Testing a proximity-based location tracking system with Bluetooth Low Energy tags for future use in the OR

Gel Han*, Gudrun J. Klinker†
Technische Universität München
Boltzmannstraße 3
D-85748 Garching b. München
Email: *hang@in.tum.de, †klinker@in.tum.de

Daniel Ostler‡, Armin Schneider§
Forschungsgruppe MITI, Klinikum r. d. Isar
Technische Universität München
Trogerstr. 26
D-81675 München
Email: ‡daniel.ostler@tum.de, §armin.schneider@tum.de

***Abstract*—Location tracking systems have become popular in recent years and have been in use in many areas such as logistics, transportation and medicine. In healthcare, various companies have been offering real time location system solutions to hospitals with great success. These systems are used for asset management, workflow improvement as well as patient and staff tracking. For test runs we decided on a low-cost location tracking system based on proximity detection and the technology Bluetooth Low Energy. The system was developed for the use in OR environments which comes with specific requirements. The goal of this work is to evaluate if people with Bluetooth Low Energy tags are reliably tracked and detected. These tests were conducted in the first stages of a development phase to see, how the tracking system behaved in a controlled office environment. Problems such as the inactivity of the tag and random changes into other nearby rooms because of multipath effects arise and are discussed.**

***Keywords*—Workflow, Tags, Anchors, RTLS, Location Tracking, Location, Proximity, Detection, Bluetooth, Bluetooth Low Energy, Received Signal Strength, RSSI, Threshold, Tracking.**

I. Introduction

Recently, with growing markets and huge potential predicted, location tracking systems have become more important in hospitals to support the medical staff with tasks such as patient tracking and asset management. Companies such as *CenTrak*[1] or *Ekahau*[2] have successfully deployed systems in many hospitals with a return on investment (ROI) of five to six digit figures and more (an example for calculating the ROI of a hospital is given in [1]). Figures like these prove the immediate as well as fast savings in money and time because of efficient tracking and finding of equipment or people. On the downside, ROI may be big but most systems available on the market are initially very expensive to deploy and also to maintain over the years. In this work, we want to evaluate a proximity-based location tracking system for the use in the OR. It was developed on a simple, low-cost basis with modern technology and with specific requirements in mind. A few of these requirements are stated in the next chapter. For the first test phase, the goal was to constantly track users (medical staff members) whenever they are in rooms with an active location tracking system installed. For now, we are satisfied in knowing the current location of the test users with room accuracy (see [2] for the definition of room accuracy). Assume that the location engine, which is responsible for calculating the locations of the users, knows which staff members have to be in which operating room through, for example, an online schedule. One possible way to use the application with tags could be in form of a notification which is automatically sent to staff members whenever they are needed for an operation in a certain operating room. This could help reduce waiting time between the operations and could accelerate the schedule and patient throughput.

[1]http://www.centrak.com/
[2]http://www.ekahau.com/

II. Related work

[3] mention in their work that, to avoid waiting time and decrease the percentage of patients left without been seen (LWBS), a real time location system (RTLS) by the company *Awarepoint*[3] was deployed in the Wilmington hospital to support the staff members in workflow and asset management as well as patient tracking. An interesting aspect here is that the installed RTLS is only tracking patients and the medical staff members in selected areas. For example, restrooms or break areas are left out and do not have any devices installed for tracking. With more than 400 sensors for location tracking deployed, the throughput of low-, medium- as well as high-acuity patients has dropped significantly over the years.

[4] state that the most common use cases of RTLS in hospitals are tracking patients (most commonly Alzheimer's and dementia patients) and alarming the medical staff if their patients left or entered certain areas and also for improving patient throughput. RTLS helps in finding and analyzing bottlenecks to optimize the workflow process. If, for example, all patients would wear tags, data about them such as health records could be easily accessed across different departments of the hospital. There are also 68 different medical devices to track in the various departments. By supporting the medical staff

[3]http://www.awarepoint.com/

with automated tasks or processes and providing them with information such as a certain device's location, the members can now spend time more productively.

According to [5], RTLS applications can be categorized into asset tracking, workflow improvement and patient as well as staff tracking. Furthermore, they are saying that many requirements regarding the use of a location tracking system need to be fulfilled and that preparations for the right way in usage are extensive. Only by considering these aspects, expectations of such a system can be met and consequently lead to a satisfying performance of the RTLS. Hybrid technologies consisting of, for example, Infrared and WiFi are also pointed out to be more reliable.

