A Simulation Platform for Proximity-based Infrared Positioning System in the Operating Room

Master's Thesis

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Contents

A SIMULATION PLATFORM FOR PROXIMITY-BASED INFRARED POSITIONING SYSTEM IN THE OPERATING ROOM

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ABSTRACT

Indoor Positioning Systems (IPS) could improve the working efficiency of the operating room (OR) due to its ability to obtain position information of medical staffs in the OR and further enhance the awareness of the current status of the surgery. Proximity-based infrared positioning system can be seen as a possible choice of IPS in the OR considering its advantages such as short-range detection, low price and less signal interference with the medical equipment. However the problem of signal blockage makes it unclear if the system could work well in the OR which is crowded with people and devices. The goal of this paper is to analyze the working performance of this system. A simulation platform was designed and developed, with which we simulated different working scenarios within the OR and were able to study the relationship among different parameters of detection rate, tag position and OR context. Results show that when using a proximity-based infrared system as an IPS in the OR, special attention should be paid to the tag positions on the human body, which have big influence on the detection rates, while the possible change of the OR context would not be a big factor of influence.

INTRODUCTION

The inability to obtain real-time information of the current status of surgical procedures can lead to operating room (OR) delays, resulting in wide variability and unpredictability in surgical procedure scheduling. This problem has a major impact on the utilization of OR, which could increase the operational cost and decrease the working efficiency of the hospitals. Hospitals are seeking methods to reduce costs and improve their financial assets, and it means that advanced technology that can provide access to the current status of the surgical procedures could be considered as a potential solution.
Since it is not always allowed to monitor the whole surgery process by video recording, one indirect yet possible way to access the current status of a certain surgical procedure could be implementing indoor positioning systems (IPS) in the OR. The reason is that the location information of the medical staffs in the OR can be used to represent different phases of a certain surgery, and successful detections of such scenarios by detecting if a certain medical staff is in a certain area within the OR could then provide useful information about the current status of the surgery.

In an IPS, the location engine software communicates with tags and location sensors to determine the location of tagged entities. The location engine transfers this information to specialized middleware and applications. The middleware in an IPS acts as the “plumbing” between the core IPS components (tags, location sensors and location engine software) and various software applications, which are capable of displaying and exploiting the real-time location and status information of tracked targets [1]. In the healthcare sector, these latter applications vary from simple IPS end-user interfaces for querying and displaying location information of tagged targets to more comprehensive integration into (or interoperability with) existing business/enterprise systems such as hospital ADT (admission, discharge and transfer) systems, HIS (hospital information systems and subsystems such as RIS (radiology information systems), operating room (OR) systems and asset management systems, etc.) via standards-based, open APIs (application programming interfaces) to enrich these systems with location information necessary for the completion of a variety tasks and process flow management operations [2,3].

There are two major working principles of an IPS: RSSI (Received Signal Strength Index) fingerprinting and proximity detection.

1) For RSSI fingerprinting, advanced algorithms are used to calculate the current position of a target based on the RSSI values it receives. RSSI method is mainly used for long-range positioning and examples include Active RFID System and WIFI Positioning System. The main drawback of using RSSI is its instability and interference susceptibleness noticed in real environments. For instance, parameters like the type of materials that tags are attached to and the relative orientation of tags and an access point can have major influence of the RSSI values of the active RFID signals [4]. Besides, the existence of

static environment and users can result in critical signal attenuation of the WIFI system [5].

2) For proximity detection, whether a target is in a certain area is determined through detecting if the attached tag is in the close proximity of a signal transmitter in that certain area. This method is featured by its short-range detection, and is mainly used for sub-room positioning. Examples include Passive RFID System, Bluetooth Positioning System and Infrared Positioning System.

Application in an OR requires sub-room positioning. Besides, considering that OR is a relatively small area crowded with people and devices, which could be seen as a big influencing factor to the accuracy of RSSI-based positioning system. Therefore proximity detection featuring short-range detection would be a better choice compared to the RSSI method. Within the three examples of proximity detection, Bluetooth technology is not seen as an ideal option in the OR, considering that it is mostly used with integration of mobile devices, which are not allowed in the OR. Furthermore, the drawback of deploying RFID systems in the OR is that it is possible to induce potentially hazardous incidents in the critical care medical equipment due to the electromagnetic interference (EMI) from the RFID system [6].

Therefore, a proximity-based infrared positioning system remains as a possible option for the OR application. However, the fact that infrared signal doesn't penetrate opaque materials may result in a new problem in terms of its application within an OR. As introduced earlier, an OR is a relatively small but crowded environment, so it may be possible that the infrared signal can be blocked by other objects which are between the tag and the transmitter, resulting in the detection failure of the target even if it is in the close proximity of the transmitter. The research goal of this thesis is to study the relationship between the detection rate and the following two parameters:

1) different body positions where the tag is attached

2) different contexts within the OR

under the same infrared transmitter network configuration (e.g. amount, position, range, emission direction and emission angle).

METHODS

Considering the costly process of developing the real system and conducting experiments in the hospitals, a simulation platform was designed and developed, with which we simulated different working scenarios within the OR and were able to study the relationship among different parameters of detection rate, tag position and OR context.

The simulation platform was developed in Unity 3D with the following requirements satisfied:

1) Reflection of real OR context

The common setting of an OR (e.g. dimension and present medical devices) should be modeled in the platform, in order to reflect the real context of an OR. This is important because high fidelity of the OR context can better covers the scenarios of signal blockage and thus is able to bring more reliable simulation.

2) Simple control of objects

Users should be allowed to manipulate the objects in the simulated OR, including medical devices and medical staffs, in a simple way.

3) Customized infrared positioning system configuration

Users should be allowed to set up their preferred system configuration in the platform. Such configurations include the division plan for the OR and the attributes of the infrared transmitter network (e.g. amount, position, range, emission direction and emission angle).

4) Accurate detection

The simulation platform should be able to decide whether a target is within the detection range of a certain transmitter and whether a target is detected or blocked.

5) Simulation for different tag positions

Detection should be enabled for tags that are attached at different body components, in order to generate comprehensive simulation results for analysis and comparison.

6) Real-time data collection and analysis

Information including the detection rate and current positions should be collected and analyzed in a real-time way.

The overview of the developed simulation platform is shown in Figure 1.

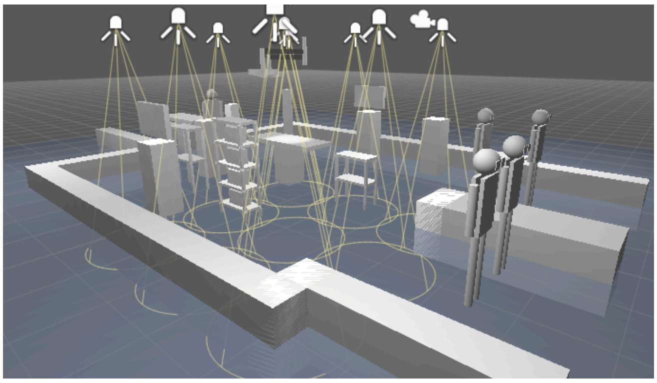


Figure 1 Overview of the Simulated OR

As illustrated in Figure 1:

1) The OR is divided by 9 zones, each of which is within the range of a transmitter.

2) Common medical devices are modeled and placed to reflect the real context of an OR. Devices are moveable, which is the prerequisite for studying whether changing OR context would influence the detection rates.

3) 5 Medical staffs are modeled, each of which is represented by 7 body components: head, chest, back, left arm, right arm, left leg and right leg, each of which represent a different tag position. This is the prerequisite for studying whether different tag positions would influence the detection rates. Modeled medical staffs are also moveable, in order to reflect different surgical activities.

A user interface (UI) when the simulation is run is shown in Figure 2. Medical staffs and devices can be manually or automatically moved and real-time calculation about where a certain medical staff is and which tag position yield the highest detection rate.

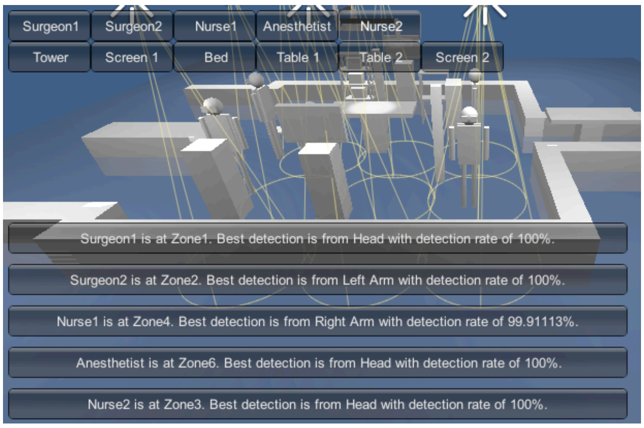
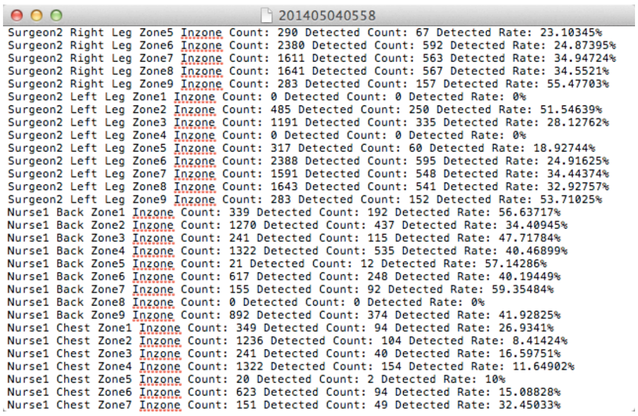


Figure 2 User Interface during Simulation

When a simulation is finished, data generated from this certain simulation would be automatically stored in a local log in the computer for the further references of data analysis. A part of a generated data set can be seen in Figure 3.



```
201405040558
Surgeon2 Right Leg Zone5 Inzone Count: 290 Detected Count: 67 Detected Rate: 23.10345%
Surgeon2 Right Leg Zone6 Inzone Count: 2380 Detected Count: 592 Detected Rate: 24.87395%
Surgeon2 Right Leg Zone7 Inzone Count: 1611 Detected Count: 563 Detected Rate: 34.94724%
Surgeon2 Right Leg Zone8 Inzone Count: 1641 Detected Count: 567 Detected Rate: 34.5521%
Surgeon2 Right Leg Zone9 Inzone Count: 283 Detected Count: 157 Detected Rate: 55.47703%
Surgeon2 Left Leg Zone1 Inzone Count: 0 Detected Count: 0 Detected Rate: 0%
Surgeon2 Left Leg Zone2 Inzone Count: 485 Detected Count: 250 Detected Rate: 51.54639%
Surgeon2 Left Leg Zone3 Inzone Count: 1191 Detected Count: 335 Detected Rate: 28.12762%
Surgeon2 Left Leg Zone4 Inzone Count: 0 Detected Count: 0 Detected Rate: 0%
Surgeon2 Left Leg Zone5 Inzone Count: 317 Detected Count: 60 Detected Rate: 18.92744%
Surgeon2 Left Leg Zone6 Inzone Count: 2388 Detected Count: 595 Detected Rate: 24.91625%
Surgeon2 Left Leg Zone7 Inzone Count: 1591 Detected Count: 548 Detected Rate: 34.44374%
Surgeon2 Left Leg Zone8 Inzone Count: 1643 Detected Count: 541 Detected Rate: 32.92757%
Surgeon2 Left Leg Zone9 Inzone Count: 283 Detected Count: 152 Detected Rate: 53.71025%
Nurse1 Back Zone1 Inzone Count: 339 Detected Count: 192 Detected Rate: 56.63717%
Nurse1 Back Zone2 Inzone Count: 1270 Detected Count: 437 Detected Rate: 34.40945%
Nurse1 Back Zone3 Inzone Count: 241 Detected Count: 115 Detected Rate: 47.71784%
Nurse1 Back Zone4 Inzone Count: 1322 Detected Count: 535 Detected Rate: 40.46899%
Nurse1 Back Zone5 Inzone Count: 21 Detected Count: 12 Detected Rate: 57.14286%
Nurse1 Back Zone6 Inzone Count: 617 Detected Count: 248 Detected Rate: 40.19449%
Nurse1 Back Zone7 Inzone Count: 155 Detected Count: 92 Detected Rate: 59.35484%
Nurse1 Back Zone8 Inzone Count: 0 Detected Count: 0 Detected Rate: 0%
Nurse1 Back Zone9 Inzone Count: 892 Detected Count: 374 Detected Rate: 41.92825%
Nurse1 Chest Zone1 Inzone Count: 349 Detected Count: 94 Detected Rate: 26.9341%
Nurse1 Chest Zone2 Inzone Count: 1236 Detected Count: 104 Detected Rate: 8.41424%
Nurse1 Chest Zone3 Inzone Count: 241 Detected Count: 40 Detected Rate: 16.59751%
Nurse1 Chest Zone4 Inzone Count: 1322 Detected Count: 154 Detected Rate: 11.64902%
Nurse1 Chest Zone5 Inzone Count: 20 Detected Count: 2 Detected Rate: 10%
Nurse1 Chest Zone6 Inzone Count: 623 Detected Count: 94 Detected Rate: 15.08828%
Nurse1 Chest Zone7 Inzone Count: 151 Detected Count: 49 Detected Rate: 32.45033%
```

Figure 3 Example of a Data Set

Different types of simulations were done using the platform in order to obatin generalized results:

1) Simulations based on random movement patterns

1.1) Random walking with fixed context

1.2) Random walking with changed context

2) Simulations based on real OR scenarios

2.1) Umbilical hernia repair

2.2) Laparoscopic cholecystectomy

RESULTS

Simulation results are summarized in Table 1 and Table 2.

Table 1 Summary of results – detection rate

	Head	Left Arm	Right Arm	Left Leg	Right Leg	Back	Chest
Random Walking Fixed Context	++	+	+	-	-	-	--
Random Walking Changed Context	++	+	+	-	-	-	--
Umbilical Hernia Repair	++	+	+	-	-	-	-- (- in center)
Laparoscopic Cholecystectomy	++	+	+	-	-	-	-- (- in center)

Table 2 Summary of results – detection stability

	Head	Left Arm	Right Arm	Left Leg	Right Leg	Back	Chest
Random Walking Fixed Context	+++	++	++	-	-	-	-
Random Walking Changed Context	+++	++	++	-	-	-	-
Umbilical Hernia Repair	+++	+	+	-	-	-	-
Laparoscopic Cholecystectomy	+++	+	+	-	-	-	-

In the tables above, the number of "+" indicates the level of positive evaluation and on the other hand, the number of "-" indicates the level of negative evaluation.

Table 1 reflects that the detection rate of a tag is indeed influenced by the position where it is attached. Whether the context is changed or not does not have a significant influence on the detection rate, which is mainly determined by the parameter of tag position. On the other hand, Table 2 reflects that different tag positions also result in different working stabilities of the system. According to the evaluations above, head and arms as tag positions are better choices than other body components. Besides, the changes of OR context (different positions of the medical devices) do not have significant influence to the detection rate distribution.

DISCUSSION

Based on Chart 5.1 and Chart 5.2, it is not difficult to draw a conclusion that a tag should be attached to the head of a medical staff in order to obtain the best detection rate and working stability. However, it would not be a good idea to attach a tag at the head of a medical staff in reality. Since medical staffs wear disposable hats during a surgery, which are designed for easy put-on and take-off as well as disposal, attaching a tag to the hat would contradict with all these convenience given by the disposable hat. Therefore, the head should be excluded from being an ideal tag position. Considering the rest of body components based on the simulation results, the best choice would be attaching a tag at one of two arms, which is a proper place for attaching tags during surgeries and also has good enough results even when it is compared with head. In fact, considering the fact that transmitters are installed at the ceiling with a downward emitting direction, the high detection rates and working stability of tags at head and arms are not surprising results since head and arms are the body components that are more exposed to the transmitters compared to other body components, and this should make them easily detected by the transmitter. It could be a fair guess at the start of the project, and the simulation results just serve as good supporting proofs for this assumption.

On the other hand, there are several limitations of this platform that needs considering for improvement.

1) The diffusion and reflection of the infrared signal was not taken into consideration in the simulation. In reality, it is difficult to limit the emission angle to our preferred value, as infrared signal would get diffused during the process of transmission. Besides, when the infrared hit any objects, a portion of the light would get reflected and transmit to other directions. Both problems would result in the confusion of the detection, as there must be areas in the OR that would be exposed to signals from different transmitters in the cases of diffusion and reflection. To better simulate the real scenarios, issues of diffusion and reflection should be included for further improvement and methods should be come up with to solve the problem caused by the overlapped signal.

2) The division of the body components of medical staff are not detailed enough to enable detections of tags that may be attached to smaller body components with different directions of exposure. However, there is an issue of compromise here: more detailed divisions and more possibilities of exposure directions would hugely increase the number of the variables in the simulation, which would remain as a big challenge for the following data analysis. One of the possible ideas of improvement could be implementing more detailed division only on the body components with high detection rates (i.e. head and arms in our case) after primary simulation results are obtained.

3) The modeled medical staffs in the simulation platform are not yet be able to bend any of their body components, which limits the possibility of exposure change which could happen in the real application. As indicated by the simulation results of the two selected surgeries, detection rates at chest at Zone 5 are higher than those at other zones. This was explained by the long exposure time of chest at Zone 5, while in the real scenario it could happen that the exposure time of chest would not increase as significantly due to the fact that sometimes a surgeon needs to bend forward to have a closer look at the patient. In that case, the chest would be hidden and blocked by the head and on the other hand, there could be a possible increase of he exposure time of back.

4) The individual dimensional differences among medical staffs were not reflected in the OR. Similar to the issue proposed in 3), this involves the question of how detailed the modeling should be with the complexity of the development and data analysis taken in to consideration.

To sum up, based on the results under this simulation environment, it can be revealed that tag position and OR context have different effects on the detection rates of tags:

1) Tag position has huge effects on the detection rate, with head and arms yielding high detection rates and the rest of body components (back/chest and legs) yielding low detection rates.

2) OR context on the other hand, does not have significant effects on the detection rates of tags.

These conclusions could provide better reference for potential application of IPS in the OR: when considering a proximity-based infrared system as an IPS in the OR, special attention should be paid to the tag positions on the human body, while the possible change of the OR context would not be a big factor of influence.

OUTLOOK

One of the flexible perspectives about developing this simulation platform is that the platform could be probably used for other possible applications in an easy way as long as necessary modifications are made.

1) By adjusting the settings of the transmitters (e.g. amount, positions, emission angles and emission directions) as well as the context modeling of the room, the platform could be then used for simulation in other scenarios, such as drug delivery monitoring within the pharmacy, asset tracking throughout the whole hospital and bedside monitoring for patients.

