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An IoT Intelligent Approach for Safety and Efficiency of Robotic Medicine Delivery in Hospitals

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Abstract: - In this paper, we introduce an IoT-based robotic medicine delivery system designed to boost safety and efficiency in hospital settings. This IoT-embedded robotic system integrates advanced sensors such as proximity, temperature, pressure, pulse rate, etc., sensors for ensuring real-time health and environmental monitoring behind this system. The robot is connected to a centralised controller, enabling healthcare workers to monitor patients using a cloud-based system. . Our robotic system moves about with the support of both line follower and LiDAR scanning technology for environmental safety and proximity detection. Experimental results show that the robotic system was able to navigate static obstacles and dynamically move away from the mobile entities within its reach without touching them. Besides, the proposed robotic system was able to reach the bed at the right time under normal operating conditions, which shows the efficiency of this approach in real-time settings. Patient feedback suggests that patients are very happy about the system, in terms of its usefulness, trustworthiness, and to their suprise to be taken care of by a robot. Overall, our study shows the potential of the proposed robotic system in streamlining the existing medicine delivery process in hospitals. It can potentially improve various aspects including safety, efficiency, patient compliance, and quality of care delivery. The promising results suggest further studies for incorporating advanced features and for ensuring compliance with regulatory requirements. Additional studies are to be conducted to further improve the proposed sensor-based robotic medicine delivery system, to facilitate its adoption in hospitals.

Keywords: Robotic medicine delivery, IoT, Healthcare, Patient care, Sensor technology

I. INTRODUCTION

The use of robotics and automation into the healthcare systems become a promising approach to improve the delivery of patient cares. With the increasing needs of more efficient medication administration processes in the hospitals, researchers have developed new robotic medicine delivery systems to provide innovative solutions to busy and needy environments. The Internet of things , artificial intelligence, and sensor technologies are used to allow the robotic systems to navigate hospital zones and deliver medications to assume positions on a patient's bed. Improving the healthcare delivery process, the robotic systems can help in improving the safety, accuracy, and efficiency of the medication delivery processes in the context of a hospital, relieving the healthcare staff, and reducing the Medication Errors [1]–[3]. This research tries to provide better solutions to the problem of improved medication delivery process in hospitals by designing and developing an internet of things solution for controlling robotic medicine delivery systems [4], [5].

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The IoT robotic medicine delivery system was designed and developed through an activity-based project where IoT technology was extensively used to develop an adaptive system. The project uses different available sensors including the proximity sensors, temperature sensors, and pressure sensors to allow the robotic to sense the environment surrounding it, make movements, and communicate with the environment to allow the assumed navigation through the hospital corridors safely and without any hindrances. Robotics has significantly evolved and improved in the delivery of healthcare throughout the years, where its applications extend to facilitating the delivery of medication to patients. As rendered from the available observational history, the da Vinci Surgical System was introduced to conduct robotic surgery. The telepresence Coordinated Care Robot is one of the modern-day applications of robotic medicine delivery systems that accept and transports medication safely to the beds of needy patients [6]–[8].

Robotic medicine delivery systems is one of the most innovative applications of robotics in the domain of healthcare and medicine meant to improve and optimize the process of medication administration within hospitals. The systems typically involve autonomous mobile robots that are fitted with a range of sensors, navigation algorithms, and medication dispensing devices . The robots move freely around the corridors delivering medication to the patients in their beds, thus accomplishing the task and minimizing errors and hospital staff workload in the process. Examples of robotic medicine delivery systems include MedEx and TUG robots that have been utilized by numerous healthcare facilities around the world. However, the notion of robotics in health is far from being limited to the physical devices, as the integration of the Internet of Things is integral to enabling the optimal ability of the robots in a hospital setting [9], [10].

