Design and Development of a Service Robot for Wi-Fi RSSI Fingerprint Data Collection

M. Q. Bakri1*, A. H. Ismail1,2, M. S. M. Hashim1, M. S. Muhamad Azmi1, M. J. A. Safar1 and M. H. Marhaban2

1School of Mechatronic Engineering, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
Dept. of Electrical and Electronics Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM), Selangor, Malaysia.
mohdkhai95@ymail.com

Abstract. We have designed a service robot that can be used for Wi-Fi RSSI Fingerprint database construction for indoor positioning system. This work aims to aid and ease the signal fingerprint database construction process which currently conducted manually by carrying the data acquisition tools around the experimental field. The robot architecture design considered the values and constraint in performance, aesthetic, cost, and expandability. Analysis of the robot’s mobile specification was made in order to choose the optimum hardware components. The robot has three main sections which are mobile platform, storage compartment, and user interactive screen that is capable to display facial expression and other useful information.

Keywords- service robot; motor sizing; Wi-Fi fingerprint.

1. Introduction
Positioning system is one of the important aspects for a service robot, especially in a complex indoor environment. This system gives information about the robot’s exact position in a closed space that is useful for further action such as path planning and navigation [1]. For outdoor application, positioning can be done by using the information from GPS, which has become the standard in outdoor environment [2]. However, GPS is unreliable when it comes to indoor positioning because of signal attenuation and severe propagation by the building [3]. Therefore it is necessary to consider other approaches such as Wi-Fi positioning system [4]. This approach provide easy and low-cost implementation since the existing access points can be used without the need to make a major work on the infrastructure modification [5].

There are several methods available that can be used to implement wireless positioning system by using the Wi-Fi signal. Such method include triangulation, trilateration, and RSSI (Received Signal Strength Indicator) fingerprint [3][6]. In this study, the focus is on Wi-Fi RSSI fingerprint method. This method works by comparing the average RSSI fingerprint values from a minimum of three access points in the room with the database to predict the exact position of the client such as service robot [7][8]. Database construction is required at the early phase, usually done by placing the data acquisition tools at the exact reference point (RP) to record the RSSI values for each access point, for instance as shown in Figure 1. Up to this point the challenges arise, it is time consuming and huge effort needed for someone to construct the database manually, especially when the number of granularity increases [8].
Ones need to bring the data acquisition tool at the exact RP in order to record the Wi-Fi RSSI fingerprint data. There are commonly a total of more than 20 RPs in an experimental field and a few times sampling needed to get an average for less data fluctuation [9].

Figure 1. Example layout of a typical experimental field for Wi-Fi RSSI Fingerprint database construction, with the notation × representing the RP and the three Wi-Fi Access Point (AP)

Therefore we have designed a service robot that can do several indoor tasks including construction of Wi-Fi RSSI fingerprint database automatically. The design is a result from our vast review of numerous service robot review around the globe [10]. One key advantage of our robot is that its’ generic platform is multipurpose with expendability capability. This robot seeks to aid and ease user effort to place the data acquisition tools around the experimental field. The robot is currently undergoing industrial fabrication process and this paper explains the design process of the robot in terms of design concept, hardware architecture, component selection, and control unit such as electronics and algorithm. The robot is planned to move from one RP to another preferably using line following method, and then record the Wi-Fi RSSI fingerprint on that specific RP from different orientations. The next section of the paper will explain about mechanical design of the robot which include design concept and mechanical specifications. Section 3 discuss the detail about controller hardware design and algorithm in order for the robot to collect data autonomously. In section 4 we discuss the results and findings d of this works. Lastly, section 5 draws the conclusions of this works and briefly suggest the possible action for future works.

