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COORDINATION OF MOBILE-ROBOT SYSTEM WITH BEHAVIOR BASED ARCHITECTURE

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ABSTRACT

In this paper we propose an algorithm for coordinating a group of mobile robots that go through predefined paths in a dynamic industrial workplace. The coordination is characterized by a decoupled approach. Then, a behavior-based architecture be used as the underlying control representation providers a useful encoding that lends robustness to control. Some robot behaviors be designed to support for accomplishing industrial task. Four Lego Mindstorms robots used to implement the proposed algorithm. This research tackles the coordination movement issue in material handling in order to minimize the delivery time. Several experiment have been done to know performances of the system. The promising results have been proved that the proposed control architecture has better capability to accomplish useful task in real industrial-like environment.

Keywords: mobile robot, coordination system, multi-robot, behavior-based architecture.

INTRODUCTION

Indoor mobile robots are becoming reliable enough in navigation tasks to consider working with teams of robots. The use of multiple robots is often suggested to have several gains over single robot systems (Burgard *et al.* 2005). First, cooperating robots have the prospective to accomplish a single task faster than a single robot. A system of collaborative robots that jointly schedule a meeting which outperformed several single robot systems designed to accomplish the same task. Furthermore, multiple robots can localize themselves more efficiently if they exchange information about their position whenever they sense each other. Finally, using several cheap robots introduces redundancy and therefore can be expected to be more fault-tolerant than having only one powerful and expensive robot (Egerstedt, 2014), (Montano and Suarez, 2013) and (Quinonez *et al.* 2013).

Parker (2008) tried to differentiate types of interactions seen in system of multi-robot. These common forms of interaction are: collective, cooperative, collaborative and coordinative. The types of interaction is depended on awareness of robots, type of goals and action advance goal of others. Burgard *et al.* (2000) developed multi-robot system to explore an unknown environment by a collaborative multi-robot. Huang *et al.* (2015) developed a multi-robot system with collaborative system as well for carrying a large size box to a given destination. Then, in (Burgard *et al.* 2005) they designed a coordinate multi-robot for the same aims as before. A coordinated AGVs that go through predefined paths in a dynamic industrial environment had been proposed by Olmi *et al.* (2011). They used Coordination Diagrams (CD) for representing the possible collision among the vehicles. Another application in coordination of mobile robot have been presented by some researcher, such as (Trigui *et al.* 2012), (Cheikhkrouhou *et al.* 2014), (Zhao and Wang, 2013) and (Hoshino, 2011).

Coordination techniques are classified in Farinelli *et al.* (2004) for the wide class of the multi-robot systems. Focusing on mobile robots systems, the coordination strategies can be mainly classified in: centralized approaches and decoupled approaches. According to Olmi *et al.* (2011), the decoupled approaches are more suitable than centralized ones for dealing with coordination problems involving a big number of robots and scope of works.

However, each mobile robot also should face unpredictable environment, perceive inaccurate sensor and act with unsatisfactory actuator in high-speed response. Behavior-based control architecture is an alternative method appropriate to address these problems (Dongshu *et al.* 2011), (Khatoon and Ibraheem, 2012) and (Mo *et al.* 2013). The architecture is able to act with fast real-time response, provides for higher-level deliberation and has demonstrated its reliable performance in standard robotic activities.

In this paper, an algorithm for coordinating a group of robots so as to efficiently in time when accomplish a specific task be presented. The coordination is characterized by a decoupled approach. In this approach, each vehicle decides its motion based on local information, therefore, the actions of each robot are guaranteed to be consistent with the actions of the rest of the fleet even in the case of communication faults. Then, a behavior-based architecture be used as the underlying control representation providers a useful encoding that lends robustness to control. Some robot behavior be designed to support for accomplishing industrial task. Four Lego Mindstorms robots used to implement the proposed algorithm. Generally, the paper is inspired by our previous work that based on behavior-based single robot (Amin and Adriansyah, 2006) and (Adriansyah *et al.* 2015).

This paper is organized as follows. In Section II, designing multi robot system is presented in detail. In Section III, some experiment results to test performance of

system are described and discussed. An industrial-like environment have been designed to do this. Finally, the paper is concluded in Section IV.

