Simon A. McGlone, Denise Junger*, Benjamin Himpel, Oliver Burgert

# Ultra Wideband Real-Time Locating System for Tracking People and Devices in the Operating Room

Integration and Evaluation within the Research OR of Reutlingen University

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**Abstract:** Position tracking within the OR could be one possible input for intraoperative situation recognition. Our approach demonstrates a Real-time Locating System (RTLS) using the Ultra Wideband (UWB) technology to determine the position of people or objects. The UWB RTLS was integrated into the research OR at Reutlingen University and the system's settings were optimized regarding the four factors accuracy, susceptibility to interference, range, and latency. Therefore, different parameters were adapted and the effects on the factors were compared. Good tracking quality could be achieved under optimal settings. These results indicate that a UWB RTLS is well suited to determine the position of people and devices in our setting. The feasibility of the system needs to be evaluated under real OR conditions.

**Keywords:** Ultra Wideband, Real-Time Locating System, Tracking, Research OR.

## 1 Introduction

Situation recognition in the operating room (OR) is one of the emerging fields in research. Several works address the recognition of the actual surgical situation, e.g. the phase, during surgery [1]. Most of the approaches use video data for this task, some detect the instruments via electromagnetic trackers or RFID to get the position or usage. The detection of devices or people in the OR was not included in [1]. Their position could also indicate the actual surgical situation, in combination with possibly other data sources. To address this possible data source, our work shows how people and devices can be detected via a locating system.

A Real-time Locating Systems (RTLS) is used for determining the locations or positions of objects or people. Several methods exist which differ in e.g. the type of radio signal or type of calculation. Often, such systems are used with WiFi, BLE, or RFID [2]. Ultra Wideband (UWB) [3] is another possible technology that can be used for this purpose. In a first analysis considering the technical specifications of the RTLS technologies (WiFi, BLE, RFID, optical tracking, and UWB) we compared the theoretical capabilities of the respective technique. The results showed that UWB got the best rating in accuracy and coverage/range.

In this work, we show how a UWB RTLS can be used for detecting people and devices within an OR. It is identified, how the system can be optimally integrated into an OR, demonstrated and optimized concerning the best accuracy, susceptibility to interference, range, and latency for the research OR at Reutlingen University. Furthermore, it is evaluated if such a system is feasible for situation recognition.

## 2 Methods

### 2.1 Requirements analysis

Goals and requirements regarding the tracking quality and functionality of the locating system were defined. To this end, the scenario "intraoperative x-ray with a C arc" was chosen [4]. We concluded:

1. A UWB RTLS measures the positions and movements of people and devices in the OR.
2. The determination of the position of people and devices by the UWB RTLS is as precise and interference-free as possible.

The above goals were specified via functional and non-functional requirements (see chapter 3.2) defining aspects like tracking accuracy.

***Corresponding author: Denise Junger:** Reutlingen University, School of Informatics, Research Group Computer Assisted Medicine (CaMed), Reutlingen, Germany, e-mail: denise.junger@reutlingen-university.de
**Simon A. McGlone, Benjamin Himpel, Oliver Burgert:** Reutlingen University, School of Informatics, Research Group Computer Assisted Medicine (CaMed), Reutlingen, Germany

## 2.2 Hardware and setup

For position detection, the UWB RTLS "Creator Kit" of Pozyx [5] was chosen. It consists of several anchors to be placed in the room, developer tags to be attached to the objects to be detected, and a master tag for the UWB communication. Via the creator controller software, the determination of the 2D and 3D positions can be visualized in real-time. Furthermore, the orientation (pitch, yaw, roll), pressure, or acceleration can be measured but are not used in our work.

For determining the positions of the tags, Two Way Ranging (TWR) is used. Therefore, the distance of the tag to the anchors is measured via sending packets and measuring the time. This information is sent to the master tag, attached to a computer. The received position data of the tags are forwarded to the computer to be visualized in the controller software or read out via the Message Queuing Telemetry Transport (MQTT) interface.

