1. Introduction

With the increased computing power and the advances in artificial intelligence, smart robots are now marching into every possible corner of the industrial field and our daily lives. Brainless machines and hard automation systems are being replaced by intelligent systems with sophisticated sensors and flexible functionalities. The design and development of such modern systems sits on the foundation of mechatronics, robotics, computer systems, artificial intelligence, machine vision, automation control, etc. An intelligent system, a robot, or a control system follows the same product development cycle just like any other product on the market. Design analysis, modifications, testing and retesting are unavoidable for any new product development. The aim of the Integrated Intelligent MechRobot System (IIMRS) is to provide a physical platform to support the design and development of intelligent machines and automation systems, which is becoming an increasingly complex and difficult task.

IIMRS is an integrated system. It mimics an automated shop floor [1]. The system consists of two robots, one microcontroller-based autonomous robot, the other is a 4-axis pick-and-place robot controlled through a PC. A pneumatic transport frame with two pallets and two robotic grippers is for transferring components between different locations. The pneumatic system is controlled using two industrial PLCs. Quality data acquisition and control relies on a computer-based vision system. All the subsystems in IIMRS can also be linked through a network. The schematic diagram of the whole IIMRS system is illustrated in Figure 1. The first version of IIMRS has been successfully implemented in the Institute of Technology and Engineering at Massey
University. It is currently used for undergraduate and postgraduate teaching and research projects. IIMRS provides a physical environment with features and functionalities commonly used in robot control, mechatronic system design, and industrial automation. IIMRS provides a platform a robot, a control system, or an assembly line to development new control strategies and test new functionalities. It also simulates and motivates designers to further improve existing systems and develop new ideas. The system has been used in studying mechatronics applications and the design and testing of autonomous robots.

2. Autonomous Robot Design

Automated Guided Vehicles (AGV) have become common facilities on the factory floor for transportation and material handling. The autonomous robot
running under IIMRS mimics the common functionalities of a real AGV [2], [3]. The “brain” of the vehicle is a microcontroller with embedded programs. It is designed to be able to perform the functions commonly implemented in an AGV such as [4], [5]:

1) Auto-recognize part loading and unloading
2) Give warning signals
3) Avoid obstacles on its path
4) Transfer parts to different destinations
5) Accurately position the parts for the robot to pick up

The starting position of IIMRS is located at position A as shown in Fig 1. At the beginning the autonomous robot will stay at position A waiting for the part to be loaded. The 4-axis pick-and-place robot is able to sense the appearance of the autonomous robot. Once the part is placed on top of the autonomous robot, it will trigger the robot to move from location A towards G via F. The route from A to G simulates an AGV on an open factory floor delivering parts to different locations with the possibility of having to overcome obstacles on the way. Different sensors and methodologies such as proximity sensors, laser guidance, electrical compass, and beacons are all successfully used for guiding the autonomous robot to avoid the obstacle and correctly guide the robot to arrive at position G. The autonomous robot is required to be parked at position G between the two dark lines for a few seconds. This imitates the situation of a part under some service. Once the time has elapsed, the robot will move towards position E by following a defined line to send a part for the robot gripper at location E to pick up. Such a functionality of an autonomous robot is often seen on production and assembly lines. The autonomous robot is required to be able to accurately position the part under the pick-and-place robot at location E for the gripper to pick up the part. When the part is unloaded, the autonomous robot will follow the path back to position A and position itself for the next cycle.

