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# A real-time accurate positioning system using BLE and wireless mesh network in a shipyard environment

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ABSTRACT

Digitalization of the shipyard environment is a challenging problem, and also it is necessary for competing the international ship manufacturers. Thus, this study introduced a real-time accurate positioning system that is an indispensable part of a digital manufacturing system. The system implementation and measurements took place in Sedef Shipyard, the largest shipbuilding facility in Turkey. Since the shipyard includes indoor and outdoor environments, Bluetooth Low Energy (BLE) systems provide the best solution for locating the staff. The most challenging problem is to determine the positions in the metallic surroundings. The constructed system solves this problem by placing gateways and sensors at essential locations and using a mesh network. With the designed user interface, the position of the staff can be monitored accurately in real time, and reports can be generated.

## 1. Introduction

The shipyard industry in Turkey has a history of more than 700 years and has experienced significant global growth, especially in recent years. As a result, the industry has sufficient facilities, technology, and workforce to make the most of global opportunities. However, the desired level of digitalization has not been reached yet, and therefore, R&D and innovation should be more important within the scope of Industry 4.0 [1].

A shipyard is a very complex environment where production parameters and dimensions change and a highly flexible working environment. This makes the control of production lines complex and requires the active participation of human resources in the business. Processes such as cutting sheet metal parts, bending-shaping-processing of unique pieces, pipe manufacturing, and combining different components with welding operations in the pool-sled will be implemented during the custom ship production. The most crucial factor determining work efficiency in these fields comes from the control and management of human-machine interaction. To achieve this goal, staff and equipment should be precisely localized in the shipyard. Wireless systems provide excellent convenience in environments such as shipyards, especially inside ships. However, such environments are entirely covered with metals, which are very good conductors, causing communication not to be provided. Because metals cause the reflection of incoming waves, transmission cannot be made from entirely metal-covered rooms such as ships. Another problem is the multipath effect. Many copies of the transmitted signal reflected from the environment may reach the receiver at different times, causing the signal to be weakened or interfered [2]. Therefore the challenges in this positioning problem can be summarized as

- The field includes both outdoor and indoor areas,
- There is a mass of metallic surroundings caused by the ships and machines,
- There are several moving big machines such as cranes that may cause interferences.

A few studies have been done to cope with these difficulties and to model the communication channel in a ship or metal-dense environment. For example, Estes et al. modeled losses by performing narrowband experiments on American Navy ships. As a result of the experiments, they observed that even though there are losses, energy can pass through non-conductive openings [3]. In another study, the

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statistical model of the channel was obtained by making measurements in the ultra-wideband (UWB) frequency band in the ship cabin environment. As a result of experiments with the measurement system consisting of transceiver antennas, network analyzer, and computer, it has been shown that the propagation characteristics are different from indoor and outdoor [4].

Although the Global Positioning System (GPS) has become the standard for outdoor location detection, studies are still ongoing in indoor location detection. Since they offer higher sensitivity, lower cost, and ease of use properties, Wi-Fi, optical and Bluetooth Low Energy (BLE) systems are good choices for reliable indoor positioning applications [5]. Although a wide area is covered with a Wi-Fi network, its sensitivity is very low. In BLE 4.0 or 5.1 technologies, on the other hand, positioning accuracy, which can be lower than 1m, can be achieved even if the range is reduced to 75 meters. A wide range and high sensitivity are provided by Ultra-wideband communication UWB. However, its cost is higher than the others. Thus, it is suitable for applications where the location must be determined precisely. On the other hand, RFID can work more closely and is mainly used in stock counting, cafeteria, or door entry applications. Furthermore, BLE systems provide the highest battery life compared to power consumption. A detailed comparison can be found in [6]. Thanks to its advantages, BLE systems are used in different and challenging indoor positioning applications such as museums [7,8] and in an university campus by combining with different sensor data [9]. However, there is still a gap in literature about the studies in shipyards.

