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Bayesian Methods for Hybrid Indoor Positioning

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I. Biography

I am a Ph.D. student at Tampere University of Technology, Finland. I received the M.Sc. degree in applied mathematics from the same university in 2012. My instructors are Prof. Robert Piché and Dr.Tech. Simo Ali-Löytty. I have worked in industrial projects co-operating with Nokia Inc., and I started in the TUT Graduate School in 2014. I am expected to graduate in 2017. My research interests are Bayesian estimation, Monte Carlo methods, and personal positioning algorithms, especially hybrid indoor positioning.

II. Outline

My topic is hybrid personal positioning in GNSS-blocked (global navigation satellite system) environments. This requires combining information from several independent channels, especially if no positioning-specific modifications are made to the hardware infrastructure. Potential measurements are e.g. inertial effects, air pressure, map-matching, and signal strength or time-of-arrival of cellular, WLAN (wireless local access network), or UWB (ultra-wideband) radio signal.

The research is based on the Bayesian statistics, which models all the unknowns as probability distributions. Different channels measure different characteristics of the user's state with different accuracies. The mathematical structure of the statistical model often becomes complex, highly nonlinear, and/or non-Gaussian. I aim at modelling factors of personal positioning with realistic probabilistic models that enable use of estimation algorithms that can be computed in a mobile device in a feasible time.

My work relies on strong knowledge of the theoretical background of statistical modelling and mathematical methods. The developed algorithms are tested with thorough computer simulations. Furthermore, I try to collect realistic positioning data in real positioning environments to validate the made statistical assumptions.

III. Research carried so far

A. Statistical path loss modelling

The well-known logarithmic path loss (PL) model for the received signal strength (RSS) in dBm units is

$$P = A - 10n\log_{10}(\|\mathbf{x}-\mathbf{m}\|) + w,$$

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where A and n are the PL parameters, $\mathbf{x}$ is the user position, $\mathbf{m}$ is the communication node (CN) position, and w is Gaussian noise [1]. No knowledge of the network is assumed, so all the parameters are learned using training data. Furthermore, the parameter learning may be based on data that are collected without any planning. Thus, the amount and geometry of the data are random and varies from CN to CN.

My PL model-based positioning research for cellular outdoor and WLAN indoor and outdoor cases is presented in the articles [2–4] as well as in my M.Sc. thesis [5]. The PL parameter variances are also estimated and used in the positioning phase. Examples of cases with high and low amounts of data are provided in Fig. 1. The real-data tests indicate that CN-specific estimation of parameters and their variances improves especially estimation consistency, which measures how realistic the variance of the position estimate is. Positioning accuracy is also improved slightly especially if the training data coverage of some CNs is poor. Consistency of the estimation is crucial when different measurements (different types, sources, or time instants) are combined.

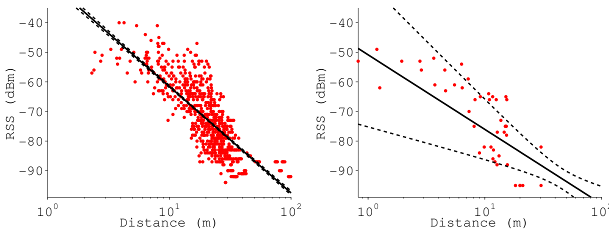

Figure 1. Fitted models with variances induced by the uncertainty of A and n (the dashed curves). Fewer samples means more variance.

B. Hybrid indoor positioning using Particle & Kalman filters

The measurement technologies used in this research are WLAN, inertial measurement unit (IMU) containing gyroscopes and accelerometers, indoor floor plan, and barometer. Measurement sources are combined in a real-time indoor positioning system by the Particle filter (PF) algorithm [6]. Nurminen et al. review different versions of this algorithm and present their own in [7].

The particles are moved with quite low noise levels in a 3D space and given reduced weight if they cross walls or floors in the map. Footstep length and absolute barometer altitude are not calibrated either, because the PF is capable of learning them. WLAN and barometer measurements and knowledge of floor elevations and staircase locations (map) provide altitude information for the PF. For ensuring adequate particle coverage, the WLAN estimates are to contain realistic variance information.

Since the PF only observes the most probable locations, it can occasionally get stuck [8]. Therefore, the paper [7] presents an efficient method for initialisation, quality monitoring of the estimate and divergence recovery. It runs a fallback Kalman filter in the background. The PDR-KF (Pedestrian dead reckoning Kalman filter) algorithm proposed by Raitoharju et al. combines IMU and WLAN measurements without linearisation errors [9]. It does not use floor plan, so the wall constraints do not prevent its recovery from divergences.

C. Map-based motion models

Many consumer-grade mobile devices are equipped with only low-quality IMU or no IMU at all, which makes reliable PDR challenging or impossible. Random-walk-based motion models carry, however, so little information that PFs using them as a proposal distribution are inefficient, since particles tend to collide walls too frequently. A solution to this problem is to use map information in the proposal distribution.

The map can be condensed into a graph, a set of links, on which the probability is distributed [10]. Fig. 2 shows an example of such a graph. Nurminen et al. [11] propose a novel rule for link transition probabilities that determine how the probability is distributed at a link end. The proposed rule assigns more probability to links that provide access to larger subgraphs in the map, such as corridors and open spaces. The presented real-data tests show that the PF using the proposed model outperforms the random-walk wall collision PF and the conventional graph-based PF methods.

Figure 2. Particles move on the links of the graph-based map. Floor plan with dim colour, links with black, particles with red.

IV. Expected future results

In future I will combine UWB radio signals with navigation-capable sensors of a smartphone. I will also continue working with indoor maps for improving efficient usage of position information in PFs' propagation step. I will study algorithms for constructing and validating the graph-based floor plan representations. An interesting future topic is floor estimation using maps and other measurements. The presented algorithms are in principle 3D or 2.5D methods, but a thorough insight into the details of floor filtering is missing.

Furthermore, my research interests include developing measures for and measuring the consistency of statistical estimates, also non-Gaussian. This is important not only for making the algorithms function better but also for achieving better understanding on the validity of the used statistical assumptions.

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