In order to convey the full potential of health-related robotic systems, it is important to understand how they are future-integrated with the Internet of Things. Generally speaking, IoT serves as an interconnected framework that utilizes sensors, actuators, and communication systems to pool the data in real time [11], [12]. The significance of IoT in the context of robotic systems for healthcare is crucial, as it allows for full integration with the existing systems on the premise and can be remotely monitored and managed accordingly. In addition, the IoT-based system can combine the data in order to optimize navigation routes and anticipate or warn regarding the upcoming situations. Continuous and large-scale data gathering also provides the healthcare professionals with specific data trends requiring attention. Moreover, the use of IoT ensures the ultimate compatibility and scalability in the context of integration with more healthcare technologies [13]–[15]. However, there are a number of challenges that still plague such robotic medicine delivery systems, which include sensing issues, navigation complexities, cost and safety concerns, as well as scalability.

The literature gap is in the development and evaluation of a robust IoT-enabled robotic medicine delivery system dedicated to hospitals. There are numerous studies on the application of robotics in healthcare delivery operations, but there are no comprehensive research studies on implementing IoT technology and sensor-based navigation in the process of delivering medicine to patients. In this regard, the purpose of the literature gap study is to develop and evaluate the robotic medicine delivery system, which will use IoT for safe, effective, and reliable delivery of medicine in the hospital environment. As such, this study is aimed at providing empirical evidence for the benefits and efficiency of delivery systems with the innovative application of technology and its empirical study [16], [17].

II. METHODOLOGY

The present research is unprecedented in creating a paramount solution for the revolution of the medicine delivery system in hospitals. The key element is that we availed a more advanced medical robot with a robust sensor system to ensure that the delivery is conducted in a timely, safe, and efficient manner. The temperature sensor, the pressure sensor, and the pulse rate sensor are essential parts that work in sync with the ubiquitous proximity sensor to constitute a delicate surveillance system, which is a guarantee that the automatic medicine delivery system will remain the most advanced and best option. The architecture of the research are shown in figure 1.

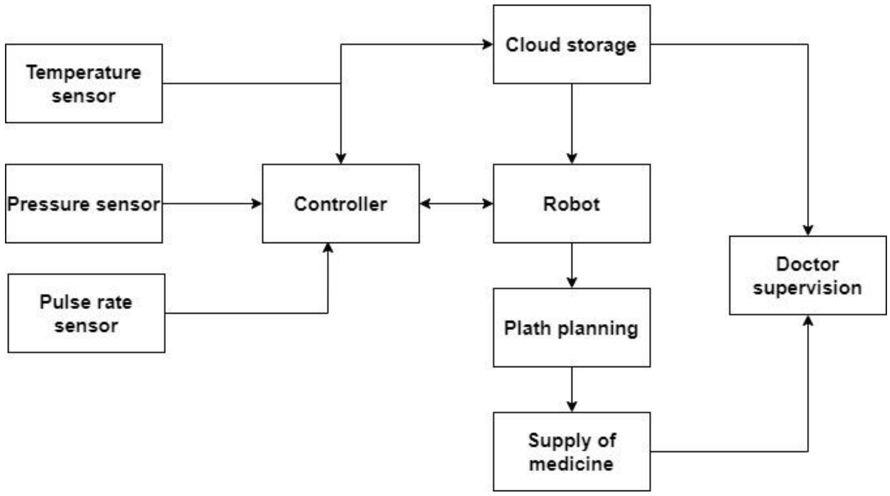

Figure. 1. Architecture of proposed system

The temperature sensor is pivotal for preserving the efficacy of a wide array of medical products that are subject to transfer. Its main functionality relies on the continuous monitoring of the temperature of the surrounding, which is a guarantee that the pharmaceutical and other medical products remain within the proper temperature range and, thus, efficacious. Its use eliminates the risks associated with temperature fluctuations and enables the products to travel longer distances without damage. The pressure sensor, which helps the robot run into a wall or another robot, gets activated in the case of an abrupt change in the current pressure values; assessment of the rate of change indicates the nature of hazard and whether it is an obstacle.