There are a lot of different technologies which can be used for location tracking in hospitals. A wide variety is listed in [6] and a brief comparison between the technologies with their advantages/disadvantages in the criteria accuracy, scalability or costs are also listed. While there are certain risks and problems with an RTLS, overall the advantages outweigh the disadvantages [7] with the market size and growth potential being high for the healthcare sector.

The so called *time-out*, a procedure done in the operating room to reduce safety and security risks such as operating the wrong patient or performing the wrong procedure on the patient, has been implemented in many hospitals worldwide [8]. During the time-out, all medical staff members communicate actively to sort out all the details before the operation starts. Normally, the time-out is done before any invasive procedures and is started and documented by one of the participating staff members with checklists. Three of the most important issues to check for the time-out according to [9], are:

- **Checking the patient ID:** Do we have the right patient here?
- **Checking the procedure:** Is that the right procedure we are going to perform on this patient?
- **Checking the site:** Is this the right site/OR for this operation?

These are the basic and most common questions asked and documented in a time-out for each operation. Since the amount to document is vastly increasing, it is more efficient to do these things digitally, and even with assists of an RTLS [10].

III. Material and methods

A location tracking system mainly consists of three components:

- **The tag:** These components are small in their form factor, light-weighted and send out signals in a periodic time interval transmitting information which can be read by the anchors.
- **The anchor:** At least one of these components is mounted stationary in each operating room where tags should be detected. The anchor scans the environment for tags and forwards the information to a location engine.
- **The location engine:** This is where all the data from the anchors is gathered and a location for each of the found tags is calculated.

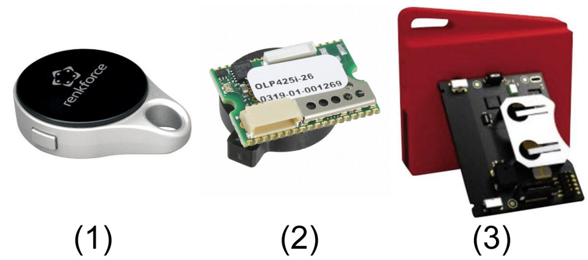

Fig. 1. From left to right: (1) the *Renkforce* Bluetooth Low Energy key chain, (2) the OLP425-tag from the company *connectBlue* and (3) the TI CC2650 SensorTag from *Texas Instruments*.

Typically, the anchors and the computer in the back-end with the installed location engine are connected. The communication between tag and anchor can happen in the following three ways: optical, radio-based and acoustic. We are using a radio-based system with the technology *Bluetooth Low Energy* (BLE). It works on the 2.4 GHz frequency band and uses channels which are not overlapping with those of either *WiFi* or *ZigBee*. The advantages of using BLE are the low battery consumption even with a few additionally built-in sensors (temperature, light etc.) and low prices for both, the anchor being around 70$ and one of the tags being 15$ (off-the-shelf, consumer product). The accuracy, the update-rate as well as the range are mediocre compared to WiFi, ZigBee or Ultra-wide-band. On a *CR2032* battery, certain BLE tags can last years without replacing the battery, thus reducing maintenance and support for the location tracking system.

As anchor, the *OBS421*-module from the company *connectBlue* is used. It can scan the environment every 1.28 seconds for tags which send out specific BLE messages, so called *advertisements*. As long as the messages are valid and conform with the Bluetooth 4.0 specifications for Low Energy [11], every module sending those out can be detected by the anchor (see figure 1 for three BLE tags). We chose to test the system with tags from the brand *Renkforce*. They are offering key chains with built-in BLE modules and a battery holder for CR2025 batteries. When the anchor scans for tags, we receive parameters such as the MAC address of the tag (which serves as their unique identification) and its measured signal strength value. All the parameters are forwarded to the location engine, where depending on the signal strength, the detected tags can be considered as far away (low signal strength value) or nearby (higher signal strength value).