2) The platform could also be used for simulation of other indoor positioning systems that are based on other working principles. For example, an RFID system could also be a good option as an indoor positioning system within the OR as long as it could pass the EMI tests. In this case, in order to simulate the detection of the RFID system, the "raycast" function that enables blockage detection should be removed and replaced with other functions that could simulate the signal attenuation after the RFID signal penetrate an object. Further study would be done mainly on the script reference and algorithm optimization for the migration in order to adapt the platform to other indoor positioning systems.

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A Simulation Platform for Proximity-based Infrared Positioning System in the Operating Room

Abstract

Easy access to the current status of a surgery in the operating room (OR) can be beneficial to hospitals since it can improve the working efficiency and reduce the operational costs. Using indoor positioning systems (IPS) to obtain the position information of medical staffs in the OR could be an indirect method to enhance the awareness of the current status of a surgery. Among various IPSs available in the market, the proximity-based infrared positioning system could be selected as a possible option for the application in OR considering its advantages like short-range detection, low price and less signal interference with the medical equipment. However, infrared signal cannot penetrate opaque materials, which poses a potential problem of signal blockage in the OR, an environment that is crowded with medical devices and medical staffs. In order to analyze the working performance of the infrared positioning system in the OR, a simulation platform was proposed and developed in this project to simulate the working behavior of the system. Using the platform developed in this project, scenarios were simulated where tags attached at different parts of a medical staff can be detected by infrared transmitters installed in the OR. Based on the results generated from the simulations, data analysis was done to evaluate the working performance of the infrared indoor positioning system in the OR. Specifically, our research focused on the relationship among the following three parameters: detection rate, tag position and OR context. Simulation results revealed that tag position and OR context have different effects on the detection rates of tags: 1) Tag position has huge effects on the detection rate, with head and arms yielding high detection rates and the rest of body components (back/chest and legs) yielding low detection rates. 2) OR context on the other hand, does not have significant effects on the detection rates of tags. These conclusions provide better reference for potential application of IPS in the OR: when considering a proximity-based infrared system as an IPS in the OR, special attention should be paid to the tag positions on the human body, while the possible change of the OR context would not be a big factor of influence.

1 Problem Description

1.1 Background

The inability to obtain real-time information of the current status of surgical procedures can lead to operating room (OR) delays, resulting in wide variability and unpredictability in surgical procedure scheduling. This problem has a major impact on the utilization of OR, which could increase the operational cost and decrease the working efficiency of the hospitals. Hospitals are seeking methods to reduce costs and improve their financial assets, and it means that advanced technology that can provide access to the current status of the surgical procedures could be considered as a potential solution.

Since it is not always allowed to monitor the whole surgery process by video recording, one indirect yet possible way to access the current status of a certain surgical procedure could be implementing indoor positioning systems (IPS) in the OR. The location information of the medical staffs in the OR can be used to represent different phases of a certain surgery. For instance, in the preparation phase before a surgery begins, it is common that an anesthetist goes into the OR earlier than the surgeons to prepare for the anesthetization. In the "time-out" session, all medical staffs gather around the surgical table (the center of the OR) for the final confirmation before the surgery actually begins. During a surgery, the positions of surgeons and anesthetist remain relatively fixed while it is also common that a nurse is circulating around the OR (present at different areas throughout the whole procedure). Through all the these given examples, it could be seen that different surgical scenarios could be represented by different positions of the certain medical staffs, and successful detections of such scenarios by detecting if a certain medical staff is in a certain area within the OR could then provide useful information about the current status of the surgery. Therefore, an IPS can be used for this purpose.

1.2 IPS for the Healthcare Sector

In an IPS, the location engine software communicates with tags and location sensors to determine the location of tagged entities. The location engine transfers this information to specialized middleware and applications. The middleware in an IPS acts as the "plumbing" between the core IPS components (tags, location sensors and location engine software) and various software applications which are capable of displaying and exploiting the real-time location and status information of tracked targets [1]. These latter applications vary from simple IPS end-user interfaces for querying and displaying location information of tagged targets to more comprehensive integration into (or interoperability with) existing business/enterprise systems such as hospital ADT (admission, discharge and transfer) systems, HIS (hospital information systems and subsystems such as RIS (radiology information systems), operating room (OR) systems and asset management systems, etc.) via standards-based, open APIs (application programming interfaces) to enrich these systems with location information necessary for the completion of a variety tasks and process flow management operations [2, 3].

The location engine, middleware and application software may run on the same computer or on different machines. These applications also often offer some kind of client interface such as a Web-browser-based or mobile interface [1].

Tags can also be equipped with push buttons (or call buttons). These can be used as panic buttons when emergency response is needed. For example when the person carrying the tag presses the panic button, the location engine raises an alert and provides the location of the individual who pressed the button. Another use of the push buttons on tags is that they can be used to indicate asset status, such as "bed occupied by patient" (hospital bed status) or "device in need of repair", as appropriate [1].

If a tag has voice-to-voice capability, it can be used to communicate with the individual carrying the tag based on his/her location. Buzzers (emitting sounds, recorded voice messages, or live messages), LEDs (light emitting diodes of different colors and blinking patterns), or LCD (liquid crystal display) screens (displaying text messages) can also be integrated on tags to communicate in- formation or alerts to the person carrying the tag, to identify or locate an asset, and to communicate with the person who has the asset or is expected to check the asset [1].

Location sensors too can be integrated with buzzers. Patient ID badges sometimes become buried in bed linen (when patients are discharged) and cannot survive the bed linen wash cycle. In this case, installing location sensors that can sound an alarm whenever badges are detected in laundry chutes could prove helpful [4].

Various sensors can be incorporated in tags to gain information about the environment, the status of the person carrying the tag, or the tagged asset. For ex- ample, motion sensors in the tag can indicate whether the individual carrying it is moving, while a temperature sensor attached to a device can indicate whether that device is in optimum thermal operating conditions [1].

Tags can also have connectors that connect to assets in order to communicate specific details about the asset or its operational state. For example, the tag can indicate not only where the tagged device is, but also whether it is powered on. Finally, tags can have writeable memory, e.g., to log and store some user and other data about the tagged asset [1].

When tracking the physical location of an asset or an individual, depending on the needs of the application(s) at hand, we may want to know the absolute position (absolute coordinates, such as latitude, longitude and altitude), relative position (distance in three dimensions with reference to a fixed point, e.g., the nurse is standing at 10 meters north of the main entrance of the ward), or symbolic position (presence in a specific area, e.g., the surgeon is in operating theatre A, or presence near something or someone, e.g., the nurse is near patient B) [1].

1.3 IPS for the OR

In terms of the IPS application in the healthcare sector, Versus Technology Inc.[1] is the leading provider of IPS for the ORs. The Versus Advantages™ OR patient flow system developed by the company can be used to track patients and caregivers who are equipped with IR-RFID tags. Critical patient information is accessible via the large-screen monitors that are mounted on walls at different locations of the hospital. A screenshot of the information display is shown in Figure 1.1.

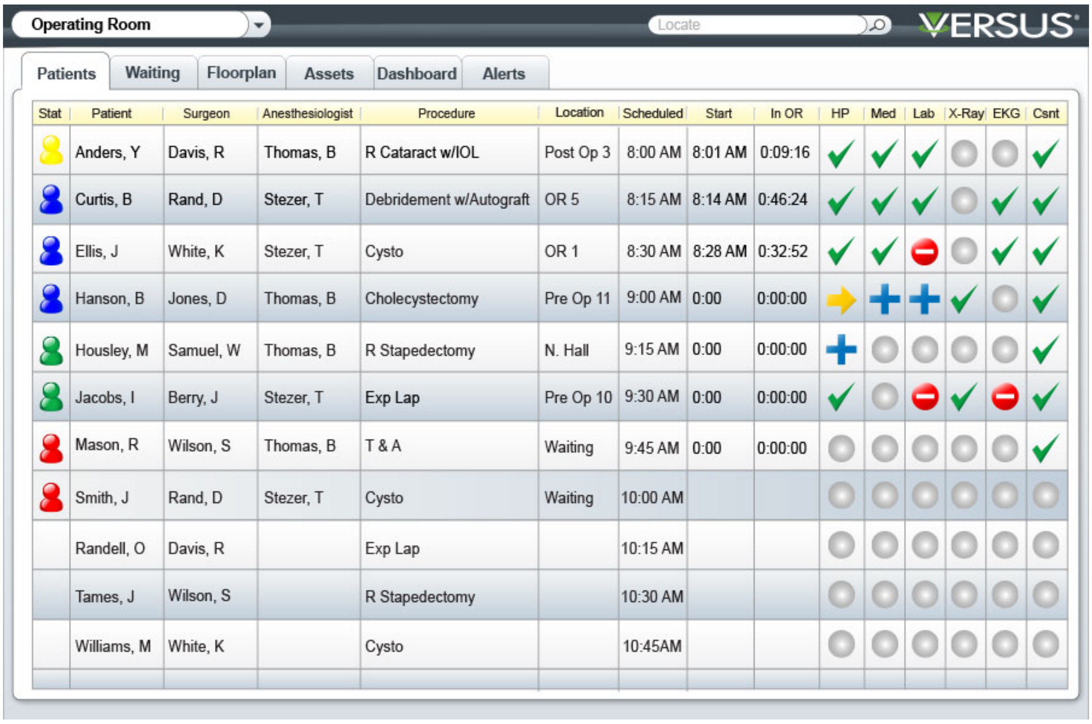

Figure 1.1 Critical Patient Information Provided by the Versus System

According to Versus, the operating room efficiency could be improved in the following perspectives:

1) Automatically providing necessary information to both medical staffs and waiting families

2) Enabling logistic department to anticipate physician needs through increased situational awareness of a surgery

[1] Versus Technology Inc. Website: http://www.versustech.com

3) Tracking case starts, room utilization and procedure times

4) Automating data entry through healthcare systems integration

5) Providing historical analytics for continual process improvement

6) Giving team leaders the knowledge to make real-time workflow and staffing adjustments

Versus has been cooperating with hospitals around the USA and proven success has been obtained. However, only room-level OR monitoring is realized by using the Versus system. This means that information is provided about who or what is in a certain OR, but there is no further indications (sub-room level detection) for the whereabouts of targets that are at different areas within an OR. If this gap between the room level positioning and sub-room level detection can be filled, precise positioning of medical staffs within the OR could then be realized, and more valuable information about the current status of surgical procedures could be obtained. To have a better idea about the possibility for sub-room detection in the OR, the first step would be study the working principles of the currently available indoor positioning systems, which will be introduced in the following session.

1.4 Working Principles of IPS

The Versus system is an example of advanced indoor positioning systems that is specialized for the application in the healthcare sector. Besides, there are different kinds of indoor positioning systems available in the market, which are used in other industries. In order to have a better insight of the application in the OR, it is necessary to understand the major working principles of such indoor positioning systems. According to our literature review, most of the currently available indoor positioning systems are based on either of the following major working principles: RSSI fingerprinting and Proximity Detection.

1) RSSI: Received Signal Strength Index

RSSI positioning is a method based on the recording the values of received signal strength index of several access points in the context. Access points are installed at different locations in the room and the tags attached to the positioning targets records the RSSI values which are the signal strength received after transmission from the access point to the tag. Advanced algorithms are used to calculate the current position of a target based on the RSSI values it receives. Examples of indoor positioning systems that are based on the RSSI principle include Active RFID System and WIFI Positioning System. RSSI method is mainly used for long-range positioning within an entire floor or building. However, the main drawback of using RSSI is its instability and interference susceptibleness noticed in real environments. For instance, parameters like the type of materials that tags are attached to and the relative orientation of tags and an access point can have major influence of the RSSI values of the active RFID signals [5]. Besides, the existence of static environment and users can result in critical signal attenuation of the WIFI system [6].

Such interference would result in incorrect mapping between the RSSI values and the target positions, reducing the overall reliability of the IPS.

2) Proximity Detection

Proximity Detection is a positioning method that determines if a target is in a certain area by detecting if the attached tag is in the close proximity of a signal transmitter in that certain area. This method is featured by its short-range detection, and is mainly used for sub-room positioning. Examples of indoor positioning systems that are based on proximity detection include Passive RFID System, Bluetooth Positioning System and Infrared Positioning System. The Versus system introduced in Chapter 1.1 is based on the proximity detection principle by using infrared signal to detect presence of the tagged targets, and RFID technology is combined as a communication module to transfer information based on the infrared detection.

One major and obvious difference between the RSSI method and Proximity Detection is the range of detection, making them suitable for different application scenarios. More details about these two working principles of indoor positioning systems can be found in the literature review attached as Appendix A for further references, and the coming session would focus on the selection among techniques of these two categories according to the restrictions posed by the OR.

1.5 Restrictions from the OR

To determine which positioning technique would be the right choice for the application within the OR, it is necessary to look at the restrictions posed by the OR context. With the research focus limited in the sub-room positioning within a single OR, it is reasonable to make a decision that proximity detection featuring short-range detection would be a better choice compared to the RSSI method. Besides, as discussed above, RSSI-based system could be hugely influenced by the obstructions in the environment. Considering that OR is a relatively small area while it is crowded with amounts of medical equipment and medical staffs, which could be seen as a big influencing factor to the accuracy of RSSI-based positioning system, it is not a hard decision to make to prefer proximity detection to RSSI method.

With three different examples given in the category of proximity detection (Passive RFID, Bluetooth and Infrared), it won’t be too difficult to make a decision that infrared positioning system would be a final choice for the OR application among all alternatives if we conduct the selection process based on the method of elimination. Firstly, Bluetooth technology is not seen as an ideal option in the OR, considering that Bluetooth technology is currently mostly used with integration of mobile devices, which are not allowed in the OR. Secondly, when looking at the differences between an infrared system and a passive RFID system, safety becomes a major factor. The drawback of deploying RFID systems in the OR is that it is possible to induce potentially hazardous incidents in the critical care medical equipment due to the electromagnetic interference (EMI) from the RFID system. According to an observation study by van der Togt et al. in 2008 [7], RFID induced 34 EMI incidents in 123 EMI tests, among which 22 were classified as hazardous. Especially, passive RFID systems induced a higher number of incidents (26 incidents in 41 EMI tests; 63%) compared with the active RFID systems (8 incidents in 41 EMI tests; 20%). Based on the test results, the research team suggested that implementation of RFID in the critical care environment should require on-site EMI tests and updates of international standards. With this drawback of passive RFID system taken into account, infrared positioning system can be seen as a final choice in the OR, considering its features such as less signal interference and low price.

1.6 Problem Definition

Through the discussions above, a primary conclusion is drawn that it could be a good idea to deploy a proximity-based infrared positioning system in the OR in order to access the current status of a certain surgical procedure, which may further reduce the operational cost and enhance the working efficiency of the hospitals.

However, despite all of the advantages of a proximity-based infrared positioning system (e.g. short-range detection, low price and less signal interference with the medical equipment), the feature of infrared signal that it doesn't penetrate opaque materials may result in a new problem in terms of its application within an OR. As introduced earlier, an OR is a relatively small but crowded environment, so it may be possible that the infrared signal can be blocked by other objects which are between the tag and the transmitter, resulting in the detection failure of the target even if it is in the close proximity of the transmitter.

Even if the infrared transmitter network is installed in a fixed manner in the OR, there are still two major variables that may affect the detection rate of the infrared positioning system: different static environments at different areas within the OR, and different positions of the body where a tag is attached. Changes of these two factors may result in different extent of infrared signal blockage, which may influence the detection rates of the target tags. In other words, with the same infrared transmitter network configuration (e.g. amount, position, range, emission direction and emission angle), the relationship between the detection rate and the following two parameters:

1) different body positions where the tag is attached

2) different contexts within the OR

would be our main interest in the performance analysis of a proximity-based infrared positioning system used in an OR.

1.7 Research Goal and Method

The research goal of this work is analyze the working behavior of the proximity-based infrared positioning system in the OR, so that a better idea about the problem stated in Chapter 1.6 can be obtained. However, considering the costly process of developing the real system and conducting experiments in the hospitals, this goal would be achieved by simulating the working status of this system in the OR and analyzing the generated data.

This means that a platform will be developed to simulate the application scenarios of the system in the OR, which would be the major part of this master thesis. Simulation results will be analyzed in order to study the relationship among the detection rate, tag positions and OR context.

1.8 Thesis Structure

This thesis is divided into four parts:

Part 1. Introduction: Chapter 1

Part 2. Development Process: Chapter 2

Part 3. Simulation and Primary Analysis: Chapter 3 and Chapter 4

Part 4. Discussion and Conclusion: Chapter 5

2 Development of the Simulation Platform

2.1 Requirement

In order to better simulate the application scenarios in the OR, the simulation platform should meet the following requirements during the process of development:

1) Reflection of real OR context

The common setting of an OR (e.g. dimension and present medical devices) should be modeled in the platform, in order to reflect the real context of an OR. This is important because high fidelity of the OR context can better covers the scenarios of signal blockage and thus is able to bring more reliable simulation.

2) Simple control of objects

Users should be allowed to manipulate the objects in the simulated OR, including medical devices and medical staffs, in a simple way. Such manipulations include adding/deleting/placing/moving the objects.

3) Customized infrared positioning system configuration

Users should be allowed to set up their preferred system configuration in the platform. Such configurations include the division plan for the OR and the attributes of the infrared transmitter network (e.g. amount, position, range, emission direction and emission angle).

4) Accurate detection

The simulation platform should be able to decide whether a target is within the detection range of a certain transmitter and whether a target is detected or blocked.

5) Simulation for different tag positions

Detection should be enabled for tags that are attached at different body components, in order to generate comprehensive simulation results for analysis and comparison.

6) Real-time data collection and analysis

Information including the detection rate and current positions should be collected and analyzed in a real-time way.

2.2 Development Software Selection

The development of the simulation platform is done with a 3D content builder called Unity 3D. Unity 3D is currently one of the most popular free game engines that is featured by the following advantages:

1) Less learning time

Developers can program in Java Script, C# or Boo based on their personal preferences. For example, since I had previous experience of programming in C#, I could then choose C# as my scripting language in this project to accelerate the development process.

2) Easy modeling of needed objects

Unity provides modeling elements like plane, cube, cylinder and capsule, so developers can easily create simple objects by combining different elements together.

3) Convenient interaction between objects and scripts

Based on the object-oriented programming methodology, it is convenient in Unity to assign a function to a created object by simply attaching a corresponding script file to the object.

4) Multiplatform development and deployment.

Development with Unity can be done on both Windows and Mac OS, and the final product can be published on multiple platforms including Windows, Mac OS, iOS and Android.

5) Mature knowledge-sharing community

Unity provides a powerful online community where a detailed reference manual of scripts is available to support the development process.

2.3 Development Process

2.3.1 OR Context Modeling

According to the measurement in the Reinier de Graaf Hospital in Delft, the common area of an OR is about 8 x 8 m^2. There are two doors at one side of the OR and one at the other side. The basic layout of the OR is shown in Figure 2.1.