The system was configured for the research OR at Reutlingen University with five anchors distributed evenly in the room (see Fig. 1). The distances and positions of the anchors were calibrated.


**Figure 1:** Floor map visualizing the anchors and tags in the research OR of Reutlingen University.

To determine the optimal system settings, four factors were defined: Accuracy, susceptibility to interference, range, and latency. The best settings are found when the determination of the position is as precise as possible, the susceptibility to interference and the latency are as low as possible, and the range is as high as possible.

The setup to determine the best settings is as follows: The tags were placed at three different defined positions, as depicted in Fig. 2, (line-of-sight (LOS), none-line-of-sight (NLOS) with fewer obstacles, and NLOS with more obstacles). Settings that do not influence the four defined factors (e.g. ranging protocol or filter type) were set once in the beginning. Then, different system settings were adapted, i.e. channel (bandwidth and frequency range), data bitrate, pulse repetition frequency (PRF), preamble length, and tx gain. It was expected that these five parameters affect the position accuracy.


**Figure 2:** Ground truth positions to determine the best settings for people or device tracking: (1) LOS, (2) NLOS with less obstacles, and (3) NLOS with more obstacles.

The position data of the tags were retrieved for 30sec via MQTT (see Fig. 3) and saved as a JSON text file. A Python script was used to read the data, to extract the actual coordinates and orientation of the tags, and to evaluate the measurements with respect to the four defined factors.

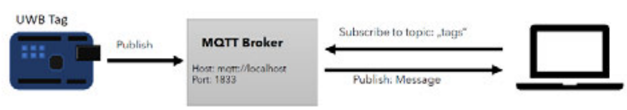


**Figure 3:** Publish-subscribe architecture of the MQTT protocol based on [6].

The accuracy was evaluated by comparing the ground truth of the position with the measured position of the UWB RTLS (median over the measurement time of 30sec). The susceptibility to interference is defined by the JSON field "success" and measured as a percentage value over the measurement time. If the field was not set to "success" the tag position could not be determined. The range was evaluated by shifting one tag as far away from the anchors (out of the OR, see arrow in Fig. 2) as possible, determining the last position before the connection gets lost (average of 10 trials). The latency is retrieved by the JSON field "latency", depicting the duration till position determination, and is defined as the median of all measures over the measurement time.

For functional evaluation, acceptance criteria were defined for the functional and non-functional requirements, assessable as "pass" or "fail". To evaluate the functional requirements, the developer rated the behavior of the system.

To check the non-functional requirements, the measurements of the optimal settings were used.

# 3 Results

## 3.1 Integration and best settings

The initial setting of the UWB RTLS was as follows:

- Algorithm: UWB Only
- Dimension: 2D
- Ranging Protocol: Precision
- Filter Type: None
- Filter Strength: 4
- Sensor Data: Coordinated, Orientation

The channel, data bitrate, PRF, preamble length, and tx gain were changed to cover different settings. The selection of the channel affects the susceptibility to interference, range, and accuracy. Channel 3 performs the best in all categories. Therefore, this channel was defined as optimal for the research OR.

The data bitrate influences the range and latency. To get a good balance between negative and positive effects caused by lower or higher rates, a data bitrate of 850 kbps was chosen.

The PRF affects the accuracy, susceptibility to interference, and range. As the system performs better with 64 MHz than 16 MHz, 64 MHz was defined as optimal.

The preamble length affects the range and latency, as well as has a minor impact on the accuracy and susceptibility to interference. Although a length of 1024 shows marginally worse results on the range, it seems to be the best choice for latency to get a good balance between negative and positive effects.

The setting of the tx gain influences mostly the range and indirectly the susceptibility to interference. A tx gain of 22 dB covers the OR, surrounding rooms incl. washroom, and partly the corridor in front of the OR. Because of using channel 3, the default value for the tx gain is 14,5 dB and therefore optimal for our setting.