Therefore, an experimental staff positioning system based on BLE was constructed and analyzed to fill in the gap in the shipyard localization problem and to make a step in the digitalization of the shipyard environment. This system includes 400 location sensors, 4870 staff tags and 200 gateway over 191,000 $m^2$ Sedef Shipyard in Tuzla, İstanbul, Turkey. The number of gateways was selected heuristically to cover the shipyard area and show the project's feasibility. The system is flexible and the numbers can be easily increased. The gateways were located in open areas, inside buildings and inside ships to cover the working site. To make an empirical analysis of the BLE positioning system, some experiments were done and the results were discussed in this paper. The system also includes a graphical user interface that can be used to report the activities of the shipyard workers. Thus, the contributions of this study can be summarized as:

- To implement a digital system that determines the locations of the staff and machines in a shipyard environment,
- To show that the indoor location of a worker or machine in a metallic surrounding such as inside of a ship can be found,
- To provide a user interface to track the movements of the workers and machines inside the shipyard campus.

After giving some necessary background information on indoor and outdoor positioning systems in Section 2, the construction of the system and the results of the measurements were demonstrated in Section 3. Finally, discussions are made and conclusions are drawn.

## 2. Background

### *2.1 Indoor/Outdoor Positioning Systems*

Global Positioning System (GPS) has become the standard for outdoor location detection; however, studies are still ongoing for indoor location detection. There are more suitable methods such as Wi-Fi and optical systems, Bluetooth Low Energy (BLE) for indoor positioning applications [5]. Wi-Fi network provides a wide range of connection, but its sensitivity is very low. On the other hand, achieved positioning accuracy in BLE 4.0 or 5.1 technologies can fall below 1m, even if the range is lower than Wi-Fi. As mentioned earlier, Ultra-broadband communication UWB, has a wide range and high sensitivity, which makes it suitable for precise measurement. RFID is suitable for locating and counting stocks rather than indoor positioning. Moreover, BLE systems provide the highest battery life when compared in terms of power consumption [6].

### *2.2 Bluetooth Low Energy*

BLE systems of especially widespread Internet of Things (IoT) applications are frequently used. Traditional BLE systems use star topology and are an important constraint coverage. To cope with this limitation, BLE 5.0 was proposed by first changing the physical layer signal bandwidth [5]. In addition, BLE 5.0 offers innovations in data rate, coverage and advertising channel functionality. As message capacity increases, two types of advertising channels are recommended. While the first channel is the same as the old versions, the second channel can also use 37 channels formerly known as data channels for messages [5]. Secondly, a mesh network is proposed to solve the coverage constraint. The advantage of the mesh network over the star network is that it can reach a wider coverage area over other devices on the network. Of course, for this structure to work efficiently, a more complex network management system should be defined [10]. The BT-SIG Smart Network Working Group was established at the beginning of 2015 to determine the standards for the mesh network structure [11]. Afterward, IETF (Internet Engineering Task Force) published the "IPv6 over Bluetooth Low Energy" RFC 7668 protocol to facilitate IoT capacity and access over the internet [11]. Thus, BLE nodes can communicate with each other via IPv6 packets and connections are made over IPSP (Internet

Protocol Support Profile) and use UDP protocol. This provides communication efficiency and allows routing at the IP layer [5]. BLE systems use the RSSI (Received Signal Strength Indication) technique, which measures the incoming signal strength among positioning techniques. To estimate the exact distance from a device using RSSI, an empirical model can be employed as in [12] that is expressed as

$$d = \alpha + \beta\left(\frac{R}{T}\right) + \gamma \quad (1)$$

where γ is the actual distance, α and β are the empirical regression coefficients, R is the RSSI value and T is a reference value which is the received signal strength for a device located at 1 meter away from the receiver.

The further away the signal comes from, the weaker it will be. For example, the P mobile device in Figure 1 represents stations broadcasting on A, B, and C. In this case, there will be $LS_1 < LS_3 < LS_2$ relationship between the signal strengths coming to the mobile device. However, reflection and multipath effects, especially indoors, can negatively affect the calculation [13, 14].

