Towards Scalable Multi-Hop Indoor Localization

Simon Schmitt
AG Computer Systems & Telematics
Freie Universität Berlin
Berlin, Germany
simon.schmitt@fu-berlin.de

Abstract — **The indoor localization problem is on the verge to be solved if near-optimal conditions are met. To solve the general case without a priori knowledge about the environment, different systems have to be combined to mitigate well known drawbacks of a single system, e.g. inertial systems (drift) and range based systems (non-line-of-sight). To cope with a low anchor density or reachability, multi-hop techniques have to be developed which incorporate all available information to refine the localization accuracy. Such solutions can be applied to search and rescue missions as well as self-localization in huge crowds of people.**

Keywords—indoor localization; radio-frequency based ranging; inertial measurement; scalability; multi-hop

I. Biography

I am a Ph.D. student in an early stage. I finished my Master's degree at the Freie Universität Berlin in end 2013 and immediately started working as a research assistant and Ph.D. student at the same university. My research area is indoor localization with a focus on radio-frequency based distance estimations. My current advisor is Prof. Dr. Marcel Kyas, who works in the same research group. My expected graduation time is 2016-2017.

II. Introduction

The process of searching a destination or the own position in an unknown environment is part of our daily life, i.e. when we look at a map in a building we do not know, when we drive to an unknown destination using satellite-based navigation systems, or simply when we ask for the right direction. In the coming years we will be able to find the product we want in a supermarket right away, find our own positions in public buildings and get the direction of the room we look for.

To achieve this goal, the research of indoor localization solutions and current applications focuses on systems of different types, i.e. inertial measurement, time-of-arrival, time-difference-of-arrival, angle-of-arrival or the difference in phase. Another common method is the recording of the received signal strength (RSS) of surrounding equipment at known locations and finding the best match when the current position is searched.

During an indoor localization competition in 2014, 21 competing teams had one day to calibrate their system in an environment, which was partly changed for the evaluation on the next day. The winning team used a ranging based approach and achieved an average accuracy of 0.72m. The second place was given to a fingerprinting approach which achieved 1.6m on average. One can ask what accuracy is enough for the task at hand. Such positioning errors should be sufficient for locating a person. However, these results were produced during optimal conditions, i.e. a high anchor density was possible, a detailed map and enough time was given to survey the testing ground.

This shows that the localization problem in indoor scenarios is reasonably solved if time and resources are not an issue. It has not been solved in terms of absolute or at least room accuracy in the general case, where it is not possible to install equipment, survey the environment or get a map of the building beforehand, e.g. in security-related or search and rescue missions.

The domain of my research is the localization of people inside unknown buildings or structures of any type during security-related or search and rescue missions. Possible scenarios are the tracking of first responders and succeeding emergency crews, but also the localization of oneself or another person in huge crowds of people.

III. Research Questions

The first research question is which methods are usable for such scenarios. Since our department has much experience with radio-frequency (RF) based range estimation and inertial measurement systems, it is obvious to combine both methods. Inertial systems suffer from drift over time, and RF based distance estimations suffer most from non-line-of-sight (NLOS) effects. Another aspect is the influence of temperature, humidity and other conditions, e.g. during a fire incident, on range based localization. It should be possible to fusion independently collected inertial measurement data of people walking alongside each other, e.g. fire fighters never enter a burning house alone, and correct the resulting drift with single distance estimations to known locations. Such known locations could be anchors in front of the building, which get their position by satellite-based systems, or other (groups of) people which possibly move and estimate their position on their own.