In conclusion, the optimal setting for the UWB RTLS was determined as follows:

- Channel: 3 (4243,2 - 4742,4 MHz (bandwidth: 499 MHz))
- Data bitrate: 850 kbps
- PRF: 64 MHz
- Preamble length: 1024
- Tx gain: 14,5 dB

## 3.2 Functional evaluation

Except for two requirements, namely local processing only and independence of the internet, all requirements could be passed successfully, as shown in Tab. 1. The failed two criteria were due to the Creator Kit which needs to have a connection to the Pozyx cloud and therefore cannot be used offline or without an external server of the vendor.

**Table 1:** Evaluation results of the functional (F) and non-functional (N) requirements.

| Req. | Acceptance criteria | Res. |
|---|---|---|
| /F01/ | Continuous determination of the position. | Pass |
| /F02/ | Determination of the position for at least three tags at the same time. | Pass |
| /F03/ | Automatical continuation of the determination after temporary disconnection. | Pass |
| /F04/ | Position data can be accessed via an interface. | Pass |
| /F05/ | All data were processed locally. | Fail |
| /F06/ | The system can be used without the internet. | Fail |
| /N01/ | Ground truth deviation of 30cm or less for LOS. | Pass |
| /N02/ | Ground truth deviation of 150cm or less for NLOS. | Pass |
| /N03/ | Latency of 1000ms or less. | Pass |
| /N04/ | Tracking area of 49m² or more. | Pass |
| /N05/ | Actualization of the position at least one time per sec. | Pass |

# 4 Discussion

Under optimal conditions, the UWB RTLS can determine the tag position to within a few centimeters (under LOS conditions the deviation from ground truth was less than 130mm). The tag position measurements should ideally be smoothed out via a moving average or moving median filter to increase system stability and accuracy. Using a filter will also prevent jittering and reduce the impact of outlier measurements. Even through obstacles, such as walls, the tracking still shows good results. The susceptibility to interference of the system is low, but interference occurs when the tag is too far away or there are too many obstacles. The number of disturbances does not increase linearly to the distance to the anchors but occurs abruptly as soon as a tag reaches a certain distance.

The high accuracy, low susceptibility to interference, low latency, and high range are expected to not be surpassed by other technologies such as BLE localization. Tracking with UWB is accurate to within a few centimeters in most cases and even obstacles such as walls do not interrupt tracking. UWB localization is therefore well suited to enable situational awareness. In summary, our results indicate that a UWB RTLS in general, and specifically the used Creator Kit, should be well suited for a situation recognition system in the OR, at least in terms of tracking quality.

It should be noted at this point, that the optimal settings for the system were determined for the research OR of Reutlingen University. If the system should be used under other conditions, it might be useful to adapt the settings, although the evaluation of the different settings showed rarely extreme differences concerning the factors accuracy, latency, and susceptibility to interference. Especially for the use in real ORs, further requirements and studies are needed to evaluate its feasibility under these conditions, e.g. concerning strength and stability. Furthermore, it needs to be evaluated if UWB signals interfere with other devices in the OR. Additional pitfalls, that might prevent or disrupt UWB tracking in an OR setting, could be the presence of many large metallic objects such as stainless steel cabinets or trolleys. To assess the amount of possible interference by such objects, additional tests would need to be carried out.

# 5 Conclusions

We integrated and evaluated a UWB RTLS based on the Pozyx Creator Kit in the research OR at Reutlingen University. Regarding the quality requirements, the system is well suited for situation recognition (e.g. for the system of [7]) due to the very accurate tracking and little susceptibility to interference. Only two functional requirements could not be met because not all data are processed locally and the controller software needs an internet connection.

Within further development, requirements for a locating system in real ORs, like patient safety, hygiene, or data security, should be determined as well. From a technical point of view, the interference of other devices in the OR should be tested.

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