### *2.3 Mesh Network*

In a mesh network structure, two types of nodes or gateways are used: routers (mesh routers, coordinators) and routers. The mesh network structure is shown in Figure 2. The coordinator is usually equipped with multiple wireless access devices and manages the routing algorithm. IEEE 802.11s standard defines integration of the WLAN link layer and mesh functions. Important mechanisms for spontaneous networking and message forwarding (routing) between mesh nodes, thus described in detail in IEEE 802.11s [15, 16]. An essential characteristic of the link determined in the model is the airtime cost (in µs) that can be estimated as:

$$c_a = \left(O + \frac{B_t}{r}\right)\frac{1}{1 - e_{fr}} \quad (2)$$

where O is a constant for the channel access and MAC protocol overhead. $B_t$ represents the test frame size, $r$ denotes the test frame data rate (in Mbps), and finally $e_{fr}$ stands for the expected frame error rate. As can be inferred from Equation (2), airtime cost depends both frame rate and error rate [15]. A more detailed analysis can be found in [17].

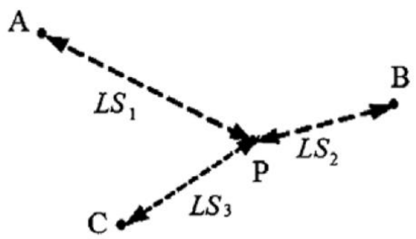


Figure 1. Positioning with RSSI [13]

There are various proactive, reactive or hybrid routing protocols proposed for mesh networks [18]. Among them, Zigbee is often used in case of low data rate and small packets. While routers constantly forward incoming messages to other routers, the coordinator sets up the routing structure and network and collects data from other routers. The Zigbee network automatically configures itself and dynamically reconfigures to repair itself if nodes are disabled or removed. As an interoperable standard, devices from many manufacturers can communicate seamlessly, helping Zigbee gain wide acceptance in home automation and industrial IoT. Costs are modest due to the many OEM equipment options on the open market [19].

## 3. Implementation of the System

Sedef Shipyard is the largest private shipyard in Turkey in terms of size and production capacity. The total area for production is 194,000 m² of which 51,000 m² is indoor production facilities in Tuzla plant. Thus, the positioning system was constructed using 200 gateways and 400 location sensors to locate 4870 staff wearing BLE 5 tags. The block diagram of the positioning system is shown in Figure 3.

The location sensors constantly broadcast their positions and tags scans the location sensor broadcasts around them. Then, tags collect location sensor ID and corresponding RSSI values and broadcasts them in Bluetooth range. The gateways receives the broadcast of the tags and send to server through Wi-Fi network of shipyard. Finally, the information is sent to Digital Shipyard platform. However, when the mobile receiver is inside the ships, gateways may not be able to reach Wi-Fi network because of the metallic surrounding. Thus, a mesh structure was constructed to gather data and reach wireless network. The mesh structure uses a routing algorithm as described in Figure 2.

Each gateway collects data from tags, if it could not connect to the wireless network, then sends data to another gateway in mesh. Travelling from one gateway to another, data reaches to coordinator gateway. Finally, the coordinator gateway sends all data gathered from the mesh network to the Wi-Fi network.