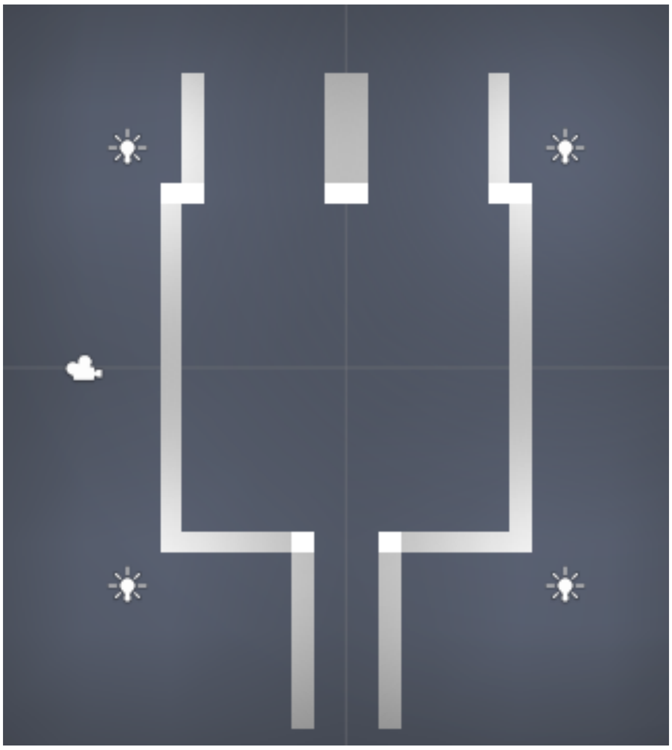

Figure 2.1 Basic Layout of the OR

Table 2.1 gives a list of common medical devices that are present in the OR. Based on the given dimensions, devices in Table 2.1 were modeled through combining the modeling elements (cubes and cylinders etc.) provided by Unity 3D.

Table 2.1 A List of Common Medical Devices in the OR

Device	Number	Width (cm)	Length (cm)	Height (cm)
Surgical table	1	50	200	100
OR lamps	2	Diameter of 60		
High instruments table	1	40	80	140
Low instruments table	1	40	80	100
Anaesthesia device	1	40	60	140
Infusion pumps	2	20	20	200
Laparoscopic tower (4 devices)	1	100	80	180
Flat screens (fixed on the ceiling)	2	40	60	180
Electrosurgical device	1	50	50	140

After modeling and placing the medical devices in the OR, an OR context with more details can be reflected (as shown in Figure 2.2).

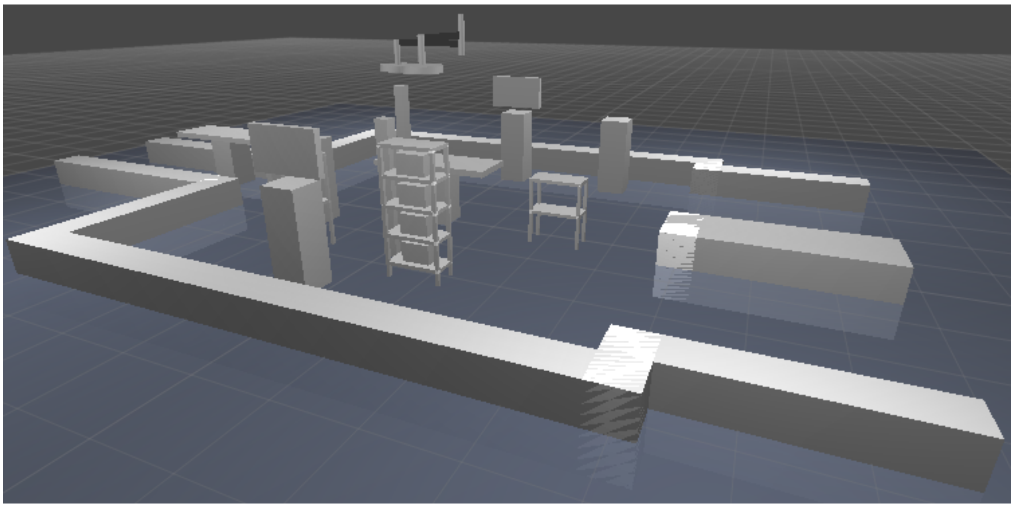

Figure 2.2 Context of the Modeled OR

2.3.2 Medical Staff Modeling

In order to enable the detection of tags those are attached at different positions of the human body, the human body was modeled with combination of seven different body components including Back, Chest, Head, Left Arm, Right Arm, Left Leg and Right Leg. Each body component would be virtually attached with a "tag" and thus can turn into a detection target. Five medical staffs (including 2 surgeons, 2 nurses and 1 anesthetist in the OR) were modeled in the same manner and one of the modeled staffs is presented in Figure 2.3, with clear division of seven body components.

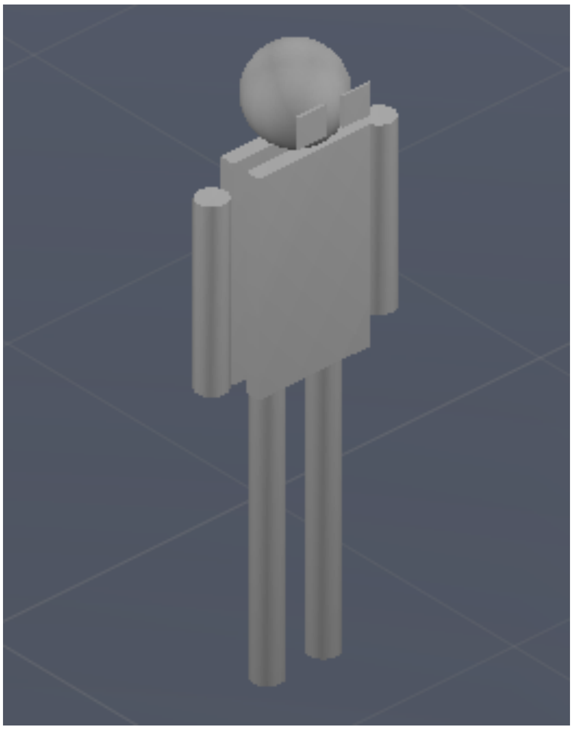

Figure 2.3 Details of a Modeled Medical Staff

2.3.3 Transmitter Configuration

For the configuration of the infrared transmitter network, a 3 by 3 grid was used in our project to divide the OR into 9 zones, each of which would then be "taken care of" by an infrared transmitter. The layout is shown in Figure 2.4.

Zone 7	Zone 8	Zone 9
Zone 4	Zone 5	Zone 6
Zone 1	Zone 2	Zone 3

Figure 2.4 Layout of the OR Division

As indicated from Figure 2.4, 9 zones can be divided to 3 different categories:

1) The center of the OR: Zone 5

2) The areas surrounding the center: Zone 2, Zone 4, Zone 6 and Zone 8

3) The corners of the OR: Zone 1, Zone 3, Zone 7 and Zone 9

With this idea of zone division, 9 transmitters were then modeled and installed in the simulated OR, each of which is responsible of covering a corresponding zone. A transmitter is represented by a spotlight with and all transmitters are modeled and placed at the same height, with the same emission direction and emission angle. The distribution of the transmitters from a top view is shown in Figure 2.5, which accords with the division plan indicated by Figure 2.4.

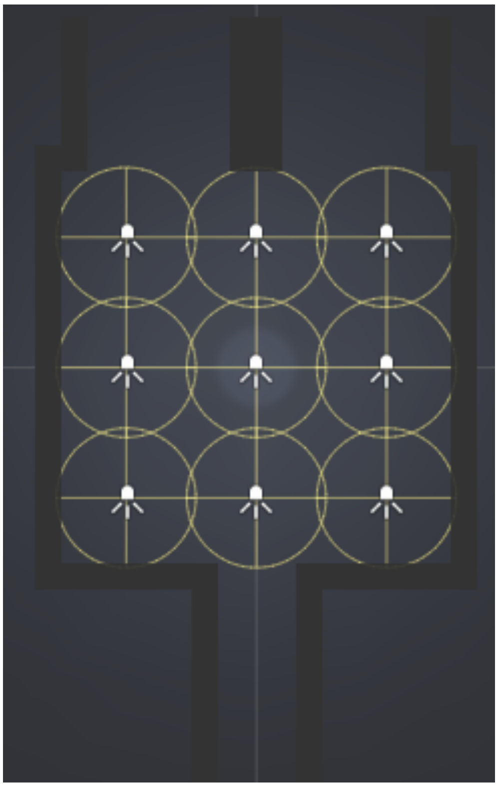

Figure 2.5 Distribution of Infrared Transmitters

2.3.4 Context Overview

With all necessary components properly modeled and placed, the final overview of the simulated OR context is shown in Figure 2.6.

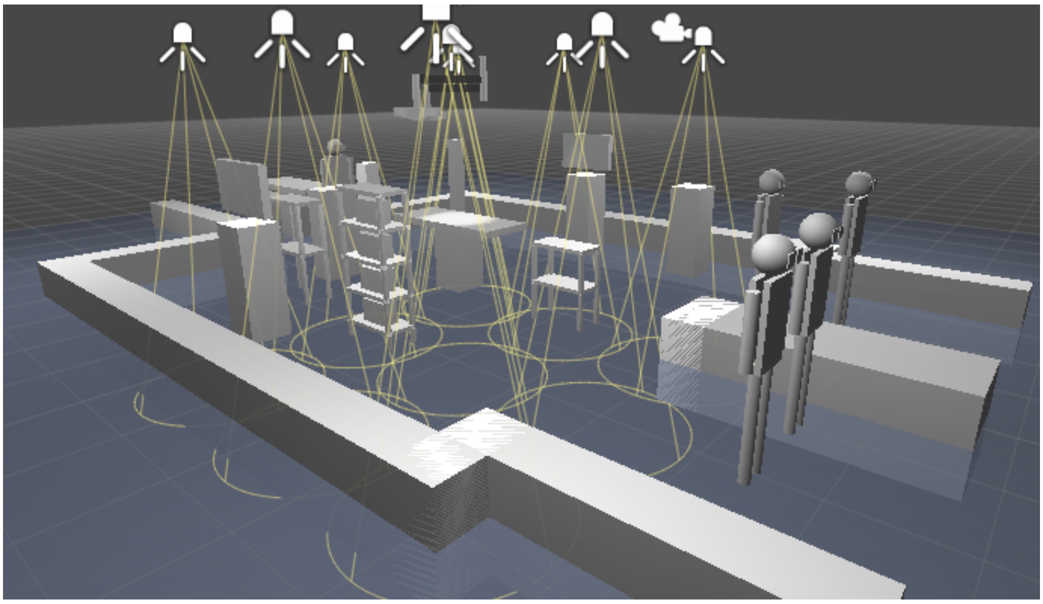

Figure 2.6 Overview of the Fully Modeled OR

At this point, the OR context modeling is finished, and the control and interaction of the objects (including medical devices and medical staffs) would follow as next steps.

2.3.5 Movement Control

With the virtual OR context successfully modeled, the next step would be writing scripts to enable the movements of different components. By writing C# scripts and attaching them to the target objects and staffs, movement control was realized:

1) When selected with a mouse click, a medical device can be moved at four directions by using keys of "A", "D", "S" and "W".

2) When selected with a mouse click, a medical staff can be moved at four directions by using keys of "Left", "Right", "Down" and "Up".

With this part of work finished, movement patterns of medical staffs and medical devices in the OR during different surgical procedures can be generally reflected and simulated in the platform.

2.3.6 Realization of Detection

The realization of detection is in fact a question of interaction between tags (represented by different body components) and the transmitters installed at the ceiling. This part of work was done through two steps.

1) Determine if a body component is within the detection range of a transmitter

Since the transmitter is assigned with an emission angle, the simplest way to determine if a body component is within the detection range would be to determine if the angle between the vector which points from the transmitter to the component and the vector with the downward direction is smaller than the emission angle of the transmitter. The situation where the head of a medical staff is within the detection range of a transmitter is shown in Figure 2.7 (Left), while the situation where the head of a medical staff is out of the detection range of a transmitter is shown in Figure 2.7 (Right).

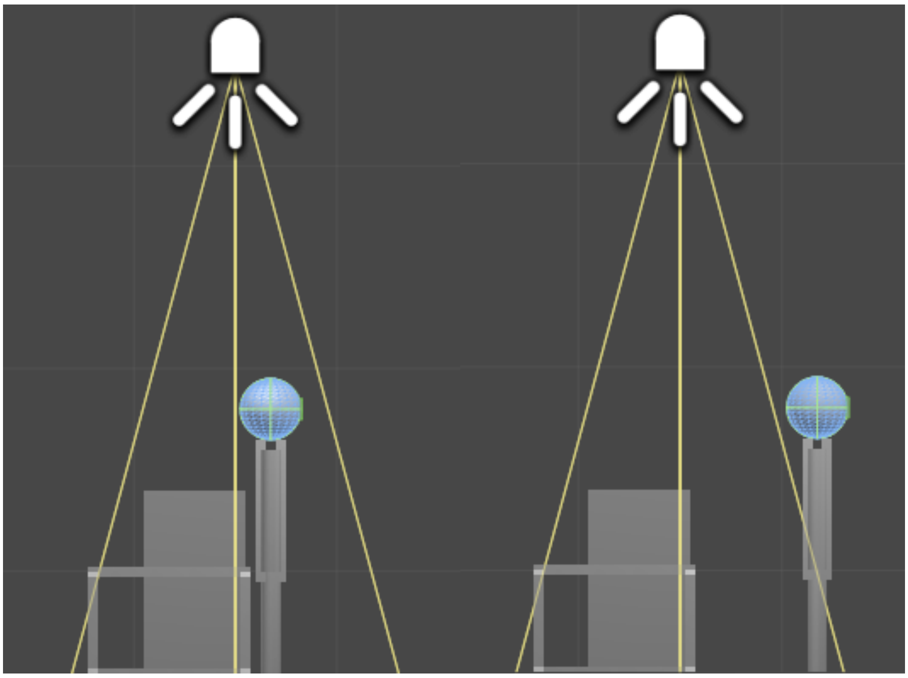

Figure 2.7 Left: Head within Detection Range; Right: Head out of Detection Range

2) Determine if a body component can be reached by the signal without being blocked by obstructions

When a body component is within the range of a transmitter, the next step would be to determine if it could be detected or blocked. In Unity 3D, there is an attribute named "collider" that can be assigned to every modeled object. With this attribute assigned to all of the objects in the OR context including all transmitters, medical devices and body components, it becomes easy to determine the "detected or blocked" problem by using a simple function called "raycast" that is also provided by the Unity library. When using a transmitter and a body component, both attached with the attribute of "collider", as inputs, the "raycast" function can return "True" if there is no other "collider" between the two input "collider", and "False" if there is one other "collider" in between. Therefore, by looking at the returned value of the "raycast" function, it can be determined if a certain body component is detected by a transmitter or not. In the example shown in Figure 2.8, with both head and chest being within the detection range of the transmitter, the head would be detected since there is no other "collider" between it and the transmitter, while the chest would not be detected since the head as a "collider" blocks the signal emitted from the transmitter.

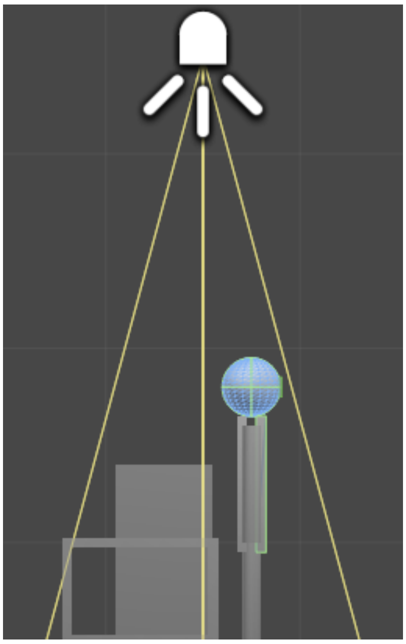

Figure 2.8 Situation when Chest is Blocked by Head

The two steps discussed above realized the function of instant detection, while the results of all instant detections should be stored and calculated in order to generate the detection rates. For each combination of a transmitter and a body component (i.e. 5 x 7 x 9 = 315 combinations in total), three variables were used to calculate the detection rate for this combination.

1) Inzone Count

When a body component enters the range of a certain transmitter, the variable of Inzone Count increases.

2) Detection Count

When a body component is both within the range of a certain transmitter and detected by this very same transmitter, the variable of Detected Count increases. It is obvious that the value of Detect Count never exceeds that of Inzone Count.

3) Detection Rate

By dividing Detection Count by Inzone Count, Detection Rate for this body component under this transmitter can be generated.

2.3.7 Real-time Data Analysis

When a simulation is being run, calculation is made every single frame for continuous result update. Calculated data is displayed in the UI for every update to provide users with real-time information describing the whereabouts and corresponding detection rates of different medical staffs. Following information is displayed in the UI:

1) The current position of each medical staff

2) The tag position at which the detection rate is highest

3) The highest detection rate, which is obtained in the tag position stated in 2)

An example of the real-time data calculation and display can be seen in a screen shot in Figure 2.9, which also shows the user interface (UI) when the simulation is run.