2. Robot Mechanical Design
Service robot design is not limited to any specific principle and architecture [11]. Perhaps, the design should consider the scope of application in the first place in order to optimize the budget and lead time especially for academic and research purpose [12]. However, most service robots have two characteristics in common: mobility and user interactive. As service robots need to manoeuvre around, component selection for mobile platform is important to ensure smooth movement from one point to another. One of the process involved in designing the mobile platform is choosing the type of wheel and its configuration. The most common wheel configuration is differential drive due to its simplicity, low-cost, and easy to implement [13]. Apart from that, omni-directional wheel provide greater degree-of-freedom to the mobile platform but usually costs more than differential drive system [14]. User interactive system enable the robot to interact and communicate with the user. Some service robot use LCD screen as the user interactive component to display useful information as well as showing facial expression [15]. There are also service robot that features speech synthesis to communicate with user verbally [16]. In some application, storage compartment is needed for the robot to carry things such as toiletries for hotel guests or medical items in hospital [17][18].

Our design mainly consists of three parts: mobile platform, storage compartment, and user interactive screen as shown in Figure 2. The robot 3D design has been done in Fusion 360 software. For
mobile platform, we have decided to implement differential drive with one castor system due to its low-cost and easy implementation. Evaluations has been made for our robot’s mobile platform specification in terms of wheel size selection and motor rated power. The evaluation method is further discussed in section 3. Our robot also equipped with a storage compartment to place the on-board computer and data acquisition devices. The storage compartment also can be divided into several partitions to store many other things for future applications. For database construction application, the user interactive screen is used to display information of the data collection process and the interface of the robot operation. There is also a platform for input devices (keyboard and mouse) on the robot to ease troubleshooting process when the robot is in operation.

Several service robot design from the other works has been studied prior to our design. It is to ensure the thorough empathetic on the general requirements for systematic planning process as the designed robot should be flexible for as many applications as possible. As a matter of fact, this mobile robot is targeted in service and hospitality industries, with the competitive development cost in the positioning system utilizing the wireless positioning system via signal fingerprinting method. The robot will be tested in the online phase of indoor positioning using Wi-Fi fingerprinting technique that can be extended to navigation and path planning. This works will eventually need some hardware modification and upgrades in terms of mobile platform, computers, sensors, manipulators, and even the robot appearance for greater aesthetical values. Therefore in designing this robot we consider the expandability in mind.

![Figure 2. Service robot design for Wi-Fi RSSI fingerprint data collection](image_url)

### 3. Design of Control Hardware and Algorithm

The core controller for this robot is a CPU unit running Robot Operating System (ROS). It is connected to several clients to control other mechanisms such as actuator and data acquisition unit. ROS has been widely used in many robotic projects. It provides a development environment that integrates necessary modules and sensors for a robot. There are five main components in our robot control hardware: power supply, main CPU, microcontroller, data acquisition device, and actuator. Each component is integrated over ROS to drive the robot for data collection tasks. Besides electronics, there is also an algorithm for the robot to automatically move from one RP to another and taking the data autonomously.

The power supply of our robot is the rechargeable 24V lead acid battery with a capacity of 7.2Ah. This battery is chosen because of its relatively low price compared to other type of cell with the same capacity. Series of regulators will regulate the voltage from the power supply before connecting it to the other modules or devices on the robot. Main CPU is responsible to control the overall process that occur on the robot systems such as giving command to the microcontroller to move the actuators, reading sensors data, and recording the data from data acquisition device. For Wi-Fi RSSI fingerprint data collection, the data acquisition device that we will use is the ESP8266 Wi-Fi module and general-purpose AP. Both devices were still in evaluation before we can decide to fully implement any of it. The actuator used to drive the robot is 100W VEXTA brushless DC motor.
Selection for the DC motor undergo evaluation process by using a certain set of formula to find the suitable parameter of the DC motor. The main objective of this evaluation is to find the minimum required torque $\tau_{\text{min}}$ of a motor that is sufficient to drive the robot in a given wheel radius $\dot{r}$, maximum acceleration $a_{\text{max}}$, and maximum payload $m_{\text{max}}$.

$$\tau_{\text{min}} = F_{\text{max}} \times \dot{r} \quad (1)$$

, where $F_{\text{max}}$ is

$$F_{\text{max}} = m_{\text{max}} \times a_{\text{max}} \quad (2)$$

Based on these equations, we developed a Windows application specifically to perform these calculations with some added features and parameters such as gear ratio and gear power transfer efficiency. We also added a parameter for the number of driving motor so that the application can calculate the torque and power for every independent motor. The snippet of the developed Windows application is shown in Figure 4.