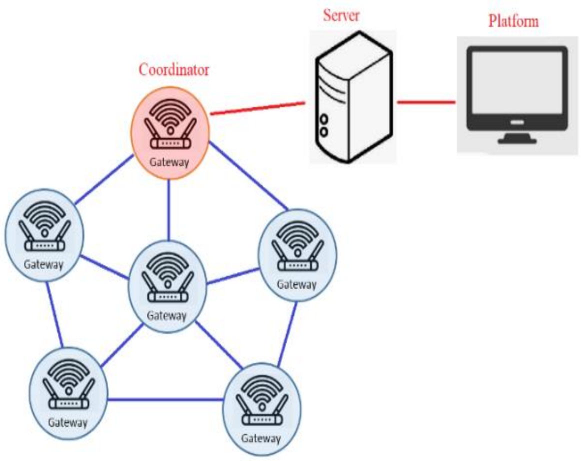


Figure 2. Mesh structure

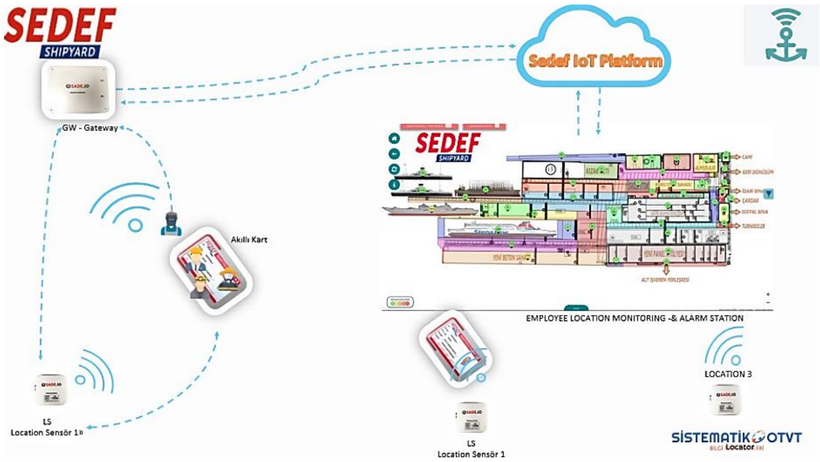


Figure 3. Real time shipyard positioning system

BLE technology is used in the design for staff identification cards and location sensors. The task of the ID cards is to listen to the broadcast emitted by the location sensors placed in the environment and to broadcast the ID information they receive from the nearest station together with their own information. As stated in the literature summary, power consumption, flash memory and RAM memory capacity are among the most important criteria for choosing a BLE device. The models produced by Nordic company produce the best circuits in terms of energy efficiency and the current drawn by the nRF chipset is much lower than the others.

Therefore, nRF52832 IC was used for ID cards in this study. The selected flash memory capacity is 256KB and the RAM memory capacity is 16KB, which is sufficient for the application to be made. PCB antenna was used for location sensors and personnel cards used in this project. It has a transmission power from -20 to +4dBm and thus provides a range of up to 40 meters. In order to ensure both long battery life and not enlarging the card sizes, 3V-3000mAh Lithium battery is used in the personnel cards and provides a lifetime of up to 3 years. Another important feature of the nRFxx modules is the easy assembly of the circuit without the need for many peripherals. It can be used with application-specific software [20].

The gateways also have BLE infrastructure in order to access the broadcasts made by tags by using nRF52832 IC. Its range reaches up to 50m. Gateways have a Wi-Fi infrastructure and antenna so that the collected packets can be transmitted to the server. Since it is supplied with 220V AC, it includes a power circuit, but there is also a backup battery circuit with a rechargeable battery to prevent interruptions of up to 4 hours in power cuts. MicroUSB circuit is also added for updating and communication. It also has a GSM module designed with M95 integrated circuit for communication.

The locations of the gateways were demonstrated in Figure 4. In this figure, indoor gateways were shown in light blue, where outdoor gateways were denoted by blue and red. The dark blue gateways were located on newly constructed poles for the project. Similarly, Figure5 shows the positions of the location sensors. The indoor location sensors are denoted as light blue and outdoor location sensors in shipyard are shown as blue and red.