The brain of the autonomous robot is a C8051F020 microcontroller from Silicon Laboratories (SiLab). The SiLab C8051F020 is a fully integrated microcontroller with mixed-signal system on a chip. The main features of the microcontroller are listed in Table 1.
Table 1. SiLab C8051F020 Microcontroller

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Peak throughput</td>
<td>25 MIPS</td>
</tr>
<tr>
<td>FLASH Program Memory</td>
<td>64K</td>
</tr>
<tr>
<td>On-chip Data RAM</td>
<td>4352 bytes</td>
</tr>
<tr>
<td>Full-duplex UARTS</td>
<td>x2</td>
</tr>
<tr>
<td>16-bit Timers</td>
<td>x5</td>
</tr>
<tr>
<td>Digital I/O Ports</td>
<td>64 pins</td>
</tr>
<tr>
<td>12-bit 100ksps ADC</td>
<td>8 channels</td>
</tr>
<tr>
<td>8-bit 500ksps ADC</td>
<td>8 channels</td>
</tr>
<tr>
<td>DAC Resolution</td>
<td>12 bits</td>
</tr>
<tr>
<td>DAC Outputs</td>
<td>x2</td>
</tr>
<tr>
<td>Analog Comparators</td>
<td>x2</td>
</tr>
<tr>
<td>Interrupts</td>
<td>2 Levels</td>
</tr>
<tr>
<td>PCA (Programmable Counter Arrays)</td>
<td></td>
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The following example is just one of the many autonomous robots running under IIMRS. This robot uses proximity detection for obstacle avoidance. Modulated IR sensors are used as the proximity detection units. The autonomous robot has two such units, one on each front corner. It is programmed to turn away from the object when an object comes within 6 cm. If both the proximity units are activated at the same time, the robot will back away from the obstacle and turn. The guidance for the robot to move from location A to G via F is provided by beacons using IR sensors. Each beacon unit has two outputs, one for directing the robot and the other for stopping the robot when it reaches the destination. The robot identifies the beacon units through different frequencies. The receivers on the robot are linked to a microcontroller and the microcontroller is able to identify which beacon it is communicating with. Using beacon units make the guidance for the autonomous robot very flexible. As the beacon units can be placed at different locations, it is easy to expand the system to have more destinations at different locations for the robot to move around. In Figure 2, location F and G each has a beacon unit to communicate with the autonomous robot. The ability of the autonomous robot communicating to the beacons and then using the beacon’s positions correctly to direct the robot to location G via F can be easily demonstrated.
3. Pick and place robot for loading and unloading

A PC-based pick-and-place robot shown in Figure 3 is integrated in IIMRS for part loading and unloading [6],[7]. A motion control card from National Instruments is implemented in the robot control system. The motion control card is a combination of a servo motor and stepper control card. It can provide full motion control for independent as well as coordinated four-axis motions. The servo axes always operate in closed loop control. All the stepper axes support half and full step as well as microstepping possibilities. The driver software called NI Motion is also from National Instruments, which allows creating motion control applications using the graphical programming Motion Assistant. With Motion Assistant, it is possible to transfer the application program to either a LabView program or a program in other computer languages such as Visual Basic, C, or C#.

The robot has 4 motors and the motion control card can cope up to 4-axis control. The 4 motion control axes for the robot are defined as:

- Motion control axis 1 - X axis (robot base rotation)
- Motion control axis 2 - Y axis (lower arm rotation)
- Motion control axis 3 - Z axis (upper arm rotation)
- Motion control axis 4 – Gripper movement
Figure 3. A 4-axis PC-based pick-and-place robot

A software program for the control of the robot is developed using LabView. The control panel for the robot arm is presented in Figure 4. The control system has two modes, automatic and manual, which can be toggled through the push button on the panel. The control panel also provides a user friendly interface to teach the robot and define the pick and place positions. There are two indicators on the panel, one for indicating that a part has arrived at location A and another for signalling the autonomous robot is ready for loading. Only until both indicators are switched on can the robot arm be activated. In other words, the Boolean “AND” of the two indicators trigger the pick and place movement of the robot arm.
Figure 4. Pick and Place Robot Control Panel

The robot works closely with a part data collection system. Based on the data of the part such as geometry and dimensions, the robot is able to identify differences and perform part sorting functions. Such processes are commonly used for product quality control. In IIMRS, each time a part is delivered to location A by pallet 1, the robot will load the good part on top of the autonomous robot and put the bad ones into a bin.

