based on First-In-First-Out (FIFO) or Last-In-First-Out (LIFO), picking and sorting scheme, the communication and data transfer scheme to the supervisory level namely the Warehouse Management System (WMS)
- Stand-alone and simple WMS

CHAPTER 3

METHODOLOGY

3.0 Methodology

This section starts with a description of the system flow. The system flow describes the requirements in the perspective of an user, implying the technologies and methods that should be applied. It also explains what is expected the system should behave. Based on the expectations, we can design the expectation accordingly.

3.1 The System Flow

The AS/RS is based on layout configuration as shown in Figure 3.1. Once power on, the Storage/Retrieval Machine (SRM) needs to be triggered manually to an original position called "Home". Using the Warehouse Management System (WMS), the user must specify the communication address before triggering any buttons. Once the communication has established, the WMS will prompt its status in text.

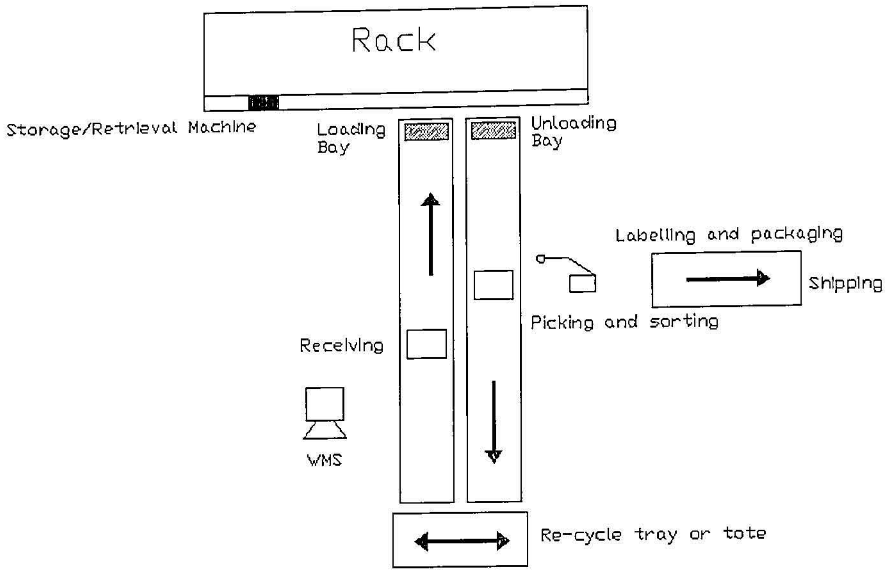

Figure 3.1: The System Layout

Once communication is setup, the user is required to trigger the SRM to an original position called "Home". Both axes consist of servo drive without any encoder feedback. Once "Home", a text message will prompt the user the status.

The WMS provides other options for critical position teaching as well. "Home" position is not equal to the coordinate (0, 0). Based on the system layout, there are three critical positions to be taught, namely coordinate (0, 0), the loading bay and the unloading bay. At teaching mode, the WMS provides options for inching step size for both X ad Z axes. The user is required to trigger the X or Z axis accordingly by selecting the step size. The user is required to monitor visually the precision of the taught positions. For example, teaching coordinate (0, 0). At near coordinate (0, 0), the user can inch X or Z axis at small step, simulating the storage/retrieval action manually for smooth action. Once the position is confirmed, the user can save the position into the controller memory.

The coordinate (0, 0) is the starting position of the rack coordinate of X-axis and Z-axis. This position is relative to a "Home" position which is defined by a proximity sensor for each axis. Other coordinate points (X, Z) are then relatively referred to coordinate (0, 0) at rack cell positioning. The loading bay and unloading bay positions are also relative to "Home" position. These three positions are critical positions to the system. Once these positions are saved, the user can still view these positions (X, Z) and modify them at any time. The taught positions will saved into the system memory. No teaching is required once the positions are satisfied. It is worthy to note that improper teaching positions would result in undesirable response at the following action mode.