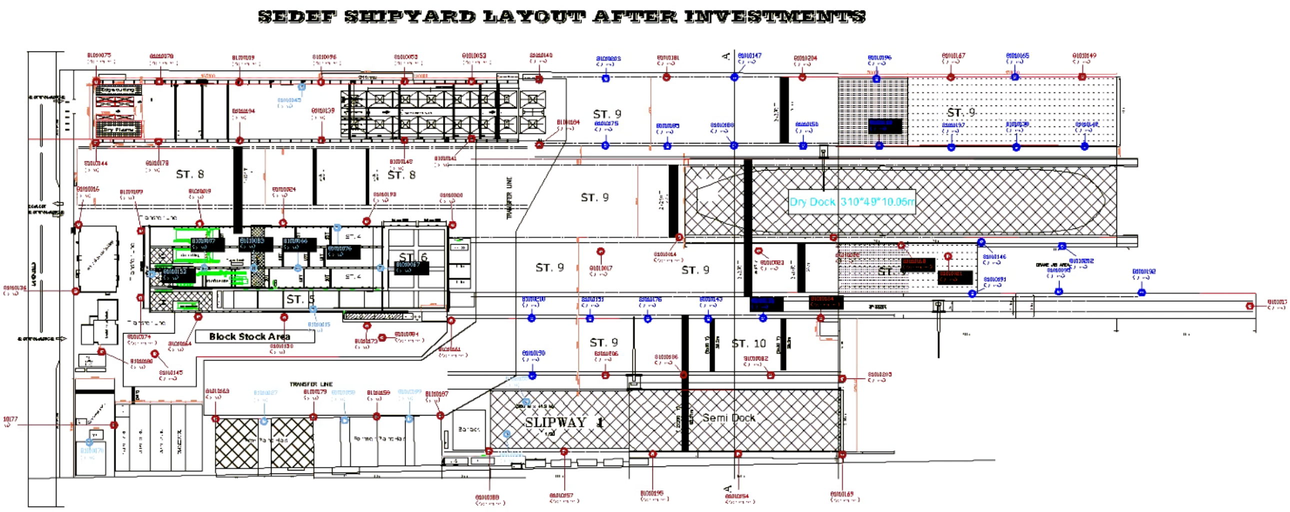


Figure 4. The locations of the indoor (light blue) and outdoor gateways (blue and red).

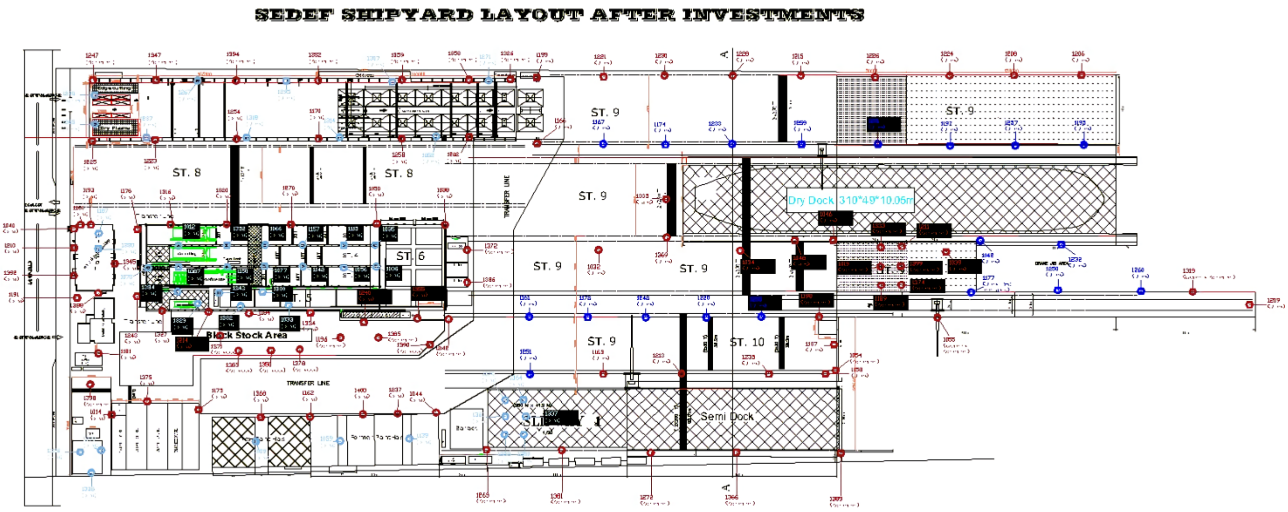


Figure 5. The indoor (light blue) and outdoor (blue and red) location sensors in shipyard

After the construction of the system, several on-site experiments were conducted to see the performance of the system. The tests included the followings:

- Adjustment of location sensor broadcast range in order to test the communication between the ID cards and location sensors. The broadcasting range adjustments were made, and the positions were changed if necessary to cover all areas.
- ID Card-Gateway communication tests to see if gateways can collect the ID and location information through BLE.
- Gateways-Server communication test which observes whether or not all the gateways can send the collected info directly or through the mesh network. Fine-tuning of the gateway locations were completed after this step.
- Staff position location experiments were implemented by walking an employee with an ID card following predefined routes. Then the locations were downloaded from the server to detect the accuracy of the locations. Figure 6 shows one of these experiments. In this experiment employee left the main building at 11:15 following the orange line and yellow stars show the positions of the location sensors which are communicated. The person reaches dock at 11:27 and then moves back with another route which is shown in red. Finally, he completes the experiment at 11:55 at the main building.
- In the final test, more ID cards were given to employees and their positions were detected via the software interface of the system. Sample screens of the systems were given in Figure 7. In Figure 7.a the numbers inside the green and red markers show the position and the number of the of the workers inside the ship in Figure7.b. is the list and details of the locations. Similarly, Figure 7.c and 7.d illustrates the workers inside the administrative building. Finaly, Figure 7.e shows a sample view from the menus. Therefore, the location of individual worker, or all workers can be monitored in once, the details of the recordings can extracted to track the activities.

