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Testbed for Development and Verification of Hybrid Localization Systems

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Abstract— **In this paper a testbed for development and verification of hybrid localization systems is presented. It allows for systematic analysis of hybrid localization methods and speed up the development of new schemes. The proposed testbed platform is composed of subsystem for sequential data collection and testing infrastructure that can be used for investigating the localization mechanisms in controllable environment.**

Keywords—**Hybrid Localization; Wireless systems**

I. Introduction

One of the most important factors in every localization system is its effectiveness, which refers to localization accuracy and reliability with respect to total system's costs. The market demand for highly accurate localization systems can be reduced due to high costs of required infrastructure. The other important factors that limit the localization systems' applicability are properties of the environment where systems will be used. Localization in harsh environments like ship's deck, where many metallic walls are present, using RF (Radio Frequency) signals and RSS (Received Signal Strength) based localization algorithms may result in poor performance and low reliability.

Localization methods differ both in measured environmental features (signals) and their properties that are extracted. The most popular methods use different characteristics associated with the propagation of radio signals [1], e.g. RSS (Received Signal Strength), ToF (Time of Flight), ToA (Time of Arrival), TDoA (Time Difference of Arrival), PoA (Phase of Arrival), AoA (Angle of Arrival), DoA (Direction of Arrival). Other methods may use images recorded by a video cameras [2], ultrasound [3] or IR (Infrared Radiation) sensors [4, 5].

The performance of the systems that rely on only one localization method can be enhanced by data processing algorithms. This however may not be sufficient as it only improves the overall system's performance and does not remove limitations concerning properties of signal distribution. To enable further improvement one can apply hybrid localization methods that rely on measurements of various signals from the environment and also different signal properties. The different components of such a hybrid localization system can mutually remove their weak points, which may result in increase of accuracy and reliability while maintaining the system's cost at reasonable levels.

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Development of hybrid localization systems [6, 7] is a complex process and usually theoretical calculations must be backed up by experimental verification. This makes the hybrid systems difficult to develop, thus most of them integrate only two localization methods. Such limited approach does not guarantee that the resulting scheme will give the best possible results. In order to optimally integrate more complex system a testbed for precise characterization of its individual localization components will be very useful. Unfortunately, the testbeds proposed in the literature for localization purposes do not refer to special needs of hybrid localization systems. Additionally, most of such testing environments are office test sites [8, 9] that can be used rather to verify overall system performance than to support development process.

In this paper we have proposed a framework of algorithms for hybrid localization methods that can be used for systematic analysis of hybrid localization and supports development of new localization schemes. Additionally, we have proposed a platform for development and verification of hybrid localization algorithms composed of system for sequential data collection from different localization components and testing infrastructure that can be used for investigating the localization mechanisms in controllable environment.

II. Framework of Algorithms for Hybrid Localization Methods

Hybrid localization systems integrate different sources of measurement data about unknown position of a localized object. In the schematic of proposed general framework of hybrid localization systems (Fig. 1) we call them *Localization Components* (LC). Each of them corresponds to a specific method of sensing localized objects, e.g. signal strength (RSS), time of arrival (ToA) or angle of arrival AoA of received signal in radio localization systems. These raw data are transferred to the next level of components called *Data Processors* (DP) for processing in different algorithms leading to a set of different computed positions. The accuracy of these results is affected by various factors that are specific for each of the LC-DP pair. In order to obtain one localization result the data from all the DP's are merged together in the last component called *Data Fusion* (DF). The DF is an algorithm for optimal combination of different position data providing the best possible reduction of localization error.

In order to show an example localization procedure within this framework we assume the presence of only one of each of LC and DP components. In this example we analyze the data flow in one LC_1-DP_1 pair for a simple localization algorithm (see Fig. 2) based on RSS trilateration (often referred to as triangulation) with signal level averaging. The LC_1 consists of K_1 anchor transceivers (elements of *localization component*) – $LC_1(1)$, $LC_1(2)$, ..., $LC_1(K_1)$. The transceiver measures the signal strength (RSS) received form an active transmitting tag being localized. The RSS data are transferred to DP_1 consisting of two algorithms – $DP_1(1)$ for real time signal averaging and $DP_1(2)$ for calculation of the tag's position by means of trilateration.