The WMS also provides manual operation option for the racking system. The manual operation includes X and Z axis jogging and SRM pneumatic grippers. Every single pneumatic cylinder can be manually driven via the WMS. The WMS provides another option for action. This option provides fully automatically actions, data searching and data matching process as well as communicating with other modules. It is the desired design that the system is supposed to response. The WMS will list down all action jobs being entered by the user with all details regarding the products such as the action, the identity (ID), the sequence number and the rack cell coordinate. The user can enter the jobs without waiting previous job to be completed. Meanwhile, the user can cancel all listed jobs if mistakenly entering an action call.

With proper setup, the system would work or perform normally as described below:

1. At the Receiving station (along the material handling conveyor), an operator loads a part on a tray and enters a relevant product ID and action mode via WMS. A job is automatically generated at the WMS and command the SRM to perform accordingly.
2. Then, he/she presses a button to release the tray with predefined products to the loading bay. The tray is then release toward the loading bay. Multiple trays can be lined up in sequence.

3. If the action mode is "Storage", the job is "Storage". The SRM would fetch the tray in the loading bay and load into a pre-defined rack cell.
4. If the action mode is "Bridge", the job is 'Bridge". The SRM would fetch the tray in the loading bay and unload into the unloading bay.
5. Besides, the operator also can enter a product ID and check the action mode: "Retrieval", together with its criteria, FIFO or LIFO.
6. If the action mode is "Retrieval", the job is "Retrieval". The system would auto figure out the coordinate location based on input ID and criteria. The SRM would retrieve the tray from the rack cell and unload it onto the unloading bay.
7. At the Picking and Sorting station, the sorter robot would sort the product based on the ID passed over from the SRM during 'Retrieval" completed. If the ID is "0124", then sort the product to the right else to the left. If the ID is "0000", no sorting is needed.
8. The empty tray would auto recycle back to the Receiving station. The process repeats.

The WMS will provide a data management facility, so that the user can read or check or modify the items in the rack cells according to the coordinate assignment. The information will provides identity (ID) and the sequence of each products being stored.

3.2 Modular Design

There are three design concepts to be achieved, namely flexibility, expandability and modularity. The system layout can be divided into multiple modules in a meaning way. Each module has its controllers and is programmable. The controllers have provided flexibility to the designer to reconfigure the logic sequence or formula without modifying tediously the wires. Besides, since the design is modular, the system can be expanded as more modules are added into. The benefit of modular design also facilitates system setup as well as maintenance because other modules will not be affected directly when any single module is setup or under maintenance.

The system is designed in module and integrated later. The system can be divided into four major modules, the Racking System and the WMS, the Material Handling System (MHS), the Sorter Robot, and lastly the Communication.

3.3 The Racking System and the WMS

The racking system is a standalone system in CIM. It is mainly to store/retrieve trays (Figure 3.2) from the rack. Each tray carries a product which is coded, and recorded by the WMS. The SRM is a two-axis servo driven mechanical machine with a multi-cylinder end-effectors. It moves at X and Z directions so that the end effectors can store/retrieve trays as commanded by the user. The racking system controller will communicate with other controllers and a host computer at the integration stage.

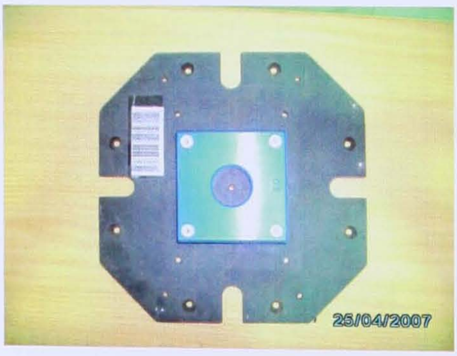

Figure 3.2: The tray, the product and the product in the tray

The racking system consists of a rack of eight rows times' nine columns as Figure 3.3 shown. Each cell is 283mm in width and 151mm in height except row3 to row4 where the height is 228mm.