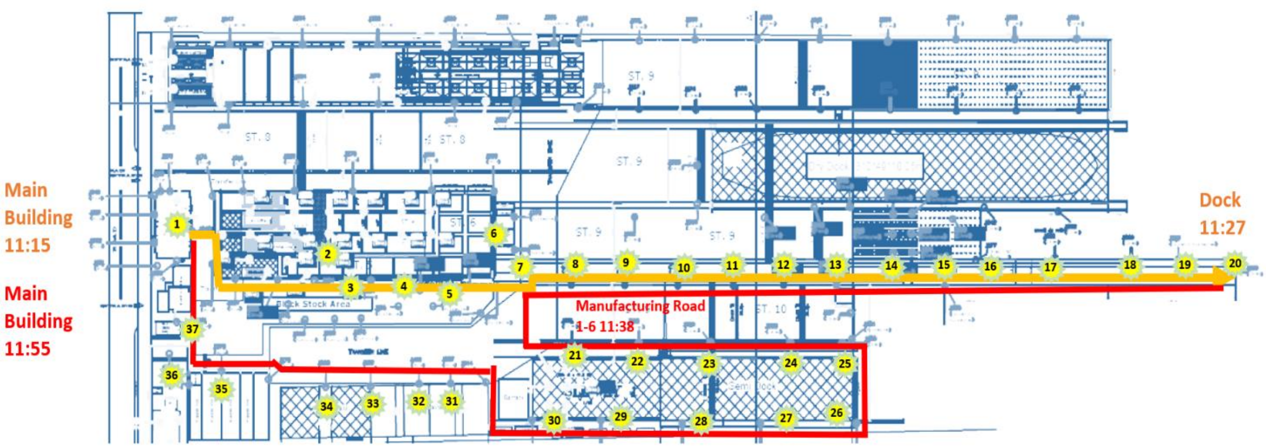


Figure 6. Experiment map for positioning accuracy

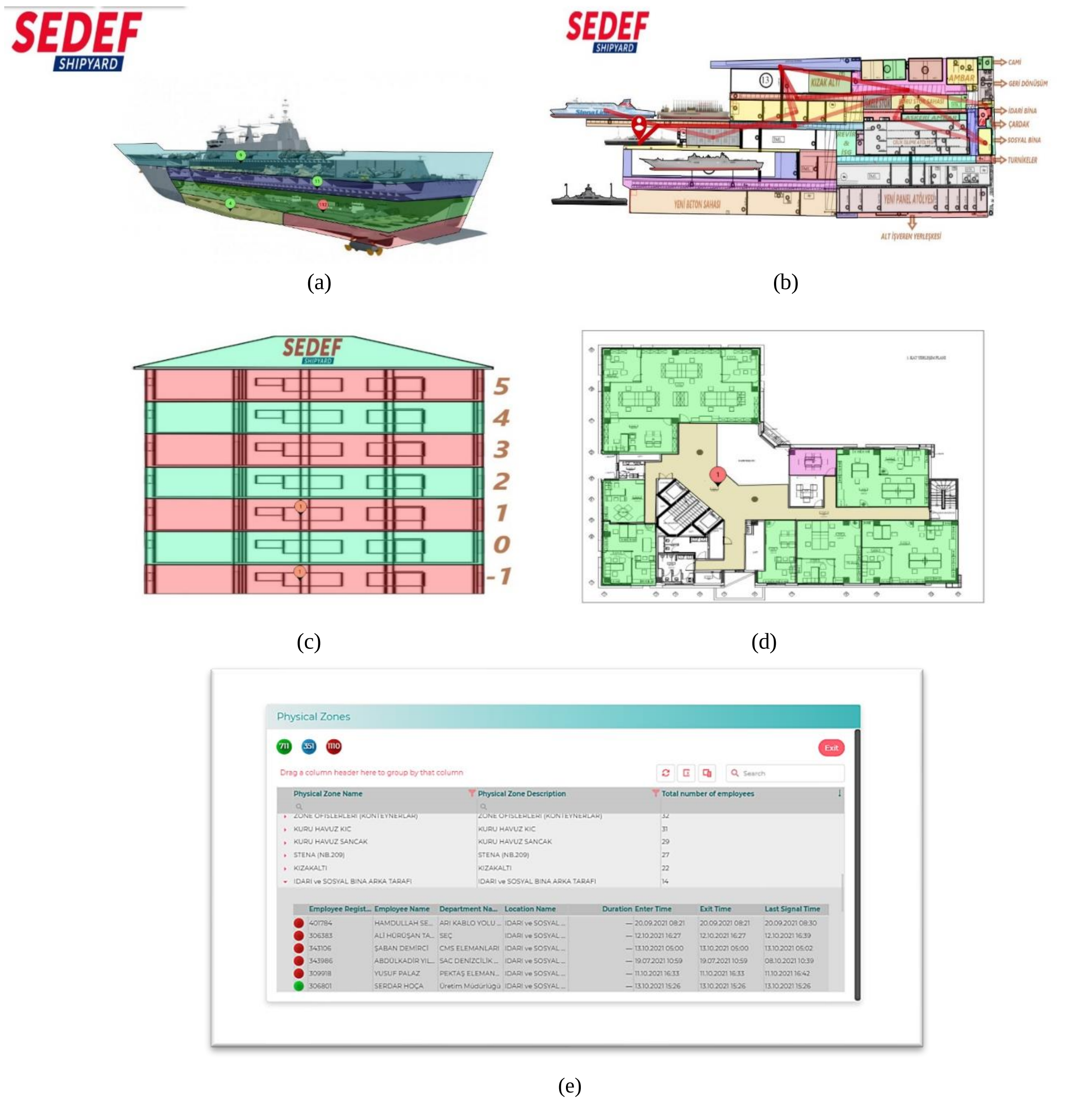


Figure 7. Graphical user interface of positioning system: a) Total number of workers inside the ship, b) tracking of a worker inside ship, c) number of workers inside the entire building, d) number of workers inside one floor of the building, e) a screenshot from user console

## 4. Discussions

A challenging case of indoor positioning was studied in this project. For increase the productivity and also safety, the workers and the machines should be traced inside the shipyard environment. Especially, determining the accurate locations inside the ship is a difficult problem. As explained in the previous sections with the combination of BLE, Wi-Fi and Zigbee technology, these challenges were overcome. The position and movements of the workers inside the metallic compartments of the ship were determined as illustrated in Figure 7.

Therefore, the advantage of the proposed method over other indoor positioning systems lies in the usage of a hybrid approach to cover the entire shipyard which includes a large open area, inside of the building and inside of a metallic ship. One limitation may be the resolution of the measurement when compared with UWB communication systems. The proposed system will not offer a centimeter-level resolution, however, determining in which room the workers are is sufficient in practice.

## 5. Conclusions

This study introduces a real time positioning system which is designed and implemented in Sedef Shipyard. Locating the staff and the machines in this huge area is a tremendous step in digitalizing the shipyard environment. The problem is challenging due to surrounding metal density, open and closed areas and mobile work machines. It is shown that an accurately working system was constructed by using and hybrid system using BLE, Zigbee and Wi-Fi via mesh networks.

## Declaration

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The authors also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

## Author Contributions

N. Ozkurt developed the infrastructure methodology of digitalization the shipyard. H. Kilinc provided all shipbuilding data and the compatibility of the yard for the process and made literature search. E. Ozgurbuz created the interface that performed the analysis. H. Erkan developed the electronic hardware of the shipyard substructure. All Authors wrote the manuscript together.