In real systems it is possible to use many algorithms $DP_i(k_i)$ in one data processor DP_i connected to one LC_i , which can form very complex data processing and intelligent decision procedure leading to substantial increase of localization accuracy [10].

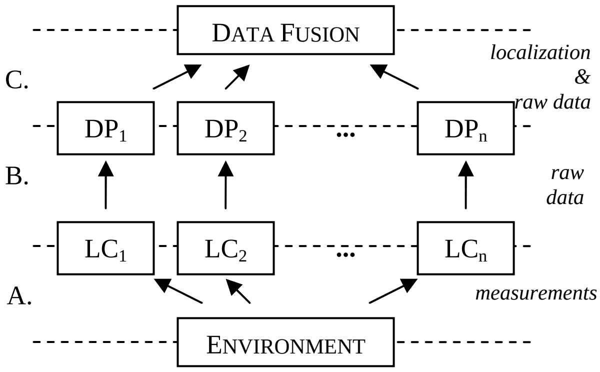

Figure 1. General scheme of a hybrid localization system: A. each *localization component* gathers data from the environment, B. raw data are passed to *data processors* to calculate localization for each set of raw data, C. processed data together with raw data are passed for data fusion.

The scheme of a hybrid localization procedure comprising two *localization components* is shown in Fig. 3. Although this example directly refers to an approach of combined fine RSS and coarse AoA methods presented in [7] it may also illustrate other two-component methods, like the one with coarse RF and fine Vision localization proposed in [6] .

The *data fusion* component (DF) that appears in such multi-LC methods poses a different challenge than the algorithms in DP, since the optimal combination of various *localization components* requires real time estimation of their actual accuracy. For developing such error estimators and final DF algorithms, a testbed allowing a systematic investigation of localization performance is recommended. For example, determining the statistical properties of correlation between different LC's would require the controlled pseudorandom obstacles disturbing the measurement of localization data.

III. Platform For Hybrid Localization Algorithms Development

Development of hybrid localization systems relies on *Data Fusion* algorithms that merge data coming from different *Localization Components*. The most popular methods [6, 7] use only two LCs and *Data Fusion* algorithms are developed based on simplified theoretical models (e.g. propagation models). As a consequence, the such algorithms are often mere combination of parameters measured by LCs and calculated by DPs. Here arises one of the biggest challenge during the development of hybrid localization algorithms – the difficulty of merging many different localization components in such a way that their weaknesses and strengths complement one another leading to improvement of accuracy and reliability of the resulting localization algorithm.

In order to take advantage of using many localization components the designers should be able to gather data that can be further freely merged to provide the best results. For creating such complex hybrid localization algorithms one has to systematize the process their development and experimental validation. To address this we propose to use a platform (see Fig. 4) for data collection from each localization component independently. The platform employs *Single Board Computers* (SBC), where the elements of different *Localization Components* can be connected. The data from the LCs gathered by the SBCs are transferred to the central server's database.

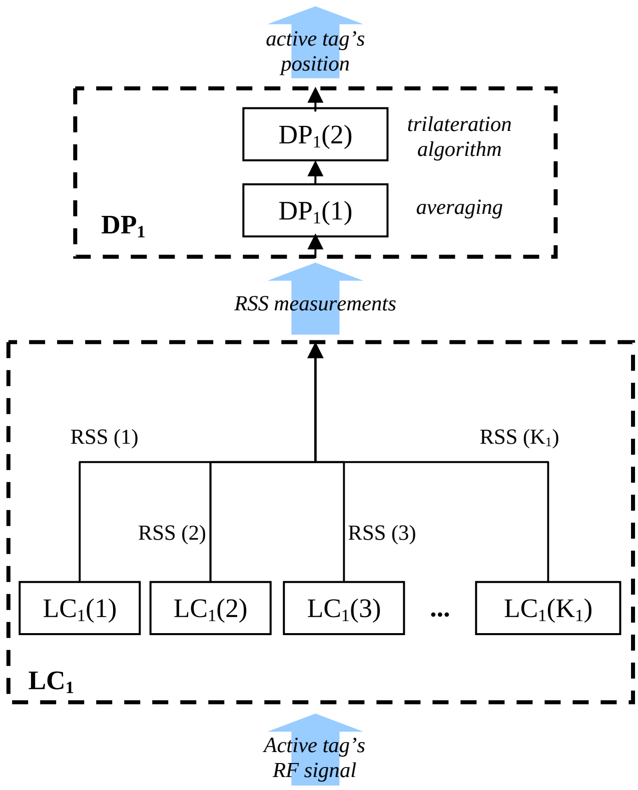

Figure 2. An example scheme for on LC-DP pair for localization using RSS trilateration and signal averaging.