MULTI-ROBOT SYSTEM DESIGN

Some robots are used more and more in industrial plants and warehouse, such an AGV. The companies working in this growing market are thus spurred to develop new technologies in order to improve the performance of their systems. The overall performance of an AGV system depends on a lot of different aspects Berman *et al.* (2008), such as time and work integration.

The most often function robot in industrial applications are to move materials around a manufacturing facility or warehouse, named as material handling. In doing material handling it needs material handling equipment that relate to the movement, storage, control of materials, good and products throughout the process of manufacturing.

This research attend to make some scenario of material handling process for moving some parts of product using four robots in specific route. Points are awarded for communicating effectively among them and finishing the task quickly. The robots are based on Lego NXT Mindstorms that developed in simple differential drive mobile robot. Each robot has three motors, two light sensors and a Bluetooth communication modules. The robot and its block diagram is depicted in Figure-1.

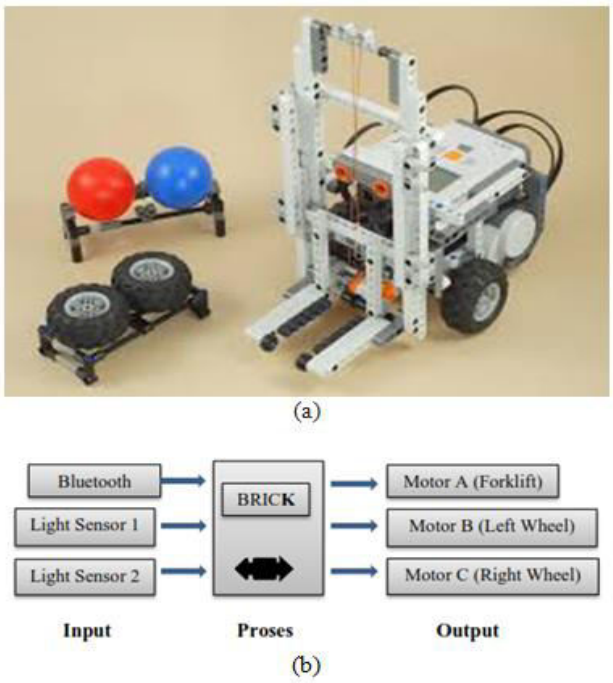

Figure-1. The robot and block diagram.

Architecture of robot is designed based on Behavior-Based Robot. Each robot has the same behavior, such as: object detection behavior, line follower behavior, forklift action behavior, position detection and communication behavior. Behavior based architcture of robot is figured in Figure-2. Each behavior is designed based on a perceptual components, such as light sensors and bluetooth communicaiton modules and actuator as well components, such as motor steppers.

Object detection behavior is an ability of robot to know the avalilablitiy of object in spescific place that based on light sensor. Loading material will be done if the material is sured at that specific place. Robot able to navigate in industrial workspace based on differential drive approach and use a light sensor to detect black line in order to do line follower behavior and loading/unloading position as well. Two stepper motors are used to move forward, turn left and turn right by setting different speed of left and right motor. A light sensor will detect black line and control movement of robot in order to move in line rightly. Another light sensor will detect yellow block for controlling some position. Then, the robot has forklift action behavior to do pick and place an object from one position to another. Direction of a stepper motor will be control to make forklift movement for loading or unloading material either in clockwise or counter clockwise direction. Finally, to make communication between robots, a coomunication behavior is developed based on bluetooth cmmunication modules.

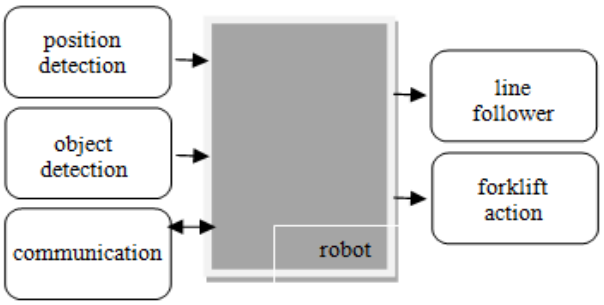

Figure-2. Robot behaviors.

The system organization is designed in four independent robots that are able to communicate to perform cooperation task. Figure-3 is a diagram of the complete system, that decomposed by a leader robot and three followeer robots. All follower robots start running and connect to the leader robot so that the leader robot can send them request. As described before, all robots have same behaviors, unless the task will be ordered by leader robot.

