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Proceedings of the 2nd GI Expert Talk on Localization

Mathias Pelka, Grigori Goronzy, Jó Ágila Bitsch, Horst Hellbrück and Klaus Wehrle (Editors)

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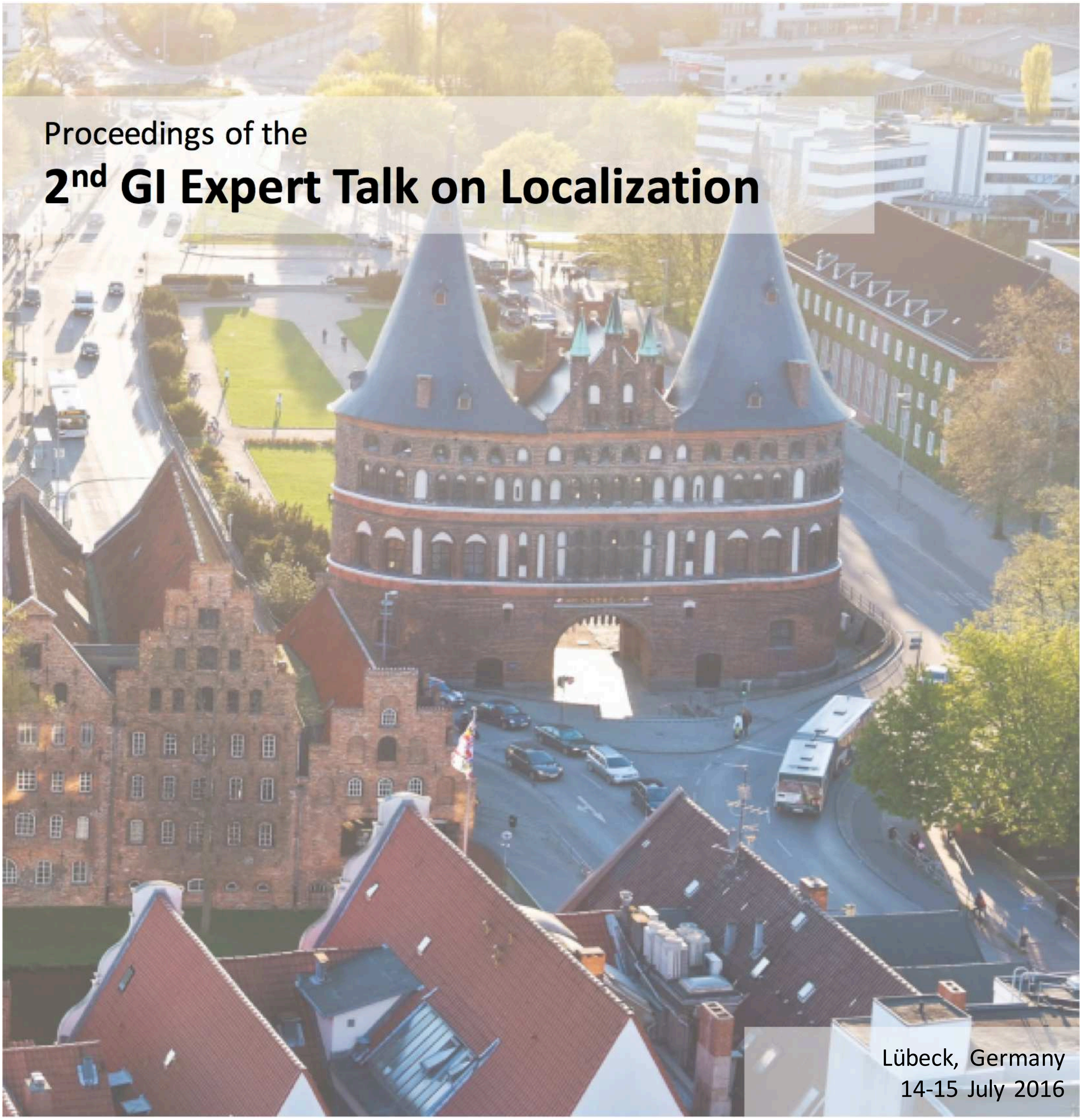

Lübeck, Germany
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Editors: Mathias Pelka, Grigori Goronzy, Jó Ágila Bitsch, Horst Hellbrück and Klaus Wehrle

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Message from the Chairs

Localization is a key technology in the field of medical, industrial and logistics applications. Especially indoor applications benefit from localization, e.g. the knowledge, where personnel is required, scarce resources are available, and goods move. Similarly, autonomous vehicles require reliable localization information for a wide range of tasks. Localization information saves time and money and can also save lives in case of emergency. However, there is no generic solution in near future that will cover all use cases and all environments.

With the 2nd Expert Talk on Localization we provide a forum for the presentation and discussion of new research and ideas in a local setting, bringing together experts and practitioners from academia and industry. As a result, a considerable amount of time is devoted to informal and moderated discussions, for instance during the extended breaks. In addition to traditional localization topics such as radio based localization, we also aim at novel technologies by encouraging submissions offering research contributions related to algorithms, stability and reliability, and applications. The high-quality program includes numerous contributions, starting with UWB range-based radio technology approaches, topological simplifications and clustering schemes, as well as automotive applications, together with visual localization approaches and fundamental limits of localization.

We thank all authors who submitted papers to this Expert Talk, and who ultimately made this program possible. We express our appreciation to Fachhochschule Lübeck for its support, CoSA Center of Excellence for the organization of the meeting, RWTH Aachen University for their additional help as well as GI and KuVS for facilitating this event.

July 2016 M Pelka, G Goronzy, JÁ Bitsch, H Hellbrück & K Wehrle

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PerfLoc: A Comprehensive Repository of Experimental Data for Evaluation of Smartphone Indoor Localization Apps

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***Abstract*—Smartphones are an important target platform for research and development of indoor localization solutions. Due to the large diversity of smartphone hardware and OS services, making general statements about the performance of indoor localization algorithms in different environments remains very challenging. In this work we present a comprehensive repository of measurement data which can be used for indoor localization, collected with four Android phones. It contains time-stamped traces of the values of all built-in sensors that are available on these phones, along with RF signal strength data from Wi-Fi and cellular networks and GPS fixes, whenever available. The data collection took place in four different buildings and according to a diverse set of mobility scenarios. After a quality assurance step through post-analysis and validation, the collected data is made available to the R&D community through a dedicated web portal. In the near future, the same portal will also be used for remote evaluation of indoor localization apps in accordance to the ISO/IEC 18305 standard.**

I. INTRODUCTION

Location awareness is an integral function of many modern systems and Location Based Services (LBS) is a growing market with multi-billion dollar potential. Outdoors, Global Positioning System (GPS) has proven its effectiveness in a wide range of domains but it does not work inside buildings. As a result, indoor localization has attracted significant attention in research and development in recent years. Prominent usage scenarios are found in search and rescue operations, equipment and personnel tracking in hospitals and mines, and increasingly in different Internet of Things (IoT) applications. Due to the rich sensing and processing capabilities and their rapid proliferation, many of these solutions are being developed using smartphones as their main target platform. The fair evaluation of smartphone-based Localization and Tracking System (LTS), however, remains very challenging, hampering their wider adaptation. The performance of such systems is affected by a wide range of factors, such as building construction material or different mobility scenario of the node to be localized (walking, running, crawling, etc.). Despite the existence of a standardized evaluation methodology, as defined by the upcoming ISO/IEC 18305 standard, many developers of indoor localization apps lack access to hardware and testing environments necessary to cover the broad mix of conditions that their system might be exposed to. In the presented work, we aim to address this problem by (i) making available to the R&D community a rich repository of smartphone sensor data, RF signal strength data, and GPS fixes collected in accordance to the procedures outlined in the ISO/IEC 18305 standard and (ii) by developing a web portal that can be used for automated remote evaluation of indoor localization apps operating on the collected datasets.

II. DATA COLLECTION

We utilized four buildings for the data collection: an office building, two industrial shop- and warehouse-type buildings and a subterranean structure. These buildings were instrumented with more than 900 test points (further called dots) that are installed on the floors. The precise locations of these dots are known to NIST. To capture some of the diversity in available smartphone hardware like built-in sensors and RF circuitry, in our data collection we used four Android phones: LG G4 (LG), Motorola Nexus 6 (NX), OnePlus 2 (OP) and Samsung Galaxy S6 (SG). To facilitate fair comparison, we performed the measurements on all phones concurrently, wiring the devices in parallel to a mechanism for simultaneous timestamping of the measurements. Armbands were used to attach the four phones to the two arms of the test person, as shown in Figure 1.

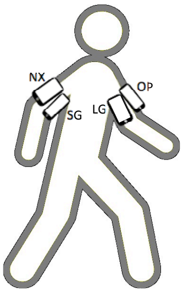

Figure 1: Positioning of the devices on the test subject's body

Two types of datasets were collected, one for training and one for testing. In addition to the timestamped data traces, the training dataset provides the ground-truth locations of the dots during a measurements run and will allow app developers to develop and configure their systems. For the testing datasets, the ground-truth locations will not be publicly provided. Instead, the developers will be asked to upload their location estimates to the PerfLoc web portal for a given time instance, and will be automatically evaluated with the help of the ground-truth data that has been held back.

A subset of the 14 Test & Evaluation (T&E) scenarios described in ISO/IEC 18305 were used because some scenarios did not apply to our data collection campaign. Including the training data, we collected data over 38 T&E runs in the four buildings.

For each scenario in each building we generated six categories of data on each smartphone: Wi-Fi, Cellular, GPS, Dots, Sensors and Metadata. This data is stored as one or more Google's Protocol Buffer Messages [http://developers.google.com/protocol-buffers] in a separate file for each data category.

1) **Wi-Fi data:** Signal strengths measured from Wi-Fi access points (APs) in range and other information provided by the APs operating at 2.4 and 5 GHz channels.
2) **Cellular data:** Identity information and signal strengths measured from cellular network signals.
3) **GPS data:** GPS location fixes.
4) **Dots:** Timestamps at dots visited during a scenario.
5) **Sensors:** Values from the built-in environmental, position, and motion sensors.
6) **Metadata:** Context information like building ID, scenario ID, device's manufacturer, model, ID, brand, etc. and initial barometer value (if the smartphone has one).

III. DATA VALIDATION

Prior to the start of our extensive data collection campaign, we took certain measures to ensure that the data we were getting from the phones was sound. These included sanity checks of the sensor data, like acceleration or gyroscope and environmental sensors. Later we checked the similarity of the measurement readings across different devices. We computed Spearman's correlation coefficient and corresponding p-values for all six pairs of devices and observed reasonably high correlation between sensor readings. The correlation across the readings from different devices are also evident from the raw data plots like the RSSI in Figure 2 or the accelerometer in Figure 3.