Figure 3. Block diagram for hardware control system

Figure 4. Windows application for motor rated torque evaluation

Figure 5. Flowchart of the planned robot algorithm for Wi-Fi fingerprint database construction
The control algorithm defines how the robot behave during operation. For Wi-Fi fingerprint database construction, we planned to program the robot to move from one RP to another in the experimental field, where the RP are connected by lines. Thus, the robot at this time perform similarly to a line following robot. At each RP, the robot will record the Wi-Fi RSSI fingerprint data from a few different orientations. This process is then repeated for the rest of the RPs. The number of RP will be assigned and marked. The greater number of RP, the better the database. Since we are using a robot for this process, increasing the number if RP is no longer a major problem. For a greater coverage, we can improve our database by using an interpolation algorithm [7]. Flowchart of the planned robot algorithm for Wi-Fi fingerprint database construction is shown in Figure 5.

4. Result and Discussion
By using the Fusion 360 software, several design versions have been made evaluate each of the design before we come up with the final version. Each design has its own unique architecture and aesthetic. Our first version of the design as shown in Figure 6(a) has a cantered driving wheel position shown in Figure 6(b) to allow zero radius turning. Later we found out that this design has the risk of castor wheel slip over the uneven floor level. Then we have decided to change the mobile platform in terms of wheel configuration to front wheel differential drive as depicted in Figure 6(c). This design is further improved in terms of aesthetical values, manufacturability, and cost effective aspect. In the final design presented in Figure 6(d), the wheel configuration was changed to rear wheel differential drive in order to provide smooth heading trajectory. The design specification of the final version is shown in Table 1.

![Figure 6: The mobile robot design in this works, (a) the first version design, (b) mobile platform of the first design version, (c) second version design, and (d) final version design sent for fabrication.](image)

| Parameters                              | Value                  |
|-----------------------------------------|------------------------|
| Dimension (H x L x W)                   | 86 x 40 x 40 cm        |
| Weight                                  | 20 kg                  |
| Max. Payload                            | 20 kg                  |
| Mobile Configuration                    | Rear differential drive|
| Battery Capacity                        | 24V 7.2Ah              |
| Type of cell                            | Lead acid              |
| DC motor                                | 100W VEXTA DC brushless|
| Max. Translation Acceleration           | 0.75 ms⁻²              |
| Max. Translation Velocity               | 3.142 ms⁻²             |
| Motor Rated Torque                      | 3.6 Nm                 |
| Motor RPM                               | 250                    |

Table 1. Specification of final version design
5. Conclusion
This paper described our state-of-the-art service robot for Wi-Fi RSSI fingerprint database construction. The development of this robot seeks to aid the data collection process which is at present is done manually. In designing the robot, we have made a deep study on different aspects of a service robot to make sure that we are able to come out with an optimal design in terms of performance, aesthetic, cost, and expandability. The optimal mechanical design for our research scope is the three layers modular design which are mobile platform, storage compartment, and user interactive display. Component selection such as DC motor was made based on the specific evaluation process. This enable us to know better about the specification and performance of our robot from the design stage. Currently the robot is in fabrication process, while the RP and the line following system are under proof test. It is also worth to note that the facial expression via interactive ‘robot face’ is also undergoing swift development from the same research group. In the future in development context, we are looking to experiment a few method such as sensor fusion technique [19], RFID or QR code to help our robot navigate more precisely between the RPs. It is possible that the meta heuristic combination of these techniques should enhance the robot capacity especially in the wireless positioning system.

Acknowledgement
The authors would like to acknowledge the support from the Fundamental Research Grant Scheme (FRGS) under a grant number of FRGS/1/2018/ICT05/UNIMAP/02/4 from the Ministry of Education Malaysia.

