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Real-Time Low Energy Indoor Positioning System to Efficient Use of Operating Theaters with Medical Asset and Staff Tracking.

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Abstract. Efficient use of operating theaters would benefit hospitals financially as well as reducing the waiting time required for surgery. The aim of this study is to determine the frequency of use of the operating theatres and the amount of waste time in the use of those rooms for the different surgical branches. For this study, ”intelligent transmitters with low energy consumption” will be placed on the operating tables, the patient's stretcher and on the all working staff. Intelligent transmitters with low energy consumption will communicate over ISM (Industrial Scientific Medical) band. By analyzing the data obtained after 6 months period; the workload of the operation theatres will be determined for the different surgical branches. With the system developed in this study, operating theater efficiency and personnel performance were examined by calculating ”insufficient time” (planned time - busy time) or ”overused time” (participated time - planned time). The results obtained with the approach in this study showed that 23.7% of the time was saved. Since the average two-year number of surgeries at Trakya University Research Hospital is around 15,000, this improvement could boost clinical quality improvement initiatives by increasing the more efficient use of operating rooms.

Key-words: Bluetooth low energy; indoor positioning; management service organizations; medical Internet of Things; operating theater information systems.

1. Introduction

Efficient use of operating theaters provides a material benefit to the hospitals as well as reduces waiting time for the surgery. In conducted studies, it is reported that increasing the number of cases in the operating theatres reduces directly and indirectly personnel expenses. In order to use operating theatres efficiently, there are some requirements. Firstly, operating theater must be allocated to a surgery-branch. This surgery branch offers an opportunity to make the operation plan of patient [1]. Secondly, it is important to make a plan of the health personnel who will work in the operating theater. Choosing trained personnel - according to the operation type that surgery branch will carry out – will help prevent wasting time. Thirdly, it is important to increase compliance with the starting hours of the surgeries. Preparation of the operating theater is an important step in order to get the patient to the operating theater in the right time. Due to the delay of this preparation, the first case will be delayed and this will affect other patients in a negative way. Finally, the interaction of surgery services where patients are hospitalized and operating theater affects the time of admission of patients to the operating theater and the time of surgeons to reach the operating theater [2].

Determining the workload of the operating theaters according to the surgical branches, and calculating the values of under-used time and over-used time is essential in the effective use of operating theaters. In the meantime, the delay reasons of the start of the first surgery must be detected [3].There are various risk factors that threaten the security of health personnel in operating theaters. One of them is anesthetic gases. Due to anesthesia gases that expelled by gas waste system, during the inhalation of anesthesia gases through masks to patients in the operating theater, and in case of insufficient inflation of the intubation tube balloon and during the expiration of the patient, contamination occurs. Exposure to these kinds of gases increases in the longest surgeries. It becomes important to take the working health personnel out of the operating theater, periodically, in order to reduce the risk to occur. Another important issues are burnout syndrome and loss of motivation, which are seen in health staff [4].

The concept of the Internet of Things (IoT) has become a standard approach in all fields today, basically on the axis of low-cost, low-power requirements. These areas cover production and service sectors such as banking, agriculture, logistics, and medical IoT is one of them with the developments in the field of health in recent years. The use of IoT applications in the field of health can be grouped under three main headings. The first group is mostly applications for data access and monitoring of biomedical tools and devices. Now the characteristic that works with the ISM (Industrial Scientific Medical) band has become mandatory for the equipment which are used frequently in the healthcare field where such similar studies [5] are conducted by Zhu and by his friends. Naturally, technological innovations have increased considerably in the health components that are used by medical personnel. Due to increase of usage and amount of the generated data, new services and dataset have been emerged. By evaluating the generated data, the systems [6] that will assist to the diagnostic process and besides those frameworks [7] which work with these systems have been developed.