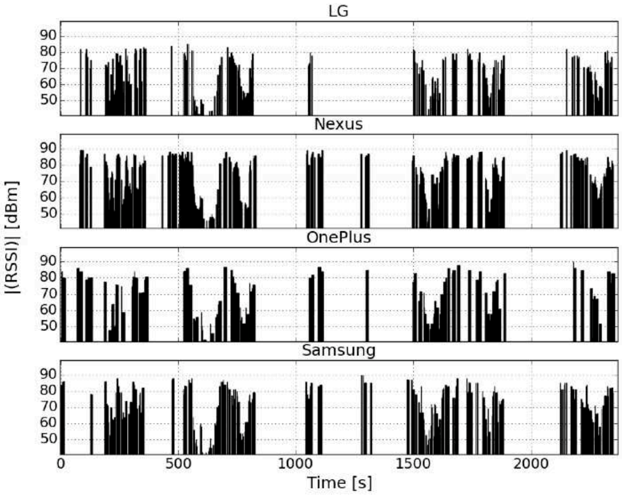

Figure 2: Wi-Fi data trace

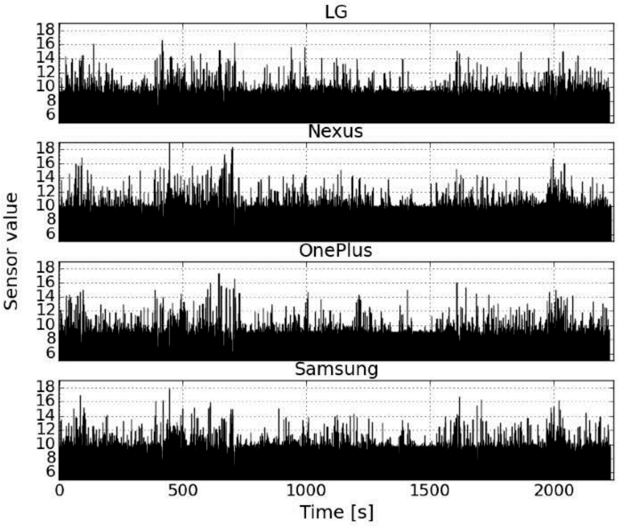

Figure 3: Accelerometer data

IV. CONCLUSIONS

This data that we have collected and are making available to the R&D world is truly unique. The dedicated resources were substantial and included instrumenting four large buildings, covering about 30,000 m^2 of space, with 900+ test points, having the locations of the test points professionally surveyed, and spending about 200 man hours on data collection using four Android phones after months of preparation. The collected data has been analyzed and we have confirmed its validity. This data will be soon made publicly available to researchers and developers across the world so it can be used in the development of smartphone-based indoor localization systems. As an ongoing work, we are developing a web portal for comprehensive automatic performance evaluation of indoor localization apps based on the ISO/IEC 18305 standard.

DISCLAIMER

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose. The scenarios involved different modes of mobility: 1) walking to a dot and stopping for 3s before moving to the next dot; 2) walking continuously and without any pause throughout the course; 3) running / walking backwards / sidestepping / crawling part of the course; 4) "transporting" the four phones on a pushcart; 5) using elevators, as opposed to stairs, to change floors; 6) leaving the building a few times during a scenario and then reentering through the same door or another.

The full version of this paper has been accepted for publication in 27th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) on 4-7 September 2016 in Valencia, Spain.

Indoor-Navigation in One of the Largest Single-Building Hospitals in Europe - a Look at Requirements and Obstacles

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***Abstract*—Indoor navigation has gained wide attention in research over the last decades. While many businesses have started implementations, wide penetration has not been achieved yet. In this work, we report requirements and obstacles in implementing an indoor-navigation system and propose possible resolutions as well as a preliminary working setup. The navigation system is developed for the largest single-building hospital in Europe, the university clinic of the RWTH Aachen University.**

I. INTRODUCTION

The Uniklinik RWTH Aachen is one of the largest single-building hospitals in Europe. It covers about eight thousand rooms with a total effective area of 130.000 square meters in 13 levels. Each level has between 1 and 3 kilometers of hallway, organized along four major corridors. All minor hallways are numbered sequentially. However, not all levels cover all areas or have the same number of minor hallways, thus the location of identical numbered minor hallways can vary up to two hundred meters between two levels. The only orientation for patients, visitors and staff are numbered elevator groups located along the major corridors. As only navigation support, ground plots with elevator location and floor numbers are handed out at the information desk at the central entrance. With 250.000 patients each year (in 2013 [1]) and up to 10.000 persons entering the building each day, an effective navigation of patients, visitors or even staff can not be guaranteed in all cases.

Recent advances in indoor navigation or positioning have addressed exactly the aforementioned problem utilizing various techniques [2]. Bitsch et al. (2011) proposed a podometrie and magnetometer-based method and applied it successfully to a limited number of routes in the building of the Uniklinik RWTH Aachen [3]. Although many noticeable efforts have been made on developing methodology, only very few applications that utilize these methods for indoor positioning or navigation are available so far. Here, we will discuss some of the requirements and resulting obstacles when developing an indoor navigation system in a challenging environment.

II. METHODS

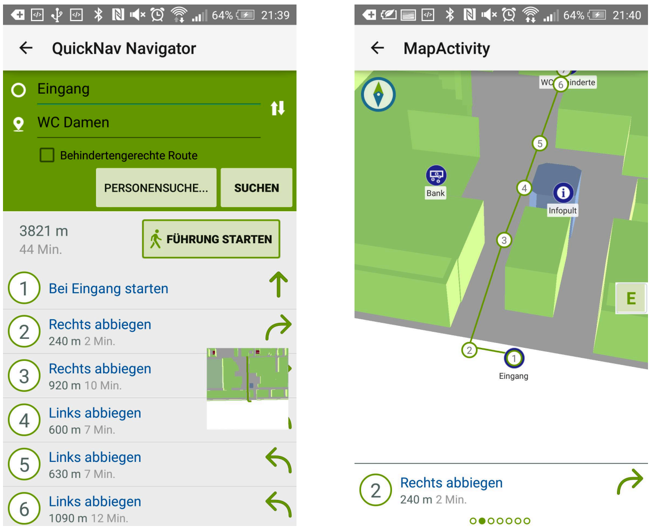
When developing a software system, the first step is usually a thorough requirement analysis. Here, we present some of the most important requirements the indoor navigation system at the Uniklinik RWTH Aachen as well as some obstacles identified during the first phase of the project. As target platform, a smartphone navigation application was chosen to achieve a maximum dissemination without the need of specialized navigational hardware.

A. Personnel and User Requirements

The building of the Uniklinik RWTH Aachen houses provider of clinical care as well as research institutes and laboratories such as a central animal facility or the library of the medical faculty. Additional institutes and units are located in an adjacent area. Navigation should be provided for the following user groups: (i) patients, (ii) visitors of patients, (iii) researchers, (iv) visitors of researchers, (v) staff, (vi) external maintenance staff. The navigation should be adaptable to disabled persons. Directions should be entered in form of room numbers, URLs or other direction markers. Minimal efforts in the creation of there markers or the distribution are mandatory. Addtionally, a directory of staff and their offices should be available for search. However, this data is so far only available semi-structured and with time-delays of up to several weeks.

B. System Integration Requirements and Obstacles

Besides offices of staff, visitors should be able to search for patient room numbers, if this information is waived by the patient. So far, this information is only available upon request at the main information desk through the hospital information system. An integration into this system is only possible with extraordinary effort, as it would require the navigation application to be approved as a medical produce, since it handles patient information.



Eingang

WC Damen

☐ Behindertengerechte Route

3821 m
44 Min.

1 Bei Eingang starten
2 Rechts abbiegen 240 m 2 Min.
3 Rechts abbiegen 920 m 10 Min.
4 Links abbiegen 600 m 7 Min.
5 Links abbiegen 630 m 7 Min.
6 Links abbiegen 1090 m 12 Min.

2 Rechts abbiegen 240 m 2 Min.

(a) Navigation instructions (b) Navigation visualized on map

Fig. 1. Navigation application Quicknav with navigation activated

C. *Infrastructure Requirements and Obstacles*

The different levels and corridors of the hospital building are separated into clinical and research areas. Patients should not be navigated through research areas unless absolutely necessary. These areas do change over time, so does the overall hospital layout. Yet, the hospital layout is visually and structurally identical in many areas of the building. Currently, no completely accurate ground plot of the building is available.

Additionally, areas with certain restrictions exist: (a) high-purity or isolation areas can only be entered by professional personnel, (b) high security areas (e.g., intensive care) do not allow the usage of cell-phones, wifi-signals or similar disturbances, (c) MRI areas have altered electrical fields and can influence the usage of magnetometers or other sensors.

As a last requirement, the existing infrastructure cannot be changed or modified without high costs, including IT-infrastructure with only a partial wifi coverage. This also includes an automated central air-conditioning that influences pressure and humidity sensors, therefore rendering solutions based on ambient sensing infeasible.

D. *Financial Requirements*

Lastly, the hospital is publicly funded and can not afford major changes in infrastructure, such as the deployment of actuators (i.e., Bluetooth beacons).

III. RESULTS

As a result of the requirements analysis, a preliminary navigation application called Quicknav has been developed (Figure 1). Localization of the user cannot be performed reliably based on smartphone sensors alone. Thus, only passive localization will be performed. That is, the user input the position himself in form of machine readable markers (QR-codes, text-recognition of doorplates, NFC-tags, etc.). In next development iterations, integration of active positioning using sparsely located bluetooth beacons and inertia data is planned to improve usability. Further integration with existing systems is not possible due to legal reasons and integration (e.g. lookup of patient rooms) and has to be performed manually by authorized personnel. Communication to the navigation application is executed through QR-codes and NFC-transmitters at the information desk. Ground plans are drawn and validated manually.

IV. DISCUSSION AND CONCLUSION

We have demonstrated that despite many efforts in the research of indoor navigation and positioning, actual applications can be quite challenging and often have to rely on simplified methodology. Many sensor-based approaches have limitations too, especially in challenging environments such as hospitals. However, if applied correctly, these applications might in future solve many problems occurring in high-frequented buildings, such as elevator scheduling, re-routing or potential optimization of elevator usage.

CONFLICT OF INTEREST

Both authors declare that they are managing partners of a company involved in the development of the proposed indoor navigation system.