4. Part Handling System

The part handling system is a pneumatic system controlled by two Omron Programmable Logical Controllers (PLC). The pneumatic frame consists of two pallets and two pneumatic grippers refer to Figure 1. Apart from picking and placing functions, one of the grippers can also rotate to place components at different orientations. Each PLC controls one pallet and one pneumatic gripper. Sequential control is implemented in the control system. The pneumatic system is activated by the autonomous robot. Each time the autonomous robot arrives at location E and correctly positions the component under Griper 2, the pneumatic system will be trigged by a sensor. Griper 2 will come down and pick up the part and travel to Location D to place it into the holder on top of Pallet 2. After Gripper 2 is returned, Pallet 2 will move the part from Location D to C. The controls are realized through an Omron PLC. The corresponding
state diagram is illustrated in Figure 5. The other PLC is for the actions from Location C to A via B. The process functions are very similar except the griper is able to rotate up to 90 degrees. Once the part is transfer to Location C, Gripper 1 will pick up the part and rotate 90 degrees first, and then transfer the part to Location B. When Gripper 1 puts the part in Holder 1, the part is in a new orientation. Pallet 1 will then send the part to Location A.

![State Diagram](image)

**Figure 5.** The state diagram for the control from position E to C.

5. **Real-time data collection**

A real-time data collection system is implemented in IIMRS. The system is running on a PC. Each time when a part is transferred from Location B to A, it will pass the data collection point where the information of the part is captured through different sensors or by a camera. The part data is processed in real time and then output the control information the pick and place robot at Location A. If the part does not have the correct geometry or wrong size, the robot at Location A will pick it out. Otherwise it will be put on top of the autonomous robot to activate the next cycle.
The following example uses a camera in the data collection system. While pallet 1 travels from position B to A, the system controlled by the PC will recognize the badly made components. When a problem part is recognized, the system will give an alarm signal. To implement such a system a computer-based vision system is developed. This system visually checks whether parts on pallet 1 moving from position B to A are faulty or not. This vision system uses a Logitech QuickCam webcam with a USB plug. The system is developed under Visual Basic 6.0 (VB). When the VB program is run the system creates a capture window to display the streaming video from the webcam. Through Microsoft WDM Image Capture driver it is possible to get the image from the webcam to the capture window. Once the image has been taken of the part the image processing is immediately done to extract the data from the image. Part length, width, and area are the three variables to be measured. The whole image is scanned and any pixel less than a preset variable is the part and coloured red and any other pixel is said to be background and set to light blue.

A Graphical User Interface (GUI) is designed to give a visual display of what is happening. Figure 7 shows a screen capture of the program running and a correct part passed through.

![Figure 7: Screen capture of a good part.](image1)

![Figure 8: Screen of a part that was short.](image2)

The top left window shows the live streaming image from the webcam, the top right window shows the captured image that is to be processed. The bottom left window shows the processed image and note the shape of the bolt has been brought out in red. The bottom right frame show data about parts being passed through. It displays the number of parts passed through, showing parts failed and parts passed. Also for each image that is processed it displays the value calculated for bolt length, bolt width and bolt area. Then there is a large clearly
visible text area which displays the result of each part processed as shown in Figure 7 and 8.

6. Conclusions

The framework and the functionality of IIMRS has been developed and implemented in the Mechatronics Laboratory at the Institute of Technology and Engineering, Massey University. The system covers the use of microcontroller, PLC, pneumatic equipment, motor control, sensing system, vision, and intelligent control. It provides a useful platform for engineering students to study both hardware and software. It is also an ideal test rig for robot design, automated pneumatic system, simulation of shop floor control, and intelligent factory automation. The system is now used for Mechatronics and engineering undergraduate teaching and as a test rig for autonomous robot design projects.

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References