As it is expected that there are many approaches in the discipline of medicine, hence it can be said that there are nearly limitless applications in applying the IoT concept. Every passing day, new developments are being emerged in determining, following up on diagnosis and treatment approaches and in sharing them with other physicians and health institutions. Executing health services by collecting personnel health data of patients and individuals over second group personal area networks by a mobile phone or an IoT gateway both inside and outside the hospital in their daily lives. Today, these personal health services are commonly used in the European countries, and it created a paradigm called mobileHealth. As parallel to the applications in these two groups, it also increases importance on data security and privacy. In addition to present health data standards on security and privacy, besides trust based [8] and policy-based [9] frameworks, there are studies [10, 11] examining possible dangers of security problems that can be encountered in accessing health data. The third group approach is a study that basically includes Real-Time Location System (RTLS) approach where applications are taking place for asset tracking in health institutions. Although, these studies, which are basically based on monitoring equipment used in hospitals with RFID (Radio Frequency Identification), are important in measuring the efficiency of health services by using especially Bluetooth technology and smart beacon. In one regard, "elements" as diagnosis and monitoring devices are used in healthcare, and assets that are used by patients and nursing personnel are an important component of these elements. These approaches, which used especially Bluetooth Low Energy (BLE) in posted survey studies, are less sought after [12] even they show up-and-coming rise.

In the context of BLE indoor localization, the integration of advanced techniques such as Extended Kalman Filters (EKF), Takagi-Sugeno fuzzy observers, neural network-based models, and pattern recognition methods holds significant promise [13]. The application of EKF and fuzzy observers aids in precise tracking and localization within complex indoor environments, mitigating noise and nonlinearities. Simultaneously, the utilization of neural networks and data processing methodologies enhances the system's ability to analyze BLE signals, facilitating accurate positioning. Furthermore, the incorporation of pattern recognition enables the identification of specific movement patterns associated with conditions like Parkinson's disease, demonstrating the potential for early detection and diagnosis within indoor settings [14, 15].

In the context of BLE indoor localization, the incorporation of advanced nonlinear modeling techniques, including dynamic Bayesian networks, recurrent neural networks, tensor product-based modeling transformations, and fuzzy logic-based methodologies, holds significant promise. By leveraging these sophisticated modeling approaches [**?**], the system can effectively capture complex cognitive processes, intricate spatial relationships, and uncertain environmental conditions within the indoor setting, leading to enhanced accuracy and adaptability in indoor positioning. The integration of these diverse modeling strategies underscores the potential to establish a comprehensive and robust indoor localization system capable of addressing the intricacies and challenges associated with real-time positioning and navigation in dynamic indoor environments.

The study aims to assess the workload of the operating theaters across various surgical branches and the efficacy of resource utilization and personnel allocation over time. This is achieved through the integration of "low energy consumption smart transmitters" on the operating tables and patient stretchers, along with their attachment to all personnel operating within the Trakya University Research Hospital, which has a bed capacity of 1000. The efficiency analysis infrastructure developed has introduced a novel perspective on efficiency, allowing for detailed examination at the stretcher level using BLE tags in place of RFID. The primary contributions of this study to the state of the art are as follows:

- Efficiency analysis and calculation of efficient usage time based on real-time location tracking on the level of operating room staff, operation stretcher, operating theaters, and rooms.
- Open source BLE gateway platform and tailor-made portable BLE beacons with a service life of more than two years.
- Patients can be easily tracked in real-time thanks to portable beacons.
- Mobile and web-based automation systems with their flexible infrastructure can be easily

expanded and they can manage the density of the research hospital where more than 10,000 operations are performed per year.

Also, to bridge this gap by introducing a novel integrated system that leverages advanced data analytics, real-time monitoring, and intelligent decision support mechanisms to enhance operating theater efficiency and resource utilization. By providing a centralized platform for seamless communication, data-driven insights, and dynamic resource allocation, the proposed system seeks to optimize or workflow, minimize surgical turnover times, and improve the overall quality of patient care delivery. The integration of this innovative solution is expected to revolutionize OR management practices and set a new standard for operational excellence and patient-centric care in hospital environments.

The rest of this paper is organized as follows: Section 2 is dedicated to the description of the hardware components and the middleware implementation that was designed. Section 3 details the features of mobile web applications used in productivity management. Results and discussion are presented in Section 4. Finally, the paper is concluded in Section 5.

2. Materials and Methods

Nowadays, studies of determining position are developed in order to succeed in indoor applications as well as in outdoor applications. Classic Global Positioning System (GPS) applications can perform outdoor positioning economically, in a fast speed. Due to GPS signals cannot reach determining people's location – does not perform well in indoor environments- is an important problem. When previous studies are examined, it can be seen that various approaches are found for the solution of problems. One of them uses Wi-Fi technology [19]. This technology requires many access point and therefore it is expensive and has sensitivity problems. Apart from this, a method which uses optical, magnetic and sound waves with its working problem is advised. It is obvious that combining some of systems will increase the costs of systems for sensitivity problems [20].