Proactive detection ensures the overall safety of the robot and its surroundings. The pulse rate sensor is an unprecedented advantage of our scientific contribution, which shifts the paradigm in the sphere of patient-centered remote care. The main key is that the robot activates the pulse rate sensor, and thus, the doctors can garner information on patients' health and make the necessary interventions if they perceive a need. Then, the obtained data transmitted by sensors and, then, analyzed and converted, are relayed to the cloud in the form of real-time health status updates for doctors. The controller position at the center of the wheels on the robot also uses the LFR approach to advance our position in the field. Its role is crucial as it is connected to all the sensors. The LFR path, of course, is predefined through infrared light to navigate to each specified human bed effectively. After arrival to the assigned human bed, the robot simply moves on its wheels in a predefined path to the bed; after arrival to the bed, the only function of the robot is to discharge the medicine.

A. Sensor and data transmission

In the framework of our innovative investigation about medicine delivery in the hospitals, we developed a high-tech medical robot embedded with a collection of sensors that are responsible for guaranteeing the safety and effectiveness of the very delivery. However, among all of the sensors implemented, it is possible to discern three that play the role of a cornerstone: proximity sensors, temperature sensors, and pressure sensors.

The first type of the sensor serves as the eye of the robot allowing it to not only see but to also perceive the surrounding space. More specifically, the proximity sensors utilize the electromagnetic field or a beam to detect the neighboring object and its position. In fact, they "emit an electromagnetic field or a beam and look for an interruption or a reflection to detect the object" . Otherwise speaking, they are instrumental for the medical robot to navigate through the hospital premise safely and efficiently, avoiding the collisions with the patients and the stuff and not permitting any delays in the delivery. Therefore, due to powerful proximity sensors, the malfunction of the robot is impossible, and the course of the delivery will be smooth.

The next sensor responsible for guarantee that the purity of the medication environment is maintained during the transportation is called the temperature sensor. It is responsible for constantly measuring the surrounding temperature and not allowing severe discrepancies to occur. The immediate signaling is to be transmitted and the prompt measures undertaken in a way that the delivery in question not deteriorates. Furthermore, it is expected that the temperature should be kept within the given range of the potentially most dangerous value. Thus, this kind of communication makes a patient safe and healthy. The same attributes pertain to the functionality of the pressure sensors however the information that they measure and process is different – pressure-related alterations. The data are wirelessly transmitted and stored in the cloud.

B. Robot trajectory

In our robotic medicine delivery system, plans play an important role in the safe and efficient delivery of medicine through hospital environments by the medical robot. Specifically, planning designates the path for the robot to move from its current location to a certain definitive location, avoiding static and dynamic obstacles. Thus, our system uses static and dynamic obstacle avoidance mechanisms, implemented with the help of advanced algorithms and sensor technologies.

Static obstacle avoidance works by identifying obstacles in the line of movement that do not change their location. Specifically, the sensor systems of the robot detect the presence of obstacles in space designations, such as hospital walls, furniture, or equipment. Then, these detections are utilized to store the location of the static obstacle within the set confines of the environment. Finally, plans are formulated to navigate the obstacle and reach the desired destination . In the existing approach, these plans are potential field-based, guided towards the positive destination by attractive forces and repelled from obstacles with the help of repulsive calculations. As the robot moves towards the destination, the static calculation of the efforts of the obstacles in its vicinity allows the alteration of the robots' direction and avoidance of the obstacle.

On the other hand, the next strategy is dynamic obstacle avoidance. This type of obstacle represents the presence of moving objects in the robot's natural environment, such as patients, hospital staff, other mobile equipment, and so on. As can be seen, this factor reduces the efficiency of static obstacle avoidance algorithms. The proposed system uses two types of sensors to construct the presence of dynamic obstacles. They use the data collected by the sensor and, specifically by the LiDAR or envelop tracking camera, to monitor the presence, amount, and location of dynamic objects.

The data from the sensor systems is analyzed by the machine learning models to predict the movement of dynamic objects in space. The anticipated values are used to alter the robot's movement, adapting it to the movements of the dynamic objects and ensuring the planning of a safe trajectory. Additionally, the existing approach uses advanced motion planning algorithms, such as RRT and A*, to track changes in the obstacles' status and configuration space. It ensures their capacity to generate a non-colliding path amongst space divided by static obstacle and dynamic obstacle movements. The developed robot is shown in figure 2 with sensors, power source.