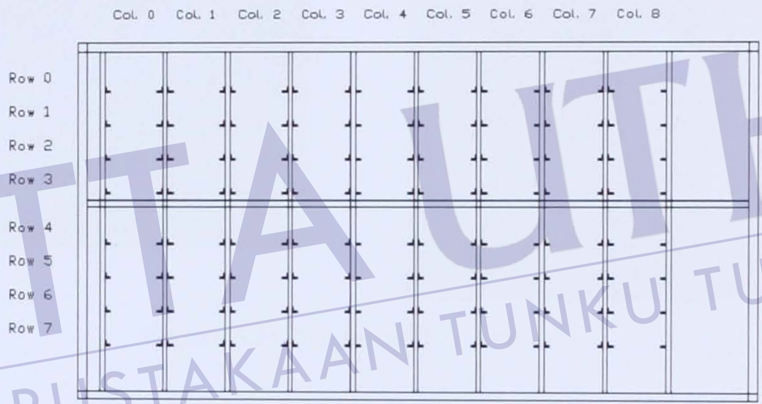

Figure 3.3: The Rack in row and column

Figure 3.4: The Racking and SRM

Figure 3.5: X-Axis and Z-Axis

In the view of the device level, as Figure 3.4 and Figure 3.5 shown, the SRM has two axes of movement, namely X-Axis and Z-Axis and a set of pneumatic end-effectors for storing/retrieving. Both axes are driven by a servomotor to achieve position exactly as command. The pneumatic end-effectors will work at two directions. One direction is facing to the rack for storing/retrieving; other direction is facing the material handling conveyor for loading/unloading. At both directions, a pneumatic gripper will be triggered to securely grip the tray (Figure 3.6).

Figure 3.6: The SRM pneumatic end-effectors for storing/retrieving

The SRM multiple cylinders end-effectors contain two linear cylinders and a rotary cylinder. The linear cylinders is named SRM_In (SRM_Out) and SRM_Grip; while the rotary cylinder is named SRM_Turn In (SRM_Turn Out).

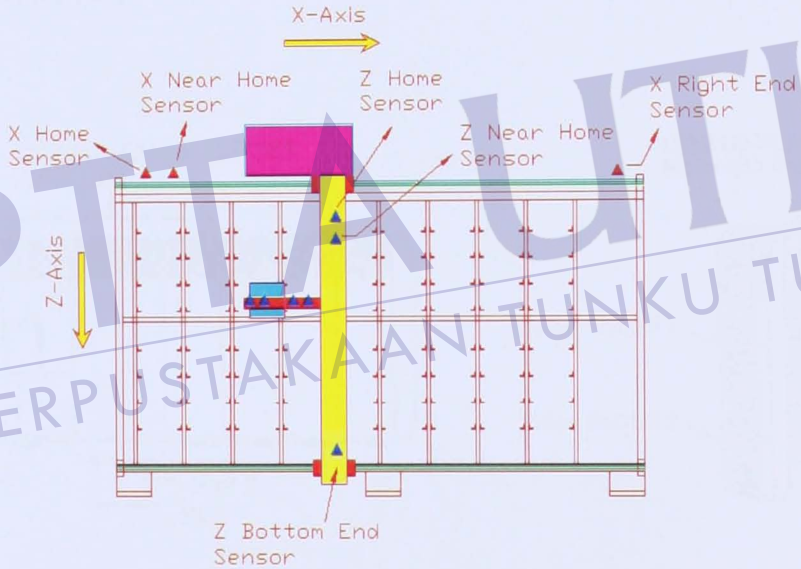

Figure 3.7: The SRM: Home position and (X, Z) direction

Figure 3.7 shows the X and Z axis sensor locations. The "Home" position is defined at left of X axis and at top of Z axis. The "Near Home" sensor would slow down the X and Z drives as the drives are approaching toward "Home" sensor. The "X Right End" sensor and "Z Bottom End" sensor prevent the drives to overrun.