The selection of BLE technology for indoor positioning was primarily based on several critical criteria, including its low energy consumption, cost-effectiveness, and compatibility with a wide range of devices. BLE's ability to operate on low power makes it ideal for long-term deployment, ensuring extended battery life for the devices, thereby reducing maintenance requirements and operational costs. Additionally, the cost-effective nature of BLE hardware and its widespread adoption in various consumer electronic devices contribute to its feasibility for large-scale indoor positioning implementations, making it a practical choice for this study

When compared to alternative technologies such as RFID or Wi-Fi, BLE stands out due to its superior power efficiency, higher data transmission rates, and enhanced accuracy in proximity detection [21]. Unlike RFID, which is primarily suited for asset tracking in close proximity, BLE offers more advanced features such as two-way communication and data exchange, enabling real-time positioning updates and enhanced interactivity with the environment. In contrast to Wi-Fi, which consumes comparatively higher power, BLE's lower energy consumption makes it more suitable for continuous operation in battery-powered devices [22, 23], making it well-suited for long-term indoor positioning applications.

The decision to choose BLE as the preferred solution for this study was also influenced by its compatibility with a wide array of smartphones, tablets, and IoT devices, allowing for seamless integration with existing infrastructure. Additionally, BLE's support for multiple data rates, low-latency communication, and enhanced security features further solidified its suitability for the study's objectives, ensuring reliable and secure data transmission within the indoor environment [24].

Specific BLE devices used in this study included the CC2541 microcontroller with Bluetooth 4.0 (BLE) compatibility, facilitating efficient communication and data transfer with minimal power consumption. The transmit power levels employed were typically set within the range of -20 to +4 dBm, ensuring optimal signal strength for reliable indoor positioning while mitigating potential signal interference and power consumption concerns [25]. Moreover, the study leveraged BLE protocols such as the Generic Attribute Profile (GATT) and the Attribute Protocol (ATT) for efficient data exchange and management, enabling seamless communication between the BLE-enabled devices and the central data processing unit. These specific device choices and protocols were selected to ensure optimal performance, power efficiency, and seamless integration within the indoor positioning system, aligning with the study's overarching objectives and requirements.

2.1. BLE for indoor positioning

Today BLE is the most preferred technology in IoT applications due to especially its low energy consumption. BLE technology is clearly distinguished from other technologies, especially with its feature aimed at reducing energy consumption. Some conducted research shows that the BLE chip, with its one-hour battery life, can operate for nearly two years without needing replacement [26]. In addition, BLE chipsets are an appropriate solution for indoor and vehicle positioning systems with their low-cost. Therefore, BLE technology which has Personal Area Network (PAN) topology is used in this project. The indoor positioning detection system consists of two components, namely "low energy consumption transmitters" and "wireless gateway device", which are also foreseen in the project proposal. Low energy consumption transmitters are determined as two types. In the study, readily available wearable technology was utilized, while modifications were made to adapt it to stretchers as part of the project development process. The low energy consumption transmitters were not configured for peer-to-peer communication (P2P) with each other or with the browsers directly. They advertise continuously in accordance with a standard data format by using 3 advertising channels offered by BLE technology. In addition, used channels are ISM, hence using them is not a problem in the field of health.

Another component of the system was the "wireless gateway device" that was developed. These modules are positioned in the operating theaters. These devices internally contain BLE technology for the close area network and Wi-Fi and LAN technology to transmit the information to the cloud server. Since this device has the possibility to be constantly connected to a power source, there is not a necessity on power consumption.

As it is seen in Fig. 1, signals that are sent by BLE-based advertising X transmitters are picked up through wireless gateway devices such as A, B, and C positioned in the operating theaters, and it is transmitted to the database with the signal strength. The developed "information management system" offers possibilities to prepare required reports and draw an inference by identifying these data [27].