Since the already developed location tracking system is based on the proximity-principle, we are only interested in finding out, in which room a tag is currently located. For testing purposes, we installed anchors in two rooms, one in each and we created three virtual rooms for the location engine: no room, room 1 and room 2. All the data was logged into a database on the location engine computer. There were two test users wearing BLE tags for three days. The location,

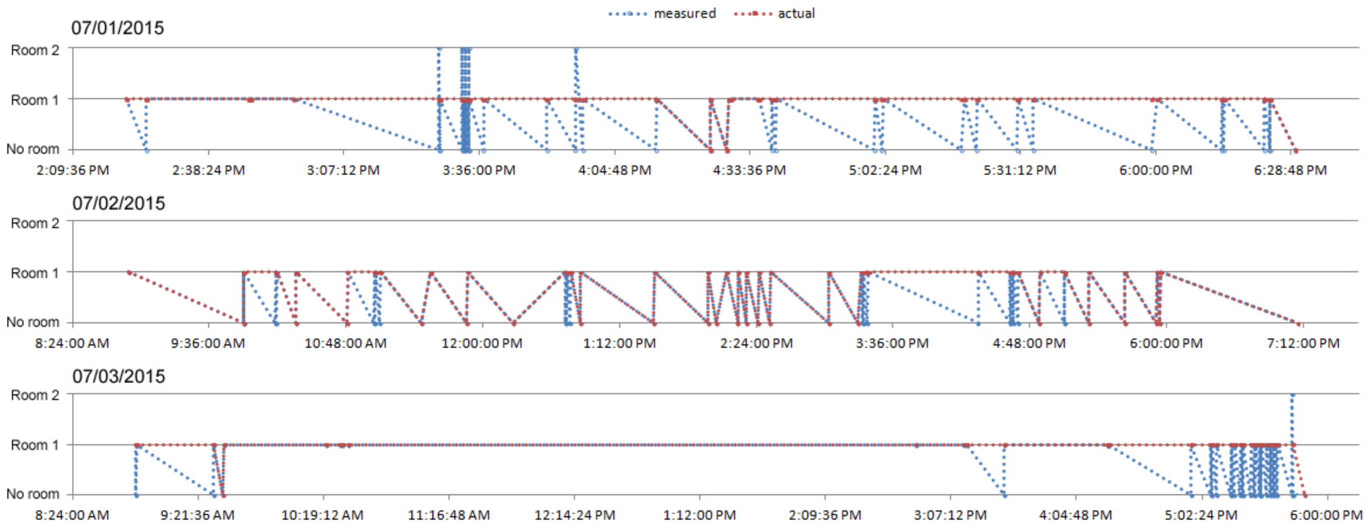

Fig. 2. Measured data from test user 1 during three days (07/01 to 07/03). The blue dotted line depicts the rooms where the tag was detected while the red dotted line represents the actual room the test user was in. The y-axis is arranged as follows: 0 - no room; 1 - room 1; 2 - room 2. The x-axis represents the time, where measurements of the tag were made and saved in the database.

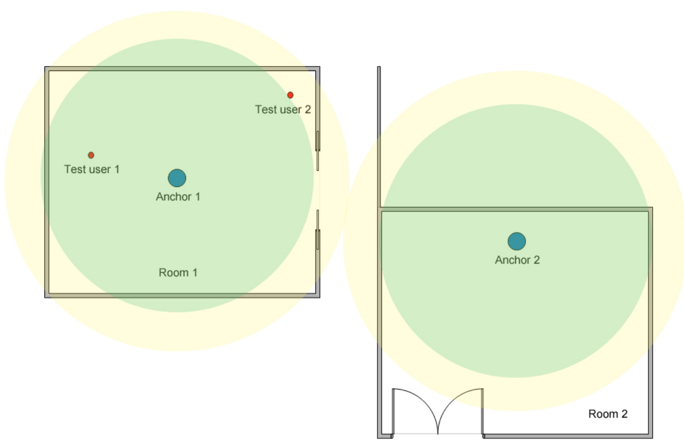

Fig. 3. The setup from the top view with test user 1 and 2 working in room 1 most of the time. The borders of the yellow and green circles around the anchors represent the areas where the tags can enter or leave a room.

where both users were working, differed for all three days. It is important to emphasize the different places (see figure 3) because the locations of the user's workspace affected the final results.