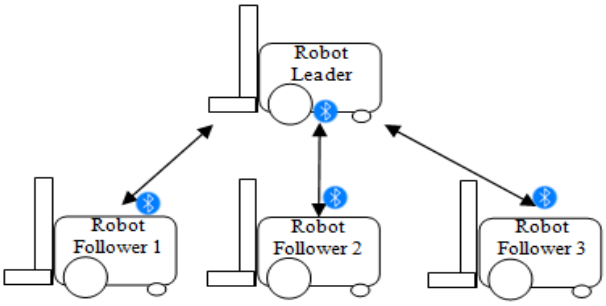

Figure-3. Organizatin of robots.

Scenario of material handling system is as follows. All robot start from their position, respectively. All material that will be moved are placed around leader robot. Leader robot moves first, brings a material to loading place, unlodings it and says to all follower robots that the material is ready to load. Leader robot will do the same task for next material loading after. Then, first follower robot goes to the place, loads the material, brings the material to objective place, and says to second follower robot that his task is finished. Second and third follower robot do the same task as first's consecutively. All of the movements of robots do concurrently and synchronously in order to time efficiently. Figure-4 showed the movement scenario and Figure-4 diplayed the Finite State Machine (FSM) of the process.

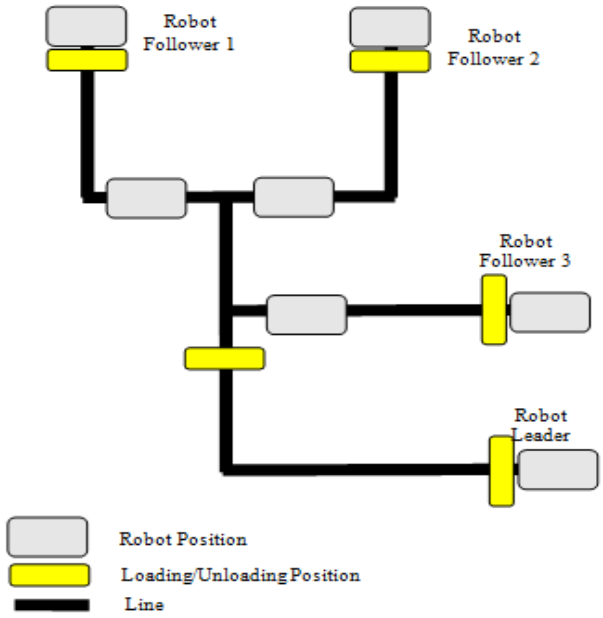

Figure-4. Movement scenario.

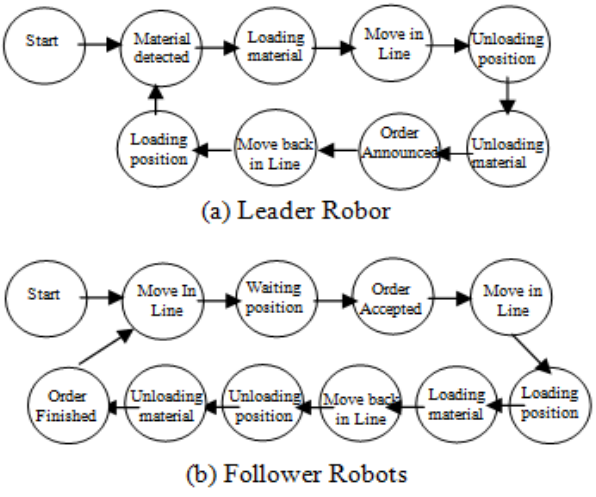

Figure 5. Finite State Machine.

RESULTS AND DISCUSSIONS

Some experiments have been performed to evaluate the performance of propossed design. Four robots have been developed using Lego NXT Mindstorms Robot. Each robot has same construction and behaviors, respectively, as descibed in previous section. The robots also have been decomposed as a leader and three follower robot with a wheel as a loading material. The robots and their loading material is showed in Figure-6.