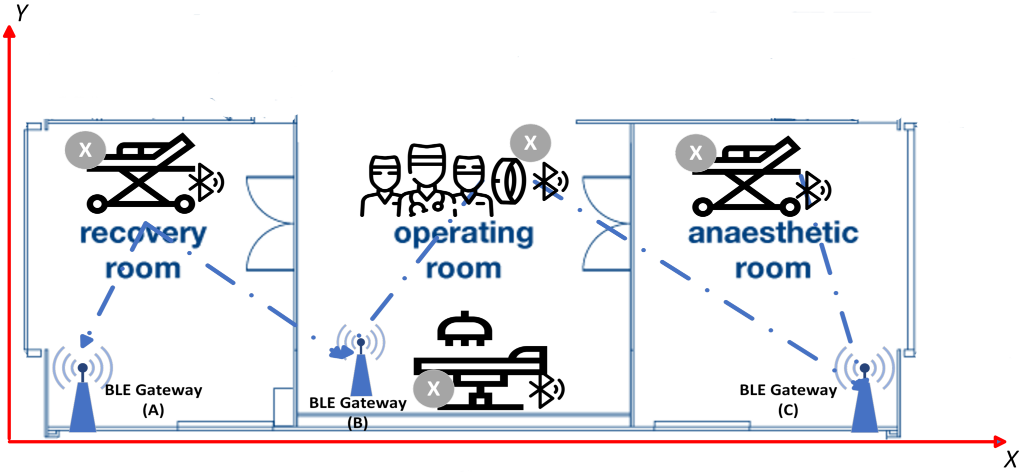

Fig. 1. BLE Gateway devices(A, B, C) are fitted into the equipment and tools of the operating theater in the hospital, and they are positioned in the appropriate places to monitor the personnel and transmitter in the stretcher.

2.2. Low energy beacons and wristbands

At the onset of the study, a low energy consumption transmitter was initially designed for use on the operating theater stretchers. In this instance, the Texas Instruments TI-CC2541 System-on-Chip (SoC) BLE platform was selected. This platform has many skills, as a minicomputer provides, as 2.4-GHz RF transceiver, 8051 microcontroller on the chip, 256 KB programmable memory, 8 KB RAM, and peripheral units. In this project, the TI-CC2541 chip was preferred due to its ready availability in the market. The platform can be programmed by using the IAR Embedded Workbench tool. It is important to state that the TI-CC2541 platform offers two different stacks. They are single-device and network processors. In the single-device mode, the controller, processor, and application are implemented as a true single-chip solution on TI-CC2541. To extend the lifetime of the devices beyond the standard two years, various power management techniques are implemented within the firmware and hardware design. These techniques include duty cycling, where the device periodically alternates between active and sleep modes to conserve power, and the utilization of low-power sleep modes to minimize energy consumption during idle periods. These time intervals last on average 300 μs and average power consumption of one Sketcher-Type BLE transmitter is 0,0120742 mA. With CR2032 battery, which is used in this study, has 230 mAh capacity. If we calculate the expected battery, life is approximately 71.000 hours. Additionally, the implementation of efficient data transmission protocols and data processing algorithms within the CC2541 contributes to reduced energy usage, thereby prolonging the operational lifespan of the devices. These meticulous power management strategies ensure that the circuit remains functional and efficient, allowing it to operate reliably for an extended period while maintaining the desired low-power consumption characteristics inherent to the CC2541 and the single-chip configuration. On the other side, the chip is only responsible for BLE wireless communication in the network-processor mode. Other features are provided by using microcontroller on interfaces such as USB, UART, SPI. Since single-device configuration requires learning a new platform, when similar studies are examined, it is seen that the network-processor approach is used in many studies. However, it is obvious that this approach increases the power consumption.

In this study, devices were designed to operate in the single-device mode and be used in stretchers. Fig. 2 given in [28] displays the circuit diagrams and designed forms of these devices. After designing and testing the stretcher-type low energy consumption transmitters in the laboratory, we searched for a transmitter that could be used by personnel with the lowest level of discomfort. In addition to being a wearable type of transmitters, supporting the BLE advertisement packet mode and format, just like the stretcher type transmitters, was the main priority. Many types of smart watches with wristbands were examined by contacting manufacturers. An agreement was made with a domestic manufacturer capable of providing the desired features and necessary customizations, and the watches were subsequently supplied. The device possesses various features including a clock, pedometer, and heart rate measurement capabilities, in addition to its technical specifications. Consequently, it was anticipated that this would foster an emotional connection between the personnel and the device. Fig. 3 given in [28] displays the mounted position of the BLE transmitters on the stretcher and the smart wristbands given to the personnel.

2.3. BLE gateway devices

While BLE has been identified as a cutting-edge technology in preceding sections, it lacks an IP stack and cannot independently support the required functions. To facilitate the implementation of the indoor positioning method, gateway access devices were necessary, providing BLE connectivity on one end and LAN/Wi-Fi wireless communication structures on the other. Consequently, hardware modifications were undertaken, incorporating Linux distribution to tailor it to the specific requirements of the study. Fig. 4 given in [28] shows gateways that are used in the hospital.

