Embedded Robotics Implementation

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1. Introduction

Technology of embedded systems has been widely implemented in the broad area, from industrial until household purposes. The term of embedded systems relates to systems that having one specific task to achieve. A printer machine, for instance, by which it is only used to perform printing purposes, however, currently it is not necessarily to having only one task. Similarly, in the area of robotics where there is an emergence idea of building embedded robotics. The idea is (1) to integrate the whole processing and controlling unit (PCU) of the robot into one integrated circuit (chip-based) system, and (2) to integrate several embedded PCU into one mechanism forming a new embedded robot.

The first approach covers the traditional implementation of embedded system onto robot mechanism. One chip, typically, responsible for the whole processing and controlling purposes. Current development is by integrating more PCU chips with one chip acting as the master PCU. The tasks that the robot can cover can be more than one, but the processing and controlling is governed by the master PCU. Hence, latency issue is raised and when the workload is increase, a bottleneck will exist in the robot mechanism.

The second idea is by integrating several PCU will be a plausible way in solving the issue of latency of the first approach. The whole PCU chips work inter-independent in which allows different tasks to be performed at the same time while keeps the coordination and synchronization within the framework.

The hardware implementation of both approaches involves the microcontroller technology and the most recent one is with the FPGA-based technology. Within the advancement of technology in areas, microcontroller and FPGA-based have become potential ways in the course of implementation of embedded robotics.

The coming subsections will discuss the aspects of robotics technology and microcontroller technology. Literature studies are also presented as the source of information on the current research works in related area. As to keep the focus of the paper on the implementation of microcontroller, the discussion on the FPGA-based will not be presented.

1.1 Robot Overview

In the book of the Robotics Primer [6], the author describes five fundamental elements of a robot, i.e. an autonomous system, exists in a physical world, senses its environment, acts towards the sensor information and achieves some goals. Relating to the theme of the paper, we will only discuss the four elements and the existence in a physical world will be excluded as it focuses on the aspect of design and robot environment.

A robot as an autonomous system forms the basis of self-reliance. In other words, the robot acting is based on its own decision and free from human control interference in the sense that robot may obtain input and advice from humans, but not completely controlled. Furthermore, with the element of robot existence in the physical world guarantee that a robot is physically existed, not an imaginative world. The last two elements cover the sensing and acting courses. Sensing relates to the sensor technology which is used to capture information and extracted into a process-able format, while acting relates to the moving of actuators in regards to specific information.

Having a brief discuss on the meaning of robot, we then now discuss the robot paradigms [9] which is a major concept in intelligent robot. There are three paradigms that are strongly related to the sense-plan-act primitive of robot. Firstly, the sequence of the robot primitives is organized in order known as hierarchical paradigm. In this paradigm, the robot senses the world, makes the plan for the next action, and then executes (sense-plan-act). Figure 1 below, shows the view of this paradigm

Robot Primitives	Input	Output
Sense	Sensor Data	Sensor Information
Plan	Information (sensed and/ or cognitive)	Directives
Act	Directives	Actuator Commands

Figure 1: Hierarchical Paradigm [9]

Secondly, the organization of robot is based on the sense then act type or reactive paradigm. It assumes that output of the sense is a direct connection to an act. Figure 2 illustrates the flow of the mechanism.

Robot Primitives	Input	Output
Sense	Sensor Data	Sensor Information
[redacted]		
Act	Sensed Information	Actuator Commands

Figure 2: Reactive Paradigm [9]

The last paradigm is hybrid deliberative/reactive paradigm. This paradigm is formed from the reactive paradigm with an addition a plan is preceded by a plan (deliberative). This type does not necessarily contain one specific behavior. Each behavior is connected to the planner and then, the planner decides which behavior is best suitable for a specific task. The organization of sensor is the combination of the hierarchical and reactive styles. Each sensor data is distributed to each behavior and to the planner for scheduling and construction of the world model of the task. This mechanism is illustrated in the figure 3, below.

Robot Primitives	Input	Output
Plan	Information (sensed and/ or cognitive	Directives
Sense-Act (Behaviors)	Sensor Data	Actuator Commands

Figure 3: Hybrid Deliberative/Reactive Paradigm [9]

1.2 Microcontroller Technology

One major distinguishing feature of microcontroller compared to any general purpose microprocessor is the integration of several elements, typically, RAM, ROM, Input/Output Ports and Communication Port onto one single chip. Several companies that produce the chips become more competitive and currently, some developments have been made by adding more features onto the microcontroller chips, such as analog to digital converter (ADC) and camera interfaces.

Regardless of the availability of various microcontroller chips in the market, there are certain important criteria in choosing a microcontroller [3]. The first one is that the task at hand to be performed. Consideration of this first criterion is

- The amount of bit representation to be involve during the processing and computing. Some options whether to use an 8-bit, 16-bit or a 32-bit microcontroller that can handle effectively the computing requirement.
- Speed of the microcontroller that can support.
- Packaging which concerns with the terms of space, assembling process and the prototyping of end product. The options are dual inline package (DIP) or quad flat package (QFP).
- Power consumption which targeted in the energy usage from battery-powered products.
- The availability of RAM and ROM size, the number of I/O ports and the timer on chip.
- Upgrading or downgrading purposes should maintain the minimum cost and the ease of the process.
- The cost of per unit which is important calculating the cost of production.