Looking at figure 3, the border of the green area represents the upper threshold to indicate that someone has entered the room. Once the current received signal strength value of one's tag surpasses the upper threshold, the location engine decides to put the user in one of the virtual rooms. If the user wanders around in the yellow area, chances are high that the signal strength value falls below the lower threshold depicted as the border of the yellow circle. Then the application removes the user from the entered room again.

The thresholds for the location tracking system in both rooms were calibrated as follows:

- Upper threshold for entering: -93 dBm
- Lower threshold for leaving: -105 dBm

Currently, the location engine uses a moving average of the last 5 signal strength values to filter and to smooth out the fluctuating signal. As with every other radio-based technology, problems because of multipath fading and shadowing are bound to happen. These problems are difficult to deal with and therefore, more and more companies are relying on combinations of two technologies to eliminate the respective disadvantages.

The *Renkforce* BLE tags are set to send out advertisements every 25 milliseconds and when inactive (not moving) for 180 seconds, they switch into a sleep mode where they stop to send out advertisements. The range of these tags is specified to 15 meters. The average life of the battery lies at around 3 months. An important function to note is that the location engine has to compensate time spans where the module might be sleeping because of inactivity. As of now, we are waiting 5 minutes to look if a tag has been inactive and we have gotten no new advertisements from it. In case we did not receive any new signals, the location engine removes the tag from its current room and puts it into the virtual "no room". Another issue is that when looking at the positions of the anchors in the two rooms, it is imaginable that tags, previously in room 1, are leaving the current room and entering room 2 when moving in the direction of the corridor.

IV. Results

The accumulated results can be seen in table I. The columns are interpreted as follows:

- **#Time:** amount of time, where measurements were made

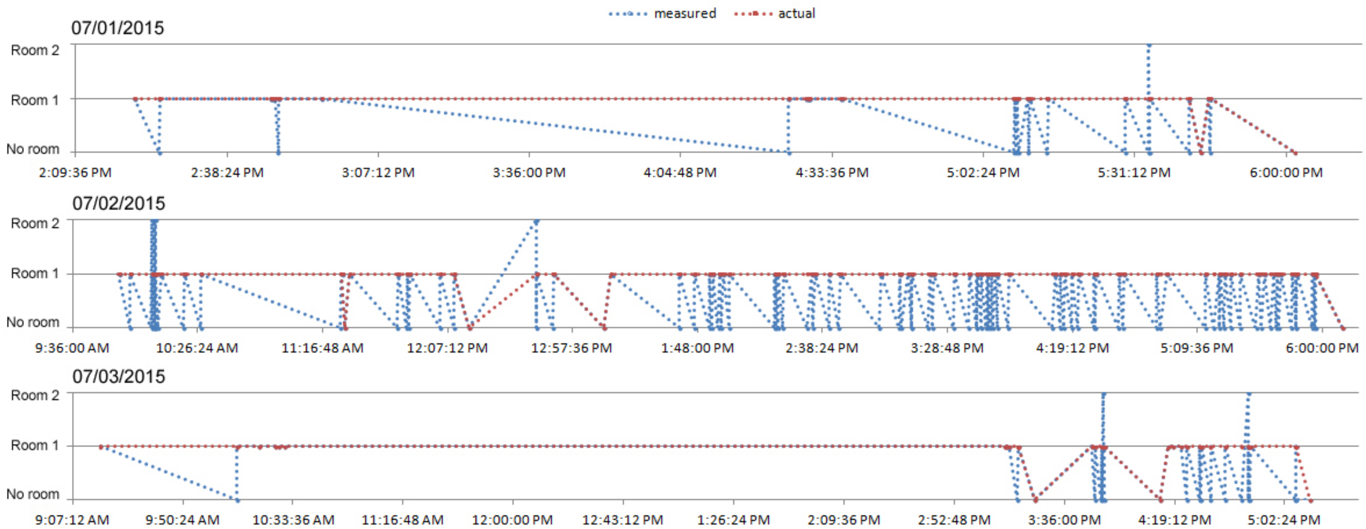

Fig. 4. Measured data from test user 2 on three days (07/01 to 07/03).

- **%Time:** the percentage of the total time where the measured and actual locations did match
- **#Message:** the amount of messages recorded during the tests
- **%Message:** the percentage of all the messages with correctly matched rooms

TABLE I
THE RESULTS FOR BOTH TEST USERS OVER THE COURSE OF THREE DAYS.