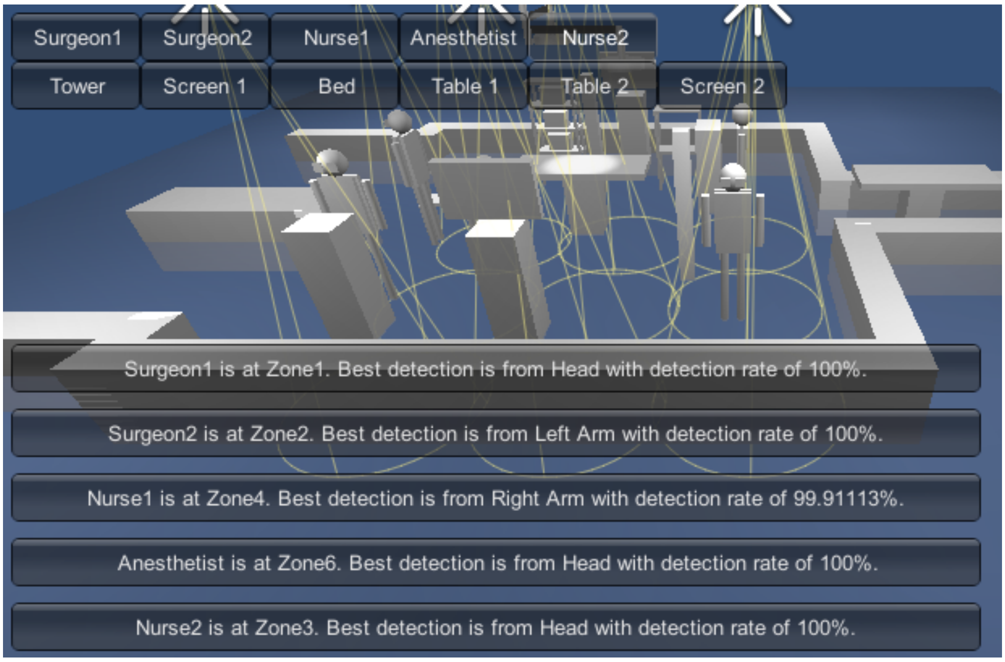

Figure 2.9 User Interface during Simulation

A script was written so that when a simulation is finished, data generated from this simulation would be automatically stored in a local log in the computer for the further references of data analysis. A part of a generated data set can be seen in Figure 2.10. The number in the title indicates the time when this certain simulation is finished.

```
201405040558
Surgeon2 Right Leg Zone5 Inzone Count: 290 Detected Count: 67 Detected Rate: 23.10345%
Surgeon2 Right Leg Zone6 Inzone Count: 2380 Detected Count: 592 Detected Rate: 24.87395%
Surgeon2 Right Leg Zone7 Inzone Count: 1611 Detected Count: 563 Detected Rate: 34.94724%
Surgeon2 Right Leg Zone8 Inzone Count: 1641 Detected Count: 567 Detected Rate: 34.5521%
Surgeon2 Right Leg Zone9 Inzone Count: 283 Detected Count: 157 Detected Rate: 55.47703%
Surgeon2 Left Leg Zone1 Inzone Count: 0 Detected Count: 0 Detected Rate: 0%
Surgeon2 Left Leg Zone2 Inzone Count: 485 Detected Count: 250 Detected Rate: 51.54639%
Surgeon2 Left Leg Zone3 Inzone Count: 1191 Detected Count: 335 Detected Rate: 28.12762%
Surgeon2 Left Leg Zone4 Inzone Count: 0 Detected Count: 0 Detected Rate: 0%
Surgeon2 Left Leg Zone5 Inzone Count: 317 Detected Count: 60 Detected Rate: 18.92744%
Surgeon2 Left Leg Zone6 Inzone Count: 2388 Detected Count: 595 Detected Rate: 24.91625%
Surgeon2 Left Leg Zone7 Inzone Count: 1591 Detected Count: 548 Detected Rate: 34.44374%
Surgeon2 Left Leg Zone8 Inzone Count: 1643 Detected Count: 541 Detected Rate: 32.92757%
Surgeon2 Left Leg Zone9 Inzone Count: 283 Detected Count: 152 Detected Rate: 53.71025%
Nurse1 Back Zone1 Inzone Count: 339 Detected Count: 192 Detected Rate: 56.63717%
Nurse1 Back Zone2 Inzone Count: 1270 Detected Count: 437 Detected Rate: 34.40945%
Nurse1 Back Zone3 Inzone Count: 241 Detected Count: 115 Detected Rate: 47.71784%
Nurse1 Back Zone4 Inzone Count: 1322 Detected Count: 535 Detected Rate: 40.46899%
Nurse1 Back Zone5 Inzone Count: 21 Detected Count: 12 Detected Rate: 57.14286%
Nurse1 Back Zone6 Inzone Count: 617 Detected Count: 248 Detected Rate: 40.19449%
Nurse1 Back Zone7 Inzone Count: 155 Detected Count: 92 Detected Rate: 59.35484%
Nurse1 Back Zone8 Inzone Count: 0 Detected Count: 0 Detected Rate: 0%
Nurse1 Back Zone9 Inzone Count: 892 Detected Count: 374 Detected Rate: 41.92825%
Nurse1 Chest Zone1 Inzone Count: 349 Detected Count: 94 Detected Rate: 26.9341%
Nurse1 Chest Zone2 Inzone Count: 1236 Detected Count: 104 Detected Rate: 8.41424%
Nurse1 Chest Zone3 Inzone Count: 241 Detected Count: 40 Detected Rate: 16.59751%
Nurse1 Chest Zone4 Inzone Count: 1322 Detected Count: 154 Detected Rate: 11.64902%
Nurse1 Chest Zone5 Inzone Count: 20 Detected Count: 2 Detected Rate: 10%
Nurse1 Chest Zone6 Inzone Count: 623 Detected Count: 94 Detected Rate: 15.08828%
Nurse1 Chest Zone7 Inzone Count: 151 Detected Count: 49 Detected Rate: 32.45033%
```

Figure 2.10 Example of a Data Set

2.3.8 Summary of Development

The whole design and development process of the simulation platform can be summarized in the following flowchart, shown in Figure 2.11.

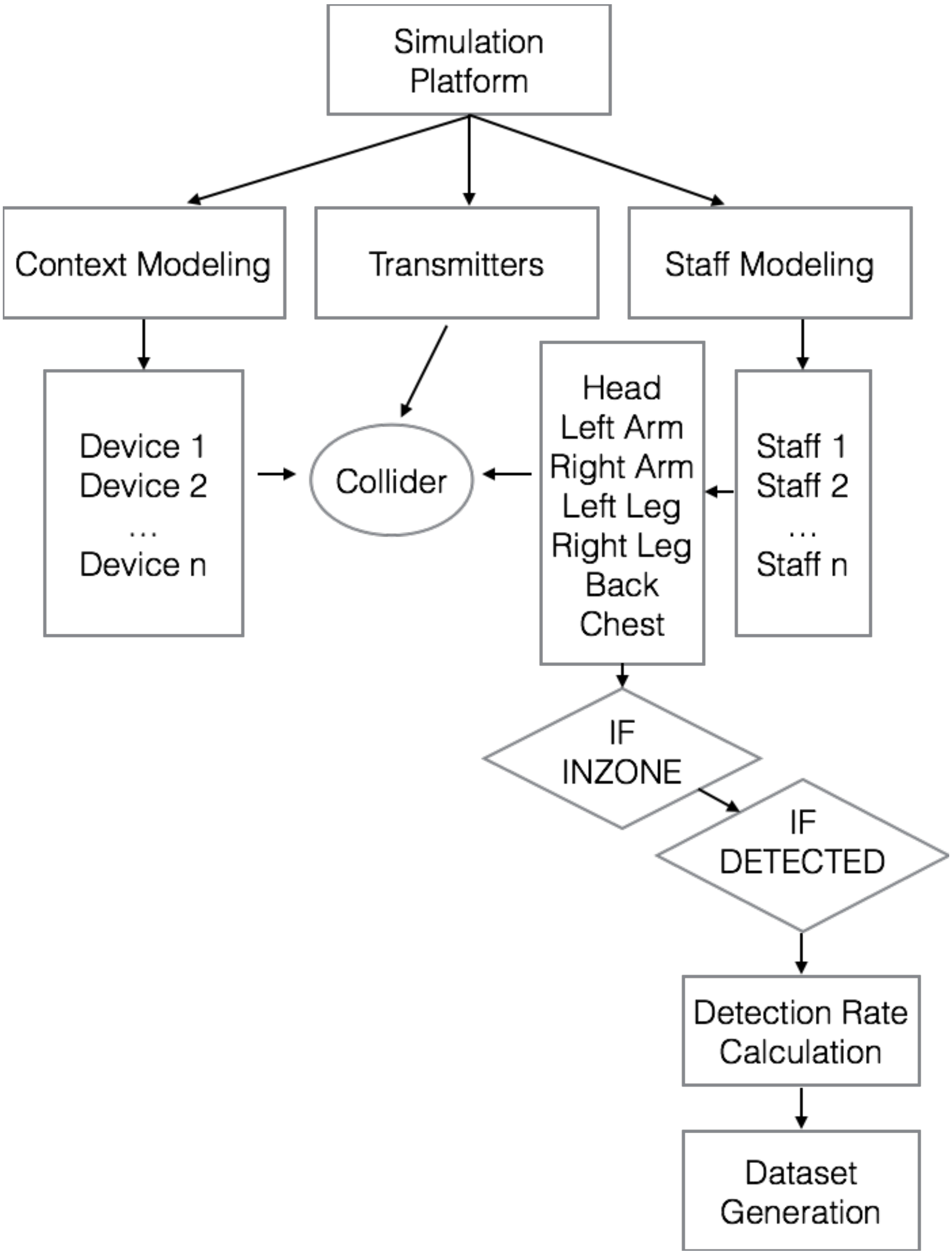

Figure 2.11 Development Flowchart of the Simulation Platform

At this point, the development of the simulation platform is finished, and the platform is ready for use under different scenarios. This part of work would described in the following chapters.

3 Simulations Based on Random Movement Patterns

3.1 How it works

The simplest way to simulate the random movement of medical staffs is to attach a script that makes each one of them move at a random direction every single frame during the simulation. In this "automatic" mode, four simulations were done, including two in the fixed OR context and two in the changed OR context. Each simulation lasted for 2 hours, a period that is long enough to ensure that every zone had been entered by every component of every medical staffs for multiple times. Based on the simulation results we can then extract primary information about the relationship between the detection rates and tag positions as well as OR context.

3.2 Simulation Results

After averaging the results that are generated from 5 medical staffs and 9 zones, the detection rates at different body components can been summarized in as follows. Chart 3.1 and Chart 3.2 show the results in the fixed OR context and Chart 3.3 and Chart 3.4 show those in the changed OR context.

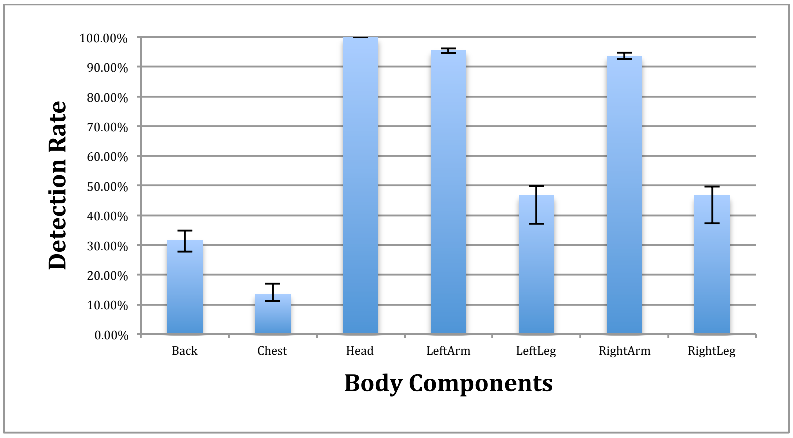

Chart 3.1 Average Detection Rates of Simulation of Random Walking with Fixed Context (No.1)

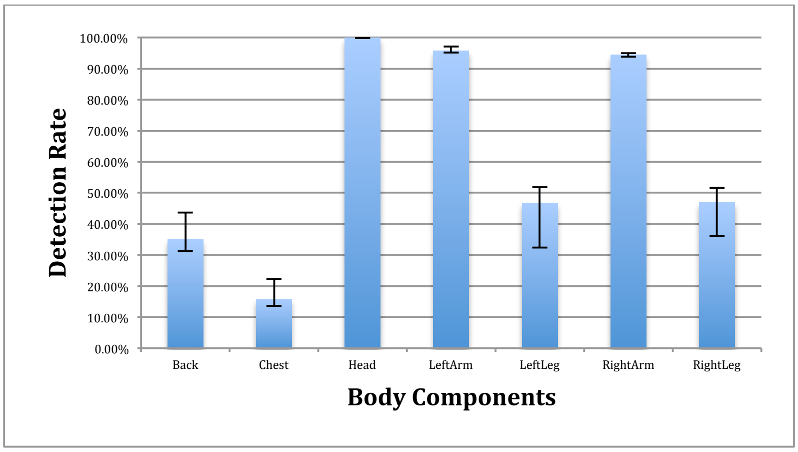

Chart 3.2 Average Detection Rates of Simulation of Random Walking with Fixed Context (No.2)

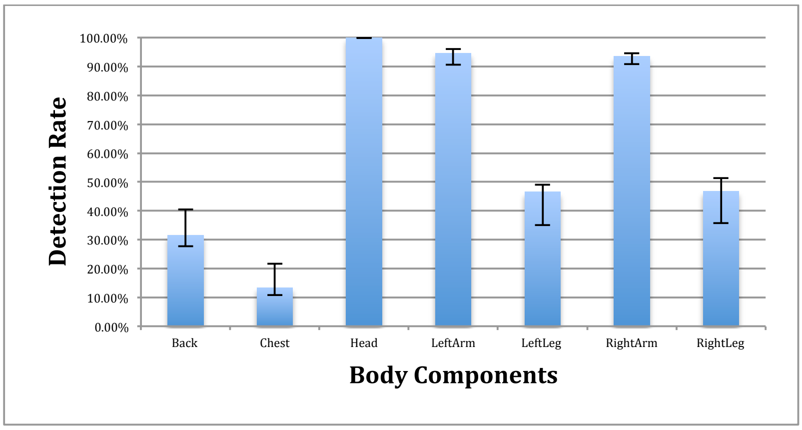

Chart 3.3 Average Detection Rates of Simulation of Random Walking with Changed Context (No.1)

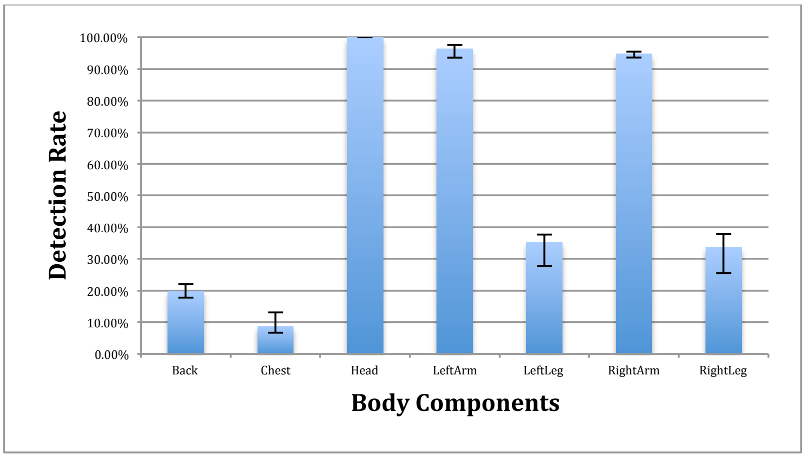

Chart 3.4 Average Detection Rates of Simulation of Random Walking with Changed Context (No.2)

The error bars in the charts indicate the highest and lowest detection rates for the same body components in different zones. As indicated in the charts above, several results can be observed from these random simulations:

1) Average detection rates were highest at head, close to 100%

2) Average detection rates at left and right hands were second and third highest, both with values of more than 90%

3) Average detection rates at the rest body components were much lower than those at head and arms

4) Detection worked much more steadily at head and arms, where high detection rates were generated, than at the rest of body components, where low detection rates were generated. Different detection rates at different zones can be reflected from the error bars.

5) The conclusions above hold no matter in the fixed OR context or modified OR context that would appear in different surgeries.

4 Simulations Based on Real OR Scenarios

Unlike the random movement patterns in Chapter 3, during a surgery, it is more common that medical staffs have their own movement patterns based on different roles of theirs. For example, it would be common that a nurse circulates a lot around the OR during a surgery while an anesthetist spends most of his time just next to his anesthetic station. To see if such specific scenarios during a surgery could yield different detection results, customized simulations have been done based on two common surgeries: Umbilical Hernia Repair and Laparoscopic Cholecystectomy.

4.1 Scenario 1- Umbilical Hernia Repair

According to the surgery observation in the Reinier de Graaf Hospital in Delft, a general workflow of the umbilical hernia repair surgery within the OR can be summarized as following steps:

1) Anesthetist enters the OR and prepares for the anesthetization.

2) Nurses enter the OR and check the medical equipment that is needed for the surgery.

3) Patient is moved into the OR, and transferred from his/her own bed to the surgical table.

4) Surgeons enter the OR, and the whole crew get together around the surgical table for the “time-out” procedure.

5) Anesthetization by the anesthetist.

6) Start of the surgery.

7) During the surgery two surgeons and an assisting nurse are working just at the surgical table, and one other nurse is circulating around the OR. Anesthetist mainly stays next to his anesthetization station.

8) End of the surgery.

9) Patient is wakened up by Anesthetist.

10) One bed comes in for the transfer of the patient.

11) Surgeons leave the OR earlier than nurses and anesthetist.

4.2 Scenario 2- Laparoscopic Cholecystectomy

According to the surgery observation in the Reinier de Graaf Hospital in Delft, a general procedure of the laparoscopic cholecystectomy within the OR can be summarized as following steps:

1) Anesthetist enters the OR and prepares for the anesthetization.

2) Nurses enter the OR and check the medical equipment that is needed for the surgery.

3) Patient is moved into the OR, and transferred from his/her own bed to the surgical table.

4) Surgeons enter the OR, and the whole crew get together around the surgical table for the “time-out” procedure.

5) Anesthetization by the anesthetist.

6) Start of the surgery.

7) During the surgery two surgeons and an assisting nurse are working just at the surgical table, and one other nurse is circulating around the OR. Anesthetist mainly stays next to his anesthetization station.

8) At the suture process, the assisting nurse switched position with the assisting surgeon, so that the assisting surgeon can better help leading surgeon with suturing.

9) End of the surgery.

10) Patient is wakened up by Anesthetist.

11) One bed comes in for the transfer of the patient.

12) Surgeons leave the OR earlier than nurses and anesthetist.

Specially, Step 8) in the laparoscopic cholecystectomy is the major difference though which it is distinguished from the umbilical hernia repair surgery.

4.3 Simulation Results

Both surgeries were simulated in the platform for 20 times in order to generate enough data. During the simulations the walking paths of medical staffs were manually manipulated according to the recorded procedure (although with inevitably slight differences every time) in order to best reflect the surgical workflows in Chapter 4.1 and Chapter 4.2. During the process of data analysis, it was found that for some medical staffs, there were some areas within the OR that they never entered. Such areas were indicated by the results that none of the seven body components had been detected even once in all of the 20 simulations, and numbers of such areas varies according to different surgeries and different medical staffs.