The most essential component of the gateways utilized in the study is the Central Processing Unit (CPU) AR9331 with a System-on-Chip (SoC) structure. This processor uses an external power source. Embedded operating system and application software running on the processor are maintained in 16 MB SPI Flash Memory. Additionally, the system has 64 MB DDR SDRAM main memory. It has 300Mbps (2.4GHz) integrated Wi-Fi transceiver. There are cabled and wireless gateway components in the Central Processing Unit. By this means, the system does not need additional integrated circuits to connect to cabled and wireless external gateways. It has an internal wireless network antenna for connecting to wireless networks on the system and two RJ45 Sockets for connecting to cabled networks. There is a BLE Integration connected to the processor, in order to realize scanning of this module. This BLE Integration receives information from low power consumption transmitter. The processor interprets this information and transmits it as cabled or wireless to the database server on which the central information system runs. This scanning device works on its own without a computer, independently. It saves the obtained data directly to the database on the network. At the same time, all BLE scanning modules transmit information to the database continuously, covering the entire workspace. The software running on the scanning device was developed by using the python 3.0 language. Gateway devices operate independently from other operating theater equipment and tools in the hospital environment. The pseudocode of this program is given in Listing 1.

```
function main()
location={room number}
    open DB();
    do for_ever [
        scan_list=scan();
        for each item in scan_list [
            if item in DB in same_ROOM_ID then DB.update { RSSI, ROOM_ID,
            MAC, LAST_SEEN}
                else DB.insert item { RSSI, ROOM_ID, MAC,LAST_SEEN }
                ]
        ]
function scan()
    hci_device= open ble_sub_system();
    scan (hci_device);
    close ble_sub_system
    return scan_list;
```

Listing 1. Wireless gateway device pseudocode

3. Efficiency Management Platform

Information Management System that we developed for this study consists of five basic applications. These applications are Database Management System, Android and iOS based Activity Tracker Application, Windows desktop application that controls the Activity of Web Service and BLE Gateway Devices.

In order to manage and report information of low energy consuming transmitters registered to the database server by wireless gateway devices, a database management system has been developed. In the developed system, location determination can be managed by wireless gateway devices. There is a dense information flow in the system, and therefore this process is carried out by the information management system on the server since determining the position of each transmitter requires serious processing power. Thanks to its visual and user-friendly interface, management functions and reporting processes can be conducted quickly and easily.

The following features are obtained by using the Management System:

- Registration of wireless gateway devices to the system and the last active time of the devices can be seen.
- Registration of low energy consuming devices to the system, and registers and daily reports of these devices can be viewed.
- Daily number of data and reports that wireless gateway devices register it to the system by scanning can be viewed.
- Activity reports of low energy consuming devices and the active/passive times of the devices can be viewed graphically.
- Low Energy Consuming Devices that fitted on the stretchers can be reported how much time they stay in the operating theater.
- It is possible to create QRCode tags for the personnel using Low Energy Consuming Devices to view their own registrations in Android and iOS applications.

Management System and was developed by using type of project called ASP.NET Web Forms. The platform and web service component programming by C# programming language.

In addition, Ext.NET component framework with integrating the cross-browser software was also used. Mobile application primarily programmed in Flutter. The database used in the backend is MSSQL. For security of application OAuth 2.0, an authorization framework was used. It allows a third-party application to access specific user data from a server without revealing the user's credentials with HTTPS encryption and token expiration policies. It operates on the concept of authorization delegation, granting access tokens to client applications by resource owners. Since server applications are hosted at the hospital's IT center, backup and other security strategies are determined by the institution. For example, thanks to the Stretcher Usage Report, which is used to determine how much time surgery has continued in the developed applications, equipment of the operating theater can be monitored more efficiently. Fig. 5 given in [28] shows the stretcher usage report and the activity report of stretcher/personnel clients in the web application.

4. Results Analysis and Discussion

The devices distributed to health personnel in the daily regular working hours in the operating room are in the form of watches that facilitate their use. Anesthesia assistant and technician, operating nurse, desk staff, surgical assistant, cleaning staff, and patient handling personnel working in the same operating theater are described. The devices that are given to the personnel are ensured to use during working hours. Devices are coded according to personnel's jobs (for instance, desk staff, anesthesia assistant, operating nurse and etc.). Due to the people in an operating theater may change according to the planned working order in the operating theater, and therefore this method has been chosen. All data that fulfilled the inclusion criteria in the Trakya University Health Research and Application Center Operating Theater between April 1, 2018 and September 30, 2018, were registered on the servers on the internet, after the completion of the monitoring system. Table 1 given in [28] displays the descriptive statistics of the data collected during this period.