Both axis of the SRM do not use rotary increment encoders to feedback the position rather the control of the position is of semi-closed type. By default, the servomotor is built in with an encoder which is feedback to the servo amplifier. The PLC does not read the encoder feedback from the servomotor. The servo amplifier would step the servomotor according to the number of pulses output by the programmable logic controller (PLC). Once at stop (power is ON), the servomotor is locked at both clockwise and anti-clockwise direction, providing an absolute position hold. In the view of the controller level, the PLC is CQM1H-CPU51 of Omron, with an inner board of pulse I/O that supports two pulse inputs and two open collector type outputs. The pulse I/O board is type CQM1H-PLB21 (Figure 3.8). The pulse output can output at maximum 50 KHz. Figure 3.9 shows the wiring example of a pulse output to a servo driver. The details of Pulse I/O board can be found in instruction manual of "Sysmac CQM1H Series" [12] as well as the PLC instruction to output pulses [13].

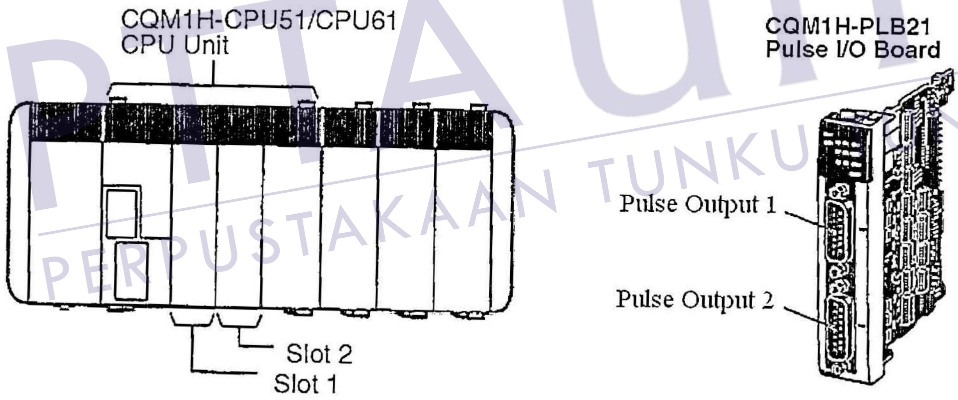

Figure 3.8: The PLC and Pulse IO Board [12]

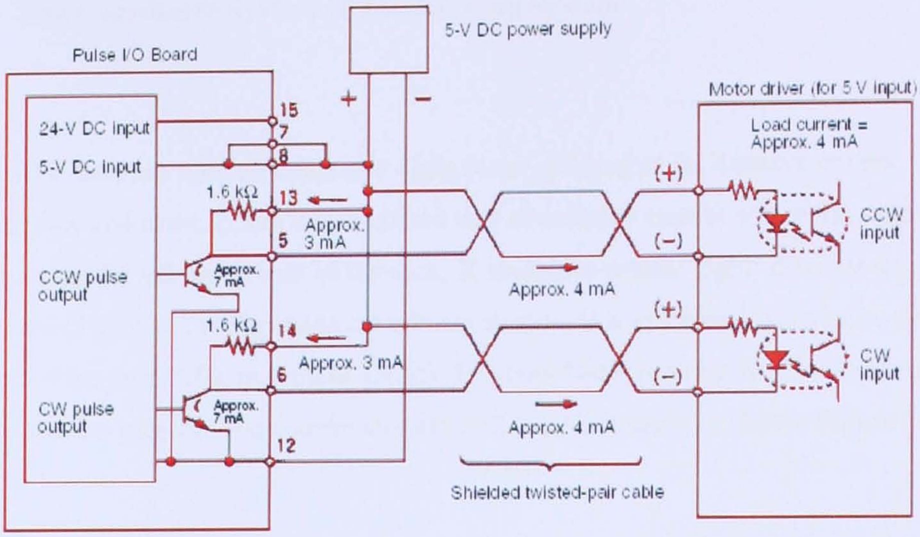

Figure 3.9: Pulse Output Wiring Diagram [12]

The X and Z servomotors are of Mitsubishi, type: HC-PQ43 with servo amplifier MR-C40A. The detail of the servo amplifier settings can be found in "Servo Motors and Servo Amplifiers Instruction Manual – MR-C" [15]. The racking system control panel is shown in Figure 3.10. More details of the IO assignment of the PLC of the racking system can be found in Appendix A.