The second criteria is the easiness whenever developing products from the chosen microcontroller. This includes the availability of

- An assembler
- Debugger
- Compiler for various programming language
- Emulator
- Technical support
- Expertise in-house and outside

The third one is quantities that available within the time when the products are initiated until the future needs. In some cases, the companies may cooperate with several different suppliers as to support the market requirements.

The last criteria is the company business strength which guarantee that the company that supply the microcontroller chip has a prolong trade record. This will assure that in the future, the designer will have a continually chip supply from the company.

1.3 Literature Studies

From the literature studies, it can be reported that implementation of microcontroller technology into the robots' PCU has been growing rapidly, particularly for education and research purposes. Several research works have been carried out, particularly, in the area of robotics, and some works are utilizing the microcontroller technology in their research experiments. Several works, for instance, in the implementation of web server-based for mobile robot, various microcontroller chips are utilized and some of these works are reported in [2]. Several microcontroller-based modules for robotic application, which are available on the market, also have employed this technology. For instance, an embedded microcontroller module, the EyeCon, which is used by the robotic group from the University of Western Australia for education purposes [4]. This microcontroller module is enriched with several features, such as a 25 MHz and 32-bit processor, LCD and color-grayscale camera interface. Similarly, with the research group at the University of Technology Sydney Australia which utilizes an embedded controller unit installed inside their four-legged robot bear project [8]. Similarly, Ferruz, *et al.* employs a microcontroller-based UAV controller as the PCU of their autonomous helicopter [5]. The authors argue that they can achieve an effective solution for lower level control, specifically power consumption and weights with the microcontroller chips. Another research work also employs this technology is reported in [11]. The authors describe that in their proposed sensor network system, microcontroller is installed for the sensor tier platform. Similarly, a fuzzy-based mobile robot control is developed through implementing the fuzzy control into a microcontroller [12]. In [13], it is reported the theoretical aspect of designing an embedded system. MCU which stands for microcontroller unit is embedded into a system forming a new embedded system called *Atomi*. In addition, the implementation of a hardware real time protocol (HRTP) for an embedded Ethernet robot system which utilizes the microcontroller technology is briefly discussed and explained in [15]. Several works in education, particularly in the undergraduate level from universities in the east region of Indonesia, have successfully implemented and developed microcontroller-based with simple task oriented robots. These works are reported in [1][7][10][14].

2. Microcontroller-based Embedded Robot Implementation

After considering the microcontroller and the robotics aspects, the implementation of a microcontroller-based embedded robot will be the main objective of this section.

2.1 Robot Organization Style

By referring to previous subsections on robotics technology, we can draw a conclusion that the most current approach in robot organization is by the Hybrid Deliberative/Reactive style. As a case study we will take a look to the design of an obstacle avoidance robot. Firstly, the implementation is by identifying and ordering specific behaviours that will take place during the robot performance. The hardware design and complete mechanism are illustrated in figure 4 and 5, below:

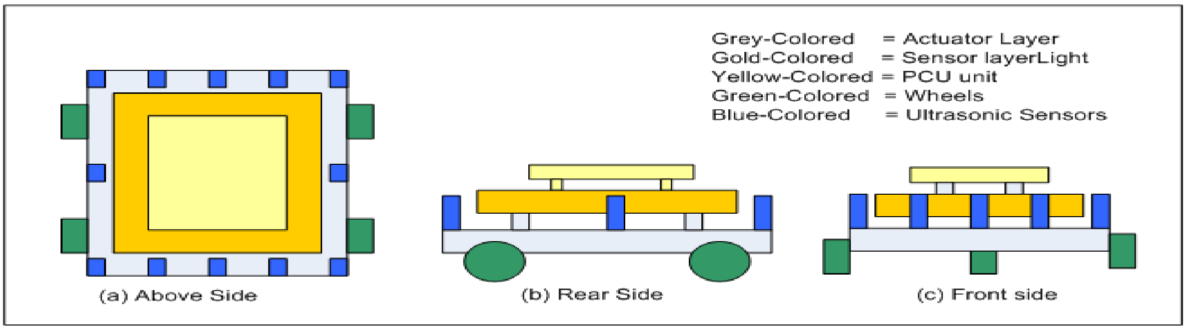

Figure 4: Obstacle Avoidance Robot

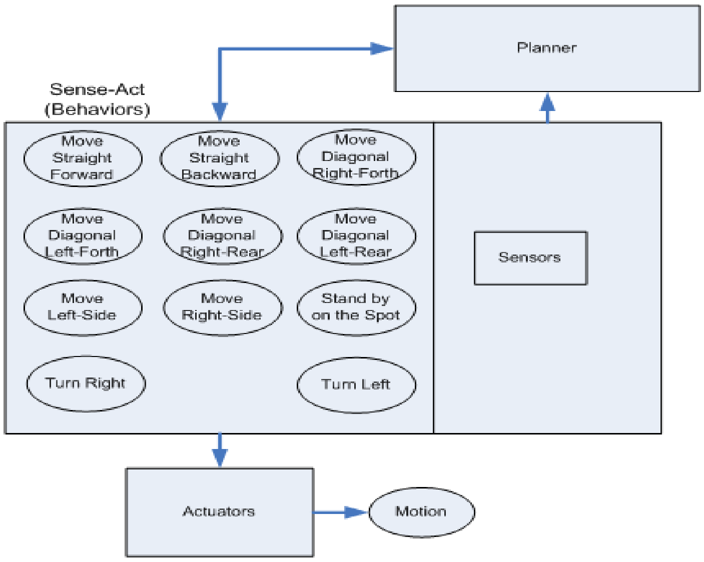

Figure 5: Embedded Robot Organizational Style

From Figure 4 and 5 above, it can be seen that there twelve sensors available for obstacle detection and PCU unit which contains sensor data extractor and eleven units of behaviour. As the Hybrid Deliberative/Reactive organization style is used, the planner obtains data from sensor extractor and delegate a specific behaviour to be executed. At the same time, data from sensors also distribute to all behaviors and will be monitored in order to match a specific behaviour to be carried out.

2.2 Microcontroller Unit

There are two approaches when implementing an embedded robot which have been mentioned in the early section and by choosing, let say, the second approach, we can decide to apply the system by utilizing several microcontroller chips. The total unit of microcontroller can be described in Table 1, below.

Table 1: Total Microcontroller Requirement

No	Name of Unit	Total Microcontroller
1	Planner	1
2	Behavior	1
3	Sensor	3
4	Actuator	1

From table 1, specifically at point 3, as the common type of microcontroller available in the market is a four-port microcontroller, the sensor unit requires three microcontroller chips. Final organizational mechanisms within the microcontroller usage is illustrated in the figure below,

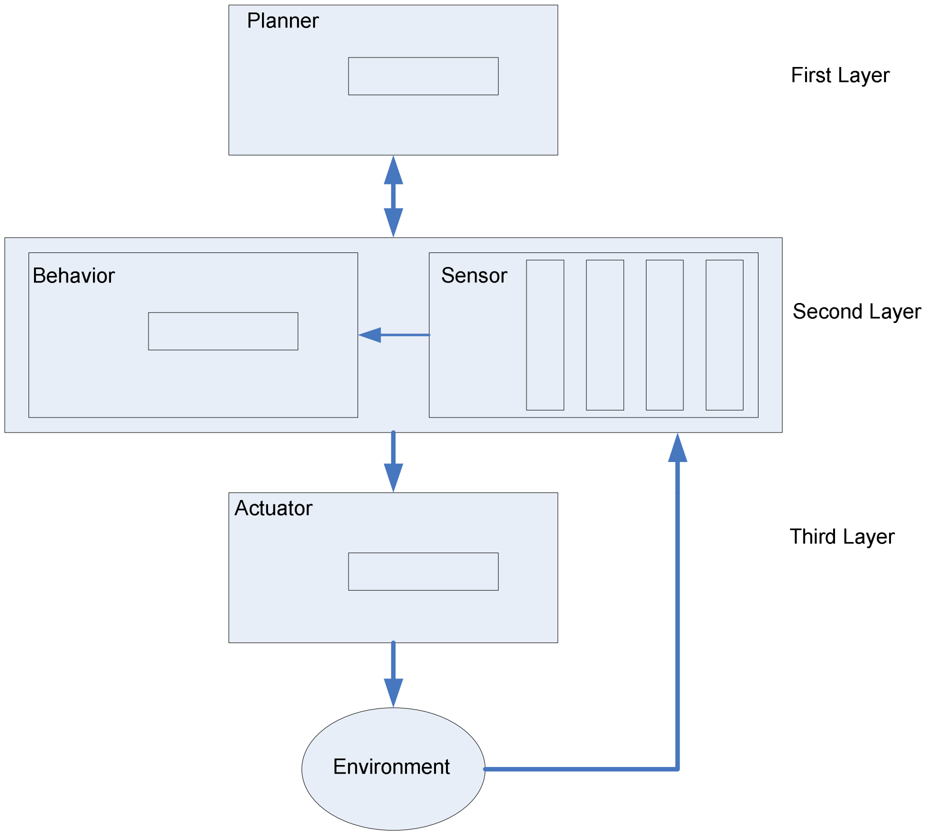

Figure 6: Microcontroller-based Embedded Robot Organizational Style

Of the figure above, those three layers which contains several microcontroller chips works in parallel allowing a faster respond to specific sensor data format.

In any implementation of embedded robotics, all layers do not necessarily involve more microcontroller chips. It must meet the designer requirement and of course, the efficiency and the effectiveness of the design.

3. Conclusions

Within the fast growing technology in robotics and chip technology, there is a seemingly increase of interest in designing embedded robotics. Within embedded mechanisms which promotes parallel processing and computing allows the enhancements on the robot capability.

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