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## References

1. Arisoy, F., Kilinc, H., Cil, İ., *An Analysis on Industrial Internet of Things in Digital Transformation of Shipyard Industry in Turkey*, Global Journal of Computer Sciences: Theory and Research, 2021. **11**(2), p. 67–87.
2. Haupt, R.L., Wireless *Communications Systems: An Introduction*. 2019, USA: Wiley – IEEE Press.
3. Estes, D.R.J., Welch, T.B., Sarkady, A.A., Whitesel, H., *Shipboard radio frequency propagation measurements for wireless networks*, MILCOM Proceedings Communications for Network-Centric Operations: Creating the Information Force, USA, October 2001. **1**: p. 247-251.
4. Zhai, S., Jiang, T., Li, D., Li, B., *Statistical Characterization of UWB Propagation Channel in Ship Cabin Environment*, 2012 IEEE International Conference on Communications (ICC), Canada, June 2012. **1**: p. 6386-6390
5. Darroudi, M.S. and Gomez, C., *Bluetooth Low Energy Mesh Networks: A Survey*, Sensors, 2017. **17** (7), p.1467.
6. Çil, İ., Arısoy, F., Kılınç, H., Yunus, A., *A comparative analysis of indoor positioning technologies in shipyard digitalization context*, Journal of Marine Technology and Environment, 2022. **1**, p.15-25.
7. Spachos, P., Plataniotis, K.N., *BLE Beacons for Indoor Positioning at an Interactive IoT-Based Smart Museum*, IEEE Systems Journal, 2020. **14**(3), p. 3483-3493.
8. Handojo, A., Octavia, T., Lim, R., Anggita, J.K., *Indoor positioning system using BLE beacon to improve knowledge about museum visitors*, TELKOMNIKA Telecommunication, Computing, Electronics and Control, 2020. **18**(2), p. 792-798.
9. Montecchiari, L., Trotta, A., Bononi, L., Di Felice, M., *Bluetooth Mesh Technology for the Joint Monitoring of Indoor Environments and Mobile Device Localization: A Performance Study*, 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC), 2022. **1**: p. 193-199.
10. IETF, IPv6 over Bluetooth Low Energy, [cited 2020 May]; Available from: https://tools.ietf.org/html/rfc7668.
11. Bluetooth SIG. *Specification of the Bluetooth System, Covered Core Package; Version 5*. 2016, USA: Bluetooth Special Interest Group.
12. Ramirez R, Huang CY, Liao CA, Lin PT, Lin HW, Liang SH. *A Practice of BLE RSSI Measurement for Indoor Positioning*. Sensors, 2021. **21**(15): p.5181.
13. Sakpere, W., Adeyeye-Oshin, M., Mlitwa, N.B.W., *A state-of-the-art survey of indoor positioning and navigation systems and Technologies*, South African Computer Journal, 2017. **29** (3): p. 145-197.
14. Cao Y, Kandula H, Li X. *Measurement and Analysis of RSS Using Bluetooth Mesh Network for Localization Applications*. Network. 2021; 1(3): p.315-334.
15. Rethfeldt M, Brockmann T, Beichler B, Haubelt C, Timmermann D., *Adaptive Multi-Channel Clustering in IEEE 802.11s Wireless Mesh Networks*, Sensors, 2021. **21**(21): p.7215.
16. Hernández-Solana, A., Pérez-Díaz-De-Cerio, D., García-Lozano, M., Bardají, A.V., Valenzuela, J., *Bluetooth Mesh Analysis, Issues, and Challenges*, IEEE Access, 2020. **8,** p. 53784-53800.
17. Akyildiz, I.F., Wang X. and Wang W, *Wireless Mesh Networks: A Survey*, Computer Networks Journal, 2005. **47** (4): p.445-487.
18. Vijayakumar, K.P, Ganeshkumar, P., Anandaraj, M., *Review on Routing Algorithms in Wireless Mesh Networks*, Int. Jour. of Computer Science and Telecommunications, 2012. **3**(5): p. 87-92.
19. Zigbee vs. Bluetooth: Choosing the Right Protocol for Your IoT Application, [cited 2020 June]; Available from: https://www.digi.com/blog/post/zigbee-vs-bluetooth-choosing-the-right-protocol.
20. nRF52832 Product Specification, [cited June 2020], Available from: https://infocenter.nordicsemi.com/pdf/nRF52832_PS_v1.4.pdf