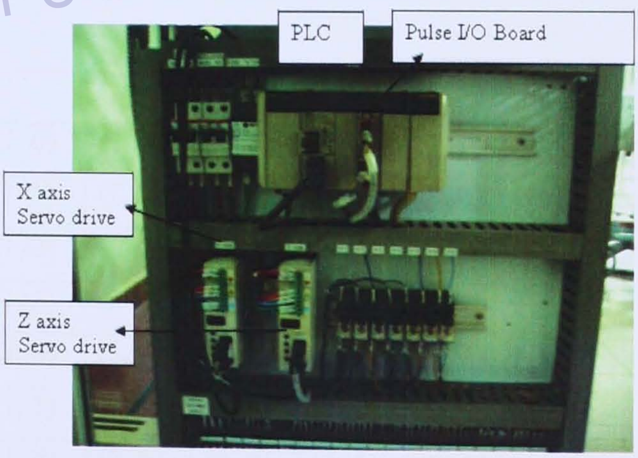

Figure 3.10: The Racking System Panel

3.3.1 The Coordinate System of The Racking System

The rack has nine columns and eight rows, pitching at fix distance except between row and row4. It can be visualized as a coordinate system where the origin start from the far left top corner of the rack; X increases toward right; Z increases downward (Figure 3.11). By using coordinate system, it is systematical to name the position of the rack cells, in term of (X, Z). The coordinate naming will be consistent through out the project. The coordinates are collected in a table as shown Figure 3.12.

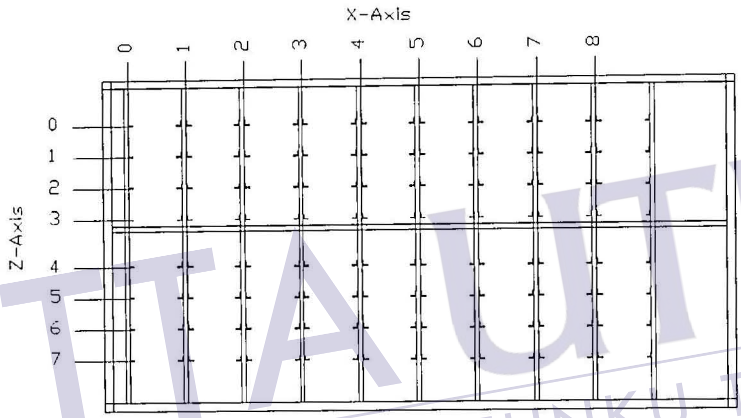

Figure 3.11: The Rack Coordinate System: (X, Z)

	X →								
	(0, 0)	(1, 0)	(2, 0)	(3, 0)	(4, 0)	(5, 0)	(6, 0)	(7, 0)	(8, 0)
	(0, 1)	(1, 1)	(2, 1)	(3, 1)	(4, 1)	(5, 1)	(6, 1)	(7, 1)	(8, 1)
	(0, 2)	(1, 2)	(2, 2)	(3, 2)	(4, 2)	(5, 2)	(6, 2)	(7, 2)	(8, 2)
	(0, 3)	(1, 3)	(2, 3)	(3, 3)	(4, 3)	(5, 3)	(6, 3)	(7, 3)	(8, 3)
Z ↓	(0, 4)	(1, 4)	(2, 4)	(3, 4)	(4, 4)	(5, 4)	(6, 4)	(7, 4)	(8, 4)
	(0, 5)	(1, 5)	(2, 5)	(3, 5)	(4, 5)	(5, 5)	(6, 5)	(7, 5)	(8, 5)
	(0, 6)	(1, 6)	(2, 6)	(3, 6)	(4, 6)	(5, 6)	(6, 6)	(7, 6)	(8, 6)
	(0, 7)	(1, 7)	(2, 7)	(3, 7)	(4, 7)	(5, 7)	(6, 7)	(7, 7)	(8, 7)

Figure 3.12: The Coordinate System Table

Since the servomotor will step according to the number of pulses, the coordinate system must be converted into pulse number format as to locate the (X, Z) position. There is a need to find out how many pulses to move X or Z 1mm linearly or what is the measurement in mm for one pulse. Studies of both X and Z drive mechanical structure is necessary as well as the characteristic of the servomotor.

