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Wireless Control of Swarm Robotics for Industrial Automation

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Abstract

In the modern world, robots and robotic technologies are engaged extensively in industrial automation. The performance of the collaborative robots has resulted in utilizing them as primary forces in industries. In this paper, we propose the concept of swarm robotics to address the drawbacks of industrial automation. Wireless communication established in the robots and the control systems enabling automation. Swarm robotics is a technology where multiple robots together solve issues by developing advantageous structures and behaviors replicating nature like swarms of bees, fish or birds. Wireless technologies (4G, 5G and Wi-Fi) are employed that aids in controlling of multiple robots in distributed locations.

Keywords: Swarm robotics, wireless communication, industry 4.0, ROS, e-Puck.

1. Introduction

Today, Industry 4.0 has evolved towards mass customization from mass production as the market demands increase to manufacture personalized goods [1]. The conventional industries employ robotics to manufacture goods but the ability to change the production process was a big question. This challenged the industry to produce customized products, as customers or end users most preferred. This drew the attention of research people to the concept of Swarms which is regarded as a type of quasi-organism adapting to environmental changes by engaging in certain behaviors [2]. Thus, Swarm robotics resulted to be an enabling technology as they are capable of performing multiple activities and processing number of parts which increases efficiency and flexibility.

However, the individual robots embed the capability to process, communicate, sense, interact internally with each other and react to the environment. To establish the integration of the robots, wireless technologies take on a crucial role. In order to effectively integrate

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wireless technologies into the various manufacturing process, a double helix strategy between the manufacturing and communication industries is essential in the modern world. The proposed work explains how swarm production allows maximum flexibility and reconfiguration of the manufacturing process in an automated environment using wireless communication. Further the related works of the proposed system are discussed in section 2. An overview of the proposed work are predominantly discussed in section 3, the experimental results are detailed in section 4 and the section 5 describes the conclusion part.

2. Related Works

The recent demand employs many conventional methods to improve the efficiency of industrial performance. This section explains various methodologies practiced in industries to attain the goal. Though many practices prevail, among them the most common systems are explained in this section. Rodriguez et al. [3] have described the replacement of the cables with wireless communication links in the production lines. It broke out to be an alternative way where existing local line controllers are replaced by cloud-dependent control servers. This resulted in flexibility as the reconfiguration is enabled in production facilities which were quite difficult in wired systems. To accomplish this, a powerful wireless communication managing the two-way traffic from different modules is required. Goldschmidt et al. [4] explained the implementation of Programmable Logic Controllers which demands manual software upgrades for any change in the process.

The intelligence in migrating from Programmable Logic Controller to the cloud was quite challenging [5]. The next methodology highlights the Autonomous Mobile Robots in which robot functionalities are migrated to cloud. This evolution has replaced the expensive and huge power-consuming sensors with economic and easy handling robots [6]. To achieve this, integration of robots with manager server or dependency of connecting robots with higher bandwidth technologies to send real time captures of robots to cloud server which could be together combined to attain cloud robotics. But the communication needs are more challenging. The proposed work can overcome all the challenges and falls in place to improve the industrial performance.

3. Proposed Work

This section explains the proposed work with each unit explained and then followed by the working methodology.

- Swarm Robotics.
- Interface Unit.
- Wireless Communication Module
- ROS

3.1 Swarm Robotics

Swarm robotics is the group of robots coordinate among themselves to exhibit collective behaviour while communicating with themselves or with an environment. They are developed with artificial intelligence in which the individual robots are simple but together they exhibit complex behaviour. Decentralization is achieved with their ability to communicate efficiently and constant feedback back & forth between them [7]. Number of control formations are used to accomplish the tasks based on the real time applications like behaviour-based approach [8] , leader follower approach [9], and virtual structure methods. In our proposed system we use Pi-Puck swarm robots in which the e-Puck robots are connected with Raspberry Pi interface units. The advantage of using Pi-Puck robots in the swarm robotics is to increase the information exchange efficiency and the low cost [10]. e-Pucks serves to an educational tool in learning the behaviour of robots and it serves well in swarm robotics. The basic architecture of the proposed system is shown in figure 1.