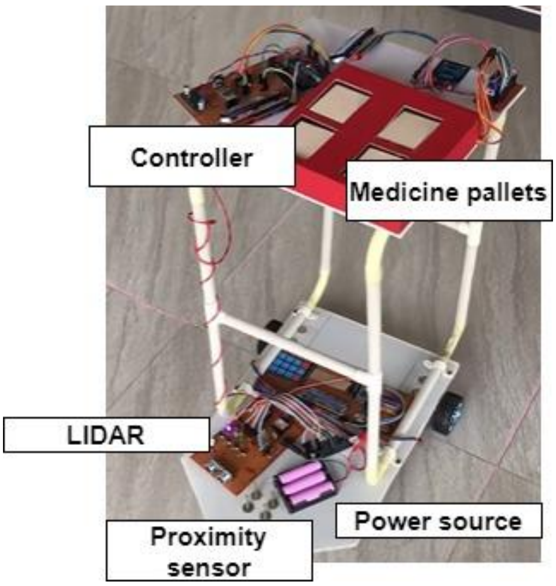

Figure 2. Robot developed in this research

III. RESULT AND DISCUSSION

In our approach to the development of the proposed system, we collected readings of different sensors from each patient throughout the day, from morning to the evening, and with the interval of one hour. This information would be the most appropriate as it combined all of the data required for the evaluation, as can be seen in Table 1, which shows the comprehensive sensor data from each patient. All of the information seemed important as it provided the values of temperature, pulse, humidity, and other factors, which could be crucial. As most patients were wearing sensors from the early hours of the morning until the evening, doctors were able to observe the state of this patient and the environment surrounding them throughout the day. However, a person slept at night, and it was the only time when sensors could not have been worn. Nevertheless, the values that were obtained provided good information in connection with the dynamics, and the data for the evening was not worse than the morning one. Thus, it made it possible to see how the person was resting and whether the performance of these or those indicators changed. For the sensor readings, it is important that the data are correct to get the opportunity to observe changes in the trend. Conducting the analysis based on results obtained throughout the day, it is possible to obtain an understanding of the behavior of the specific patient's organism. As these subsequent data are collected with the interval of one hour, such information allows having a clear idea of the state of this patient during the day and the opportunity to provide optimal treatment.

TABLE I. SENSOR READING AND RESPONSE

Time	**Patient ID**	**Temperature (°C)**	**Pulse Rate (bpm)**	**Pressure (mmHg)**
08:00 AM	P001	36.7	78	120
09:00 AM	P001	36.8	80	122
10:00 AM	P001	36.9	82	124
11:00 AM	P001	37.0	84	126
12:00 PM	P001	37.1	86	128
01:00 PM	P001	37.2	88	130
02:00 PM	P001	37.3	90	132
03:00 PM	P001	37.4	92	134
04:00 PM	P001	37.5	94	136
05:00 PM	P001	37.6	96	138

With the characteristics of our preliminary experimentation , the robot assistant system was provided with a task of arriving at the patient's bed with two static obstacles on its way. According to Figure 3, the robot accomplished the mission by avoiding the obstacles while reaching the destination. The ability of the system to go around the barriers using the dynamic approach was enabled by the use of both the line follower and LiDAR. In this detail, the information from LiDAR devices was used to make a decision to choose the path to move around the obstacles. However, the line follower enabled the robot to always move through the center. The two devices made such robots dynamic while sensing different objects in the pathway hence making the right decision at a specific point. The adaptability of the robotic navigation system to other experiments is presented by time results in Table 2.