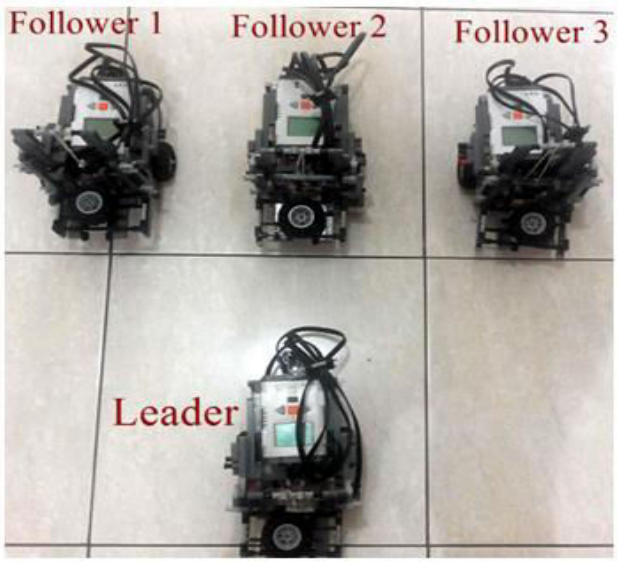

Figure-6. Multi-robot system.

A site plant as movement scenario for loading and unloading material has been designed as weel, named as industrial-like environment. Some robot positions and some loading/unloading material positions is also showed in site plant. Robot will move in black line by line follower behavior. There are some special path black line for each robot and also common path black line for for three follower robot. This common path blak line is used for reduction of time. Figure-7 showed the site plant for robot navigation. The site plant is designed based on movement scenario and FSM as showed in Figure-5 and Figure-5.

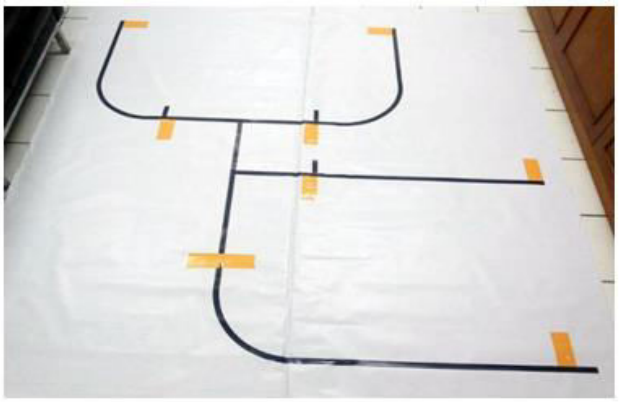

Figure-7. Site plant for robot navigation.

Figure-8 described an experiment to test ability of each robot for some behaviors, such as: position detection, object detection, line follower and forklift action. Based on Figure-8, it can be said that every robots have good performance for those behaviors. The robots able to know availability of material to be loaded (1), able to move exactly in black line (2 and 7), able to load and unload material (4, 5, 6, and 8), and able to detect some positions (3 and 8).

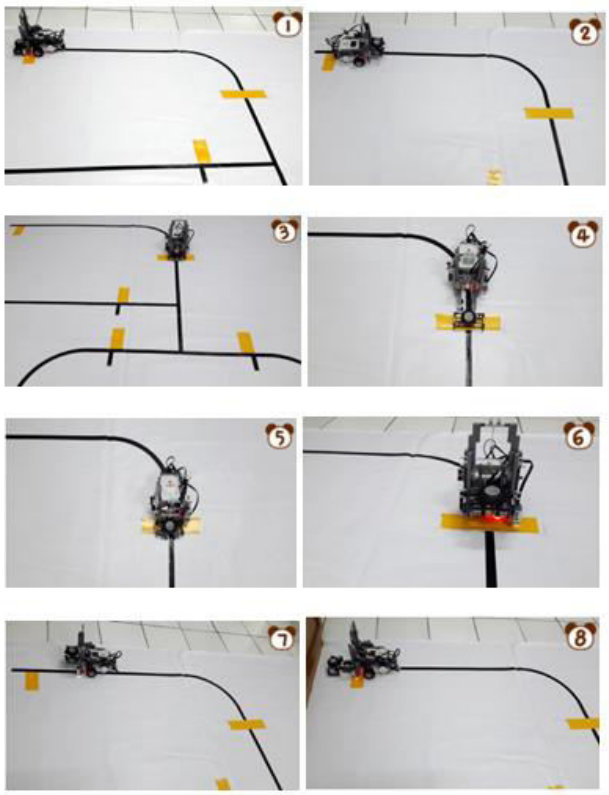

Figure-8. Experiment of basic robot behaviors.