Test user	#Time	%Time	#Message	%Message
1	23h 21m	97%	229	63%
2	19h 48m	95%	257	55%

The percentage of incorrectly matched rooms for both users (time as well as messages) can be derived by simply subtracting the percentage values from 100%. For test user 1, a visual representation of all the test runs is given in figure 2, with time stamps on the x-axis and the rooms on the y-axis. Figure 4 shows the results for test user 2 for the same days. When looking at the data closely, it can be observed that the blue dotted line (the measured and calculated location) fluctuates quite a lot and differs from the actual position in many spots for both users (especially for test user 2 on the second day). This can be explained with the location where the test user was constantly working with the tag. Unlike test user 1, the second test user was sitting/standing in room 1 in close vicinity to room 2. This and multipath effects caused the tag to leave room 1 quite often. Still, looking at the total test duration and the durations in which the users were put into the right rooms, test user 1 was 97% of the time in the correct room while the percentage for test user 2 was 95%. When analyzing the test results in more detail (see table II), it can be seen that whenever tags were detected in certain rooms correctly, they stayed longer in these than when being detected in the wrong rooms. The average duration for being tracked in the correct rooms for test user 1 was 00:06:43 while the value was 00:08:10 for user 2 (all values in HH:MM:SS). When the tags were detected in the wrong rooms, the average durations were 00:01:50 and 00:00:30 respectively.

TABLE II
MAXIMUM AND MINIMUM OF THE DURATIONS WHEN TAGS WERE DETECTED IN CORRECT/INCORRECT ROOMS (IN HH:MM:SS).

Test user	Max. ✓	Min. ✓	Max. ✗	Min. ✗
1	04:20:35	00:00:01	00:27:25	00:00:01
2	04:42:06	00:00:06	00:05:34	00:00:01

V. DISCUSSION

Looking at the test setup and the results, it is not surprising to see that test user 1 got a better percentage of correctly matched rooms than user 2. With test user 2 being a borderline case in terms of position in room 1, this outcome was expected. We already mentioned that the location engine works with a timeout of 5 minutes to see if any of the tags have been inactive. If they are not detected any longer, they are removed from their current rooms. This also means that we need to subtract 5 minutes from all the data points in the figures where the tags left the rooms to acquire the correct times. Entering the rooms is still measured and displayed with a latency of maximum 10 seconds.

Since these rooms were separated through thin walls and partly no ceiling, the multipath effects are a valid explanation for the constant room changes for both users. To prevent such phenomena (and that is applicable to all radio-based technologies), it is recommended to deploy and install location tracking systems in environments which are controlled and built/designed for it. One suggestion to make it more reliable is to watch for the space between two adjacent rooms. If the space is marginal and radio waves can penetrate the walls, chances are high that the measured location of a tag shows a lot of false-positives.

Further research and tests regarding the other tags and their performance need to be done. Are they going into sleep mode faster than the *Renkforce* BLE tag? It is possible to program and change the advertisement-interval of the OLP425-tag which leads to longer battery life. It would be interesting to remove the sleep mode altogether and instead of stopping the advertisements, send them out in a lower frequency than in normal, active mode. In addition to the different tags, the location engine has to be adjusted for more thorough tests. The moving average could be modified or a completely different filtering algorithm could be used altogether.

The location tracking system has to be improved continuously until the issue of tags jumping into incorrect rooms too many times is solved. This could be also done by implementing separate algorithms to prevent the constant jumps (for example by looking at the fluctuating signal strength value).

VI. Conclusion

In this work, we evaluate if a relatively cheap location tracking system based on proximity detection and the technology Bluetooth Low Energy can be used to provide the current location of potential patients, devices or medical staff members. Using the calculated location from the location engine, we could support existing processes and procedures such as the surgical team time-out by documenting the current state in the ORs. Two users were testing the system over the course of three days and the results show that for boundary conditions, the locations become unreliable as they change too much between the rooms. Under specific requirements (test user is constantly close to one of the anchors or the environment consists of non-penetrable walls), the results were satisfactory. Nevertheless, the location tracking system needs to be improved further to make it even more reliable.

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