1) Overview of entered zones in the umbilical hernia repair surgery (Table 4.1):

Table 4.1 Entered Zones in the Umbilical Hernia Repair Surgery

	Zone1	Zone2	Zone3	Zone4	Zone5	Zone6	Zone7	Zone8	Zone9
Anesthetist	×	√	√	×	√	√	×	×	×
Nurse 1	√	√	√	√	√	√	√	√	×
Nurse 2	√	√	√	√	√	√	√	√	√
Surgeon 1	√	√	×	√	√	×	√	√	×
Surgeon 2	√	√	×	√	√	×	×	×	×

2) Overview of entered zones in the laparoscopic cholecystectomy (Table 4.2):

Table 4.2 Entered Zones in the Laparoscopic Cholecystectomy

	Zone1	Zone2	Zone3	Zone4	Zone5	Zone6	Zone7	Zone8	Zone9
Anesthetist	×	√	√	×	√	√	×	×	×
Nurse 1	√	√	√	√	√	√	√	√	×
Nurse 2	√	√	√	√	√	×	√	√	×
Surgeon 1	√	√	×	√	√	×	×	×	×
Surgeon 2	√	√	×	√	√	×	×	×	×

Excluding the un-entered zones indicated by "×" in the tables above, simulation results could be then averaged over 5 medical staffs, 9 zones and 20 times as what was done in Chapter 3. Average results of two surgeries are shown as follows:

1) Average detection rates in the umbilical hernia repair surgery (Chart 3.5):

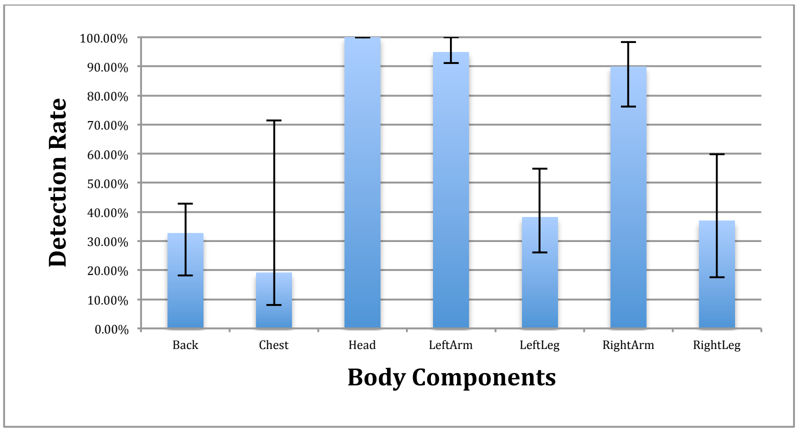

Chart 3.5 Average Detection Rates in the Umbilical Hernia Repair Surgery

2) Average detection rates in the laparoscopic cholecystectomy (Chart 3.6):

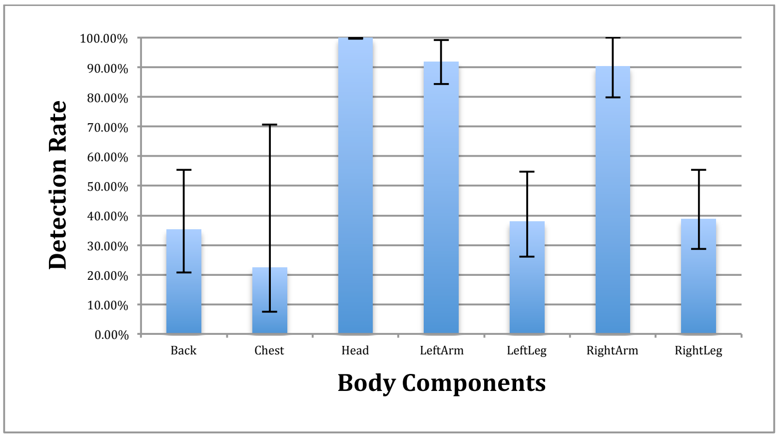

Chart 3.6 Average Detection Rates in the Laparoscopic Cholecystectomy

Again, The error bars in the charts indicate the highest and lowest detection rates for the same body components in different zones. The simulation results can be interpreted from different perspectives.

1) When looking at the average detection rates only, simulation of both surgeries gave detection rate distributions similar to those of random simulations in Chapter 3: Highest average detection rates were obtained at head (close to 100%), while second and third highest ones were obtained at left and right arms (around 90%).

2) In spite of the steady detection rates at head that didn't vary a lot, detection rates at other body components varied much more at different zones than those from the "random walking" simulations in Chapter 3. Especially, the highest detection rate at chest was three times higher than the average one, which applied for both surgeries.

A closer look at the detection rates at chest at different zones for both surgeries could give possible explanations to the phenomenon above. As shown in Chart 3.7 and Chart 3.8, the detection rates at chest in Zone 5 was much higher than those in other zones. Since Zone 5 was where the surgical table was, one possible explanation could be the long exposure time of the chest to the transmitter at Zone 5 since it was likely that medical staffs stood at the same position when they were working in Zone 5, facing to the patient with their chest exposed. Such a scenario could be illustrated in Figure 3.1, in which a medical staff was working beside the surgical table in Zone 5.

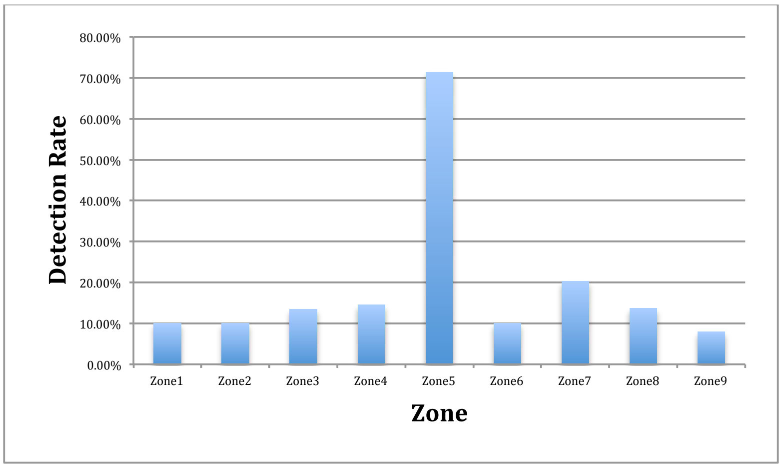

Chart 3.7 Detection Rates at Chest during Umbilical Hernia Repair Surgery

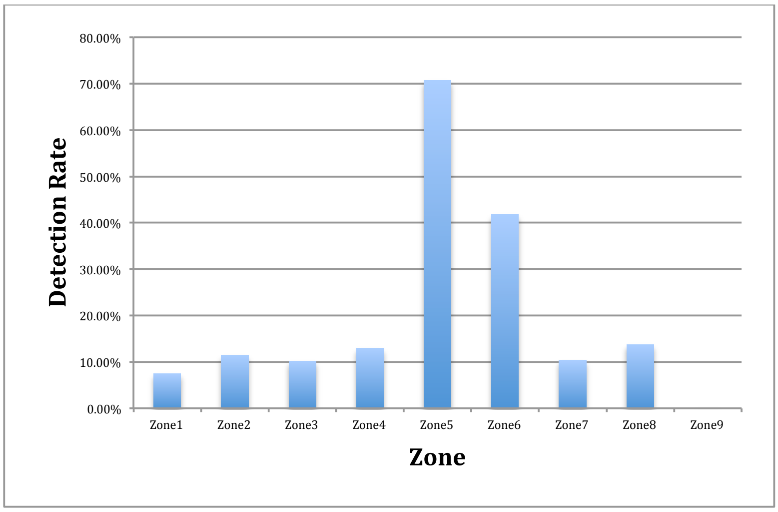

Chart 3.8 Detection Rates at Chest during Laparoscopic Cholecystectomy

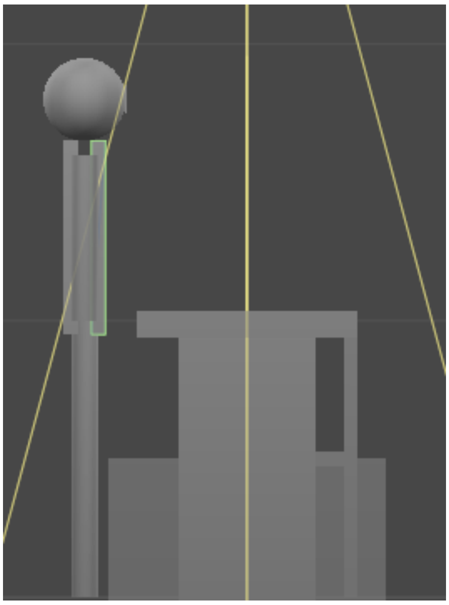

Figure 3.1 Situation when Chest is Exposed for a Long Time

5 Conclusion and Outlook

5.1 Summary of Results

From the data analysis from Chapter 3 and Chapter 4, results reflected from the simulation can be summarized in the following Table 5.1 and Table 5.2.

Table 5.1 Summary of Results-Detection Rate

	Head	Left Arm	Right Arm	Left Leg	Right Leg	Back	Chest
Random Walking Fixed Context	++	+	+	-	-	-	--
Random Walking Changed Context	++	+	+	-	-	-	--
Umbilical Hernia Repair	++	+	+	-	-	-	-- (- in Zone 5)
Laparoscopic Cholecystectomy	++	+	+	-	-	-	-- (- in Zone 5)

Table 5.2 Summary of Results-Detection Stability

	Head	Left Arm	Right Arm	Left Leg	Right Leg	Back	Chest
Random Walking Fixed Context	+++	++	++	-	-	-	-
Random Walking Changed Context	+++	++	++	-	-	-	-
Umbilical Hernia Repair	+++	+	+	-	-	-	-
Laparoscopic Cholecystectomy	+++	+	+	-	-	-	-

In the tables above, the number of “+” indicates the level of positive evaluation and on the other hand, the number of “-” indicates the level of negative evaluation. Results are displayed in the charts above only in a general way, while the entire output dataset for each medical staff in each simulation scenario can be found in Appendix B for further references.

Table 5.1 reflects that the detection rate of a tag is indeed influenced by the position where it is attached. Whether the context is changed or not does not have a significant influence on the detection rate which is mainly determined by the parameter of tag position. On the other hand, Table 5.2 reflects that different tag positions also result in different working stabilities of the system. According to the evaluations above, head and arms as tag positions are better choices than other body components. Besides, the changes of OR context (different positions of the medical devices) do not have significant influence to the detection rate distribution.

5.2 Further Discussion

Based on Chart 5.1 and Chart 5.2, it is not difficult to draw a conclusion that a tag should be attached to the head of a medical staff in order to obtain the best detection rate and working stability. However, it would not be a good idea to attach a tag at the head of a medical staff in reality. Since medical staffs wear disposable hats during a surgery, which are designed for easy put-on and take-off as well as disposal, attaching a tag to the hat would contradict with all these convenience given by the disposable hat. Therefore, the head should be excluded from being an ideal tag position. Considering the rest of body components based on the simulation results, the best choice would be attaching a tag at one of two arms, which is a proper place for attaching tags during surgeries and also has good enough results even when it is compared with head. In fact, considering the fact that transmitters are installed at the ceiling with a downward emitting direction, the high detection rates and working stability of tags at head and arms are not surprising results since head and arms are the body components that are more exposed to the transmitters compared to other body components, and this should make them easily detected by the transmitter. It could be a fair guess at the start of the project, and the simulation results just serve as good supporting proofs for this assumption.

On the other hand, there are several limitations of this platform that needs considering for improvement.

1) The diffusion and reflection of the infrared signal was not taken into consideration in the simulation. In reality, it is difficult to limit the emission angle to our preferred value, as infrared signal would get diffused during the process of transmission. Besides, when the infrared hit any objects, a portion of the light would get reflected and transmit to other directions. Both problems would result in the confusion of the detection, as there must be areas in the OR that would be exposed to signals from different transmitters in the cases of diffusion and reflection. To better simulate the real scenarios, issues of diffusion and reflection should be included for further improvement and methods should be come up with to solve the problem caused by the overlapped signal.

2) The division of the body components of medical staff are not detailed enough to enable detections of tags that may be attached to smaller body components with different directions of exposure. However, there is an issue of compromise here: more detailed divisions and more possibilities of exposure directions would hugely increase the number of the variables in the simulation, which would remain as a big challenge for the following data analysis. One of the possible ideas of improvement could be implementing more detailed division only on the body components with high detection rates (i.e. head and arms in our case) after primary simulation results are obtained.

3) The modeled medical staffs in the simulation platform are not yet be able to bend any of their body components, which limits the possibility of exposure change which could happen in the real application. As indicated by the simulation results of the two selected surgeries, detection rates at chest at Zone 5 are higher than those at other zones. This was explained by the long exposure time of chest at Zone 5, while in the real scenario it could happen that the exposure time of chest would not increase as significantly due to the fact that sometimes a surgeon needs to bend forward to have a closer look at the patient. In that case, the chest would be hidden and blocked by the head and on the other hand, there could be a possible increase of he exposure time of back.

4) The individual dimensional differences among medical staffs were not reflected in the OR. Similar to the issue proposed in 3), this involves the question of how detailed the modeling should be with the complexity of the development and data analysis taken in to consideration.

To sum up, based on the results under this simulation environment, it can be revealed that tag position and OR context have different effects on the detection rates of tags:

1) Tag position has huge effects on the detection rate, with head and arms yielding high detection rates and the rest of body components (back/chest and legs) yielding low detection rates.

2) OR context on the other hand, does not have significant effects on the detection rates of tags.

These conclusions could provide better reference for potential application of IPS in the OR: when considering a proximity-based infrared system as an IPS in the OR, special attention should be paid to the tag positions on the human body, while the possible change of the OR context would not be a big factor of influence.

5.3 Other Possible Applications

One of the flexible perspectives about developing this simulation platform is that the platform could be probably used for other possible applications in an easy way as long as necessary modifications are made.

1) By adjusting the settings of the transmitters (e.g. amount, positions, emission angles and emission directions) as well as the context modeling of the room, the platform could be then used for simulation in other scenarios, such as drug delivery monitoring within the pharmacy, asset tracking throughout the whole hospital and bedside monitoring for patients.

2) The platform could also be used for simulation of other indoor positioning systems that are based on other working principles. For example, an RFID system could also be a good option as an indoor positioning system within the OR as long as it could pass the EMI tests. In this case, in order to simulate the detection of the RFID system, the “raycast” function that enables blockage detection should be removed and replaced with

other functions that could simulate the signal attenuation after the RFID signal penetrate an object. Further study would be done mainly on the script reference and algorithm optimization for the migration in order to adapt the platform to other indoor positioning systems.

5.4 Contributions of the Work

During this project a dynamic simulation platform has been developed, with which it is possible to simulate the working status of a proximity-based infrared positioning system within the OR. Currently available IPS systems applied in the healthcare sector mainly work on the room-level detection on the entire floor of a building, without enabling further detection at different areas in a single room. Our work moved a step forward to study how an infrared positioning system would work within a single OR. To some extent the simulation results could provide better ideas about the relationship among the detection rate, tag position and OR context. While there are still limitations about the work as stated in Chapter 5.2, the major significance of the work is that a simulation platform has been built, which is flexible enough for simple modeling and simulation in the OR as well as other possible simulation purposes with necessary functions extended.

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Appendix A: Literature Review

Literature Review: Enhancing OR Workflow Analysis using Indoor Positioning Technologies

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Definition of Terms

RSSI: Signal attenuation can be exploited for distance estimation based on RSSI values. RSSI are observed RSS (Received Signal Strength) values averaged over a certain sampling period and usually specified as received power in decibels.

ToA: The principle of Time of Arrival (ToA) is based on measuring the absolute travel time of a signal from a transmitter to a receiver. The Euclidean distance between two devices can be derived by the multiplication of the signal travel time by the wave speed (i.e. speed of light in vacuum). Since the wave velocity depends on properties of the propagation medium, knowledge of the penetrated material is required. For all building materials the propagation speed depends on the square root of the dielectric constant k. For example, for glass and dry concrete $k \approx 5$, slowing down electromagnetic waves by a factor of more than 2. For ferroconcrete $k \approx 9$, resulting in a factor in travel speed velocity of one third compared to the speed of light.

TDoA: Time Difference of Arrival. Taking time differences of ToA measurements has the advantage that a possible receiver's clock bias is not relevant. Any constant time offset of a non - synchronous receiver's clock is eliminated by subtraction. In contrast to ToA, the receiver does not need to know the absolute time at which a pulse was transmitted - only the time difference of arrival from synchronized transmitters is needed.

AoA: Angle of Arrival (AoA) information, i.e. direction of incidence, can be obtained by the use of directionally sensitive antennas. In real application, AoA is usually based on crude sector information.

CoO: The Cell of Origin (CoO) method, also called proximity detection, is used to determine the position of a mobile device merely by its presence in a particular area or based on a physical phenomenon with limited range. The procedure consists in simple forwarding of the position of the anchor point where the strongest signal is received. The accuracy of CoO relates to the density of anchor point deployment and signal range. CoO is a simple positioning method used for applications with low requirements for accuracy. Examples are sensors detecting physical contact, automatic ID systems and mobile wireless positioning systems.

EMI: Electromagnetic interference, also called radio-frequency interference or RFI when in radio frequency, is disturbance that affects an electrical circuit due to either electromagnetic induction or electromagnetic radiation emitted from an external source.

Abstract

Indoor positioning technologies have been used to provide location information of people and objects for decades. Appropriately deploying such technologies in the operating room (OR) environment could be considered as a technically possible way to enhance the OR workflow analysis, since the access to instrument/staff/devices positions in the OR could help to improve the awareness of different phases of a surgery. In this paper, a comprehensive review of several major indoor positioning technologies is presented, and feasibilities of deploying the technologies into the specific OR environment are discussed. Based on the context requirements posed by the OR, comparison among different technologies is made and an initial conclusion is also drawn.

1. Introduction

Workflow analysis in the hospital, especially in the operating rooms (OR) is an interesting research topic as it plays an important role in the healthcare efficiency analysis. Among many perspectives within this topic, an important one is to study how to acquire real-time information about the surgical activities in order to enhance the awareness of different phases of a surgery. One possible method is to apply sensor technology to detect the working status of staff and instruments in the OR.

Through studying the sensing technologies that facilitate the workflow analysis in the OR, a better overview about how to enhance the workflow analysis can be expected. This literature review focuses on the indoor positioning techniques as supporting sensing technologies for enhancing OR workflow analysis. Four different techniques are described in details from Chapter 3 to Chapter 5, and a comparison of the introduced techniques is given in Chapter 6. At last in Chapter 7 discuss the feasibility of deploying the introduced techniques in the OR is discussed and future research direction is concluded.

2. Workflow Analysis

2.1. Relevant Background

In a hospital, the OR is where many expensive equipment and instruments are implemented, which requires labor-intensive maintenance. According to a study in the Netherlands, malfunctioning or missing equipment resulted in operating room delays in nearly 16% of scheduled surgeries [1], and this fact has indicated the need of equipment tracking and monitoring in the OR. Besides, the utilization rate of the OR is another important aspect of OR management, since both underutilization and overutilization of the ORs could add up the unnecessary costs for hospitals [2]. This problem is caused by the fact that the workflow in the OR is very complex and the acquisition of perioperative data is not adequate [3]. In order to enhance the workflow analysis and working efficiency in the OR, one possible way is to ensure the availability of real-time information during the perioperative processes [4].

With the help of existing or additionally installed sensors in the OR, a rich source of information is available and workflow monitoring can be realized by using advanced analysis techniques to provide surgical context information from the sensors. In Bouarfa's research, she focused on using pattern recognition techniques to process pre- [5], intra- [6,7,8] and post-operative [9] data to predict safety and efficiency parameters in surgery. Bouarfa's work was motivated by the aim to reduce adverse events and improve surgical efficiency through analyzing sensor data with pattern recognition techniques, and her major contributions include a tracking system to detect instrument use in laparoscopic surgeries and a method to predict the length of stay of patients in the Post Anaesthesia Care Unit using peri-operative data. In addition to the pattern recognition technique, it is also feasible to analyze the OR workflow based on the Petri net approach, which maps in a surgical procedure into a Petri net in a clear and straightforward manner, defining the workflow nets in a subclass of Petri nets [10].