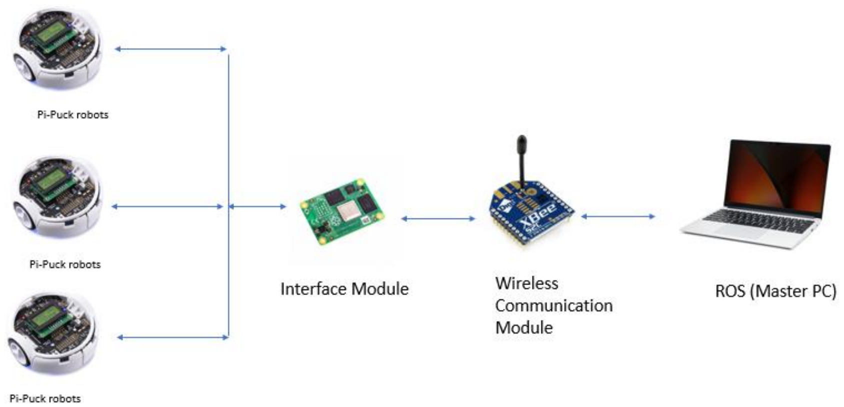

Figure 1. Architecture of the proposed system

3.2 Interface Unit

The interface module for the proposed work includes the interface between the e-Puck swarm robots and a Raspberry Pi board which paramount the networking capabilities, processing speed and memory of the robot economically. This allows high-level control over algorithms, complex computational process and wireless communication. The robot camera can also be added to this interface which could be accessed easily. It also establishes connection with WiFi to receive data and to control the robots from remote location through the ROS system [11]. Open sources for hardware and software installation is also an added advantage of this system. The interface, Raspberry Pi uses Python language to communicate between sensors and wireless communication module.

3.3 Wireless Communication Module

The proposed system includes a Zigbee communication protocol which supports dynamic routing and self-organizing network along with accommodation of large network nodes which enables flexible addition of robots in future. The system employs XBee which is a wireless communication module allowing each robot to communicate. XBee sends and receives information over air wirelessly communicating with intelligent devices through serial interface [12]. Based on application, the industries can use different wireless technologies as given in the below table:

Table 1. Different wireless technologies

Type of Network	Wireless Technology	Description
Private Network (Local)	5G NR , 4G LTE, Wi-Fi 6, Wi-Fi 5	Private core
Dedicated operator network	5G NR , 4G LTE	Public core
Positioning	Ultra-Wideband	Enterprise solution

3.4 ROS

Robot Operating System is a collection of software tools and libraries that helps in building robotics. This is an open source that provides the functionality of an operating system on a computer. This establishes various functionalities such as communication over processes in a machine network, hardware implementation, device control, etc. It enables you to design complex software designs with uncertainty in the hardware orientation. In the industries, the robots are programmed externally through the ROS which results in a software-based methodology to program the industrial robots.

3.5 Methodology

Earlier, not all industries have opted for advanced manufacturing techniques like swarm production. But now the era is digitalized and every industry is moving to cloud integration. Though not all the industrial manufacturing sectors invest in advanced systems, but definitely huge number of industries will seek out revolutionary changes with wireless technologies. This change has revolutionized the industries resulting to Industry 4.0 and evolution will lead to Industry 5.0 and more. The swarm robots adapt to a formation and remain the same during the whole process.

$p^{k}_{i,j}$ explains the position of the robot, where ‘i’ is the column, ‘j’ is the row and ‘k’ is the sampling step. On every sampling step, the robots in the swarm detect the environment and perform actions by coordinating with other robots and the environment. This is achieved by the swarm behavior adoption. Each robot is connected to Raspberry Pi which collects the signals from the sensors and sends to the communication protocol module. Communication among the robots is a complex process that is organized by ZigBee based wireless sensor network. This allows the robots to be much more interactive and sends messages to the centralized network. The system analyzes the current state of the robot , check for its coordination and sends feedback. In the same way, the ROS system, the heart of our system which is a computer controls the swarm of robots which ends up in accomplishing the task at a higher efficiency.