After performance test for some basic behaviors for each robot, coordination system test is performed. Figure-10 displayed movement of all robots to do material handling in industrial-like environment for a work cycle. All robots had in all start positions (1). Then, leader robot moved first to do his job (2, 3). After that, all follower robots moved to waiting position synchronously (4, 5). Follower robot 1 then performed his task correctly to load and unload the material (6, 7, 8). So, follower robot 2 (9, 10, 11) and follower robot 2 (12, 13) also performed their task. Finally, all robot stayed in their original positions after a cycle work that have been performed appropriately (14).

Based on Figure-9 it can be said that all basic behavior, such as: position detection, object detection, line follower and forklift action, for all robot have been work properly. After that, it can believed that communication behavior for all robots work properly as well. The leader robot able to order to all follower robot, and vice versa. And, all follower robot worked consecutively, one by one. In general, it can be said that this coordination of multi-robot system has the ability to accomplish the entire work accordance with the design and scenarios.

Commonly, the algorithm provided the system could be perform the task consecutively, concurrently and synchronously. Than if the entire work was done by single robot, so when done together by coordinated multi-robot can be perform in less than a third.

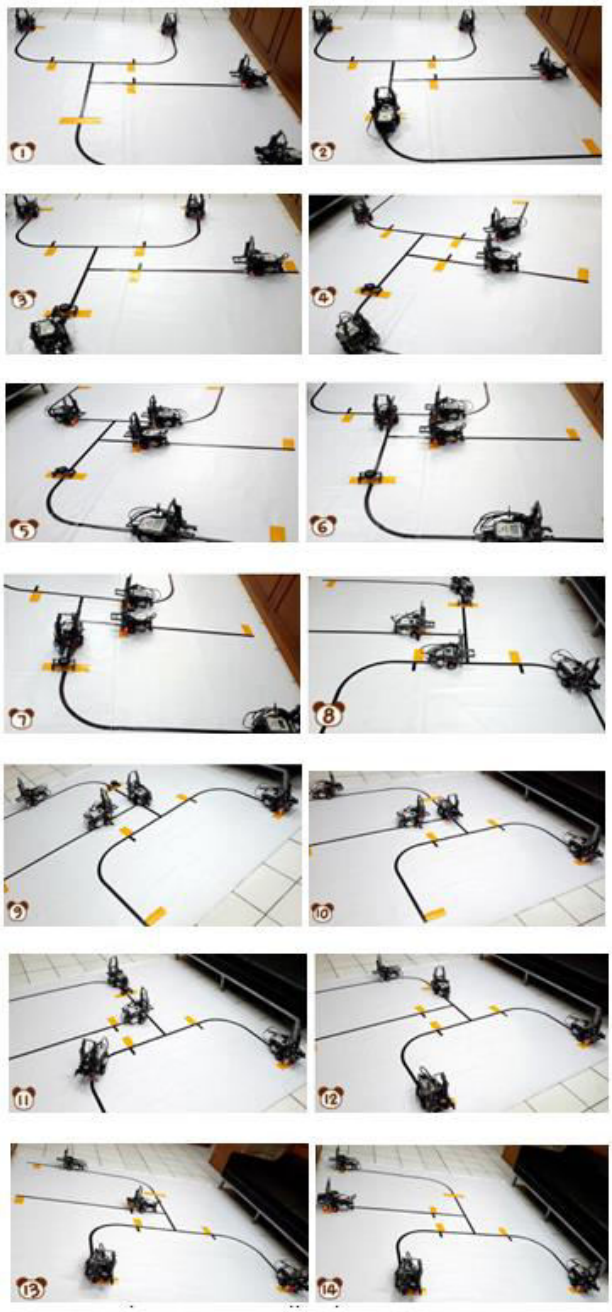

Figure-9. Coordination system test.

CONCLUSIONS

A coordination multi-robot system based on behavior-based architecture has been developed. Four Lego Mindstorms robots have been used to implement the proposed algorithm that are decomposed in a leader robot and three follower robots. All robots have same

construction and behaviors. The coordination is characterized by a decoupled approach. A scenario for accomplishing task is designed in an industrial-like environment. Based on some experiments, it can be concluded that the scenario able to complete properly. Generally, this coordination able to minimize the delivery time of material handling using consecutively, concurrently and synchronously movements in less than a third.

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