2.2. Input Information for Workflow Analysis: Sensor Technology

In order to implement the OR workflow analysis, different kinds of information reflecting the context of the OR can be used as input knowledge for pattern recognition, Petri net analysis and other workflow analysis techniques. Particularly, sensors that can facilitate the indoor "track and trace" process of instruments are considered to play an important role in the context of workflow monitoring. In [6,7,8], Bouarfa proposed a framework to use available sensor data (data from active RFID tags for example), to detect the instruments as valuable signals in the OR environment, aiming to provide better input information for surgical activities recognition. This is a good example to support using indoor positioning technologies to assist workflow monitoring, and instruments are chosen as tracking targets because it is easy to detect whether they are in use through RFID.

Various techniques can be deployed in the area of indoor localization, among them radio frequency identification (RFID) and WIFI positioning techniques are the two that are most adopted in the hospitals. Besides, other techniques employed for indoor positioning such as infrared and Bluetooth are also interesting examples. Detailed introduction about these four techniques will be given in the following sections, followed by the discussion on their limitations when considering application in the specific environment of operating rooms.

3. Indoor Positioning Technique: RFID

3.1. General Background

RFID (radio-frequency identification) technology is able to track persons or to mobile devices by tracking the tags attached to them, using fixed RFID readers at different locations. The main components of an RFID system consist of the hardware (tags, readers and antennas) and the software systems. The tags can be either passive or active, categorized based on the powering techniques. Passive tags can only communicate with the reader after getting activated by the electromagnetic field of the reader since they are not driven by battery power, and a passive RFID system is mainly based on the proximity detection of mounted tags. On the other hand, active RFID tags are equipped with self-supporting battery, which can power the integrated circuits inside the tags and broadcast the radio-frequency signal to the reader. An active RFID system can thus be able to cover a larger range thanks to the powered tags, and RSSI fingerprinting can be used as positioning principle. An RFID reader scans the tag and sends the tag information to the back-end database system that filters, analyzes, and stores the data and then passes on useful information to other enterprise application systems for further processing. The database system can have multiple readers located in different places sending data through wired or wireless networks. In addition, enterprise application systems, such as hospital information systems (HIS) and supply chain management systems, can connect to the middleware to retrieve tags information via security protocols. In healthcare, RFID systems are usually combined with other technologies such as Bluetooth, mobile devices, and sensors for different purposes.

3.2. RFID Application in Healthcare

An analysis report from Wamba [11] revealed that the publication of articles on RFID technology in the Journal of Medical Systems (JMS) has been rapidly growing recently. In spite of only one article on RFID technology published in 2003, 2008 and 2009, the number increased to 6 articles (27% of overall publications) in 2010 and even rocketed to 13 articles (59% of overall publications) in 2011 [11]. According to the report from RAND Europe published in 2009 [12], the most promising applications of RFID technology in healthcare include: 1) tracking of assets and patients, 2) identification of patients and 3) automatic data collection and transfer.

1) <u>Tracking of assets and patients</u>

With the help of RFID systems, a more transparent operational overview about of the assets in the hospital can be available, which can improve the general asset management. Besides, location information of staff and patients can be given in order to prevent potential errors and improve working efficiency. In 2007, Wayne Memorial Hospital in the USA was used as a beta site where an RFID-based real time asset management solution called RadarFind was adopted with the aim to track tagged devices like infusion pumps, diagnostics machines, blood warmers, and computers on wheels and wheelchairs [12].

2) <u>Identification of patients</u>

Using RFID systems to identify patients can improve the overall reliability of medical procedures such as drug prescriptions and patient administration. An example can be given by Aguilar et al., whose team set up an RFID system to identify patients at the Department of Medical Physics and Bioengineering at the University College Hospital Galway, Ireland [13]. In this case, each patient was given a RFID wristband which contained demographic information (patient ID number, patient summary, hospital code) of the patient and RFID readers were then used by the medical staff to read the patient's wristband and identify the patients.

3) <u>Automatic collection and transfer of clinical data</u>

RFID systems can facilitate the automatic collection and transfer of data within the integrated information system in the hospital, and thus enhance the overall supply chain management of the healthcare delivery organization. For example, Cangialosi et al. described in their paper how a properly implemented RFID system could integrate the clinical data collected throughout the patient life cycle (admission, examination, patient care, recovery, and discharge) and thus enhance the medical care service [14]. With RFID properly integrated into a hospital information system, a lot of valuable clinical information can be digitally recorded and processed in an automatic way. As long as patients are equipped with an RFID badge when he is admitted, they can be tracked from the time they are admitted to the time they are discharged. Moreover, the tagged patient can be monitored as he or she enters or leaves any room. With RFID systems supporting, clinical information about the performed procedures and the condition of patients can be thus entered via wireless communication between handheld scanners and terminals.

3.3. Benefits and Barriers of Deploying RFID in Healthcare

The main advantages of applying RFID technology in healthcare include enhanced patient safety, reduced costs, and improved efficiency. Yao et al. has summarized that the perceived benefits of deploying RFID systems in a hospital include: 1) improved patient safety and reduced medical errors, 2) time and cost saving, 3) improved medical process and so on [15].

1) Improved patient safety and reduced medical errors: First, the deployment of RFID technology makes it possible to quickly retrieve valuable clinical data such as patient information and patient locations, which leads to the improvement of patient identification [13], especially infants [16]. Patient drug compliance can be also improved by notifying patients with their medication schedule [17]. Second, when possible medical errors and other dangerous situations occur, alerting devices can be activated and notify care provider for assistance. For instance, an RFID system can notify medical staff in the OR when sponge and other unwanted material are detected left inside patient body [18] and also alert nurses and drug providers when the patient takes the medication in an incorrect way. Third, in the situation of emergency, RFID can reduce the time required to find the needed equipment and thus increase the possibility to save lives [19]. Fourth, integrating RFID with existing healthcare information system (HIS) can provide more reliable information for diagnosis and decision making, as medical staff will have immediate and accurate access to patient information and make quick and correct decisions based on that [20].

2) Time and cost saving: RFID-based systems can be applied for the purpose of asset management and help prevent valuable medical devices from being stolen [21], which can save a huge amount of money in hospitals each year. On the other hand, using RFID to monitor the interaction between people and assets can improve device utilization and regulatory compliance [22]. This can also reduce medical staff a lot of time in searching for medical devices and can enable them to focus more on their work [23]. Thanks to RFID systems, such improvements can contribute to the reduction of medical costs, as much as $1 million annually for a small-scale hospital [19].

3) Improved medical process: It would be beneficial for hospitals to save costs and improve patient satisfaction by improving medical process. With automatic data collection and processing which is enabled by RFID, traditional manual work like recording clinical data can be automated. By better monitoring assets and patient flow in the hospital, RFID has the potential to improve workflow efficiency [14]. Less waiting time can also be expected and with real-time patient information update, those suffering from serious symptoms can be given high priority in treatment [14]. Besides, benefits can be gained by saving time from manual work and reducing onhand inventory [24]. Last but not least, as mentioned above, Automatic collection of data from tagged patients and devices could improve resource utilization and decision making [25].

4) Others benefits: RFID technology also brings other benefits such as improving drug supply [26], improving resource utilization [27], and enhancing patient satisfaction [28].

However, we should also see the diverse challenges against applying RFID technology in healthcare. Such barriers can be divided into four main categories:

1) Technical issues

Special application environment in the hospitals can bring technical limitations to deploying RFID systems for healthcare. First, there may be electro-magnetic interference (EMI) between RFID systems and other medical devices in the hospital environment [29]. Especially, the potential problem of EMI would be a critical issue that constrains its further deployment in the OR where more RF-based devices may be influenced by EMI and this may result in life-threatening incidents. In 2008, van der Togt et al. [30] did a research to reveal that RFID techniques had induced 34 EMI incidents in totally 123 EMI tests in their observation, and came to a conclusion that implementation of RFID in the critical care environment should require on-site EMI tests and updates of international standards. Second, the reliability of RFID systems can be another concern. The detection accuracy of a RFID system does depend on a variety of factors like tag density, tag placement, angle of rotation, and read distance [31]. Besides, lack of universally accepted industrial standards also impedes RFID deployment in large scale. Such necessary standards include those of RFID data structure and human-computer interface.

2) Economic issues

Costs for deploying RFID systems include initial hardware and software expenditure, staff training, and the continuously high costs of maintenance fees that follow. Generally speaking, active tags are $25 and up and active tags with special protective housing, extra-long battery life or sensors can run $100 or more [32]. Considering the deployment of RFID systems in a big hospital, the total cost can be substantial if all equipment and patients are tagged. Besides tags and readers, the infrastructure also requires additional servers, databases, middleware and applications. In addition, RFID integration with back-end systems and data synchronization networks is needed to make the whole system functional. It is obvious that the total cost can be huge.

3) Social and legal issues

It can be beneficial to use RFID systems only when it is guaranteed that the transmitted data will not be misused against patients [33]. When an RFID tag is associated with a patient, all kinds of personal information, such as patient name, gender, home address, and medical history can be collected and associated to the ID code. Such information is highly mobile and sensitive and should be stored in a secure server in compliance with the Health Insurance Portability and Accountability Act (HIPAA). Therefore, healthcare organization should ensure neither personal nor confidential information is transmitted and exposed via RFID. Besides, to relieve the anxiety of hospital staff and patient, it is important to tell them the purpose of this data collection [34].

3.4. Examples

To give a better overview about the deployment of RFID systems, WhereNet positioning system [35] will be introduced here as an example.

WhereNet positioning system is developed by Zebra Technology Company [35], and its design purpose is to provide indoor and outdoor real-time positioning for various devices. With a number of tags mounted on the target devices or persons, the system uses RFID technology identify the locations of different targets by identifying the tags. The system uses a mature time difference of arrival (TDOA) algorithm to calculate the locations of these tags and returns absolute location information of the tags, which can be used by location-based applications.

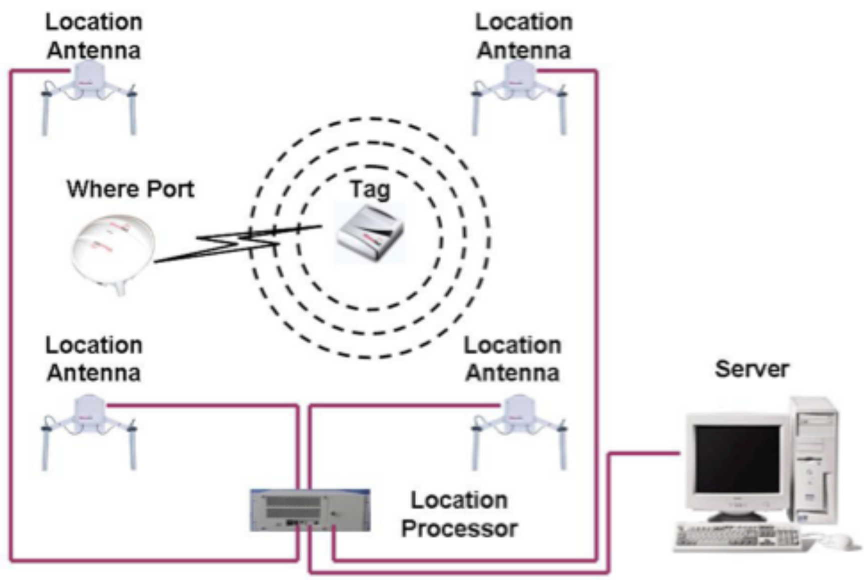

Fig. 1. WhereNet's Real-time Localization System [35]

The system consists of the following parts: tags, location antennas, location processors, servers, and Where Ports, as shown in Fig.1. Tags are attached to their objects such as persons and devices, so that it is possible to track location. Location antennas mounted on the ceiling at fixed positions receive signals from tags and transmit the data to a location processor. The location processor performs location calculation using the data collected from the antennas, based on which it can return the location information of the tags. A location processor can communicate with up to 8 location antennas via coaxial cable and track many tags at the same time. Calculated location information of tags is transmitted from the processor to the server, where the information can be stored and used by location-based services such as real-time tracking services. Where Ports fixed in different locations send low frequency electromagnetic signals to the tags to indicate the required behaviors of the tags based on the users' applications. For example, a Where Port offers specifications of the transmission frequency of the tags based on the location and the needs of the location-based services.

While the WhereNet system is a mature example that can represent the typical working principle of a common and commercial RFID-based localization system, there are also several RFID-based projects that were done in the hospitals. Fuhrer at al. developed a system called RFIDLocator to facilitate the asset management in the hospital and presented the required steps for its configuration to the concrete case of the hospital [36]. Ku et al. developed their web-based, RFID-initiated PAM-S system to facilitate the perioperative care provided in a hospital in Taiwan [37].

4. Indoor Positioning Technique: WIFI

4.1. General Background

It would be a tempting solution to use a WIFI-based system to estimate the location of devices and people, since WIFI access points are readily available in many indoor environments, which could make the installment easier and more convenient.

The two main options for doing Wi-Fi localization are triangulation and fingerprinting, both options are based on the use of RSSI (Received Signal Strength Indicator).

1) Wi-Fi triangulation is a method that builds a mapping relationship between RSSI and distance. A steep linear characterization curve is required in order to properly implement such a method. An (x, y) location prediction can be generated using functions that describe the curves combined with live RDDI values.

2) Wi-Fi fingerprinting on the other hand, creates a radio map of a given area based on the RSSI data from several access points. Based on the RSSI data a probability distribution of RSSI values for a given (x, y) location can be generated and stored in the fingerprint database. Live RSSI values during real application are then compared to the fingerprint database to find the closest match that corresponds to a certain RSSI value, which indicates a predicted (x, y) location.

Navarro et al. found through their experiments that the triangulation method did not show promising results while on the other hand, the fingerprinting method had promising results with various ways of making predictions [38].

4.2. Disruptive Factors

Like other wireless radio-signal-based localization systems, WIFI systems are also confronted with many confounding factors during the signal transmission. Disruptive factors that can influence the accuracy include:

1) Signal attenuation by static environment: When the WIFI signal reaches the static barriers such as a wall, the signal would be attenuated by the barrier and the strength would be reduced due to reflection from the barrier. This is caused by the fact that part of the signal would be absorbed and converted into heat while the signal strike the barrier. While the loss might not be noticeable by a human, it would influence the signal distribution in the real application environment, resulting in an incorrect match with the fingerprint database. The extent of the signal loss is related to the material, specifically its thickness [39].

2) Signal attenuation by user: The presence of a user would also be another factor that influences the signal strength. This would be an especially important problem when it comes to the fingerprinting-based location method, because the mean values of the WIFI signal would be changed by the presence of a user as the signal can be partially absorbed by the water in the human body and then be attenuated [40].

4.3. Examples

To give a better overview, several WIFI-based indoor localization systems will be introduced as follows:

1) RADAR: RADAR [41] system is an indoor position tracking system developed by a group at Microsoft Research, which makes use of the existing WIFI technology. Packet signal strengths are measured at different building locations and stored in a radio map for the system's use. When the user's wireless device measures the signal strength from the access points (AP) within its range, the wireless device can searches the radio map for a signal strength that best matches the measured one, based on which the location of the user can be determined. To improve its estimate, user's recent movement history and any other changing factors like temperature and user density that may affect the radio map are taken into consideration. Using RSSI fingerprinting technique, 2-D absolute position information can be provided and used for location-based applications.

In the demonstration where the system was tested in a typical indoor environment [41], 3 PCs are used as APs and 1 laptop is tracked as the target object. The signal strength from the APs is measured by the target laptop and the results are used to calculate a 2-D position of the target. An accuracy of about 4 m with about 50% probability can be achieved [41].

The main advantages of this system are that the it makes good use of existing indoor WIFI infrastructures and it only needs few base stations to do the job, which means that the RADAR system can be implemented easily and conveniently. However, it also requires the target object to be equipped with WIFI technology, which could be difficult for some projects expecting a low-weight and low-cost solution. Also it should be considered that a person who simply uses a device with WIFI interface may be tracked without permission granted. In addition, the RADAR system suffers from the limitations of RSSI positioning methodology like the problem of signal attenuation [42].

2) COMPASS: Making use of readily available WIFI infrastructures and digital compasses, the COMPASS system [43] provides positioning services featured by low cost and relatively high accuracy. The system is used to track a user carrying a WIFI-enabled device, the position estimation of which is also based on the RSSI fingerprinting technique. A probabilistic positioning algorithm is also employed to determine the location of a user. The COMPASS system can be seen as a breakthrough when considering that the user's orientation is also measured in the location sensing process by a digital compass (a component of small size integrated into a chip with low cost and low power consumption) to reduce the blocking influence. This consideration enables the system to better cope with signals with different strength in each position with different orientations.

To demonstrate the COMPASS system, experiments were done in an area of 312 m^2 inside a building [43]. Seeing from the results, the COMPASS system could achieve an accuracy of about 1.65 m, while it only considers tracking a single user. Tracking multiple users at the same time has not been studied.

3) Ekahau: The Ekahau positioning system [44] uses the existing indoor WIFI infrastructures to continually monitor the motion of WIFI devices and tags. The triangulation positioning techinique is used for locating any WIFI enabled device in Ekahau positioning system. The received signal strength indication (RSSI) values of the transmitted RF signals recorded at different APs are used to determine the targets' locations. The Ekahau positioning system offers 2-D location information, which can be used by location aware services and applications.

This solution is inexpensive and flexible to perform indoor positioning by tracking the tags with respect to reference devices, which are standard APs. The Ekahau system consists of three parts: site survey, WIFI location tags and positioning engines, as shown in Fig. 2. Site survey is a software tool, which provides site calibration before the real-time position estimations, and demonstrates the network coverage area, signal strength, SNR, data rate and overlapping of the WIFI network in users. social and professional places. The mapping of the network environment is quick with about 1111 m^2 per hour. Another part is WIFI location tag, which can be attached to any tracked object to enable real-time positioning. The tags transmit RF signals. APs measure signal strength of the received RF signals. The measured data is forwarded via WIFI to the third part, which is a positioning engine, a software tool, offering real-time positioning to any device such as laptop, PDA, etc., using WIFI technology. Combining signal strength and site calibration done by site survey, the positioning engine calculates and displays the locations of WIFI location tags mounted on devices on the map of the local place.