TABLE 2. TIME RESULT OF ROBOT AT VARIOUS DISTANCE

Distance (m)	**Number of Obstacles**	**Time to Reach Bed (s)**
5	2	15
10	3	30
15	4	45

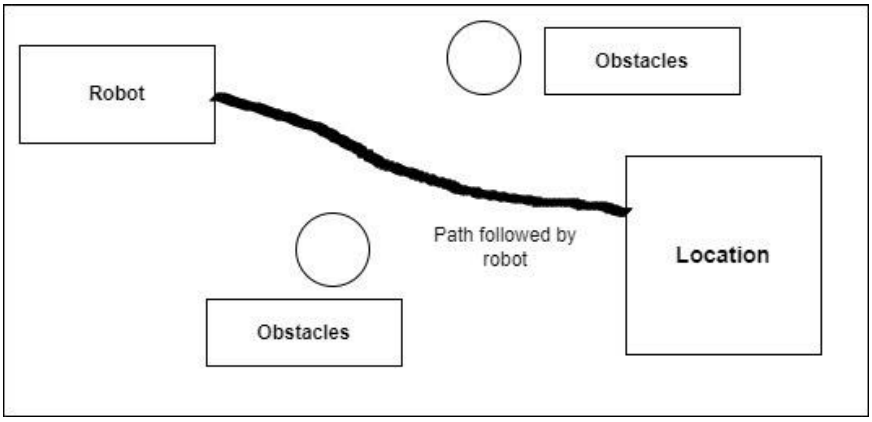

Figure. 3. Robot path flow

The first experimentation involved the use of two static obstacles with a distance of 5 meters. The robot arrived at the patient's bed in 15 seconds. The performance implies that the robot was dynamic while moving around this distance as presented. Notably, the product has the ability to move across barriers as it reaches the destination in a short period. With an adjusted distance of 10 meters and three obstacles, the robot reached the bed in 30 seconds . Simultaneously, when the distance was increased to 14 meters and four barriers, the product moved around the obstacles reaching the destination in 45 seconds . The three experiments verify the superiority of the robot in moving around objects and reaching other destinations with adapted nature.

The robotic medicine delivery system was tested for the dynamic obstacle scenario, where the system was assessed in a real-time working environment to evaluate how it would function in simulating the unpredictability found in a bustling hospital. The robot made use of both the LiDAR and proximity sensors to plan its path dynamically, continuously scanning its surroundings for obstacles. When the sensors detected an obstacle in its path, the robot would instantaneously stop in order to make use of the real-time data from the sensors; this helped it analyse the situation to calculate its best response. With the collision avoidance mechanism in place, the robot would dynamically replan its path, attempting to calculate alternative paths to reach the bed for the patient's medicine drop and avoid any potential collision in the process with the dynamic obstacle. This showcased the system's ability to navigate dynamically.

The ability of the robotic medicine delivery system showcased it could navigate through any dynamic environment in real-time effectively using the sensor data and decision-making algorithms to respond to dynamic obstacles by avoiding them. The inclusion of an efficient mechanism facilitated the lowest impact for the medicine delivery process in response to the dynamic obstacle; once a dynamic obstacle was encountered, the system could continually keep pace alongside delivery to the patient's bed.

The robotic medicine delivery was tested through experiments as they conducted the tests of whether the system could be useful to navigate in dynamic obstacles. To carry out the experiments, the specific distance was set from the robot to the bed on which it should transport the medicine. Moreover, the number of dynamic obstacles in the robot's designated pathway varied . The performance score that can be seen in Table 3 is a quantitative measure of how well the robot can navigate the dynamic obstacles from the origin to the bed. It was the measure regulated from the information furnished such as which time it took to get to the drug, the few declared obstacles, and smoothness . The level of the parameter was determined from the robot's performance compared to a perfect ideal performance, was the proper robots' movement in terms of speed, accuracy, and ease of obstacle avoidance. The ideal and actual performance are compared as a graph in figure 4.