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S-TDoA – Sequential Time Difference of Arrival - A Scalable and Synchronization Free Approach for Positioning

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***Abstract*—In the past various solutions for localization evolved to productive usage for wireless applications. These solutions are robust, precise and energy efficient. However, scalability, complexity and flexibility are still open issues. Especially the supported number of objects or update rates for localization are still limiting factors for the usage of the systems. In this work we suggest an approach called S-TDoA which stands for sequential Time Difference of Arrival that supports an unlimited number of objects and high update rates. The key concept is a sequential triggering of anchors that send periodic messages. Tags determine their position by listening to the anchor messages and measuring time intervals. Additionally, this approach enhances security because tags are not visible as they do not send messages. We implement and evaluate S-TDoA in a localization system based on UWB-RF-Chips. The preliminary results demonstrate the advantages of our implementation regarding scalability and update rates as well as privacy.**

***Index Terms*—Localization, Wireless Networks, Time Difference of Arrival, Two Way Ranging, Scalability**

I. INTRODUCTION

In this work we suggest a concept with passive tags and a clock synchronization free approach for anchors to reduce complexity, increase the privacy and support for an unlimited number of tags [1].

The contributions of our work are as follows:

- We discuss scalability for TWR and TDoA.
- We suggest sequential time difference of arrival (S-TDoA) to solve the scalability and privacy problem of positioning systems.
- We present a positioning algorithm for S-TDoA and show preliminary evaluation results.

ACKNOWLEDGMENTS

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QRPos: Indoor Positioning System for Self-Balancing Robots based on QR Codes

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***Abstract*—Localization systems for mobile robots are a trade-off between accuracy, robustness and costs. Current solutions for landmark based indoor localization are either expensive or inaccurate and unreliable. Accurate solutions for instance require costly infrastructure and/or high computational power. Additionally, self-balancing robots have particular challenges due to the unstable nature of the system. In this work, we design and develop an accurate landmark-based positioning system (QRPos) with low computational requirements that is based on QR codes mounted on the ceiling. Extended QR codes are recorded with a standard low-cost camera and are extracted and decoded with low computational requirements. Self-localization is implemented with 3D pose estimation based solely on camera data to allow for inexpensive positioning with arbitrary camera orientations. We evaluate QRPos by simulation and experiments with a low-end embedded camera against a baseline approach that is not capable of handling arbitrary camera orientations. We find that QRPos estimates pose with satisfactory accuracy and achieves positioning accuracy and robustness suitable for self-balancing robots.**

I. INTRODUCTION

Our localization method uses extended QR codes as artificial landmarks that are mounted on the ceiling. This infrastructure is minimal, unintrusive and inexpensive. The QR codes are extracted and processed with feature extraction and decoded to calculate the position of the robot. We evaluate the system in simulations and under practical conditions [1].

Our contributions are:

- We present an optimized method for fast extraction and decoding of extended QR codes.
- We design an approach for 3D pose estimation based on camera data and extended QR code landmarks.
- We design and implement a complete positioning system (QRPos) based on extended QR code landmarks and integrated visual 3D pose estimation.
- We evaluate the positioning accuracy of QRPos by simulation and experiments in comparison with standard approaches.

ACKNOWLEDGMENTS

This publication is a result of the research work of the Center of Excellence CoSA in the projects LOCIC and m:flo which are funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), FKZ KF3177202PR4, FKZ KF3177201ED3.

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InPhase: Localization based on Distance Estimation via Phase Measurements

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***Abstract*—Enabling localization in wireless sensor networks is generally accompanied by additional measurement hardware on each sensor node. The InPhase distance estimation allows localization by employing an already available radio transceiver. However, the implemented phase measurement has some deficiencies. In this paper, we discuss the current state of the InPhase system and propose multiple improvements that are investigated in this work in progress.**

I. INTRODUCTION

Specially designed localization services for outdoor and indoor applications are often considered to need a high precision. Therefore, one of the main goals for optimization in such systems is measurement accuracy that is consequently the most important benchmark to compare them. However, when an existing system is originally designed for communication and the localization feature can be retrofitted without extra cost just by uploading additional software, the benefit of enabling localization at all may justify lacking accuracy. The InPhase distance estimation system is the foundation for such applications [1]. It allows the measurement of distances between wireless sensor nodes by employing the existing radio transceiver's built-in function to measure the phase response of the radio channel.

In its current state, InPhase is able to estimate distances between nodes only. Therefore we need a localization algorithm that can cope with the caveats of phase-based distance estimation. We present a basic implementation for the localization step and introduce our next steps in this area.

We present our work in progress on improving different parts of InPhase to make localization without extra cost for additional hardware possible. We identified multiple aspects during evaluation of the InPhase system where additional work can improve the system's performance greatly. The different aspects *Phase Measurement*, *Distance Estimation*, and *Localization* are covered in the next three sections respectively and their possible improvements are discussed.

II. PHASE MEASUREMENT

Phase measurement is the basis for the whole localization system and it is based on the Active-Reflector principle by Kluge and Eggert [2]. The current software implementation is based on the AT86RF233 radio transceiver by Atmel [3] and supports basic phase measurements in the 2.4 GHz band.

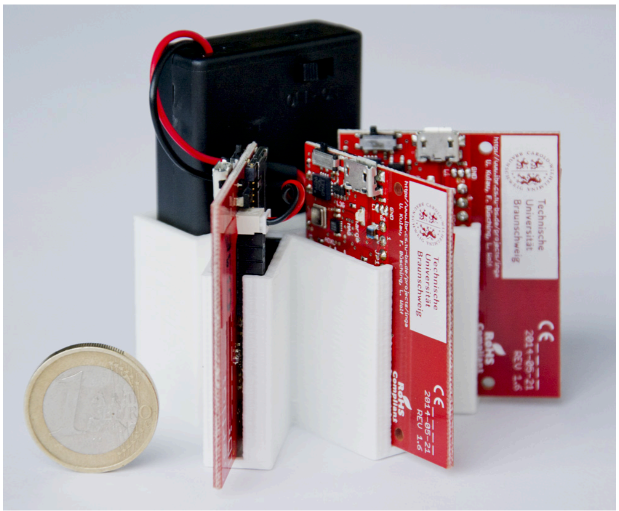

Fig. 1. Anchor node consisting of three INGA sensor nodes. Reproduced from [6].

The more recent AT86RF215 offers better support for phase measurements [4] by enabling automatic averaging of measured values and better synchronization via a built-in timer. Furthermore, via its two independent radio front-ends, it allows measurements in the sub-GHz spectrum as well as in the 2.4 GHz band. The higher wavelength should make phase measurements more precise. We plan to further investigate the feature set of this chip.

Our current hardware is an INGA sensor node [5] with a PCB antenna. This antenna has a predominant direction towards the edge of the PCB. Our experiments show that estimated distances vary with PCB orientations between the sensor nodes. To mitigate this effect we are employing multiple INGA sensor nodes at the same location with different orientations, see Figure 1. In the next step we will investigate omnidirectional antennas to make the system more resilient to non-ideal antenna orientations. This will also allow the reduction to one antenna, radio transceiver, and sensor node per anchor node.

III. DISTANCE ESTIMATION

Although the current distance estimation works better than Atmel's reference implementation *Ranging Toolbox* [7], as shown in [1], it gives undesirable results in some cases.

First, the InPhase system sometimes returns wrong distance estimations with very big errors although the measurement conditions are reasonably well. This may occur due to interference with other systems using the frequency band. The system should be extended to detect these situations and mark the measurements invalid before reporting them. This may be possible by evaluating the raw phase data reported from the measurement.

Second, Non-Line-Of-Sight (NLOS) conditions, where an obstacle blocks the direct path between sender and receiver, result in wrong measurements due to shifting phase information of the transmitted signal. As a valid distance estimation cannot be calculated from NLOS measurements we plan to investigate if the NLOS condition itself can be detected to mark the resulting distance estimation as invalid.

Increasing the performance of the distance estimation is another objective. The current approach calculates the autocorrelation and Fast Fourier Transform (FFT) and is computationally very expensive. We implemented the algorithm on the INGA sensor nodes's 8-bit processor, but a more lightweight algorithm could greatly enhance performance in a low power wireless sensor network. Especially when multiple distance estimations are needed in fast succession as for localization, the computational load on the processor is very high.

IV. LOCALIZATION

A basic implementation for a localization system based on the InPhase distance estimation was evaluated at the Microsoft Indoor Localization Competition 2015 [8] and presented in [6]. The algorithm is able to mitigate effects of wrong measurements and NLOS conditions. However, the current algorithm is computationally expensive and cannot be implemented on an 8-bit processor as stated above. Figure 2 shows an example output of our software. The deployment area is divided into a grid. For each cell a relative probability of the node being located here is calculated. Probabilities are visualized in a blue to red color scale.

The software uses additional hints to mitigate effects of NLOS conditions. Before operation, the user marked areas with NLOS conditions in red. This includes walls, columns and all rooms completely separated by walls. Areas marked in green have a Line-Of-Sight (LOS) but are invalid as locations. The algorithm uses this information to improve the localization accuracy.

We are working on a localization algorithm based on a particle filter approach. Controlling the number of particles allows to adapt the computational load to the underlying platform's performance.

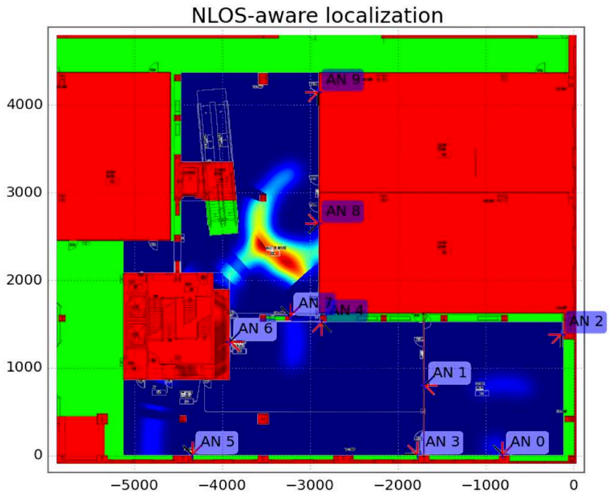

Fig. 2. Relative probabilities of a node's position as calculated by our current software. Both axes in cm. Reproduced from [6].

V. CONCLUSION

We presented our work in progress on improving the InPhase distance estimation and localization system. Multiple parts of the system were identified and their possible improvements were outlined.