Both X and Z axis dynamic drives are studied as shown. It is worth to note that both X and Z axis use timing belt for linear movement; the revolution movement of the servomotors are changed to linear movement via gear and timing pulleys, with pre-defined ratio. Figure 3.14 and Figure 3.14 show both Z and X axis drives structure. Figure 3.15 shows the side view of a timing belt. Both X and Z axes use the same type of timing belt.The servo drive and servo motor is of Mitsubishi as listed below:

Servo Amplifier	MR-C40A
Servo Motor	HC-PQ43

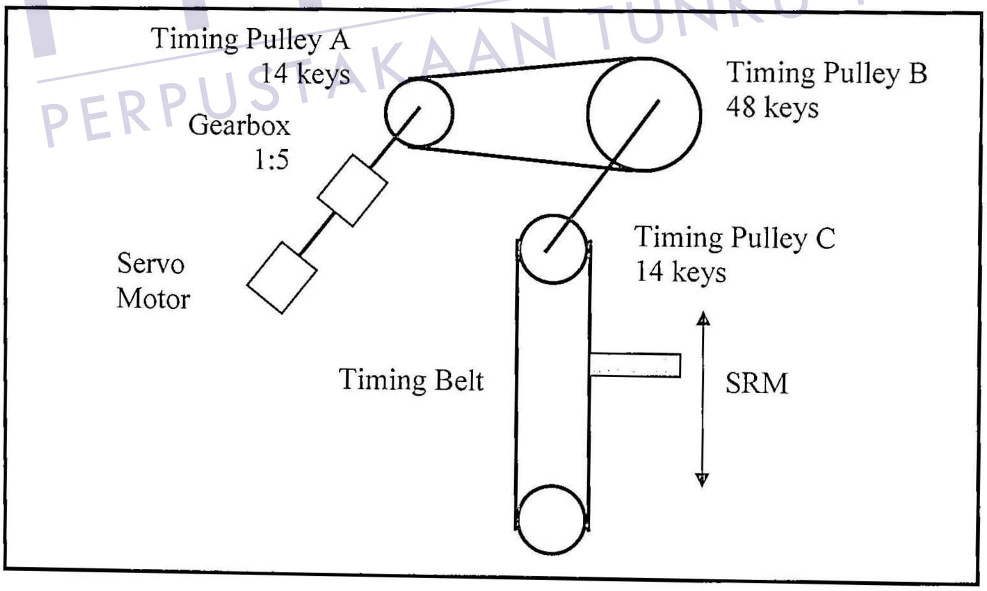

Figure 3.13: Z-axis Drive and Gear Ratio

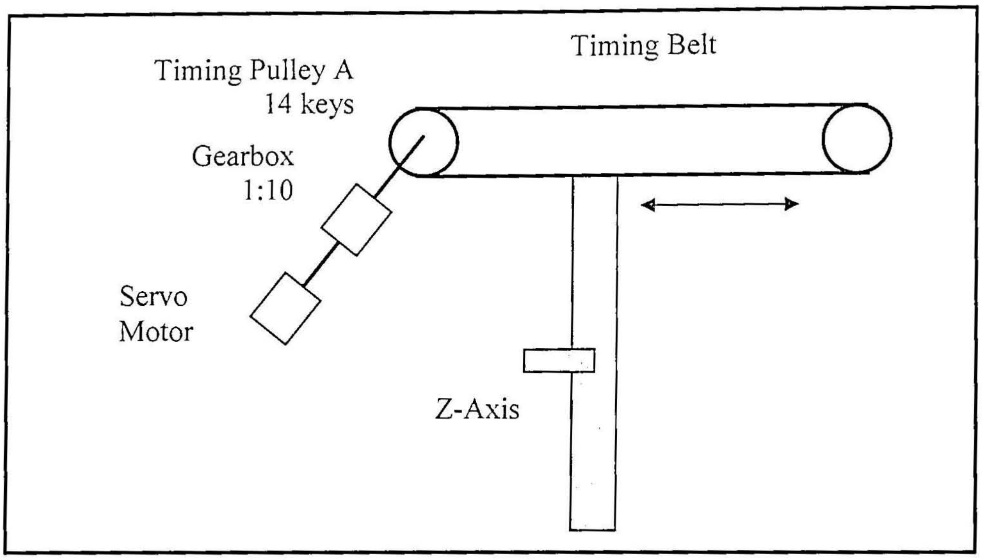

Figure 3.14: X-Axis Drive ad Gear Ratio

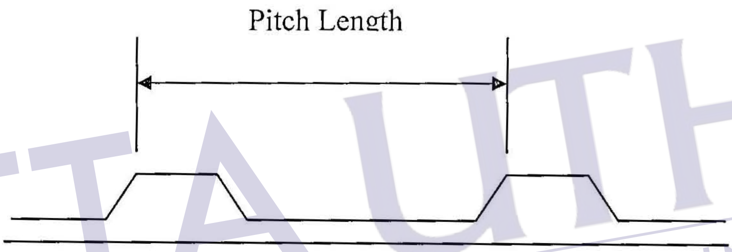

Figure 3.15: The Timing Belt

Via the relationship of the gear, we can calculate the linear movement in term of millimeters if a certain amount of pulses is fed into the servomotor. Before we actually drive the servomotor, there is a key function of the servo amplifier that would affect the precision. The function is the electronic gear, as shown in Figure 3.16.

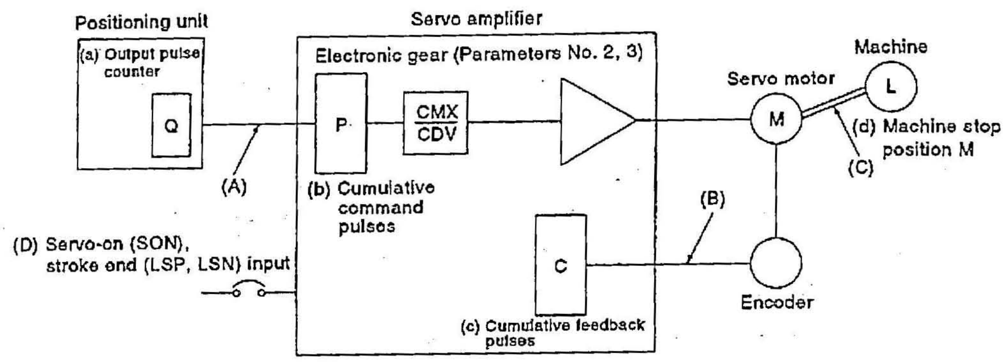

Figure 3.16: Electronic Gear [15]