In this study, an examination was conducted to determine the measures necessary for optimizing the efficiency and effectiveness of operating theaters. This involved assessing the frequency of theater use, the duration between patient admissions and discharges, and the factors influencing these intervals. Therefore, the daily number of patients in the operating theaters, the duration of the surgery (minutes), the time of admission of patients to the operating theater and discharge of them from the operating theater, and the total time (hours) of all personnel working in the operating theater were calculated. By analyzing the data in a computer environment, descriptive statistics such as average, standard deviation, median, minimum, maximum, number, and percentage were calculated. In the operating theaters of Trakya University Hospital, the average duration given for the surgery is determined as 480 minutes. As mentioned earlier, the times obtained from the devices attached to the stretchers and distributed to the staff were calculated, along with the results obtained during the three-month period. The values of overused time and inefficient time are computed as follows:

$$TM = \tilde{X}\left(PT - \left(\sum_{1}^{n} BST_n + \sum_{1}^{m} PWBT_m\right)\right) \tag{1}$$

$$T = COV(UTSDepth, TM)(UTSDepth, TM) \tag{2}$$

The following notations are used in (1) and (2):

TM = Time Median
PT = Planned Time
T = Time Results for Overused or Insufficient Times
BST_n = *BLE Beacon Stretcher Time*
$PWBT_m$ = *Personal Wrist Band Time*
USTSDepth = UsingTimePerSurgeryDepartment

For the calculation of overused time, departments with insufficient performance were identified in a timely manner based on the variables mentioned above, utilizing the covariance calculated in (2). To calculate insufficient time, variables were rearranged as demonstrated in (1), followed by the computation of the covariance. Figs. 6 and 7 given in [28] display the results obtained using the proposed approach.

As observed from the graphical representations of the results obtained, it was identified that certain departments consumed more time than the allocated duration under standard conditions. Although surgical interference quality among departments shows the difference, units operating in less time than the time allotted for them and the remaining time here could be used by other needed units in a way. During this time, it can be expected to reduce the time gap among other waiting operations. Efficient usage of time reduces the waiting time of patients, too.

One of the findings derived from this study was the comparison of tests conducted between April-June and July-August. During the personnel leave period (July-August), a notable increase in the time utilized in operating theaters for trauma and emergency surgeries was observed. Furthermore, based on the results obtained in the application, it was observed that certain operating theaters experienced prolonged intervals between surgeries. This delay was attributed to the time taken for patients to be transferred from their respective wards to the operating theaters. The findings are deemed valuable for enhancing hospital management, optimizing surgical planning, and improving overall operational efficiency.

Over the last two months, result of obtained data, hospital management has imposed restrictions in the allocated time in some surgical branches. As a result, in the analysis of the duration of usage, a total of 23.7% time usage savings were achieved in the ENT and orthopedics departments. In this paper, it is deemed important to contribute to the existing literature through the results obtained. The prolonged lifespan of the utilized low energy devices is particularly vital for the sustained operation of the developed system. Not only does this ensure cost savings attributed to prolonged usage, but the cost-effectiveness of the equipment employed is also anticipated to augment such applications. A comparison of this study's approach with similar studies is provided in Table 2.

In this paper, numerous difficulties that indoor positioning systems encounter might have a substantial impact on their accuracy and overall efficiency. One such important element that can result in inaccurate placement is signal interference. Signal deterioration and erroneous position estimates may result from interference caused by electronic devices, construction materials, or other wireless technologies operating in the same frequency band. Additionally, multipath propagation, in which signals reflect off surfaces, can amplify and distort signals, which makes it more difficult to pinpoint the exact location of devices. The problems encountered here were overcome by providing additional gateway and wearable devices. As for the problems arising from the users, since it is a public organization, effective and careful participation in the project was ensured by the managers.