The Single Board Computers will be installed both in office environment and in anechoic chamber (for reference measurements), thus they should include the following features:

- ARM9 microcontroller with Linux OS (scheduling of measurement sessions, synchronization, data acquisition and processing, communication)
- 4 UART interfaces for communication with elements of *Localization Components*

- 1 SPI interface for communication with additional elements of *Localization Components* or with devices equipped with SPI interface
- RS-232 communication port for the SBC configuration
- Ethernet port for communication with server during verification tests (in the office environment)
- Fiber optics port for communication with server during tests in an anechoic chamber
- Power supply: battery or Power over Ethernet (PoE)

The whole process of data collection has a form of a SBC program that can be written down in the following scheme:

1. User determines parameters of the measurement session via server's web application
2. Server programs SBCs with a measurement schedule
3. Server synchronizes SBCs
4. Each SBC at the same time sends requests to elements of LC_1 ($LC_1(1)$,...,$LC_1(K_1)$) and collects measurement results
5. Data processing of the measurement data is performed in each SBC
6. Each SBC prepares for the next measurement and performs point 4 for the next *Localization Components* (LC_2, LC_3, ..., LC_n)
7. After measurement session is finished, results are sent to the server's database
8. If next measurement sessions are scheduled SBC performs points 3-7.

The measurement platform allows one to program several measurement sessions that can be performed in a long sequences to capture statistical behavior of analyzed *Localization Components*. This will also enable gathering data for development and verification of hybrid localization systems.

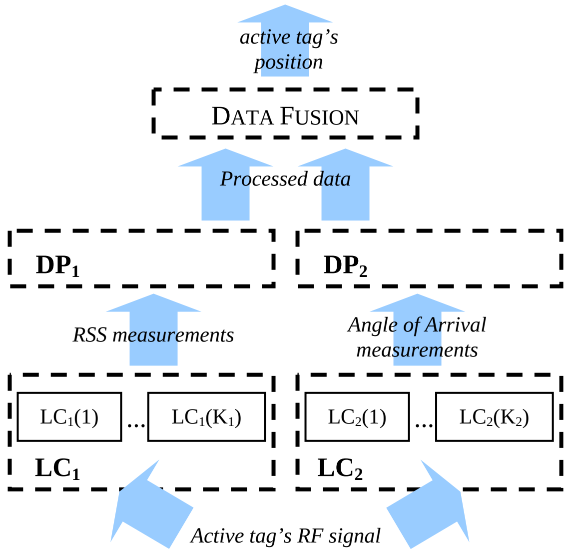

Figure 3. An example scheme for a two-LC hybrid localization using RSS and AoA measuremenrs.

IV. Development of Hybrid Localization Methods

The platform for testing localization algorithms presented in the previous section is a powerful tool that can also be used for development of hybrid localization methods. However, the platform should be complemented the correct methodology that will not only measure the overall performance of the system or its individual components, but also give an insight into the underlying phenomena and relation between different localization mechanisms. The concept for development of hybrid localization methods proposed in this paper relies on two basic steps:

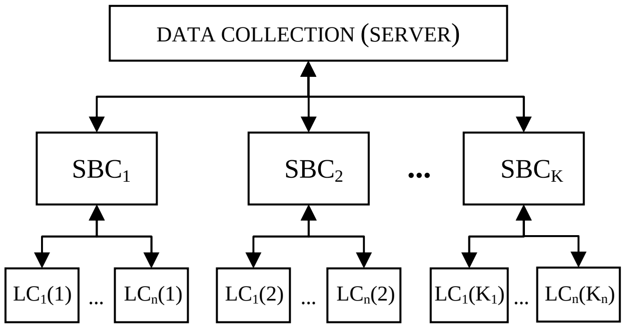

Figure 4. The idea of a platform for development of hybrid localization systems for equal number of elements for each localization component (K_1=K_2=...=K_n=K).

- system modeling – the process that allows one to capture the behavior of any *Localization Component* in an environment with controllable propagation conditions
- system verification and testing – the process that is conducted in an environment with controllable propagation conditions but also in real word setup.