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Critical Configurations in Range Positioning:
Error-Analysis by Simulation

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***Summary*—A simulator for investigation of range-positioning problems is presented. The concept of classical lateration (only ranges between static and mobile nodes) is extended to include ranges between mobile nodes as well. Critical problem-types are identified and investigated by simulation with emphasis on accuracy and stability. In the accuracy context, sensitivity of calculated positions against range measurement-errors is investigated. Discussion is based on the concept of precision, rightness and accuracy. Concerning stability, convergence problems and ambiguous solutions are discussed.**

Keywords — simulation; range; positioning; gauss-newton; newton; graph; convergence; error; solution-set

I. INTRODUCTION

A. Definition of range-positioning

Within the scope of this paper range-positioning means position calculation based on range-data only. This can include attenuatuation data (e.g. RSSI), especially in case of a good rotational symmetric field distribution, where the range can be directly evaluated from the field-strength. It also includes measurements of signal propagation times (ToA) in case of isotropic signal propagation and perfect synchronization. Evaluation of angular dependencies and pseudoranging would constitute extensions, which exceed the scope of this paper.

B. Problem-Description and Critical Aspects

A range-positioning scenario consists of a set of nodes and a set of range-measurements between pairs of nodes. Node positions have to be computed based on the available range-values by solving an equation-system of the form:

$$\sum_{k=1}^{N_D} (x_{i,k}-x_{j,k})^2 = r_{i,j}^2 \qquad (1)$$

Every range-measurement gives rise to one equation within this system, where r is the measured range, indices i,j denote the node-numbers, N_D the number of spacial dimensions (1 or 2) and **x** the unknown node-coordinates. If the number of equations according to (1) equals the number of unknown node-coordinates the equation-system is called "**minimal**" in this paper. In this case Newton's method is used for solution.

In order to show the effect of connectivity, alternatively, the case of a maximal number of equations will be discussed, i.e. the case, that a range-measurement exists between every possible pair of nodes, including tags. This case is called "**full**" equation system. It was "solved" in the sense of minimal least squares, using Gauss-Newton.

Measurement-errors lead to errors in the computed coordinate-values. This aspect is discussed in the Section III "Accuracy". The stability of the above mentioned solvers depends on the quality of an initial guess to the position. This aspect is discussed within the Section IV "Stability". In order to properly demonstrate these aspects error-models for range-measurements and initial guess of point-locations are implemented. This aspect is discussed in the following Section II.

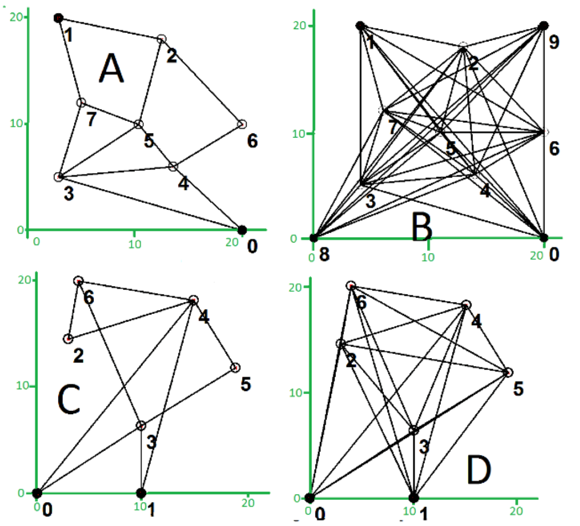

Fig. 1. Test problems: minimal-inner (A), full-inner (B), minimal-outer (C), full-outer (D). Lenth-units are shown in green color. Static nodes, indicated by solid circles are 0,1 (in case of A, C, D) and 0,1,8,9 in case of B, All other nodes are mobile.

II. OUTLINE OF THE SIMULATOR

The input-data necessary to simulate a localization scenario, describe the desired configuration using a graph-model. Examples are shown in Fig.1. Prior to simulation a "true" configuration is defined. The "true" ranges between nodes are disturbed by generating Gaussian or uniformly distributed errors. This model is used to investigate the accuracy-issue (Section III). Similarly the starting-values of the mobile (unknown) nodes are picked by random within given circles (2D) or spheres (3D) around the "true" node-coordinates (**start-radius**). This model is used to examine stability problems (Section IV). A set of simulation-sweeps (typical: 10000) is run, using one or both of the above described error-models. Statistical parameters (variances etc.) of coordinate values are extracted from results. Convergence problems are recorded.

III. ACCURACY

The concept of precision, rightness and accuracy (s. e.g. Loeffler [1]) has become a well established tool to assess the quality of position-data. Standard-deviation (σ_x), Bias and root mean square error (RMSE) are extracted from the measurement. These parameters can be evaluated independently but are also shown to satisfy the following relationship [1]:

$$RMSE = \sqrt{\sigma_x^2 + Bias^2} \qquad (2)$$

Table I shows the values for different problem-types according to Fig.1. For range-measurement errors different models, gaussian (gs) and uniform (uni) are applied. In Table II an additional column RMSE_chk was inserted where RMSE was evaluated using (2). The data show, that (2) holds with good accuracy within the simulation environment for different error-models.

TABLE I. STANDARD-DEVIATION, BIAS AND RMSE FOR THE X-VALUE OF THE WORST NODE IN SCENARIO DEPENDING ON PROBLEM-TYPE (SEE FIG.1)

Probl.Typ	**Err**	**σ_x**	**Bias**	**RSME**	**RSME_chk**
min, outer	gs	3.90275	0.62979	3.95324	3.95324
full outer	gs	1.90989	0.05572	1.91071	1.91070
min inner	gs	1.66106	0.65535	1.78569	1.78567
full inner	gs	0.58190	0.00440	0.58191	0.58191
min, outer	uni	4.53438	0.82448	4.60873	4.60873
full outer	uni	2.02243	0.07453	2.02380	2.02380

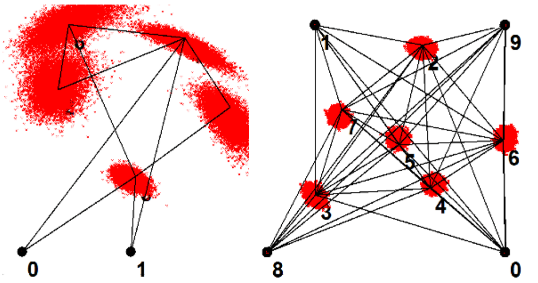

Fig. 2. simulation of effect of range measurement error on calculated node-coordinates with standard deviation of measured ranges of 0.5 length-units. The minimal outer problem exhibited the the highest sensitivity, the full inner problem proved to be most stable.

Fig. 2 shows the straggle of calculated node-coordinates caused by a certain range measurement error (here: standard-deviation 0.5 length-units). Critical configurations are identified via large standard deviations of calculated positions (as Fig.2, left example). The advantage of high connectivity of the measurement graph is clearly demonstrated.

IV. STABILITY

The performance of the Gauss-Newton Solver was explored in dependence of problem-type (Fig.1) and start-radius (Section II). Table II shows, that increasing the connectivity of the measurement graph stabilizes the computation. Choosing the static nodes in the periphery of the mobile ones (inner problem s. Section II) can also help, but not in case of minimal connectivity. Critical configurations are identified via divergence or multiple solutions. The differences of convergence behavior of exact- and least square solutions are discussed.

TABLE II. PERFORMANCE OF THE GAUSS-NEWTON SOLVER IN DEPENDENCE ON THE PROBLEM-TYPES (AS SPECIFIED IN FIG.1) AND START-RADIUS.

start-radius	**max. No. of Newton-steps**		**multiple solutions**		**Instances of divergence**	
Min.Probl.	inner	outer	inner	outer	inner	outer
5	75	18	12	3	2905	0
20	86	28	16	5	8322	2774
Full.Prbl.	inner	outer	inner	outer	inner	outer
5	5	5	1	1	0	0
20	8	18	1	2	0	606

V. CONCLUSION

A simulator realizing an extension of the classical lateration concept on an arbitrary graph was developed. Problems with inner/outer positioning of mobile nodes and with minimal/full connectivity were constructed to demonstrate error-sensitivity, and problems concerning the nonlinear equation-system solution. High connectivity, including inter-tag distances, was found to be the best way to stabilize the position-calculation in means of both, accuracy and stability of the nonlinear iterative scheme.

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Hardware Design for an Ultra-Wideband Positioning System using Off-the-Shelf Components

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***Abstract*—Localization has gained increased attention due to the availability of powerful processing systems and grown demands on software. Meanwhile, there are many software applications benefiting from the Global Positioning System for outdoor scenarios, but lacking indoor support, since systems for indoor positioning are either inaccurate or too costly. Being aware of this problem, the IEEE 802.15.4a standard was compiled, incorporating explicit support for Ultra-Wideband positioning with the first chips being available now. The paper presents the steps taken to design the hardware for an Ultra-Wideband radar using off-the-shelf components.**

I. INTRODUCTION

Localization is becoming a driving factor for new hardware platforms. With the Global Positioning System (GPS), there exists a cheap and readily available solution for outdoor scenarios, which is currently widely applied in modern embedded systems. However, GPS is not an operative solution within buildings, since its signals are attenuated heavily due to concrete and brick material [1]. In contrast to that, for indoor applications there is no standard solution. On the one hand, systems exploiting already available communication hardware, for instance by utilizing the Received Signal Strength (RSS), are cheap but inaccurate. As an example, for Wireless Local Area Networks (WLAN), the error can range up to 30 m [2]. On the other hand, there are proprietary solutions providing high accuracy, which are costly, e.g. Frequency Modulated Continuous Wave (FMCW) radar [3]. With the extension of the IEEE 802.15.4 standard, i.e. IEEE 802.15.4a, towards supporting accurate positioning based on Ultra-WideBand (UWB) radar, this issue has been addressed [4]. Currently, the first commercial chips are available.

In this paper, the hardware design for an accurate UWB positioning system is introduced. The paper is focussed on reducing the time to market, hence off-the-shelf components are used. Another requirement on the system is to be prepared for hybrid localization in future releases. The software for the system as well as experiments will be described in [7].

The rest of this paper is organized as follows. In section II UWB is shortly introduced. This is followed by the hardware design in section III. The last section concludes the paper.

II. ULTRAWIDEBAND RADAR

UWB can be employed either for communication or localization. For the former, pulses represent the basic means for encoding information. Thereby, the timely arrangement as well as the polarity of the pulses can be utilized. In contrast for localization, the delay between sending and reception is measured to determine the distance between the transmitter and receiver. Due to the high bandwidth of UWB, narrow pulses with steep rising edges can be employed. A leading edge detection algorithm is applied on the receiver to determine the arrival time of the first pulse. This enables to exclude multi-path reflections, arriving with greater time delay [4].