By default, the electronic gear $\frac{CMX}{CDV}$ is at ratio 1:1 and the servomotor would revolute 360^{o} if 10000 pulses are fed into the servo amplifier. If $\frac{CMX}{CDV} = \frac{2}{1}$, then the servo amplifier needs only 5000 pulses to drive the servo motor for 360^{o}. If $\frac{CMX}{CDV} = \frac{1}{2}$, then the servo amplifier needs 20000 pulses to drive the servo motor for 360^{0}. It is a linear form of relationship. In that sense, the electronic gear amplifies or reduces the pulse number. Somehow, if the electronic gear is set above 1, the servomotor is said to lose its precision. While, if the electronic gear is set below 1, the servomotor would take more pulses to make a 360^{0} revolution. This would take more time to complete a revolution. Through out the project, both electronic gear settings for X and Z axis are set at 1:1, which means 10000 pulses to make a 360^{o} revolution.

Based on the mechanical drive structure and the servo amplifier characteristic, we need to formulate a mathematical relationship so that we can feed in a certain amount of pulses to the servo amplifier and to move X and Z-axis linearly as planned. It is a linear formula since all the gear ratio and the electronic gear all in linear form. X is pitching in 283mm while Z in 151mm. Hence, it is necessary to find out the number of pulses to drive X axis so that it will move linearly 283mm. So does the Z axis. After that, the rack coordinate system can be converted in pulses number format, of which is necessary in the application.