TABLE 3. PERFORMANCE SCORE WITH DYNAMIC OBSTACLE

Trial Number	Distance (m)	Number of Dynamic Obstacles	Performance Score
1	10	2	90%
2	15	3	85%

3	20	4	80%
4	15	2	88%
5	12	3	82%

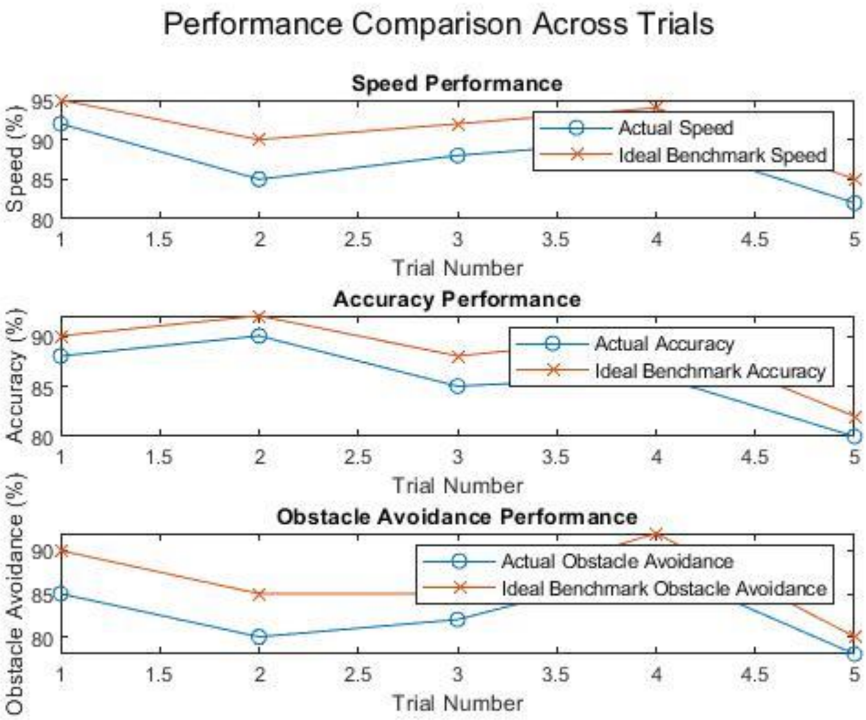

Figure 4. Ideal and actual performance

The scores of how well the robot performed to the perfect performance were equivalent to the percentage of the ideal. The output from the ideal had higher performances because the expectation and the requirements of the robot reaching the patient's bed were between dynamic obstacles. The process was likely to be more smooth and with no declared obstacles. The calculated percentages showed the efficiency of how the robot was capable of transporting the medicine from its location to the physician's bed through the obstacles.

The positive feedback was given on the side of patients who stated that the robotic system of medicine delivery was efficient and accurate. For them, the fact that they could get medication in time and at their bedside was essential as they were absolutely sure not to miss the dose and not wait for too long. It was also noted that the system was smooth and quiet, so no discomfort was left after the culmination of the delivery process. In general, robots succeeded in making the healthcare process comfortable for the patients and assured that medicine was actually delivered.

IV. CONCLUSION

The research has indicated that an IoT-enabled robotic medicine delivery system is a viable and efficient approach to improving safety and efficiency of healthcare delivery for hospitals. The outcomes of this project have found that the system is able not only to overcome static obstacles but also dynamic ones, and navigate to different locations autonomously. In addition, the evaluation of its performance has shown that the system can quickly administer patients' beds and the point of delivery regardless of the direction needed. As the complex composed of sensors, location technologies, and algorithms, the system acquired an opportunity for real-time monitoring and on-time adaptation to new conditions, reducing the perspective of failing to deliver medicine. Moreover, the evaluation of patients' opinion has proven that it is quite beneficial to the initial assumption that the technology affects the provision of healthcare. According to the customers, they are quite satisfied with the system and feel that it is a great part of healthcare. However, the outcomes of further research are needed in order to understand what has to be changed about the system, specifically, what issues should be fixed. Beyond the project, further efforts will also have to be focused on improving scapability and simplicity in application for any healthcare setting. These changes will enhance the safety and reduce the costs of implementation of IoT-enabled robotic medicine delivery systems.

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