UWB systems operate with large bandwidth; hence their signals interfere with frequency bands used by different applications. In the IEEE 802.15.4a standard, disturbances are avoided by keeping the power spectral density of UWB very low. Three frequency bands are specified in this standard, i.e. the sub-GHz band from 250 to 750 MHz, the low-band between 3.244 and 4.742 GHz and the high-band between 5.944 and 10.234 GHz [5].

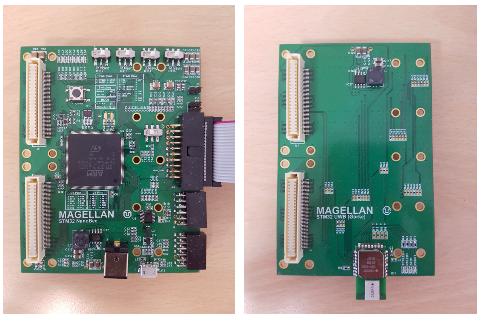
For determining the distance, the two-way-ranging algorithm comes into play. Here the system consists of two stations, in the following denoted as host or tag. The algorithm is initiated from the side of the tag by sending a poll message to the host. The host receives the message, waits a specified delay and answers by sending a response. The response is received by the tag, which also waits a specified delay and transmits a final message just after. This message contains as information all time-stamps measured on the side of the tag. With the help of this data and its own time-stamps, the host is capable of calculating the distance. If necessary, the host might transfer a result message to the tag, containing the distance [6].

III. HARDWARE DESIGN

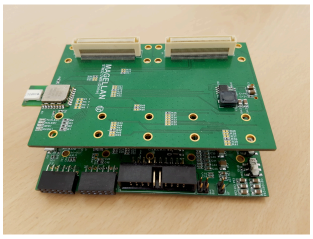
Our objective is to build an indoor localization system providing accuracy in the centimetre range. To a certain extent, the system performance should be robust to multi-path. Our system is intended be low-priced and easy to set up. Since the system is to be applied as one part of a hybrid localization system in future, additional positioning techniques must be possible to be included easily.

The demands for high accuracy and low price represent contrary requirements. As an example, RSS-based WLAN positioning is a cheap variant with low accuracy. In contrast, proprietary solutions like FMCW radar, which involve IC design, offer high accuracy but are usually very costly.

The IEEE 802.15.4a specification approaches this problem by incorporating positioning techniques additionally to the nor-



(a) Data processing PCB (b) UWB PCB



(c) Stacked PCB

Fig. 1: Printed circuit boards

mal communication. With the first corresponding components being manufactured, both requests can now be fulfilled using these off-the-shelf components. Moreover, UWB is a natural choice due to its certain robustness to multi-path.

One of these chips, is the *DW1000* from *DecaWave*, which we chose for our system. It implements the UWB hardware compliant to IEEE 802.15.4a. Amongst others, it contains the crystal and the antenna. It is configured via the Serial Peripheral Interface (SPI), for example through a micro-controller. For the latter, we consider variants from *ST Microelectronics*, since they offer easy applicable interfaces and pin-compatibility between different variants of the same package.

To facilitate the extension of the system regarding the inclusion of additional positioning techniques for hybrid localization in future releases, the hardware design process is split into the development of two individual Printed Circuit Boards (PCB): a data processing PCB responsible for controlling the overall system and another PCB containing the UWB-related components (see figure 1). The interface between both PCB is carried out by four 100-pin inter-board connectors from *Hirose Electric Co Ltd.*. On each board there are two male connectors on the top and two female connectors on the bottom, where the pin-assignment between top and bottom is identical to enable variable stacking of PCBs. In figure 1 these connectors are the white elements on the left. The stacking height is 16 mm, offering sufficient margin for equipping the individual boards. Below, both PCB are introduced in detail.

A. *Data processing PCB*

The micro-controller is the core of the data processing board. Since this system is intended to be part of a hybrid positioning system in future, we select the powerful *STM32F746* from ST Microelectronics. It is based on a 216 MHz *ARM*$^{®}$ *Cortex*$^{®}$*-M7*, offering non-volatile flash for the firmware and providing 140 I/O-pins. Due to the pin-compatibility to cheaper variants, the costs in a productive system can be reduced, compared to our prototype system, if lower performance is sufficient. The PCBs are designed with *Altium Designer*. With *STM32 CubeMX*, ST Microelectronics offers a tool to define the working conditions of the chip, for instance the pin allocations. The import into Altium Designer was executed by custom scripts. Since our solution is intended to be a prototype, LEDs, buttons and switches are included for testing purposes. All remaining GPIO from the micro controller are linked to the board-to-board connectors.

B. *UWB PCB*

The configuration of the DW1000 UWB chip is performed via SPI. Since all SPI interfaces from the micro-controller are passed to the board-to-board connectors, one of these is linked to the module on the UWB PCB. Besides, in our prototype all available SPI interfaces are driven to the DW1000, where the SPI in charge is selected with solder-in resistors. The reason for this is to allow maximum flexibility for the hybrid localization system in a future release. This can be necessary, if one of the SPI signals needs to be utilized otherwise. Again, this PCB is developed with the help of Altium Designer.

IV. CONCLUSION

This paper presented the hardware design of a cheap and accurate positioning system based on IEEE 802.15.4a UWB radar. Besides introducing the background knowledge, the requirements on the system are compiled. Special emphasis is put on extensibility, since the system is intended to be part of a hybrid positioning system in future. In a subsequent paper, the software is developed and experimental results are presented [7]. The first measurements show an average error of 0.30 m.

ACKNOWLEDGEMENT

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Investigation of Anomaly-based Passive Localization with IEEE 802.15.4

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***Abstract*—Localization has important applications, for instance intrusion detection and elderly care. Such applications benefit from Device-free passive (DfP) localization systems, which employ received signal strength measurements (RSSM) to detect and track entities that neither participate actively in the localization process nor emit signals actively. This paper compares different RSSMs for DfP localization and presents detection results of a DfP anomaly-based detection system employed by IEEE 802.15.4 compliant devices.**

I. INTRODUCTION AND RELATED WORK

The term device-free passive (DfP) localization systems was introduced in [1] and describes systems that detect, track and identify entities with the help of wireless networks.

DfP localization systems assume that entities e.g. humans or objects in the target area influence radio frequency (RF) signals which are measured in return. Entity motion within the target area causes fluctuations of received power which are recorded by received signal strength measurements (RSSMs).

We introduce RSSM as a general term for input values of an DfP localization system. Several RSSMs are commonly available for IEEE 802.15.4 RF chips: Received signal strength indicator (RSSI), energy detection (ED) and link quality indicator (LQI).

The RASID system [2] introduced anomaly-based detection, which was later adopted and enhanced with the ability to track entities via a particle filter algorithm in Ichnaea [3]. RASID requires a short training period where a *silence profile* is measured in the room without the entity. The silence profile will be applied and adapted during the runtime. Continuous adaption of the silence profile with measurements with absence of an entity in the target area, increases robustness for changes in the environment.

In our work, we investigate anomaly-based DfP localization with IEEE 802.15.4 compliant devices and we aim to find the best RSSM for DfP systems to improve the performance — in our case the ability to detect the presence of an entity within the target area of a DfP localization system.

Our contributions consist of the comparison and evaluation of RSSMs e.g. RSSI, ED and LQI values for DfP localization systems and the implementation and evaluation of an anomaly-based detection for DfP localization with IEEE 802.15.4.

The rest of the paper is organized as follows, Section II describes the principles of DfP systems and the approach of the underlying anomaly-based DfP localization system. In Section III the implementation with IEEE 802.15.4 is described. Section IV presents the preliminary evaluation results. Finally, we provide a summary and an outlook for future work in Section V.

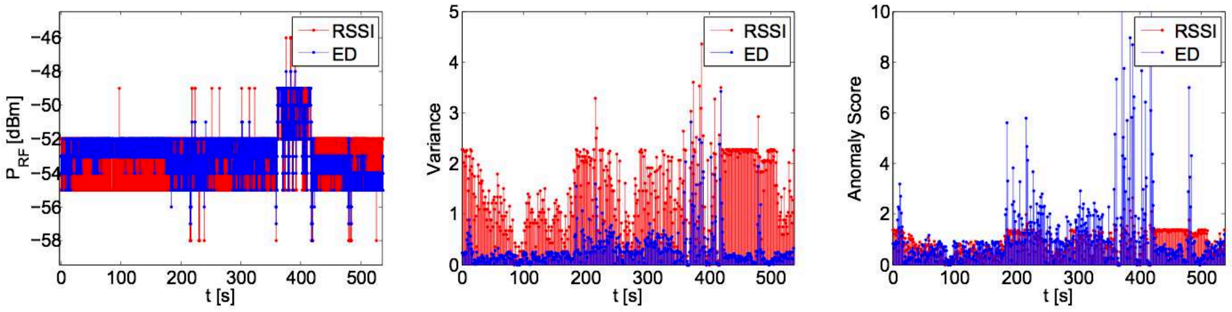
II. APPROACH & SYSTEM DESCRIPTION

A DfP system assumes that received RF signal power changes – either increases or decreases – when an entity moves within a target area. During RF signal propagation, reflection, scattering and diffraction occurs and results in *multipath phenomena*. Typically, RSSMs are decreased when an entity disrupts the line-of-sight path. Literature suggest the variance as a feature for processing of the raw RSSM. Variance is a suitable indicator for the change of the values caused e.g. by entity motion [1], [2], [3].