There is no detail mechanical design specification, regarding the rack dimension and the drive system. Thus, the drive precision per rotation cannot be calculated through the mechanical drive ratio. It is necessary to map the coordinate system into a coordinate system made-up of servomotor pulses number, both X and Z axis. The servomotor has the two main characters. Firstly, it can revolve as according to the number of pulses. Secondly, it always maintains at the specified position once stop. These characteristic can be used to formulate a linear mathematical equation. The result is retrieved through an experiment. The experiment is performed to retrieve the pulses precision. By default, the servomotor is capable of revolving 360^0 per 10000 pulses. This experiment does not need to consider the gear ratio of the mechanical structure. Both X and Z servomotors are fed with 40000 pulses separately, making four proper revolution. The traveling distance of the SRM in X and Z axis are measured. Pulse frequency is not important.

The experiment results show that:

Z-axis: pulses : mm = 40000 : 104

X-Axis: pulses : mm = 40000 : 177.875

Finally, we can conclude the experiment results into a mathematic equation for each axis, using the relation as below.

$$pulses\_numbers = \frac{Desire\_Length(mm)}{Length\_after\_40000\_pulses} \times 40000$$

The Z-axis: $$P\_Z = \frac{L\_Z}{104} \times 40000$$

The X-axis: $$P\_X = \frac{L\_X}{177.875} \times 40000$$

In X axis, the rack cell is pitched at 283mm which is equal to 63640 pulses. In Z axis, the rack cell is pitched at 151mm which is equal to 58077 pulses. Figure 3.17 shows the coordinate system in term of pulse number.

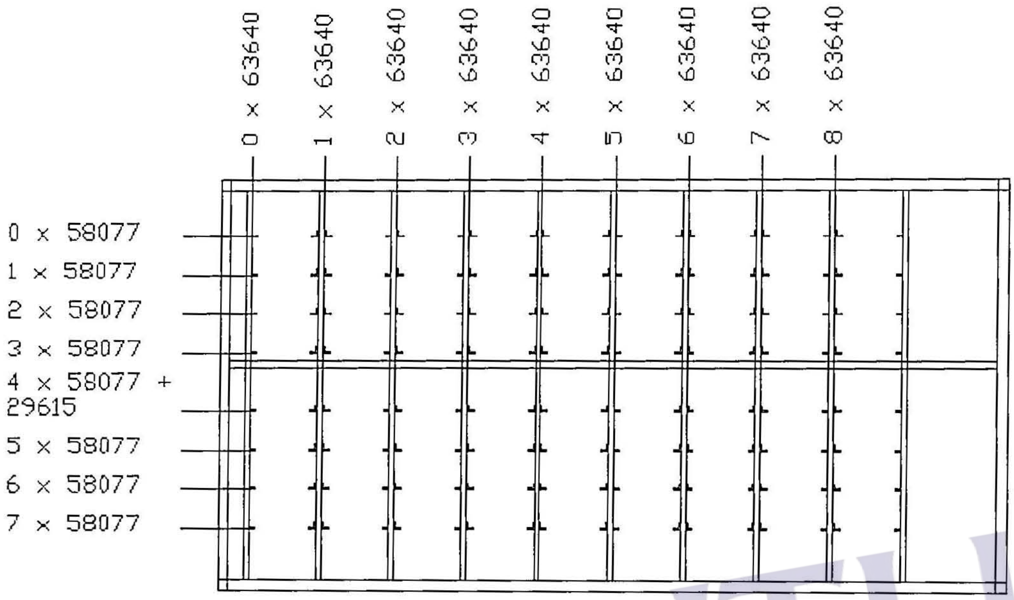

Figure 3.17: The Coordinate System in pulses number

3.3.2 Software Planning of The Racking System

This section explains the structure of the racking system software and functions. A host computer is communicating with the PLC. The host computer displays graphic user interface (GUI) which acts as the function of the racking system local control as well as a simple WMS. For the purpose of local system control, the GUI has the following functions, namely Manual Operation, "Home" Operation, Coordinate Teaching Operation and Text Status.

The Manual Operation will provide a GUI for command the SRM when the operation mode is manual. It includes individually commanding X and Z axis and the

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