References
[1] Mingzhe X, Jiabin C, Chunlei S, Nan L and Kong C 2015 The Indoor Positioning Algorithm Research Based On Improved Location Fingerprinting The 27th Chinese Control and Decision Conference (2015 CCDC) (Qingdao, China: IEEE) pp 5736–9
[2] Zhao Y, Zhou H, Li M and Kong R 2008 Implementation of indoor positioning system based on location fingerprinting in wireless networks Wirel. Commun. ... 8–11
[3] Moghtadaiee V, Dempster A G and Lim S 2011 Indoor localization using FM radio signals: A fingerprinting approach 2011 International Conference on Indoor Positioning and Indoor Navigation, IPIN 2011
[4] Li B, Salter J, Dempster A G A, Rizos C, Beomju Shin, Jung Ho Lee, Taikjin Lee and Hyung Seok Kim 2006 Indoor Positioning Techniques Based on Wireless LAN LAN, First IEEE Int. ... 2 574–7
[5] Zhao F, Huang T and Wang D 2019 A Probabilistic Approach for WiFi Fingerprint Localization in Severely Dynamic Indoor Environments IJEE Access 7 116348–57
[6] Houria C and Mouhcine C 2017 Indoor Localization Using Wi-Fi Method Based on Fingerprinting Technique 2017 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WTIES) (Fez, Morocco: IEEE)
[7] Ismail A H, Kitagawa H, Tasaki R and Terashima K 2016 WiFi RSS Fingerprints Database Construction for Mobile Robot Indoor Positioning System 1561–6
[8] Thuong N T, Phong H T, Do D T, Van Hieu P and Loc D T 2016 Android application for WiFi based indoor position: System design and performance analysis Int. Conf. Inf. Netw. 2016-March 416–9
[9] Sun W, Xue M, Yu H, Tang H and Lin A 2018 Augmentation of Fingerprints for Indoor WiFi Localization Based on Gaussian Process Regression IEEE Trans. Veh. Technol. 67 10896–905
[10] Bakri M Q, Ismail A H, Hashim M S M and Safar M J A 2019 A Review on Service Robots: Mechanical Design and Localization System IOP Conference Series: Materials Science and Engineering
[11] Reiser U, Connette C, Fischer J, Kubacki J, Bubeck A, Weisshardt F, Jacobs T, Parflitz C, Hagele M and Verl A 2009 Care-O-bot® 3 - Creating a product vision for service robot applications by integrating design and technology 2009 IEEE/RSJ Int. Conf. Intell. Robot. Syst. IROS 2009 1992–8
[12] Van Osch M, Bera D, Van Hee K, Koks Y and Zeegers H 2014 Tele-operated service robots: ROSE Autom. Constr. 39 152–60
[13] Yazdjerdi P and Meskin N 2018 Fault tolerant control of differential drive mobile robots using sliding mode controller 2017 5th Int. Conf. Control. Instrumentation, Autom. ICCIA 2017 2018-Janua 270–4
[14] Padgett S T and Browne A F 2017 Vector-based robot obstacle avoidance using LIDAR and mecanum drive Conf. Proc. - IEEE SOUTHEASTCON 1–5
[15] Hegel F 2012 Effects of a Robot’s Aesthetic Design on the attribution of social capabilities Proc. - IEEE
[16]  Kantharak K, Sombooncha C, Trong N and Thinh N T 2017 Design and Development of Service Robot based Human - Robot Interaction (HRI) 293–6

[17]  Tasaki R, Kitazaki M, Miura J and Terashima K 2015 Prototype design of medical round supporting robot “Terapio” 2015 IEEE International Conference on Robotics and Automation (ICRA) (IEEE) pp 829–34

[18]  Zhaohui Z, Mei X, Bian X, Cai H and Ti J 2017 Development of an intelligent interaction service robot using ROS Proc. 2016 IEEE Adv. Inf. Manag. Commun. Electron. Autom. Control Conf. IMCEC 2016 1738–42

[19]  Dobrev Y, Gulden P and Vossiek M 2018 An Indoor Positioning System Based on Wireless Range and Angle Measurements Assisted by Multi-Modal Sensor Fusion for Service Robot Applications IEEE Access 6 69036–52