Anomaly detection was first introduced by Kosba et al. for DfP localization systems in [2]. A detailed description is available in [2] and [3]. We implemented the same steps that are done for each stream j, namely: 1. Calculate a feature value $x_{j,t}$ such as the variance from a time window $W_{j,t}$ with the window length l, so that $x_{j,t} = g(W_{j,t})$ 2. Estimate the probability density function (PDF) $\hat{f}$ of the silence period via a kernel density estimator with an Epanechnikov kernel 3. Calculate an upper bound $u_{j,t} = \hat{F}^{-1}(1-\alpha)$ based on the estimated PDF $\hat{f}_j$ and the resulting cumulative distribution function (CDF) $\hat{F}_j$ of the silence period 4. Calculate the anomaly score $a_{j,t} = \frac{x_{j,t}}{u_j}$, which also serves as a normalization 5. Calculate the global anomaly score $a_t = \frac{\sum_{j=1}^{k} a_{j,t}}{k}$, where k is the number of streams 6. Calculate the smoothed global anomaly score $B_t = (1-\beta)B_{t-1} + \beta\alpha_t, B_0 = a_0$

III. IMPLEMENTATION

Our testbed contains IEEE 802.15.4 compliant devices with an Atmel AT86RF233 radio chip that is controlled by an ATxmega128A1. For the tests, the monitoring points (MPs) (receiver nodes) are connected to a laptop via a serial port. The target area is a laboratory room of the Fachhochschule Lübeck with tables and lab equipment that produce multipath conditions. Four MPs and two transmitters were employed which results into eight streams. The MPs wait for the transmitter to send a message. When an MP detects a start of a packet, it measures the RSSI and generates the ED and LQI automatically. Note: For a better comparison the ED and RSSI



(a) Raw RSSI and ED data
(b) Variance of RSSI and ED
(c) Anomaly score of RSSI ED

Fig. 1: Example of the processing of one stream

values will be converted into received signal strength (RSS) values in dBm. At the end of the packet, the RSSM and the source address of the corresponding packet are saved and the MP enters the listen state to wait for the next message.

IV. EVALUATION

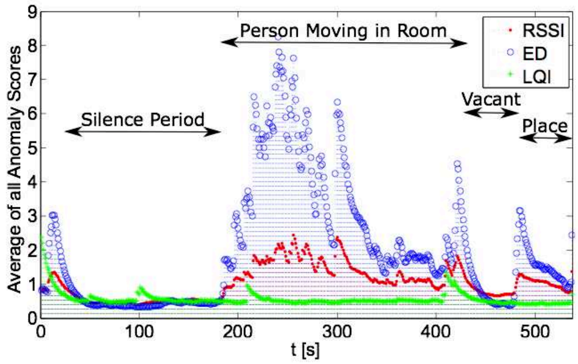


Fig. 2: Average of the smoothed anomaly scores of all streams for RSSI, ED and LQI

This section presents preliminary measurement results.

A. Evaluation of different RSS measurements within the Anomaly Detection

Figure 1 shows the progress from the raw RSSM over the signal feature — in our case the variance — to the anomaly score of one stream. The first 15 s of the test were used to start the test to ensure that everything was working properly and to leave the room. The silence period is from 15 s – 180 s. 180 s – 420 s a person was moving within the target area. Between 420 s – 480 s the room was vacant, and for the last 60 s a person walked to a place left next to a transmitter and sat down. Figure 1 also shows the comparison of the different RSSMs. The ED value serves as the best input due its measurement resolution of 1 dB. The RSSI value results in detection but its measurement resolution of 3 dB limits its precision significantly and therefore reduces the performance of the DfP system. The LQI measured by the AT86RF233 radio chip is not suited as a RSSM for DfP localization system (the results are shown in Figure 2). Neither during the silence period, nor with an moving entity within the target area, the measured values show different behavior compared to e.g. the ED values.

B. Evaluation of the Anomaly Detection

Figure 2 shows the result of the anomaly detection. Each transmitter broadcast a message every 10 ms, l was chosen as 100, α as 0.01 and β as 0.1. Those values were chosen heuristically. The ED values serve as the best parameter for the DfP detection system, the RSSI shows the same behavior but does not have values as large as the ED. The LQI does not indicates motion of an entity reliably.

V. CONCLUSION AND FUTURE WORK

In this work we demonstrated entity detection with a DfP localization system based on IEEE 802.15.4. We compared different RSSMs namely the RSSI, ED and LQI and found that detection of a person within the testbed was possible. The higher measurement resolution of the ED value is better suited than the RSSI value. The LQI value did not result in detection. In the future, we will adapt the upper bounds for each stream to the dynamic radio environment. Furthermore, we will enhance the anomaly detection with a localization estimation via a particle filter.

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Attack Detection in Wireless Networks Using Channel State Information

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***Abstract*—The introduction of wireless communication in industrial automation systems has opened up attack vectors that cannot be mitigated by traditional security. As a possible remedy, we discuss an attack detection architecture that complements traditional cryptographic mechanisms. The detection concept is based on leveraging the attacker's location by considering physical properties of the wireless link. We underline the concept with 802.11n channel measurements, which show characteristics that indicate possible approaches for attack detection.**

I. INTRODUCTION

In recent years, industrial automation systems have become more interconnected and flexible due to significant advances in communication technology. Sophisticated wireless communication systems have led to a paradigm shift from purely wire-based communication to the deployment of wireless systems in industrial applications. Although profitable for the company and desirable for the production process, increased vulnerability is the price that has to be paid for this paradigm shift. The introduction of more interconnected devices and the usage of a broadcast medium for communication leads to an increasing number of potential attack vectors.

Industrial automation systems oftentimes require communication to be dependable in addition to having wire-equivalent latency and performance. Although challenging, traditional cryptographic mechanisms can be designed to meet these strict requirements and to provide data confidentiality and integrity, as well as authentication [1]. Traditional cryptographic approaches, however, are weak against an inside attacker, who is, for example, equipped with (partial) knowledge of the secret keys. This additional information enables the attacker to inject messages to misconfigure machines or extract intellectual property, while remaining unnoticed by the system.

Therefore, we discuss the design of a misbehavior detection system for active attackers, which complements traditional security approaches. The misbehavior detection system is based on the assumption that an attacker may enter the facility but must carry out any attack from a location sufficiently far away from any automation system.

Since the location of the attacker and honest nodes differ, physical properties of the wireless link, such as Received Signal Strength Indication (RSSI) or Channel State Information (CSI) can be leveraged to detect malicious activity. These physical-layer properties vary over time and depend on the sender's location [2].

In contrast to localization systems [3], [2], where devices want to be located, we invert the traditional paradigm and locate attacker devices. However, we do not strive for location in a geographical sense. Instead, our goal is to collect sufficient information to distinguish data streams from attackers from those of honest nodes—independent of their exact location. We specifically aim to detect attacks using wireless communication means that are already used for data transmissions, eliminating the need for additional, specialized localization hardware. Existing infrastructure may not be ideal for collecting localization information in generic scenarios. But typical industrial automation systems exchange information at high frequencies and within known topologies, which we leverage for our mechanisms.

Related work on using RSSI values for spoofing attack detection [4], [5] is based on simultaneous channel measurements by different access points at distinct locations. The resulting measurement vectors differ from those of the impersonated node, which can be detected by the system. In contrast to these existing RSSI-based approaches, our approach relies on more fine-grained CSI measurements [6] and less node collaboration due to bandwidth restrictions in industrial networks.

II. MISBEHAVIOR DETECTION CONCEPT

We assume an active attacker with insider knowledge, i. e., details of the production process and partial knowledge of secret keys. Furthermore, the attacker has access to the facilities but cannot reside close to honest network nodes for a longer period of time. The model is motivated by the scenario of an attacker disguised as IT-maintenance personnel.

The network model, inspired by industrial systems [7], consists of multiple groups of nodes. Every group is composed of a master node which communicates with several slaves in a star topology. Direct communication between slave nodes is impossible. The master nodes are themselves connected via other master nodes, forming a hierarchical structure.

In our concept, misbehavior detection can occur at different stages and over different time intervals in this particular network model. In order to categorize these possibilities, we use the terms *local* and *global* detection to indicate the degree of cooperation, as well as *instantaneous* and *aggregate* decisions for the time domain.

Local detection means that each node monitors its communication and employs algorithms to detect abnormalities and

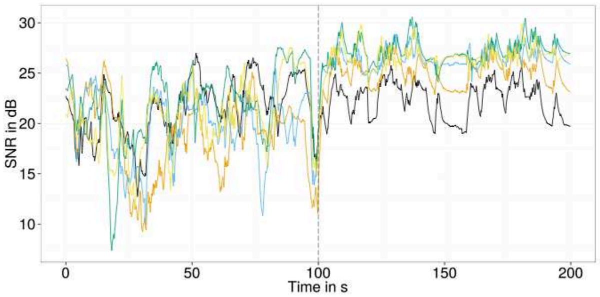

Figure 1. SNR values of 5 equally spaced subcarriers over time.

ignore spurious senders. In global detection approaches, nodes communicate detection results to their respective master node. These higher-hierarchy nodes either decide to take action or to ignore the request. To save bandwidth, local detection may be combined with global approaches.

In the time domain, decisions can be either based on very few measurements or longer time series to increase accuracy, which we define as instantaneous and aggregate, respectively. Since network nodes are usually lightweight, only limited space is available for storing past measurements; thus, local detection happens mostly instantaneously. As a consequence, algorithms at lower tiers are error-prone, whereas the detection accuracy increases at higher tiers, where more data can be processed. Since the local detection acts as a filter for the global detection, the low accuracy is not problematic.

III. MEASUREMENTS & EVALUATION

In order to initially validate the discussed concept, we performed measurements of the wireless link using 802.11n hardware equipped with a custom firmware [8]. This firmware reports the current CSI value as a channel matrix, characterizing the phase and amplitude of every OFDM subcarrier for each sending and receiving antenna pair.

The measurement setup consisted of three nodes in an office environment: master, slave, and attacker. The nodes were positioned in a straight line in this order, each pair placed $\approx 10\,\mathrm{m}$ apart. The wireless link was measured every $200\,\mathrm{ms}$.

Figure 1 shows the Signal-to-Noise-Ratio (SNR) values over time for a subset of 5 equally spaced OFDM subcarriers of one receiving antenna. For better readability, an exponential average with $\alpha = 0.125$ was applied to the data. In the first $100\,\mathrm{s}$, the honest node communicated with the master, whereas in the following the attacker sent packages to the master. The left half shows the honest node's channel whereas the right half depicts the channel between attacker and master.

It can be seen that the honest node experiences severe, periodic drops in the channel quality and more variance of the SNR in general. In contrast, the attacker's channel experiences good SNR values and little variance. Hence, the channel properties differ significantly, which can be seen at the $100\,\mathrm{s}$ mark, where the attacker started the attack. As an example numerical characterization, the arithmetic mean and standard deviation are shown in table I. The observed difference in channel characteristics enables algorithmic detection approaches.

Table I
MEAN AND STANDARD DEVIATION OF THE SNR

Metric	Honest	Attacker
Mean	20.1994	25.7147
StD.	5.8003	3.5703

We are currently investigating the detection of malicious activity with machine learning methods, such as n-gram analysis or support vector machines (SVM) [9], which allow attack detection without exact channel models. Both approaches attempt to classify data sets based on vector space analysis. A vector in this scenario can either be a series of measurements over time (in the case of n-grams) or one measurement over all subcarriers in the case of an SVM. The classifier can be trained with labeled data for honest and attacker channels, based on which new measurements are classified.

