A Simulation Environment for PDR-aided Localization in Wireless Sensor Networks

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***Abstract*—In this paper, a simulation environment for person localization and pedestrian dead reckoning (PDR) in wireless sensor networks (WSN) is presented. The purpose of this simulation environment is to provide a simple possibility to evaluate different localization approaches under varying environmental conditions. In particular received signal strength (RSS) localization in combination with pedestrian dead reckoning (PDR) is targeted. We present a first error analysis of the simulation and compare the results to experimental data on position level.**

I. Introduction

Localization in wireless sensor networks (WSN) has gained a lot of attention recently. This results mainly from the fundamental interest in the relation between a measured value, its time and its location. A special case for WSN is person localization in emergency scenarios, e.g., firefighters entering a burning building or police operations in and between buildings. In such scenarios no previously installed infrastructure can be assumed and seamless in- and outdoor localization is required. The evaluation and optimization of different algorithms and parameter settings is a difficult task because experimental evaluation needs a WSN testbed to be set up which is very time consuming. While real world data is needed to determine the applicability of localization concepts, some aspects are not sufficiently taken into account. For example scalability or the effects of random or partially random variations in the anchor node positions cannot easily be tackled for single instances of collected data. Hence, an approach to a modular simulation environment for error evaluation of a combined pedestrian dead reckoning (PDR) and WSN localization system is presented.

II. Related Work

As there is a large WSN community and many WSN related problems are evaluated through simulations only, a large number of different network simulators have been developed [1]. However, there is still a lack of simulators for the specific problems occurring in localization scenarios. Especially the option to include different sources of localization information, i.e., PDR or map knowledge is still missing in most WSN simulators. The simulation of PDR-trajectories on position level has been studied in comparison to classical inertial navigation systems (INS) [2]. Also the influences of magnetic disturbances have been simulated [3].

III. Simulation Environment Overview

An overview of the presented System is depicted in Fig. 1. A modular approach is pursued to allow further extensions.

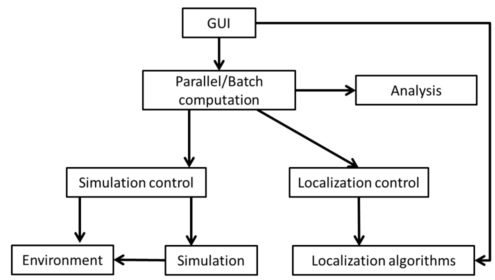

Fig. 1. Simulation Environment Overview

The main functionality is represented by the *Simulation* block. The paper focuses mainly on the different subsystems of this block. The *Environment* block basically consists of a database which delivers environmental parameters. Different localization algorithms can be evaluated by the *Localization* block. Furthermore there are *Control* subsystems, a *Parallel/Batch* execution module to allow for running different simulations as parallel threads. Settings and parameters as well as graphical visualization of any result is separated in a *GUI* whereas localization data are being analyzed by the *Analysis* module. The next paragraphs describe the main simulation tasks of the *Simulation* module.

A. Trajectory Generation

The reference trajectory generation is not included in the simulation environment. Trajectories are generated externally and stored within the *Environment* subsystem. To allow the creation of realistic pedestrian trajectories, a trajectory-generation model based on the Blender 3D graphics software is used. Thus, the user can walk through a building virtually while the trajectory is generated.

B. Received Signal Strength

The localization is carried out by measuring received signal strengths (RSS) of incoming radio packets from anchors at known positions. To simulate the behavior of RSS values under different environmental conditions a large number of packets have been recorded in various experiments. Based on these data, parameters for the log-distance path loss model are obtained [4]. To simulate the behavior, a white Gaussian noise term according to the experimentally determined distribution of the real data is added. This statistical simulation approach is preferred over ray-tracing methods due to its lower computational complexity and lesser need for an accurate simulation of the environment. Walls between sender and receiver result in a constant drop-off in the corresponding simulated RSS value depending on a parameter for each wall.

C. Pedestrian Dead Reckoning

The trajectory of any pedestrian dead reckoning (PDR) system is characterized by an accumulating error over time. Depending on the accuracy of the used inertial measurement unit (IMU) and the applied signal processing, different accuracies can be achieved. The error is usually given in a percent figure of the traveled total distance and typically in the range of a few percent. If PDR-algorithms shall be evaluated within a simulation environment the reconstruction of acceleration and turn-rate-signals is necessary. However, as long as just the error of the trajectory is of interest, it is sufficient to simulate the errors on position level. This allows a simulation of IMUs with different performance characteristics, but also different approaches to PDR in general (e.g. hip or foot mounted). In this paper the errors of the PDR-system are modeled by adding a normally distributed white Gaussian noise with mean and variance in each step. A new position $pos(i)$ is calculated from the last position $pos(i-1)$ by adding the distance $\Delta pos(i)$ derived from the reference trajectory and a Gaussian noise term N.

$$pos(i) = pos(i-1) + \Delta pos(i) + N \tag{1}$$

This simple approach simulates errors in the target coordinate frame (navigation frame) only. If an error in body-frame (b-frame) coordinates needs to be modeled the b-frame needs to be reconstructed from the reference trajectory. By defining a right handed coordinate system with an x-axis aligned with the pedestrian's movement the direction cosine matrix (DCM) can be obtained. This allows adding additional errors which occur in the b-frame.

IV. PDR Error Simulation

The PDR system considered in this paper uses a hip mounted IMU which calculates its attitude based on a triad of gyroscopes, accelerometers and magnetometers. From the acceleration pattern steps are recognized and the step length is estimated. Together with the attitude a new position is obtained. There are mainly three error sources occurring in the considered PDR approach. Errors in step detection can arise and introduce an error of one step length. The step length estimator introduces the second kind of error with each step. The third error is characterized as a misalignment of the IMU to the user's body. An in depth error analysis of all error sources is beyond the scope of this paper, but an approximation by a white Gaussian noise in the n-frame can serve as a simple starting point. Fig. 2 shows the reference trajectory recorded by a differential GPS system, the reconstructed PDR trajectory and an exemplary simulated PDR trajectory. The simulation was carried out using a white Gaussian noise with mean of $0.01 m/s$ and a variance of $1 (m/s)^2$. It can be seen that with this simple approach realistic trajectories can be generated. However, for a more comprehensive study more parameters have to be taken into account to allow for a fine grained trajectory generation.

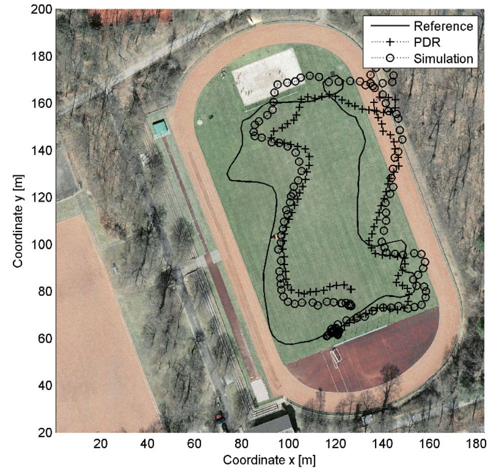

Fig. 2. Simulated vs. calculated PDR trajectory

V. Conclusion and Future Work

A simulation environment for combined PDR and WSN localization is presented. One of the design goals is a very modular system which can be extended by additional modules. In this paper a very simple approach to PDR trajectory-simulation is given as a starting point for the PDR simulation module. Future work will include a deeper analysis of the error evolvement of PDR and WSN localization systems. Also, investigations in simultaneous localization and mapping (SLAM) methods will be done in the near future.

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