4. Result and Discussion

Based on the design adopted for the proposed system, the following results were obtained and discussed below:

- Maximum speed/ minimum speed
- Dynamic accuracy
- Centralized Control.
- Swarm robotics behavior.
- Zigbee based localization.
- Long range distance sensing.

4.1 Maximum speed / minimum speed

The maximum and minimum robot speeds are conducted under no-load conditions and this has been carried out to avoid the impact of load. The maximum speed observed in the opposite direction are between 89 mm/s and 402 mm/s with an average of 276 mm/s. The need of a minimum speed test is to analyse the motor speed to obtain the critical state of the robot in relationship to motor speed. This value is obtained as 18% of the maximum value.

4.2 Dynamic Accuracy

This is determined with the speed of movement of robot within two adjacent time frames. This verifies the recognition frame rate and also accuracy of the positioning systems. The difference between the time frame resulted to be stable. The dynamic accuracy of the robots will counts for the overall efficiency of the system.

4.3 Centralized Control

The robot operating system, ROS, which is specially available software framework for programming the robots is highly advantageous in controlling the swarm robots. It is commendable over other framework because it is peer-to-peer, multi-lingual , free and open source.

The signals received from number of robots are managed and the feedback for each robot is sent after the manipulation every time on receiving the signal from robots. This reduces the cost of wired network greatly. It is a great solution for automation industries where human intervensions are highly reduced.

4.4 Swarm robotics behaviour

Swarm robotics, when compared with all other industrial production methodologies discussed, operates in a distributed fashion and exhibits many advantages such as quick reaction to information, adaptability, spatial organization, navigation, decision making and robustness. The artificial intelligence of the system and programmable nature are added advantages.

4.4.1 Spatial Organization

The swarm robots exhibits excellent spatial organization in the environment where the individual robots spatially organize themselves or with other objects. This behavior is characterized by aggregration, pattern formation, self-assembly and object clustering & assembly.

4.4.2 Navigation

This behavior of the swarm robots coordinated the movement of all robots in a swarm. This results with collective exploration, coordinated motion, collective transport and collective localization.

4.4.3 Decision Making

This behavior allows the robots in the swarm environment to make a common solution for a provided issue. This is achieved by the inbuilt consensus, task allocating ability, collective fault detection, collective perception and synchronization.

4.5 Zigbee Based Localization

As discussed, the interaction between the robots in the swarm network is achieved with Zigbee. It proves to be an effective method in compared to other methods such as DR and RSSI methods. The localization error has been greatly reduced by 0.4 cm on comparison to other methods. This also contributes to the overall efficiency of the proposed system as it cuts doen the error in each robot. Figure 2 represents the localization error of the RSSI, DR and Zigbee techniques.

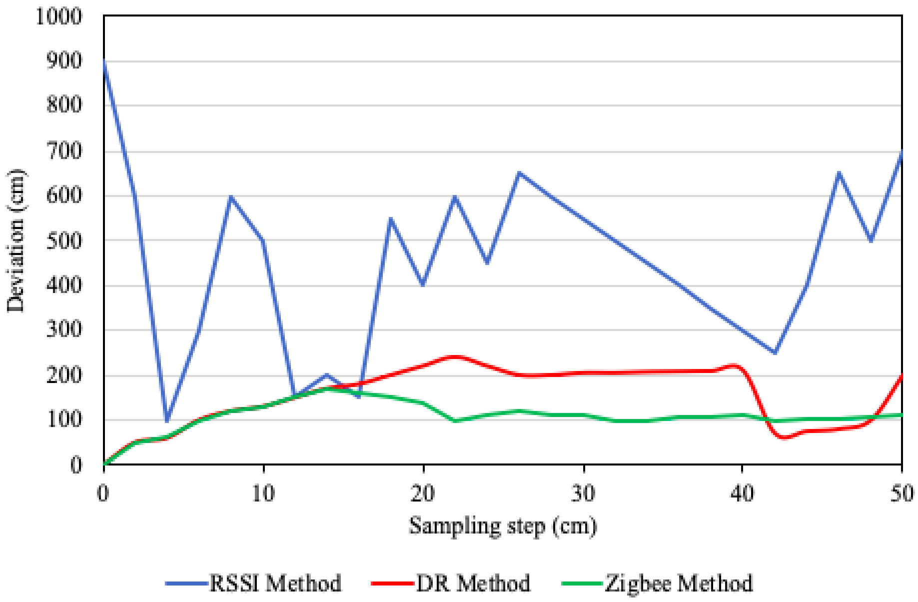

Figure 2. Comparison of localization error implementing RSSI, DR and Zigbee method