In future work, we will conduct more thorough experiments in industrial facilities and consider other machine learning approaches suited for time series analysis.

IV. CONCLUSION

We have discussed the idea of detecting attackers in wireless networks based on their location. The proposed misbehavior detection architecture complements traditional security mechanisms and leverages position-dependent channel characteristics to detect malicious activity. A first experiment with three nodes and 802.11n hardware was carried out in order to understand the wireless link and to evaluate the proposed concept. Results indicate that attack detection is indeed possible and can be tackled with methods of machine learning.

ACKNOWLEDGMENT

The work was partly funded by the German Federal Ministry of Education and Research under BMBF grant agreement no. 16KIS0222.

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Parking lot monitoring with cameras and LiDAR scanners

Daniel Becker[1], Andrew Munjere[2], Oliver Sawade[2], Kay Massow[1], Fabian Thiele[1], Ilja Radusch[2]

***Abstract*— Automation in complex indoor parking scenarios promises significant efficiency and safety gains. To achieve this, an accurate sensing of the environment is required. Due to the line-of-sight limitation of vehicle sensors, infrastructure camera or LiDAR sensors represent an alternative means for object detection, localization and classification. In this work, we focus on the central task of monitoring the parking lot occupation state. To this end, we present a visual parking lot monitoring system based on monocular cameras, that employs a cascade of Random Forest and Artificial Neural Network classifiers, which exhibits a detection accuracy of 94.98% in our parking testbed. In addition, we propose a hypothetical parking lot monitoring approach based on infrastructure LiDAR scanners. Both low-level sensor data and high-level object detection data can be plotted in our minimalistic visualization platform VPIPE, which is an extension of the PHABMACS platform, to provide an intuitive understanding of the sensing data and algorithm results within the parking environment.**

I. INTRODUCTION

Multi-level parking environments are common in modern cities but present many challenges to human drivers as the search for a parking spot can be time-consuming and difficult in the narrow spaces with frequently low visibility and highly dynamic activity [1]. Thus, automation of the parking process promises significant benefits through improvements in efficiency and safety. To achieve a fully automated vehicle navigation, several tasks are required. In this work, we focus on the task of detecting the parking lot occupation state. We have equipped the infrastructure with monocular cameras and LiDAR scanners to monitor the parking lot occupation state. Firstly, we propose a visual parking lot monitoring (PLOM) approach based on a cascade of Random Forest (RF) and Artificial Neural Network (ANN) classifiers. We have evaluated this approach in our realistic parking testbed. Secondly, we also deployed Velodyne Puck VLP-16 LiDAR scanners [2] in the infrastructure and we discuss a hypothetical parking lot detection approach based on the 3D point cloud data. Thirdly, we propose the minimalistic 3D sensor visualization platform VPIPE which is an adaption of the PHABMACS simulator [3]. VPIPE enables the visualization of both low-level sensor data (e.g. 3D LiDAR point cloud) as well as of high-level algorithm results (e.g. parking lot status). Fig. 2 depicts three representations of the same parking scene for the visual parking lot detection, virtual 3D model and LiDAR point cloud respectively.

II. VISUAL PARKING LOT MONITORING

As described in detail in [3], the basic assumptions for the proposed parking lot detection system are that the infrastructure cameras are fixed and cover in average 4 lots each (see Fig.2 left). Due to the fixed mounting positions, relevant regions of interest (ROI) can be manually annotated for each parking lot. Each extracted ROI is individually provided to a classifier that assesses if the corresponding lot is either empty or occupied (i.e. a binary classifier). Finally, the parking lot detection result can be provided to an application, e.g. a parking lot guidance system or the VPIPE visualization (see Fig.2 center). The image classification approach relies on Bag of Words (BoW) models which is a supervised learning technique based on a visual word codebook. The codebook is created by clustering extracted local invariant image descriptors with the *K-Means* algorithm. In simple terms, the bag of visual words is a vector of K bins that counts the number of occurrences of distinctive image patterns. This histogram of visual words serves as input for multi-class classifiers, which are trained with labelled images. We selected a dataset of about 22,000 images for the training process. For both classes, available and occupied, we use images from our parking test site, as well as from public datasets [4] [5].

Additionally, we employed a testing data set of 757 manually labelled images for both occupied and available parking lots captured randomly over a period of months. We have evaluated various combinations of feature detector and descriptor methods along with a Random Forest (RF) [6] and an Artificial Neural Networks (ANN) [7] classifier. As it turned out based on our testing data, the optimal combination of keypoint detector and classifier was achieved for a RF-ANN-ANN classifier cascade with a BoW cluster size of ***K***=20,000 with FAST and SIFT descriptors.

Thus, the visual detection approach reaches an $accuracy$ of 94.98%. The true positive rate TPR is 91.53% and the true negative rate TNR 98.42%. The median processing time per frame is $107ms$ with a standard deviation of $14ms$.

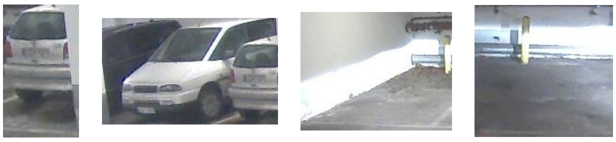

Fig. 1: Testing image examples (1-2 occupied, 3-4 available).

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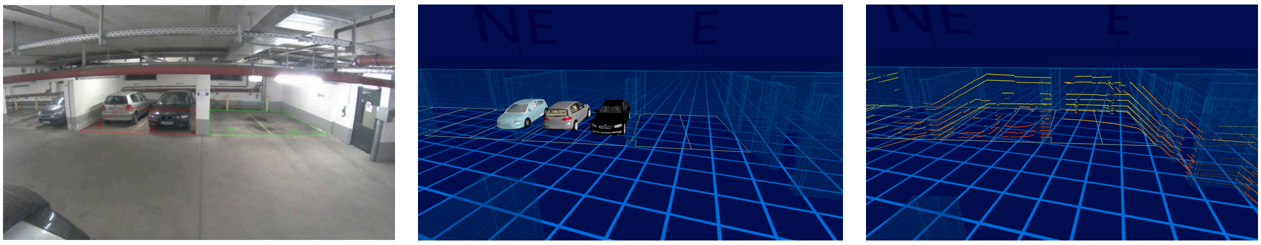

Fig. 2: Three parking lot perspectives: Visual (left), virtual (center), LiDAR scanner (right).

III. LiDAR PARKING LOT MONITORING

Fig.2 (right) displays a visualization of a single Velodyne VLP-16 LiDAR scan [2] of the same parking lot which is also observed by the camera (see Fig.2 left). The color coding is according to distance, where the color from close to far objects ranges from red to green. The LiDAR points are overlaid onto a semi-transparent virtual representation of the fixed parking lot structures (e.g. walls, pillars) derived from a 2D map source and a fixed height component. It is relatively easy for people to recognize the difference between the available and occupied parking lots in the LiDAR scan visualization, especially as the LiDAR sensor features a high accuracy (average error $\pm 3cm$ [2]). As the LiDAR accuracy is more than an order of magnitude higher than the objects which are to be measured (i.e. parking lot size in the range of $2m$ to $3m$), single scans are sufficient for assessing the parking lot state with a very high signal-to-noise ratio.

We envision two different approaches for detecting the parking lot state. Approach A) is a distance histogram comparison per calibrated azimuth angle range. For each parking lot, the angular range in the LiDAR scan is manually annotated. For instance, the rightmost parking lot in Fig.2 would be in the azimuth angle range of $0°$ to $15°$, the next one from $15°$ to $30°$ and so on. A LiDAR scan of the empty lot is then recorded as reference. The lot occupation state can then be determined by calculating a histogram of the distance for each scan point in the specific azimuth angle range. A comparison of the histograms of the current and reference scan (e.g. by Chi-Square goodness of fit) indicates scan similarity. Thresholds need to be set accordingly so that the occupied parking lot is consistently detected while remaining robust to minor disturbances and partial occlusions.

Approach B) in contrast projects the relative location of the LiDAR points into a planar 2D grid. Given the fixed known 6 degree of freedom (DoF) pose of the LiDAR scanner, reflections on the ground and ceiling can be removed so that in an empty scenario only structural objects remain (e.g. walls and pillars). Also, the exact extent of each parking lot is annotated into the 2D projection. Finally, the parking lot state can be determined by counting the number of LiDAR detections residing inside the parking lot boundaries. To achieve a robust detection, noise filtering can be applied and a threshold for the covered width of the parking lot needs to be determined, e.g. in the presence of misaligned vehicles.

IV. CONCLUSION AND OUTLOOK

An accurate and reliable parking lot detection is a critical step on the path towards automation of the parking process. In this work, we present a visual detection system based on a RF-ANN-ANN classifier cascade which achieves an overall detection accuracy of 94.98% in our parking testbed. Moreover, we propose ideas for parking lot detection based on LiDAR sensors for future realization. Comparing the basic properties of both technologies, we assume LiDAR to be superior to monocular cameras, for several reasons: LiDAR is an active technology which is independent on ambient light whereas cameras need a sufficient level of illumination to operate reliably. Especially in parking lots where the illumination is often relatively weak, LiDARs have a clear advantage. Another difference is that LIDARs directly measure the depth while monocular cameras provide a 2D projection. Even though a perspective calibration between the camera image and 3D scene can be calculated, we assume LiDARs to be more robust in this regard. Cameras do have an advantage in terms of object classification due to their higher vertical resolution as well as wide range of color information, compared with the LiDAR reflectivity measure. Another advantage of cameras is the price as they are cheaper than LiDAR scanners. However, this might change with new technologies (e.g. solid state LiDARs) or economy of scale effects (e.g. mass deployment in modern cars).

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Lane-Precise Navigation on Incomplete Maps

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***Abstract*—We propose a method to support lane-precise navigation systems in case of incomplete map data. No prior information on the existence, length, and number of turn lanes is required, information such as geometry and topology is sufficient. The environment is perceived through a visual lane-marking detection and radars used for adaptive cruise control and blind spot monitoring systems. Their data is used independently to estimate probabilities whether a lane-change in turn direction is advisable. The proposed method has proven to be successful in real driving scenarios in urban and highway situations.**

I. INTRODUCTION

Many modern navigation systems provide lane-level navigation with abstract schemes or 3D renderings of intersections and highway exits and interchanges and advise the driver which lanes to take to reach his destination. The next generation shall furthermore check whether the currently used lane is recommended or whether a lane change is advisable.