A. *Hybrid Localization System Modeling*

To model the behavior of each LC of hybrid localization system precisely we propose to conduct modeling process in an anechoic chamber that is adapted to localization measurements.

Inside an anechoic chamber with dimensions 5m x 6m x 11m we will set 6m high wooden columns that can be placed in any position within the anechoic chamber (see Fig. 5). Columns will serve as reference points and are constructed in such a way, that it is possible to attach one SBC to each column at freely determined height. Each SBC will be powered by a battery source and will be connected to a server using fiber optics connection. Such configuration is necessary to minimize radio frequency reflections from the test-bed, which in case of using cables providing external power source and communication could be significant.

Additionally, to provide testing points inside anechoic chamber smaller 2m height columns will be placed. Like in the case of reference columns Active Tags will be attached to test columns at freely chosen height. An example of placement reference columns with SBC and test columns wit AT is presented in Fig. 6.

Modeling of LC parameters using anechoic chamber allows one to take into account all parameters that are present in devices being a part of elements of localization components used to gather data from environment (discretization of power levels in RF transceivers, influence of radiation patterns in antennas, resolution of cameras used in computer vision systems, etc.). As a consequence accurate modeling will help to develop more optimal algorithms for localization in hybrid systems.

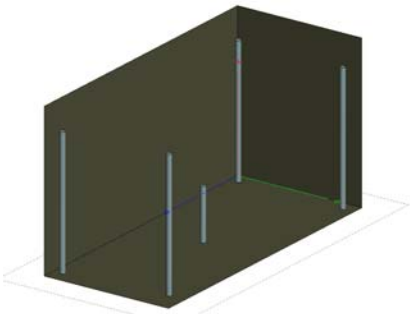

Figure 5. An anechoic chamber with 4 reference and 1 test columns for the reference measurements of LCs.

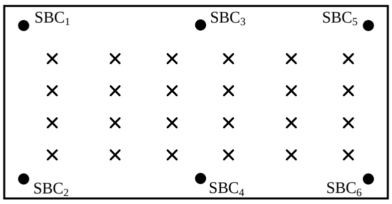

Figure 6. An example distribution of SBCs (dots) and ATs (croses) inside an anechoic chamber for the modeling of *localization components*. All SBCs are attached to the reference columns at 3m, while all ATs are attached to the test columns at 1,5m.

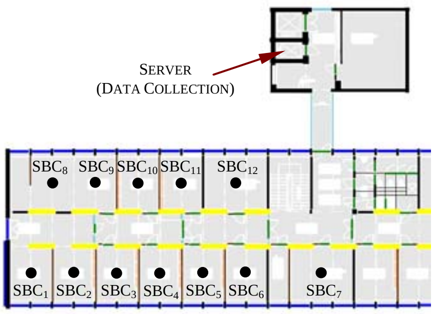

Figure 7. Office environment for final test of developed hybrid localization systems. All SBC (dots) are attached to the ceiling (height 2,8m) and are connected (power and communication) to the server using ethernet cable via PoE switch.

B. *Hybrid Localization System Verification*

Once algorithms for hybrid localization system are developed one has to verify the quality and reliability of the localization system. Initial tests will be conducted in an anechoic chamber (in a system similar to this in Fig. 6), where propagation conditions will be modified by placement of obstacles. Such test will verify immunity of the hybrid localization system for different disturbance factors. Moreover, it will be possible to isolate such cases, where accuracy loss in the system will be observable due to the presence of obstacles in specific locations within the chamber. Once such cases are determined one can improve underlying algorithms to increase the accuracy and reliability of the system.

Final verification of the developed hybrid localization system will be conducted in the office environment presented in Fig. 7. This is a real world scenario where many disturbance factors will appear in unpredictable manner (way). The final test will show how developed hybrid localization system will work in conditions close to future system deployments. Active Tags for system verification can be attached to test columns and distributed randomly or in order over the scene. Moreover, some of ATs can be attached to devices that can be moved freely or serve as badges for personnel to provide information of the system behavior when ATs are mobile.

V. CONCLUSIONS

We have proposed a platform for development and verification of hybrid localization algorithms composed of system for sequential data collection from different localization components and testing infrastructure that can be used for investigating the localization mechanisms in controllable environment.

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