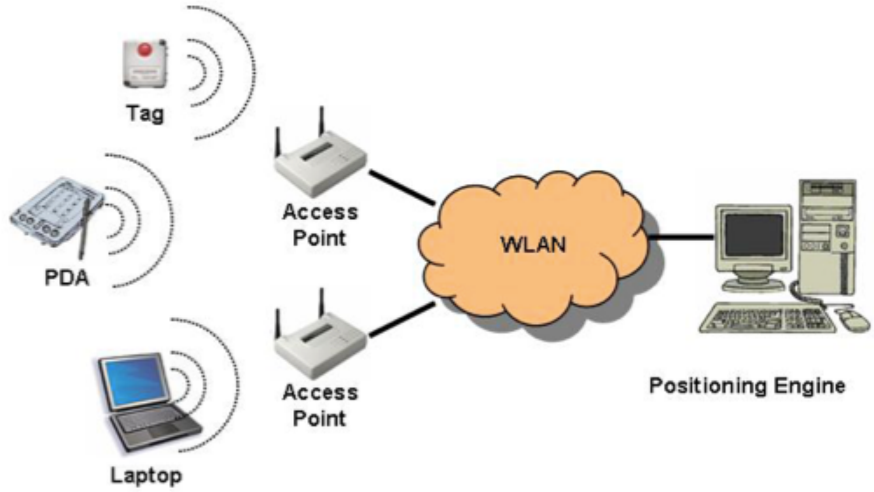

Fig. 2. System Architecture of Ekahau Positioning System [44]

The accuracy of the positioning system can achieve 1m, if there are three or more overlapping APs that can be used to locate objects. The engine can simultaneously track thousands of devices. The Ekahau system achieves low cost by sharing the existing WIFI APs. The tags tracked are comfortable for the users to take them, with a size of 45 mm × 55 mm × 19 mm and weighing 48 g. The battery lifetime can last up to 5 years with low battery warning alerts to avoid the performance degradation because of the low power level of the battery. When the tags move, they start to work and be tracked, which offer an energy efficient solution and less influence to other WIFI-based communication.

5. Indoor Positioning Technique: Infrared

5.1. General Background

The feature that infrared (IR) light is invisible to human eyes under most conditions makes it a possible less intrusive technique used in the OR.

An infrared localization system usually consists of infrared transmitters and infrared receivers. Beacons fixed at several places in a room transmit modulated infrared signals as unique codes. The signal strength can be modified, which enables adjusting the maximum transmission distance of the infrared signal. Receivers are localized based on the infrared codes they receive that represent corresponding location information. Since IR signals don’t penetrate opaque materials like walls, IR-based systems can be of huge advantages when applied in situations where accurate localization is required between neighboring rooms separated by a wall. Besides, the cost of making an IR-based localization system is relatively low and the possibility of radio electromagnetic interference can be ruled out since it is not based on RF technology.

5.2. Examples

One of the earliest and most widely recognized IR indoor positioning systems is the Active Badge System, designed by Want et al. [45] with the aim of locating people at room level. In this project, fixed infrared receivers are placed at known spots throughout the indoor environment and mobile beacons are used as tracking targets. Only one receiver would be used in every room in the case of simple room level proximity detection (i.e. CoO), while additional AoA capabilities would be needed for sub-room precision. Besides, when it comes to an IR tracking system aiming to achieve meter-level precision or better, the system may also require multiple receivers implemented in each room to disambiguate various physical settings of the room. The active badges carried by users are called "beacons" which is able to emit short IR pulses with unique codes at a low frequency. Based on which fixed IR receivers deployed in the room collect the signals, the position of the badges can be determined. Since the Active Badge concept is based on the Cell of Origin (CoO) principle, the positional accuracy depends on the operating range (signal strength) of an IR sender, which is typically several meters. One major drawback of this project is that it is not suitable for real-time applications due to its low working frequency.

Based on the CoO principle, Pfeifer et al. [46] developed a commercial hybrid IR/RF local positioning system whose component architecture is introduced as follows:

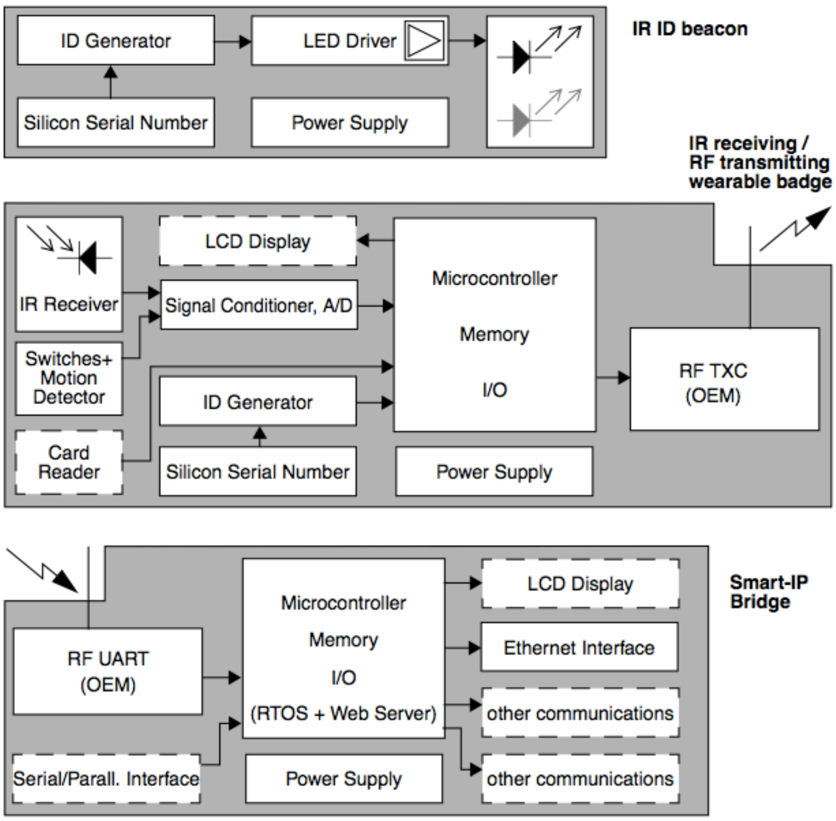

Fig. 3. Component Architecture of the System designed by Pfeifer [46]

There are three major parts in the system: IR beacon, IR receiving/RF transmitting badge and smart-IP bridge, which are shown in Fig. 3. The beacon is used to emit unique location information with a low frequency. Then the badges that receive the IR signal are able to send the location information via RF transmission to the smart-IP bridge, which is a RF base station with a built-in web server. This system is a good example for deploying infrared localization technique using the CoO principle.

Systems like this one from Pfeifer can be powerful when it is necessary to discriminate objects in two adjacent rooms separated by walls. Besides, since the transmission range is adjustable by modulating the signal strength, it is also possible to further deploy infrared to the detection of smaller area within a single room.

In addition to the CoO principle, the Angle of Arrival (AoA) principle can also be used for infrared positioning. One example can be given by Atsuumi and Sano in 2010 [47]. Their proposed system aims to compensate the sensor drift of integrating positioning systems through providing angular information of the signals. Using polarized infrared light, the azimuth angle of incidence is estimated with respect to a single beacon. The beacon consists of an IR light source and an optical polarizing filter, which only passes light through that oscillates along a single plane. The receiver consists of a photo detector and a rotating polarizer that causes attenuation of the signal intensity depending on the horizontal angle. The phase of the time-varying signal is then translated into the angle of the polarizing plane. This allows estimation of the absolute azimuth angle with an accuracy of 2% (or a few degrees) as first experiments have shown.

6. Indoor Positioning Technique: Bluetooth

6.1. General Background

Bluetooth is a technology that allows electronic devices to communicate wirelessly. It was designed for low power consumption and is based on low-cost transceiver microchips. Radio communication via Bluetooth is done using radio waves with frequencies between 2.402 GHz and 2.480 GHz, which is within the 2.4 GHz ISM frequency band, a frequency band that has been set aside for industrial, scientific and medical devices by international agreement. The Bluetooth specification was conceived in 1994 and is now managed by the Bluetooth Special Interest Group (SIG).

Bluetooth devices can be categorized into 3 classes in terms of different signal transmission range, and the Class 3 Bluetooth devices could be an ideal choice for indoor positioning systems due to the smallest signal transmission distance of around 5m. Bluetooth technology has been implanted in various types of devices such as mobile phone, laptop, desktop, PDA, etc. In addition, Bluetooth chipsets are low cost, which results in low price tracked tags used in the positioning systems.

6.2. Examples

One of most recent and promising Bluetooth-based indoor positioning systems is the iBeacon project, which is the collaboration between Apple Inc. and Estimote Inc., the beacon manufacturer [48]. An application scenario of the system in a clothes shop is shown in Fig. 4. This system is based on the latest Bluetooth 4.0 technology which is featured by its extremely low energy consumption, and it detects if any Bluetooth compatible device is within range of one of the Bluetooth signal emitting beacons fixed at different places. Based on this, any pre-stored location-related information can be pushed to the corresponding devices that are nearby. The signal transmission range is also adjustable by through signal strength modulation. Since the purpose is to detect if a device is close to a fixed location-indicating beacon, users can target their interested areas by attaching the beacons and no complex calculation is needed for the RSSI-based fingerprint database.

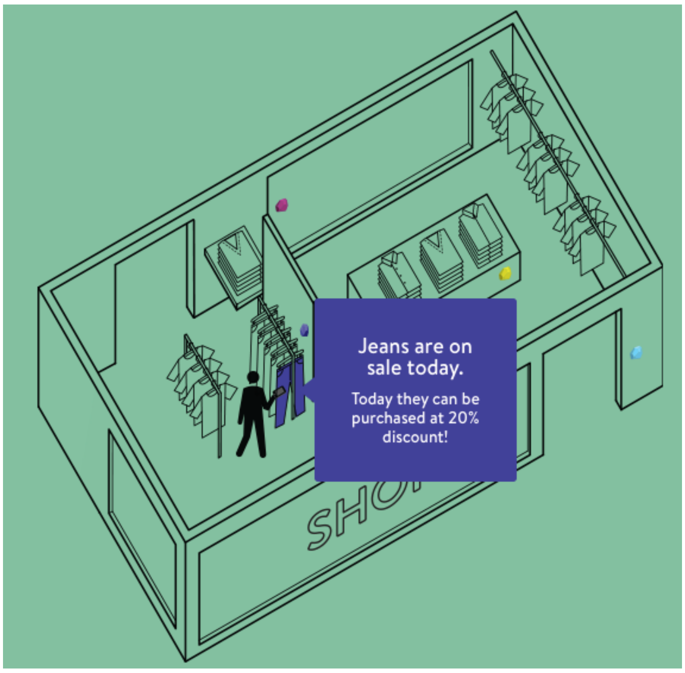

Fig. 4. Application scenario of iBeacon in a clothes shop [48]

7. Comparison of Different Techniques

With four different indoor positioning techniques introduced above, it is necessary to summarize their technical specifications respectively, in order to provide a clearer understanding of them. To do so, three major technical requirements (working principle, coverage and accuracy) are taken for comparison. Besides, special concerns upon the OR application are needed as design criteria.

Taking into account several perspectives, a summary of the four techniques is shown below.

RFID

Principle: CoO/Proximity detection (passive RFID) or RSSI fingerprinting (active RFID) or TDOA

Coverage: From several meters (passive RFID) to tens of meters (active RFID)

Accuracy: several meters (active RFID) or within 1m/sub-room level (passive RFID)

Special concern: Potential EMI

WIFI

Principle: RSSI triangulation or RSSI fingerprinting

Coverage: Large area

Accuracy: several meters

Special concern: Irregular attenuation of signals in the OR

Infrared

Principle: CoO/Proximity detection or AoA

Coverage: scalable between several meters to tens of meters (via signal strength modification)

Accuracy: several meters/room level

Special concern: Signal blockage within the OR

Bluetooth

Principle: CoO/Proximity detection

Coverage: Several meters

Accuracy: within 1m/sub-room level

Special concern: Limitation of using Bluetooth compatible mobile devices in the OR

In the next chapter, our interested application environment of OR would be used as a filter, as it poses special requirements for the technologies. Based on the requirements given below, discussion would be made upon whether the techniques above would be our feasible options considering the summarized features.

8. Discussion: Interesting Application Scenario - Operating Room

Derived from the general issue of staff and device management in the hospital, here in our research we only focus on the indoor positioning of staff and devices within the operating room. The goal of the research would be to find a method to detect whether staff and devices are working around the surgical table, as different stages of a surgery could be roughly told based on the what different staff and devices are involved around the surgical table at a certain moment. With the application area constrained within the OR, there are several special requirements on the positioning techniques considering the unique context in the OR:

The size of an OR is generally smaller than 50 m^2 and the central working area around the surgical table is around 10 m^2. With staff and all kinds of devices present in the OR, any techniques that are based on TOA, TDOA or requires direct light transmission might not be suitable due to the problem of signal reflection in the OR.

In such a relatively small area many people are moving and working, which also means that the accuracy of the technique shouldn't be seriously distorted by the dense mobility of people. Therefore, a WIFI-based system might not be suitable in this context as the WIFI signal strength is sensitive to the medium density change caused by people movement.

When we narrow down the research interest to detect whether certain devices are in the area around the central surgical table in the OR in order to provide input information about the surgical stages, it comes to the choice of proximity detection. In this case, short-distance detection techniques based on the CoO principle can be considered as possible options for the OR environment. These include RFID, infrared and Bluetooth. The major drawback of RFID would be the potential problem of EMI, making it less convincing to deploy this technique in the OR. On the other hand, the Bluetooth-based systems might not be working so well in the OR, where Bluetooth compatible mobile devices are not readily available. Infrared-based localization systems can be a possible solution, considering its features such as safety, low-cost and independency. Our goal for the future work can be concluded as further investigating the feasibility of deploying infrared-based indoor positioning systems in the OR. Inevitably during our research, a lot of problems need to be solved. For instance, despite its several advantages, the fact that infrared couldn't penetrate opaque object would still pose a new challenge in the research, when some of our concerned devices or people may be blocked from the infrared signal by other devices or people in between. Further research work needs to be done to provide better insights towards similar problems.

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Appendix B: Simulation Data

B.1 Simulation of Random Walking with Fixed Context No.1

1) Anesthetist

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	8.01%	6.78%	100%	98.92%	57.48%	93.88%	21.62%
Zone 2	12.40%	8.81%	99.87%	96.85%	63.33%	91.41%	33.02%
Zone 3	17.49%	11.89%	100%	97.94%	68.14%	92.35%	38.59%
Zone 4	16.17%	13.45%	100%	100%	72.34%	91.16%	37.26%
Zone 5	9.52%	11.68%	100%	99.24%	57.55%	92.56%	18.82%
Zone 6	17.28%	11.95%	99.88%	97.39%	67.60%	90.78%	36.60%
Zone 7	16.54%	11.73%	100%	97.79%	63.95%	91.63%	34.89%
Zone 8	13.17%	8.86%	100%	97.39%	63.42%	90.94%	31.89%
Zone 9	14.63%	11.64%	100%	98.31%	68.51%	92.90%	37.42%

2) Nurse 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	36.84%	10.79%	99.92%	93.16%	34.94%	93.09%	34.61%
Zone 2	37.28%	9.72%	100%	92.43%	31.13%	91.14%	31.66%
Zone 3	51.52%	21.45%	100%	92.29%	45.79%	92.39%	48.25%
Zone 4	34.72%	8.03%	100%	92.06%	36.40%	92.20%	36.24%
Zone 5	50.46%	8.70%	100%	91.89%	19.46%	95%	23.62%
Zone 6	36.40%	8.99%	99.90%	92.78%	34.45%	93.57%	35.38%
Zone 7	42.34%	9.64%	99.84%	92.09%	36.19%	89.12%	35.87%
Zone 8	46.64%	16.50%	100%	94.43%	43.15%	93.45%	43.22%
Zone 9	44.33%	11.67%	100%	94.34%	33.91%	91.85%	33.26%

3) Nurse 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	43.59%	11.04%	100%	97.93%	67.14%	88.44%	68.97%
Zone 2	56.36%	18.09%	100%	99.43%	75.21%	93.58%	76.15%
Zone 3	42.52%	13.69%	100%	99.17%	55.96%	92.51%	55.25%
Zone 4	37.24%	8.97%	100%	99.14%	63.78%	93.14%	63.37%
Zone 5	61.54%	11.11%	100%	99.18%	65.28%	92.37%	63.90%
Zone 6	45.69%	14.39%	100%	97.93%	71.60%	92.46%	72.29%
Zone 7	45.63%	15.30%	100%	98.59%	62.68%	95.97%	65.92%
Zone 8	39.06%	9.63%	100%	98.70%	66.03%	93.70%	65.38%
Zone 9	40.29%	11.42%	100%	99.06%	67.89%	91.97%	67.83%

4) Surgeon 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	34.41%	12.73%	99.86%	96.26%	23.90%	99.30%	56.81%
Zone 2	42.47%	14.72%	99.92%	92.62%	40.03%	97.79%	68.36%
Zone 3	43.98%	16.44%	99.88%	93.13%	33.87%	99.07%	64.22%
Zone 4	33.86%	11.15%	99.91%	95.59%	26.27%	98.53%	58.72%
Zone 5	36.66%	12.79%	99.84%	94.07%	23.04%	99.12%	58.86%
Zone 6	38.66%	12.97%	99.95%	93.50%	36.38%	98.28%	63.22%
Zone 7	37.15%	14.42%	99.89%	93.94%	29.93%	99.30%	61.29%
Zone 8	40.74%	12.94%	99.77%	94.63%	36.57%	98.89%	66.31%
Zone 9	44.42%	15.07%	99.91%	94.97%	35.19%	99.03%	68.18%

5) Surgeon 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	16.16%	21.88%	100%	93.88%	30.06%	93.51%	27.46%
Zone 2	12.83%	14.85%	100%	92.16%	32.07%	92.65%	31.62%
Zone 3	15.56%	21.84%	100%	92.97%	34.51%	94.02%	34.24%
Zone 4	17.08%	14.12%	100%	91.70%	44.76%	92.18%	46.40%
Zone 5	12.50%	34.13%	100%	91.18%	20.55%	94.73%	20.83%
Zone 6	17.27%	13.15%	99.94%	91.33%	39.22%	93.21%	39.36%
Zone 7	32.76%	14.81%	100%	98.46%	55.92%	86.89%	50.96%
Zone 8	14.81%	17.19%	100%	92.20%	31.44%	92.96%	31.63%
Zone 9	13.95%	15.64%	100%	94.17%	37.23%	92.79%	37.20%

B.2 Simulation of Random Walking with Fixed Context No.2

1) Anesthetist

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	15.04%	12.35%	99.85%	99.07%	68.76%	93.76%	37.02%
Zone 2	15.22%	11.03%	99.82%	97.61%	75.85%	92.76%	35.51%
Zone 3	15.29%	12.38%	99.75%	98.56%	63.16%	93.24%	32.43%
Zone 4	15.76%	10.70%	99.73%	98.71%	67.50%	93.34%	34.57%
Zone 5	13.50%	19.23%	100%	99.40%	59.04%	92.99%	22.17%
Zone 6	17.00%	11.60%	99.94%	98.24%	66.68%	93.35%	35.18%
Zone 7	13.87%	10.87%	99.69%	98.45%	66.84%	93.05%	35.36%
Zone 8	15.58%	10.76%	99.71%	98.95%	67.53%	93.51%	32.36%
Zone 9	13.43%	10.04%	99.81%	98.60%	66.64%	93.12%	32.67%