The proposed system must adhere to stringent security and privacy measures to safeguard sensitive data, ensure patient confidentiality, and comply with pertinent regulations like the Health

Table 2. Comparison with similar approaches to that proposed in this paper

Study	Description	Technologies	Location accuracy	Calculated quantity
[29]	Real-time location systems in nursing homes	RFID	-	-
[30]	Reviewing RTLS literature and proposing a model for hospitals	-	-	-
[31]	Analyzing the deployment of a BLE based asset tracking system on a hospital	RFID, Wi-Fi	Room	Tag design, operational support
[32]	Improving Documentation	-	-	The proportion of eligible patient encounters
[33]	Automatic Patient Pathway Characterization	IR	Room	Patient pathway
[34]	Analyzing Patient wait time	RFID	Room, Patient	Wait Time
This Study	Asset and Medical staff tracking	BLE, Wi-Fi	Room, Operating Theaters, Staff, Stretcher	Efficiency Time

Insurance Portability and Accountability Act (HIPAA) and the General Data Protection Regulation (GDPR). Robust data protection protocols should be implemented to secure patient information from unauthorized access, data breaches, and malicious activities.

Encryption of data at rest and in transit is crucial to prevent unauthorized interception or access to patient records. Strong encryption algorithms, such as AES (Advanced Encryption Standard), can be employed to protect data integrity and confidentiality, ensuring that only authorized personnel can access and decipher sensitive information. Additionally, secure transmission protocols such as HTTPS should be used to protect data while it is being transmitted over networks.

Data anonymization and pseudonymization techniques should be utilized to protect patient privacy. Personal identifiers, such as names, addresses, and social security numbers, should be replaced with unique identifiers to prevent the direct identification of individuals. By implementing these techniques, the system can maintain data utility for research and analysis purposes while safeguarding the confidentiality of patient information.

5. Conclusions

Although the developed system is for operating theaters utilization efficiency, it has the capacity to provide an important solution for different needs in some aspects. This system can help to solve the events by reporting the places where it happened without the need for monitoring the cameras by matching the digital footprint determined after the event happened with the video images. In addition, it can be used in order to follow instantly routine routes for the security guards. Besides it is different from frequently used and fixed positioned “guard control system" applications and it eliminates the observance of a fixed route plan. Dynamic routes can be planned in compliance with time and special situations. When similar smart sensors are given to the patients, violations can be detected in areas that are not proper for entry. Importantly, it can prevent actions such as infant abduction.

Moreover, it is anticipated that the developed system will find application in the following areas in the future:

1. Inventory Tracking: Mobile and fixed inventors can be monitored and reported, instantly. If it requires maintenance or if it is out of order, service can be requested on the device. It is useful in the positioning of costly devices or the common use of portable devices.

2. Monitoring Status: With the sensor that positioned in the special places, the status can be monitored. For example, many parameters such as how many people entered the toilet, temperature and humidity level, and occupancy rate of the medical trash cans can be collected. If the toilet was cleaned six hours ago and is used heavily, autonomous solutions can be developed to arrange cleaning order and give priority to the toilets that are used more.

3. Security: Even though security camera systems provide security in a certain level, they are generally used with the aim of solving events after that happened or collecting evidence. With the system to be developed, personnel positions can be tracked instantly or people whose digital footprints are detected on their smartphones can be monitored instantly or this information can be kept in order to use evidence.

The practical implications of this research suggest that the integration of our system can significantly alleviate the burden on healthcare facilities, enabling them to allocate resources more effectively, reduce operational costs, and improve staff productivity. Furthermore, the seamless integration of data-driven insights can empower healthcare providers to make informed decisions, leading to personalized and targeted patient treatments, ultimately enhancing the overall standard of care.

Looking ahead, future research endeavors should focus on advancing the system's capabilities by exploring cutting-edge technologies such as artificial intelligence and machine learning to enable predictive analytics, early disease detection, and proactive patient management. Additionally, the integration of telemedicine solutions and remote monitoring functionalities can extend the system's reach, ensuring continuous and comprehensive healthcare services beyond the traditional care setting. Overcoming technical challenges related to data interoperability, system scalability, and real-time data processing will be crucial for ensuring the seamless integration and sustained performance of the proposed system in diverse healthcare environments.

By addressing these future research directions and technical advancements, our study sets the stage for a transformative shift in healthcare practices, promising a future where technology-driven solutions can effectively augment healthcare delivery, enhance patient outcomes, and contribute to the advancement of a more efficient and patient-centric healthcare ecosystem.

Ethical considerations This article does not contain any studies with human participants performed by any of the authors. This study was approved by Scientific Researches Ethics Committee of Trakya University Medical Faculty.

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