The number of possible distance estimations to static and known positions heavily depends on the environment, the anchor density, and the radio range of the devices in use, among other things. If this number is too small, one-hop trilateration techniques might not allow a good position estimation or no estimation at all. If there are NLOS effects, then the result will suffer from even greater error. If multiple participants are to be located which are at least partly in radio range of each other, then they might be able to cooperate and solve the task together. The case where one estimates a position based on other movable participants which themselves estimate their position is called multi-hop localization. This technique might help to mitigate the effects of a limited radio range and allow to recognize NLOS distance estimations. Much research has been done to localize a single person inside the convex hull of static, precisely located, and with much thought installed anchors. If we look at the multi-hop case, we might not have enough anchors in the vicinity, such that we are outside of the convex hull of static anchors. This case is much harder to solve. If there is only one or no connection to static anchors, the estimated positions of a group of participants will drift and rotate in a random direction over time. The question addressed in this topic is two-parted. First, we should ask how we can improve the positioning result outside the convex hull by cooperation between multiple mobile participants that see different static anchor sets, and second, if and how it is achievable to improve the resilience by combining possibly multiple inertial measurement systems and fusion their data with distance estimations between the participants.

If we only look at emergency scenarios, privacy is not a big issue, since all participating people benefit from each other in a way which enables a more efficient rescue of people in need. But privacy is a huge issue when considering the case when a private individual wants to locate certain other people. This is not a problem if we have a one-hop connection to the target device, since both participants can decide to take part in the process or not. The multi-hop case however is only possible when multiple devices take part in the localization process. So an attacker might be able to read or estimate the position of devices or people between him and his actual target. So one question is if, and if yes how, we can guard people against such an attack.

IV. Methodological Approach

To answer the first research question, we have to look at well-established data fusion possibilities which allow the combination of both separate localization systems and reduce the overall error. It might be helpful to look at raw information of the inertial system, e.g. speed, and use these information to filter distance estimations, the trilaterated position, or even incorporate it into trilateration algorithms. This technique can of course be also applied vice versa, e.g. by using single distance estimations to correct the drift of the inertial system. In order to test and evaluate these fusion approaches, one can simulate both systems or design real-world experiments. Since on the one hand the simulation of all components would be a research topic on its own, and on the other hand our research group has the resources and experience to perform real-world experiments, it is wise to build on and develop this know-how further. To allow for numerical analysis of the developed solution, mobile robots can gather ground truth data of the participant or a group of participants. As shown in section V, we already have experience with such solutions.

These robots can also be used to examine the effects of position estimation outside of the convex hull of static anchors in range. The experiments can be designed to gather both ranging data to static anchors and other mobile participants in range and all ground truth positions simultaneously which allows for offline development of multi-hop cooperation algorithms on real-world data. The same technique can be applied to develop a calibration technique for the inertial system in neighboring and possibly moving participants.

The privacy issue of knowing the position of neighboring participants is hard to solve. Since the mere presence of a signal indicates a sender, the best solution is not to take part in any communication at all. If we allow for distance estimations, an attacker can estimate the position of the participant by triangulating its position. If we further communicate own estimated positions, an attacker has no problem at all to find the participant. Since we have to send signals and communicate distances between participants in order to localize them, the only solution is to seek some kind of tradeoff. A possible solution is to limit the allowed requests depending on the density of known participants, anonymize the positions themselves, and still allow collaboration, which shall be pursued in this topic.

V. Research Done So Far

During my Bachelor's thesis I built a general and independent reference system for indoor localization solutions [1]. This mobile robot can carry and track a localization system and evaluate its positioning error. I used this system during my Master's thesis to build a database of real-world measurements which can be used to analyze localization algorithms numerically and visually [2].

In order to deepen the knowledge about physical effects of ranging based localization systems, I looked into anchor placements and influencing properties of buildings [3]. This work shows the spatial distribution of ranging errors in typical indoor scenarios. To further evaluate the current achievable accuracy of indoor localization algorithms, I looked into the spatial error distribution of localization algorithms [4].

Previous experiments were conducted with the localization system placed on top of a robot and without any human interference. To include that factor I conducted an experiment to evaluate the impact of a human carrying the device to be localized next to his body [5]. This work strongly suggests that it might be feasible to use multi-hop localization to enhance the accuracy, if static anchors are scarce.

References

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