2) Nurse 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	49.99%	14.11%	99.96%	93.48%	38.52%	93.47%	38.05%
Zone 2	45.98%	11.28%	99.87%	93.76%	35.12%	93.47%	34.86%
Zone 3	49.03%	15.60%	99.77%	93.09%	35.72%	93.38%	36.16%
Zone 4	31.20%	8.33%	99.91%	94.84%	28.90%	94.81%	28.99%
Zone 5	60.92%	13.03%	100%	93.37%	21.33%	94.14%	19.79%
Zone 6	44.29%	11.90%	99.84%	92.54%	34.71%	93.80%	35.08%
Zone 7	47.53%	14.90%	99.94%	93.09%	38.51%	92.75%	39.50%
Zone 8	41.42%	8.05%	99.93%	93.89%	28.46%	92.00%	29.20%
Zone 9	46.00%	12.97%	99.73%	93.46%	36.75%	92.61%	36.81%

3) Nurse 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	48.26%	14.62%	100%	98.74%	71.32%	93.42%	70.83%
Zone 2	43.68%	11.86%	100%	98.43%	67.12%	92.66%	66.61%
Zone 3	46.72%	12.14%	100%	99.00%	59.55%	93.51%	59.92%
Zone 4	46.47%	11.72%	99.95%	98.40%	69.27%	93.67%	69.52%
Zone 5	68.03%	18.31%	100%	99.21%	56.64%	95.94%	57.88%
Zone 6	45.63%	14.02%	100%	98.51%	69.25%	92.66%	69.23%
Zone 7	48.59%	16.20%	100%	99.04%	71.11%	92.46%	71.84%
Zone 8	46.94%	13.52%	100%	98.93%	70.63%	92.94%	69.80%
Zone 9	54.11%	12.20%	100%	99.11%	63.31%	93.64%	62.24%

4) Surgeon 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	42.59%	18.39%	99.94%	93.32%	34.40%	98.91%	67.61%
Zone 2	45.18%	18.66%	100%	92.93%	35.18%	98.35%	68.61%
Zone 3	44.33%	17.97%	99.74%	93.60%	34.34%	98.32%	64.32%
Zone 4	45.12%	18.68%	99.84%	92.63%	36.54%	98.54%	67.71%
Zone 5	57.71%	28.65%	100%	99.08%	5.70%	99.70%	59.50%
Zone 6	46.30%	19.29%	99.84%	93.59%	38.98%	98.24%	70.08%
Zone 7	49.89%	19.55%	99.91%	93.46%	42.55%	98.38%	69.97%
Zone 8	44.47%	17.56%	99.90%	93.39%	37.40%	98.24%	68.10%
Zone 9	50.11%	22.41%	99.43%	94.97%	38.45%	98.20%	72.38%

5) Surgeon 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	12.87%	18.61%	100%	100%	31.90%	93.59%	32.68%
Zone 2	15.03%	20.38%	100%	100%	37.99%	93.89%	38.06%
Zone 3	17.20%	20.07%	100%	100%	33.19%	93.76%	32.78%
Zone 4	17.30%	18.61%	100%	100%	36.78%	94.34%	36.73%
Zone 5	18.49%	32.20%	100%	100%	19.05%	92.37%	21.48%
Zone 6	15.49%	19.87%	99.77%	99.77%	34.04%	92.49%	33.11%
Zone 7	19.52%	19.68%	100%	100%	40.26%	93.29%	41.36%
Zone 8	16.81%	19.03%	99.95%	99.95%	35.49%	92.45%	35.54%
Zone 9	15.53%	20.16%	100%	100%	36.55%	93.44%	36.79%

B. 3 Simulation of Random Walking with Changed Context No.1

1) Anesthetist

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	14.12%	8.96%	100.00%	99.31%	66.48%	91.31%	32.38%
Zone 2	16.50%	12.10%	100.00%	97.98%	66.03%	91.79%	35.05%
Zone 3	19.13%	18.06%	100.00%	99.02%	70.73%	93.31%	45.51%
Zone 4	17.91%	12.14%	99.91%	99.07%	67.53%	93.45%	36.70%
Zone 5	17.01%	10.34%	100.00%	98.40%	57.38%	93.47%	19.88%
Zone 6	20.35%	8.20%	99.78%	99.18%	62.32%	94.21%	30.26%
Zone 7	12.44%	9.39%	99.93%	95.87%	63.27%	89.66%	32.07%
Zone 8	12.50%	9.82%	100.00%	97.26%	61.77%	91.67%	31.79%
Zone 9	30.95%	23.83%	100.00%	100.00%	73.43%	92.74%	58.30%

2) Nurse 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	42.15%	12.13%	100.00%	91.94%	35.94%	92.63%	34.84%
Zone 2	38.46%	11.36%	100.00%	91.76%	37.33%	93.37%	38.26%
Zone 3	30.51%	4.07%	100.00%	94.01%	22.30%	92.16%	20.73%
Zone 4	39.34%	10.96%	99.87%	93.80%	37.06%	91.66%	35.79%
Zone 5	47.46%	7.69%	100.00%	93.22%	20.25%	90.04%	21.94%
Zone 6	46.29%	14.26%	99.75%	93.88%	40.66%	92.65%	39.10%
Zone 7	35.82%	10.30%	99.93%	90.44%	33.90%	92.07%	34.22%
Zone 8	39.73%	11.32%	99.92%	92.59%	35.83%	92.71%	35.92%
Zone 9	37.81%	8.61%	100.00%	92.87%	31.98%	93.07%	32.47%

3) Nurse 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	34.83%	8.64%	100.00%	98.44%	60.43%	91.55%	65.12%
Zone 2	33.38%	6.32%	100.00%	97.71%	57.61%	90.05%	57.45%
Zone 3	45.32%	16.61%	100.00%	97.01%	70.41%	93.47%	70.83%
Zone 4	63.95%	26.91%	100.00%	97.39%	80.56%	93.49%	80.80%
Zone 5	65.93%	25.47%	100.00%	99.07%	56.28%	91.30%	58.54%
Zone 6	39.92%	12.40%	100.00%	98.90%	67.51%	92.86%	66.54%
Zone 7	38.63%	10.29%	100.00%	93.29%	64.93%	90.41%	64.29%
Zone 8	38.20%	9.38%	100.00%	98.37%	66.13%	92.33%	65.83%
Zone 9	39.05%	9.58%	100.00%	98.84%	66.23%	92.65%	65.60%

4) Surgeon 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	42.00%	14.79%	99.94%	91.87%	42.91%	97.95%	97.95%
Zone 2	39.03%	12.78%	100.00%	91.97%	40.84%	98.07%	98.07%
Zone 3	37.94%	12.19%	99.94%	93.08%	35.42%	98.87%	98.87%
Zone 4	35.66%	13.67%	100.00%	92.91%	35.81%	98.98%	98.98%
Zone 5	63.20%	34.75%	100.00%	95.40%	22.91%	98.74%	98.74%
Zone 6	41.25%	12.43%	99.88%	93.91%	37.60%	98.88%	98.88%
Zone 7	38.42%	13.72%	100.00%	90.24%	29.71%	92.71%	92.71%
Zone 8	32.73%	11.76%	99.72%	92.40%	28.70%	98.92%	98.92%
Zone 9	39.69%	12.54%	100.00%	93.28%	38.64%	97.98%	97.98%

5) Surgeon 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	16.59%	15.03%	99.95%	92.85%	39.59%	94.12%	39.39%
Zone 2	19.30%	13.19%	100.00%	91.23%	38.79%	93.41%	39.38%
Zone 3	17.82%	14.59%	100.00%	93.91%	45.06%	92.19%	44.73%
Zone 4	10.64%	12.38%	100.00%	91.67%	24.30%	93.43%	24.04%
Zone 5	8.60%	29.59%	100.00%	94.37%	18.41%	90.65%	17.29%
Zone 6	14.98%	15.10%	100.00%	91.95%	35.57%	94.82%	36.72%
Zone 7	13.18%	10.33%	100.00%	83.00%	34.96%	89.37%	34.07%
Zone 8	15.14%	11.73%	99.88%	91.78%	37.27%	93.10%	36.70%
Zone 9	16.61%	11.31%	100.00%	92.94%	33.91%	95.79%	34.18%

B. 4 Simulation of Random Walking with Changed Context No.2

1) Anesthetist

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	15.15%	10.22%	99.97%	98.58%	64.99%	92.16%	33.65%
Zone 2	12.56%	8.37%	99.77%	98.76%	64.89%	94.05%	27.13%
Zone 3	17.90%	17.58%	100%	98.54%	66.87%	93.44%	43.39%
Zone 4	14.32%	9.93%	99.91%	98.44%	66.28%	92.46%	33.73%
Zone 5	13.74%	12.77%	100%	99.17%	60.03%	90.61%	21.16%
Zone 6	24.70%	16.35%	100%	98.93%	70.28%	93.47%	46.36%
Zone 7	15.55%	11.53%	99.95%	94.77%	66.65%	89.52%	33.00%
Zone 8	14.94%	10.95%	99.87%	99.18%	68.62%	93.39%	36.52%
Zone 9	15.69%	9.30%	99.96%	98.95%	63.90%	93.23%	35.39%

2) Nurse 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	40.11%	13.10%	99.95%	91.98%	37.77%	92.39%	37.91%
Zone 2	34.98%	8.63%	100%	93.22%	26.82%	91.35%	27.83%
Zone 3	46.16%	17.18%	99.81%	94.78%	50.14%	93.48%	50.39%
Zone 4	38.18%	10.86%	100%	93.09%	35.15%	92.30%	34.77%
Zone 5	54.43%	15.99%	100%	94.26%	22.25%	92.22%	21.43%
Zone 6	42.62%	12.89%	99.94%	91.80%	40.09%	92.86%	40.07%
Zone 7	43.20%	11.94%	100%	86.02%	34.71%	91.11%	34.89%
Zone 8	41.37%	12.12%	99.96%	92.51%	35.46%	92.82%	36.14%
Zone 9	40.01%	11.84%	99.94%	92.43%	36.96%	92.91%	37.80%

3) Nurse 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	14.74%	1.49%	100%	99.64%	38.11%	98.09%	38.17%
Zone 2	14.13%	0.81%	100%	99.75%	35.64%	98.11%	35.30%
Zone 3	14.71%	0.95%	100%	99.66%	34.70%	98.03%	33.61%
Zone 4	15.18%	1.06%	100.00%	99.71%	38.29%	97.96%	38.26%
Zone 5	13.64%	0.46%	100%	99.75%	35.00%	98.09%	34.28%
Zone 6	16.14%	1.85%	100%	99.66%	37.49%	97.60%	36.18%
Zone 7	14.87%	0.69%	99.99%	99.59%	37.53%	97.76%	37.37%
Zone 8	15.87%	1.48%	100.00%	99.68%	38.60%	97.70%	37.93%
Zone 9	15.42%	0.88%	100%	99.62%	35.41%	97.70%	34.01%

4) Surgeon 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	10.09%	1.23%	100.00%	99.59%	5.51%	99.93%	29.97%
Zone 2	10.76%	1.49%	100.00%	99.49%	6.43%	99.93%	31.50%
Zone 3	9.95%	1.07%	100.00%	99.61%	4.45%	99.96%	29.05%
Zone 4	11.11%	1.63%	99.99%	99.34%	7.69%	99.90%	31.90%
Zone 5	9.68%	1.00%	100.00%	99.62%	4.61%	99.96%	28.92%
Zone 6	10.67%	1.38%	100%	99.35%	5.27%	99.88%	30.29%
Zone 7	10.65%	1.39%	100.00%	99.13%	7.17%	99.73%	31.12%
Zone 8	11.29%	1.65%	99.99%	99.27%	8.08%	99.90%	32.22%
Zone 9	10.91%	1.54%	99.99%	99.40%	7.27%	99.91%	31.88%

5) Surgeon 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	15.20%	13.60%	100%	92.67%	36.10%	92.21%	35.55%
Zone 2	16.37%	14.15%	100%	92.53%	39.78%	91.16%	39.62%
Zone 3	14.43%	14.11%	100%	92.32%	32.28%	92.82%	32.51%
Zone 4	13.69%	12.79%	100%	91.97%	33.83%	92.93%	34.04%
Zone 5	18.52%	35.64%	100%	94.85%	16.57%	90.51%	21.21%
Zone 6	13.12%	15.23%	100%	93.94%	31.39%	90.72%	31.74%
Zone 7	14.79%	15.74%	100%	87.86%	32.98%	89.89%	32.29%
Zone 8	13.85%	15.99%	100%	92.90%	34.05%	90.39%	36.10%
Zone 9	13.77%	15.44%	100%	92.33%	31.88%	91.04%	23.12%

B.5 Simulation of Umbilical Hernia Repair (Results Averaged Over 20 Simulations)

1) Anesthetist

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	0%	0%	0%	0%	0%	0%	0%
Zone 2	37%	21%	100%	86%	39%	78%	27%
Zone 3	28%	13%	100%	99%	55%	84%	24%
Zone 4	0%	0%	0%	0%	0%	0%	0%
Zone 5	6%	39%	0%	99%	16%	98%	12%
Zone 6	21%	13%	100%	100%	27%	96%	38%
Zone 7	0%	0%	0%	0%	0%	0%	0%
Zone 8	0%	0%	0%	0%	0%	0%	0%
Zone 9	0%	0%	0%	0%	0%	0%	0%

2) Nurse 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	15%	5%	100%	86%	36%	83%	32%
Zone 2	18%	9%	100%	97%	13%	95%	28%
Zone 3	41%	17%	100%	89%	21%	89%	27%
Zone 4	36%	16%	100%	91%	29%	86%	30%
Zone 5	17%	64%	100%	99%	29%	97%	21%
Zone 6	32%	7%	100%	90%	28%	95%	26%
Zone 7	44%	20%	100%	86%	38%	91%	37%
Zone 8	44%	6%	100%	94%	14%	90%	28%
Zone 9	0%	0%	0%	0%	0%	0%	0%

3) Nurse 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	22%	6%	100%	99%	99%	95%	30%
Zone 2	21%	11%	100%	98%	98%	94%	23%
Zone 3	24%	9%	100%	95%	95%	84%	39%
Zone 4	29%	15%	100%	98%	98%	91%	36%
Zone 5	25%	60%	100%	100%	100%	99%	40%
Zone 6	52%	12%	100%	98%	98%	91%	58%
Zone 7	43%	24%	100%	98%	98%	89%	58%
Zone 8	38%	23%	100%	100%	100%	70%	63%
Zone 9	43%	8%	100%	100%	100%	76%	61%

4) Surgeon 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	21%	12%	100%	92%	28%	97%	97%
Zone 2	53%	44%	100%	95%	60%	96%	96%
Zone 3	0%	0%	0%	0%	0%	0%	0%
Zone 4	41%	15%	100%	87%	30%	98%	98%
Zone 5	20%	77%	100%	97%	35%	98%	98%
Zone 6	0%	0%	0%	0%	0%	0%	0%
Zone 7	36%	7%	100%	95%	37%	98%	98%
Zone 8	34%	16%	100%	90%	32%	97%	97%
Zone 9	0%	0%	0%	0%	0%	0%	0%

5) Surgeon 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	12%	18%	100%	93%	30%	95%	26%
Zone 2	17%	3%	100%	97%	37%	96%	21%
Zone 3	0%	0%	0%	0%	0%	0%	0%
Zone 4	11%	5%	100%	84%	34%	87%	34%
Zone 5	28%	85%	100%	100%	43%	99%	39%
Zone 6	0%	0%	0%	0%	0%	0%	0%
Zone 7	0%	0%	0%	0%	0%	0%	0%
Zone 8	0%	0%	0%	0%	0%	0%	0%
Zone 9	0%	0%	0%	0%	0%	0%	0%

B.6 Simulation of Laparoscopic Cholecystectomy (Results Averaged Over 20 Simulations)

1) Anesthetist

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	0%	0%	0%	0%	0%	0%	0%
Zone 2	16%	39%	99%	99%	62%	89%	46%
Zone 3	19%	23%	100%	99%	54%	87%	40%
Zone 4	0%	0%	0%	0%	0%	0%	0%
Zone 5	53%	15%	0%	99%	16%	88%	15%
Zone 6	13%	8%	100%	100%	22%	97%	20%
Zone 7	0%	0%	0%	0%	0%	0%	0%
Zone 8	0%	0%	0%	0%	0%	0%	0%
Zone 9	0%	0%	0%	0%	29%	100%	45%

2) Nurse 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	35%	7%	100%	87%	33%	91%	40%
Zone 2	23%	6%	99%	95%	23%	92%	23%
Zone 3	70%	0%	100%	76%	59%	100%	57%
Zone 4	39%	15%	100%	86%	32%	89%	29%
Zone 5	15%	70%	100%	99%	37%	99%	40%
Zone 6	64%	49%	100%	81%	60%	76%	61%
Zone 7	33%	13%	100%	84%	50%	83%	39%
Zone 8	64%	4%	100%	87%	34%	87%	30%
Zone 9	0%	0%	0%	0%	0%	0%	0%

3) Nurse 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	27%	8%	100%	99%	35%	96%	34%
Zone 2	23%	9%	100%	96%	25%	84%	26%
Zone 3	36%	8%	100%	97%	52%	90%	57%
Zone 4	21%	8%	100%	98%	30%	98%	25%
Zone 5	46%	60%	100%	99%	25%	0%	27%
Zone 6	0%	0%	0%	0%	0%	88%	0%
Zone 7	28%	9%	100%	99%	41%	96%	45%
Zone 8	29%	23%	100%	93%	36%	0%	35%
Zone 9	0%	0%	0%	0%	0%	96%	0%

4) Surgeon 1

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	13%	7%	100%	95%	21%	94%	24%
Zone 2	28%	16%	100%	88%	21%	96%	38%
Zone 3	0%	0%	0%	0%	0%	0%	0%
Zone 4	52%	7%	100%	86%	31%	99%	65%
Zone 5	38%	72%	100%	100%	24%	99%	24%
Zone 6	0%	0%	0%	0%	0%	0%	0%
Zone 7	0%	0%	0%	0%	0%	0%	0%
Zone 8	0%	0%	0%	0%	0%	0%	0%
Zone 9	0%	0%	0%	0%	0%	0%	0%

5) Surgeon 2

Detection Rate	Back	Chest	Head	Left Arm	Left Leg	Right Arm	Right Leg
Zone 1	11%	8%	100%	97%	19%	94%	19%
Zone 2	20%	26%	100%	82%	40%	87%	48%
Zone 3	0%	0%	0%	0%	0%	0%	0%
Zone 4	19%	22%	100%	87%	40%	85%	40%
Zone 5	34%	82%	100%	99%	23%	100%	25%
Zone 6	0%	0%	0%	0%	0%	0%	0%
Zone 7	0%	0%	0%	0%	0%	0%	0%
Zone 8	0%	0%	0%	0%	0%	0%	0%
Zone 9	0%	0%	0%	0%	0%	0%	0%