For this purpose, robust lane-precise localization on navigable maps is needed. While impressive localization results were shown on maps with camera-, radar- or lidar-based landmarks [1]–[3], the problem becomes more difficult on digital maps containing only road or lane geometry and topology [4], [5]. However, commercial maps only contain all lanes, including turn lanes, at some complex intersections and highway interchanges. In other places, they are limited on the number of through lanes, which is typically used for estimating average speeds in routing and map rendering.

Lane guidance, however, is also desired in these places where neither the complete number of lanes nor the recommended lanes are known. It is expected to be beneficial to guide the driver to the outermost lane when approaching a turn right or turn left maneuver. This can be achieved by determining whether there is another drivable lane next to the ego-vehicle in maneuver direction. It is necessary to keep the number of false lane-change advises low as they might lead the driver onto sidewalks, grass verges or into parking cars.

In this work, we propose a method to heuristically determine whether a lane-change in turn direction is possible using environment sensors available in a production vehicle. After a short introduction to the used sensor data in Section II, the proposed method is described in Section III. Section IV shows the results of an evaluation in different traffic situations before Section V sums up the main findings.

II. SENSORS

The proposed method employs three environment sensors and information on vehicle velocity and the turn indicator state. With a camera behind the windshield, lane markings on the road are detected. The system provides information on the type of marking (continuous, broken, …), the detection quality, and a signal when a lane-change is detected.

The adaptive cruise control system in the vehicle detects other traffic in front of the vehicle using a radar sensor. The information on these objects contains the relative position and velocity in x- and y-direction, a lane-assignment relative to the ego-vehicle (e.g. first/second lane to the left/right, ego-lane), an existence probability and a classification in some general categories (car, truck, guardrail, …). These objects are filtered according to their existence probability, relative and estimated absolute velocity to avoid misclassified traffic signs and other static objects in the next processing step.

Radars employed by the blind spot monitoring system are used to detect traffic to the left and right rear sides. The available data only shows whether another vehicle has been detected within the radar's field of view or not.

III. DETERMINATION OF POSSIBLE LANE-CHANGES

Identifying whether a lane-change towards the turn direction is possible, differs from many localization problems in that we do not want to find out where the vehicle is, but where it is not. The number of total lanes on the road is not surely known and determining a lane index for the current position does not help. Luckily, for navigation purposes, it is often enough to find out whether the vehicle is already on the outermost lane.

As soon as the next turn maneuver is approached – i.e. between 100 m and 500 m before the actual maneuver, depending on the road class –, the system determines from map data whether there is another intersection on the way to the maneuver. If so, it waits until the next intersection and starts looking for crossings again. Otherwise, the system starts to use data from environmental sensors to estimate scores that relate to probabilities for the existence of another lane in turn direction. Additionally, it notices performed lane-changes and adapts its behavior accordingly. The latter two steps are described in the following.

A. Existence of Adjacent Lanes

For the three types of environment sensors, separate scores are determined. Whenever a not-continuous marking is detected in maneuver direction, the score is increased. This increase depends on the number of lanes in driving direction according to map data – this might be zero if no lane attribution is given – and the detected marking types in the non-turn direction, as shown in Fig. 1. This is due to e.g. the assumption that when turning right on a road with more than one lane, a continuous marking on the left indicates that we are on the leftmost lane. Hence, it is more likely that further lanes exist to the right. The precise values were tuned empirically in sample situations. When a continuous road marking is detected in turn direction five times, the score is reset to zero. This sensor is not applicable for turn left maneuvers on roads where both traffic directions share the same roadbed, as the central lane separator to the oncoming traffic may be mistaken for a lane-marking between adjacent lanes.

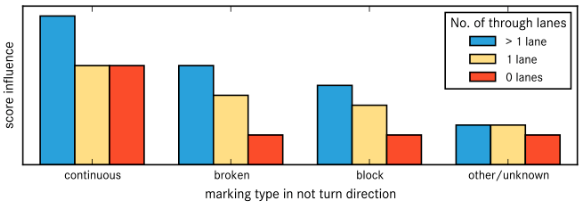

Fig. 1: Increase of score in different situations.

Radar objects in front are considered valid when they are detected and assigned to the same relative lane multiple times in a row. As soon as a valid object was seen on a lane in maneuver direction, an adjacent lane is assumed certain. As the blind spot monitoring system only rarely suffers from misdetections, its score is increased to maximum value as soon as a vehicle is detected in the blind spot.

B. Lane-Change Detection

When a lane-change is recommended to and then performed by the driver, it should be detected and the system should not recommend a lane-change any further – unless another one is necessary. Therefore, it is required to detect lane-changes as well which can be intuitively achieved through lane-changes noticed by the lane marking detection. Unfortunately, not all lane-changes are detected and other methods are needed. Therefore, the relative lane assignments of radar objects in front of the vehicle are tracked. Whenever two vehicles change their relative lane almost at the same time, we assume a lane-change of the ego-vehicle. The same happens when one valid vehicle changes its relative lane and the turn indicator of the ego-vehicle is active in the respective other direction.

IV. RESULTS

We have evaluated a total of 144 turn maneuvers in urban and highway situations: 85 turn right, 59 turn left maneuvers. We denote situations with existing adjacent lanes in maneuver direction as "positives" and those where we already are on the outermost lane "negatives". As it is crucial to avoid false positives as they could lead the driver onto grass verges or into oncoming traffic, the system was tuned to not show any advise rather than prematurely recommend a lane-change.

As can be seen in Table I, in turn right situations, a majority of adjacent lanes was detected. Most false negatives occurred in cases with very short turn lanes or where the system was activated only shortly before the maneuver due to other roads. Adjacent lanes were detected after, on average, 2.8 seconds or 20 m. Once a lane-change was recommended where already on the rightmost lane. In this case, a moving object to the right of the ego-vehicle, i.e. on the sidewalk, was detected.

TABLE I: Results: detected adjacent lanes.

	Turn right		Turn left	
	Negative	Positive	Negative	Positive
False	15.3%	1.2%	18.6%	1.7%
True	31.8%	51.8%	42.4%	37.3%
Precision:	97.8%		95.7%	
Recall:	77.2%		66.7%	

In 56% of the turn left cases, an adjacent lane to left existed, and in two thirds of these it was detected. The false negative ratio increased compared to the turn right scenario because the lane-marking detection is not used in case of single-carriageway roads. Adjacent lanes were found after 3.9 s or 25 m on average. One false positive appeared when a curb was continuously classified as a broken lane-marking.

As the evaluation was performed offline on the same log files for the turn left and turn right maneuvers, the driver did rarely follow recommended lane-changes when an adjacent lane was detected. Only six lane-changes were performed during the evaluated turn right maneuvers. Three of them were before the adjacent lane was detected, three of them after that. All six of these were detected. During the active turn left maneuvers, no lane-change to the left was performed.

V. CONCLUSION

We have presented a method to determine whether the outermost lane in turn direction is already used when navigating. The system uses inputs from driver assistance systems such as an adaptive cruise control, lane departure warning, and blind spot monitoring that are used independently of each other. Therefore, it is possible to apply the algorithm, even when only one or two of the used sensors are available. The presented method does not require complete information on the number of available lanes from a digital map but instead relies solely on the through lanes, geometry, and topology from a state-of-the-art infotainment map. Evaluation shows that the false positive rate for the detection of adjacent lanes is low and that lane-changes during active maneuvers can be detected.

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Thursday 14.07.2016

13:00 - 13:30: Welcome and Introduction

13:30 - 14:30: Panel discussion: Quo vadis localization research

- Short introduction of attendees
- Brainstorming for breakout sessions

14:30 - 15:00: Coffee break

15:00 - 16:30: 1st Session – Smartphone Based Positioning

- PerfLoc: A Comprehensive Repository of Experimental Data for Evaluation of Smartphone Indoor Localization Apps
  Nader Moayeri, Mustafa Onur Ergin, Filip Lemic, Vlado Handziski, and Adam Wolisz
  National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA,
  Telecommunication Networks Group (TKN), Technische Universität Berlin

- Indoor-Navigation in One of the Largest Single-Building Hospitals in Europe - a Look at Requirements and Obstacles
  Marko Jovanovic and Stephan M. Jonas
  Department of Medical Informatics, RWTH Aachen University

- Demo Presentation (S-TDoA and Mobile Telepresence)
  Mathias Pelka, Grigori Goronzy
  Department of Electrical Engineering and Computer Science, Lübeck University of Applied Sciences, Germany

16:30 - 17:00: Coffee break

17:00 - 18:00: Break-Out Sessions (Specific challenges of localization research)

19:00 Dinner

Friday 15.07.2016

09:00 - 09:30: Result presentation of the breakout session

9:30 - 10:00: Panel Discussion: Results from the breakout sessions

10:00 - 11:30: 2nd Session -- Lateration

- InPhase: Localization based on Distance Estimation via Phase Measurements
  Yannic Schroder, Lars C. Wolf
  Institute of Operating Systems and Computer Networks, Technische Universität Braunschweig

- Critical Configurations in Range Positioning: Error-Analysis by Simulation
  Albert Seidl, Olaf Friedewald
  Engineering Science and Industrial Design, Hochschule Magdeburg-Stendal

- Hardware Design for an Ultra-Wideband Positioning System using Off-the-Shelf Components
  Marco Gunia, Niko Joram and Frank Ellinger
  Chair of Circuit Design and Network Theory (CCN), Technische Universität Dresden

11:30 - 13:00: Lunch

13:00 - 14:00: 3rd Session – RSSI

- Investigation of Anomaly-based Passive Localization with IEEE 802.15.4
  Marco Cimdins, Mathias Pelka and Horst Hellbrück
  Department of Electrical Engineering and Computer Science, Lübeck University of Applied Sciences, Germany

- Attack Detection in Wireless Networks Using Channel State Information
  Sebastian Henningsen, Stefan Dietzel Björn Scheuermann
  Computer Engineering Group Humboldt University of Berlin, Germany

14:00 - 14:30: Coffee Break

14:30 - 15:30: 4th Session – Automotive

- Parking lot monitoring with cameras and LiDAR scanners
  Daniel Becker, Andrew Munjere, Oliver Sawade, Kay Massow, Fabian Thiele, Ilja Radusch
  Daimler Center for Automotive Information Technology Innovations, (DCAITI), Fraunhofer Institute for Open Communication Technologies (FOKUS)

- Lane-Precise Navigation on Incomplete Maps
  Johannes Rabe and Benjamin Joswig
  Daimler AG, Sindelfingen, Germany

15:30 - 16:00: Wrap Up

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