4.6 Long range distance sensing

The Pi-Puck robots employs sensors that are capable of sensing long distance of around 2 meters and the sensors interface with Raspberry Pi through I^2C. This enables them to sense and detect objects at a greater distance on comparison with standalone e-Puck or other robots. This characteristic reduces the number of robots used in the environment towards a task which in turn reduces the required communication bandwidth. This also facilitate reduction of information exchange time resulting in increased efficiency. Figure 3 represents the converted ADC values of the RSSI, DR and Zigbee techniques.

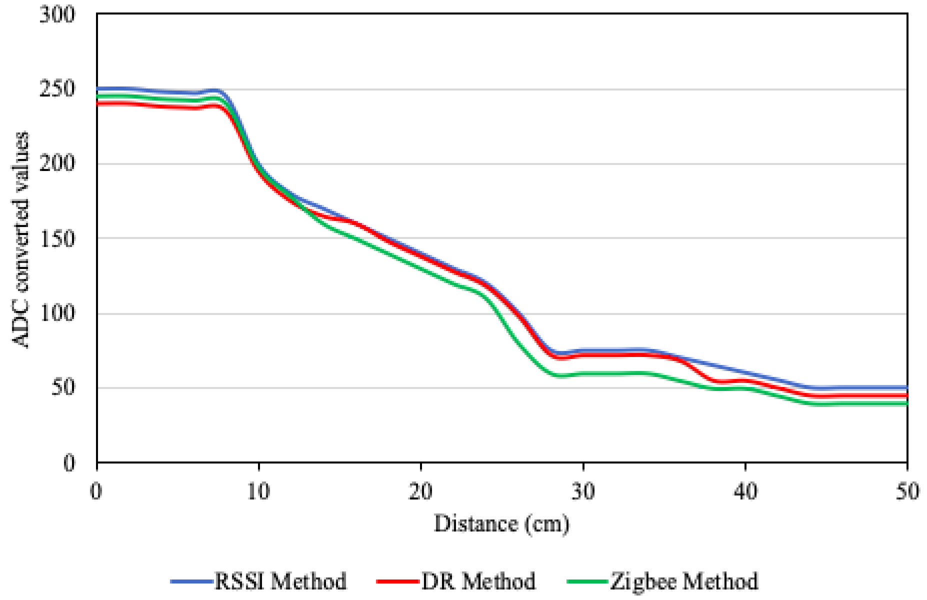

Figure 3. Comparison of ADC converted values of RSSI, DR and Zigbee method

5. Conclusion

In this paper, the application of swarm robotics to the industries was presented where wireless communication is established. Swarm robotics is an interesting field in the industrial sector because of its high performance, flexibility, and improved task performance. These characteristics make it the right solution for the flexible manufacturing industry where mass customization products are aimed. Swarm production coupled with advanced wireless communication can serve all the applications since the swarm behavior has many features. The Pi- Puck robots are highly advantageous as the e- robots are embedded with the Raspberry Pi interface which collectively receives the signals and send them to a centralized robot operating system (ROS). This overall system performs well in comparison to many of the existing systems employing many advanced methodologies. Also the cost of the swarm robots are comparatively low and the other systems proposed in this work are economic. The digitalization of the industries and the need for it called for huge hype cloud control systems. The system interfaces the e-puck platform with Raspberry Pi offering a highly supportive replacement to Linux platform which was time-consuming and low efficient compared to the proposed system. The future enhancement would rely completely on SaaS where one control any process inside the industry from anywhere around the world. Also the system can be operated with different differential drive motors of different manufacturers and the centralized control system behaves the same way. To facilitate this, a unique number for the identification of individual robot has to be added, which will provide added advantage to robots in Robot Operating System (ROS) environment.

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