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Research on Pedestrian Indoor Multi-Source Positioning Algorithm Based on Strapdown PDR and Magnetic Field Matching for Smartphone

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ABSTRACT

To meet the needs of consumers for outdoor/indoor seamless location-based services (LBS), there is an urgent need for indoor positioning technologies. This thesis proposes an indoor multi-source positioning solution based on the smartphone built-in sensors, environmental magnetic field distortion feature, and Bluetooth Low Energy (BLE) fingerprint. The highlights of the thesis are 1) enhancing the autonomous recursive positioning ability of pedestrian dead reckoning (PDR) by using strapdown inertial algorithm that is fully self-contained; 2) using the relative trajectory pattern generated by PDR to improve the accuracy of magnetic field feature matching and BLE fingerprint matching, to ultimately improving the performance of the multi-source integrated positioning.

Based on the proposed key techniques of robust PDR, magnetic field matching, and real-time/post-processing multi-source fusion positioning, this thesis has formed a complete set of indoor pedestrian positioning solutions. The solution meets the needs of consumer indoor LBS applications and has the characteristics of reliability, scalability, real-time response, and low cost. The research results of this thesis provide a feasible reference design case for solving the indoor positioning problem of consumer pedestrians. The relevant solution and sub-solutions in this thesis have won multiple international indoor positioning championships in NIST PerfLoc 2018, IPIN2018, and IPIN2020 competitions.

Chapter 1 introduces the research background and related previous works. By commenting the advantages and disadvantages of the existing consumer indoor positioning methods, the proposed design of the scheme in this thesis is expounded.

Chapter 2 introduces the basic principles of the consumer pedestrian indoor positioning technologies as the theoretical preparation of the whole thesis, including reference coordinate systems, typical pedestrian inertial navigation algorithms, wireless signal fingerprint matching algorithms, typical magnetic field navigation algorithms, and commonly used estimation methods.

Chapter 3 designs a pedestrian dead reckoning algorithm based on strapdown inertial mechanization. To mitigate the positioning drift of the strapdown result, the user motion status observation and various constraint information are used to construct the filter observation models, which include zero velocity, zero angle rate, walking speed, pedestrian motion constraint, relative position increment, accelerometer observations of tilt angle, quasi-static magnetic field vector, and the orientation of the building layout. And the movement speed maintained by the PDR is used to

estimate the difference between the user's movement direction and the phone orientation, thereby improving the availability of the PDR that is often affected by the user's behavior and habits. The proposed robust and reliable PDR algorithm in this chapter helps to reduce the development cost and increase the robustness and scalability of the whole multi-source positioning system.

Chapter 4 proposes a high-efficiency and high-precision indoor magnetic field feature matching and positioning scheme, including a fast construction method of magnetic field map based on foot-mounted PDR and a magnetic field contour matching algorithm. In the magnetic field map generation stage, this thesis adopts the idea of a foot-mounted PDR + a smartphone built-in IMU + sparse ground control points, which can provide the high-precision coordinates and attitude tags required for the generation of the magnetic field map with high efficiency and low cost. In the real-time positioning stage, a matching algorithm based on a magnetic field contour is designed, so as to improve the probability of success matching. The algorithm first uses traversal search to provide rough matching results, and then uses Gauss-Newton iterative search algorithm to complete fine matching, and finally provides high-precision magnetic feature matching positioning results.

Chapter 5 proposes a complete real-time multi-source fusion positioning algorithm based on the PDR relative trajectory constraints. Similar as the proposed magnetic feature matching, the conventional BLE fingerprint matching is also boosted by using the relative trajectory pattern of PDR, so as to enhance the reliability. Since fingerprint matching methods inherently cannot provide the error level of each positioning epoch, the constraint conditions constructed by the PDR relative trajectory sequence are used to evaluate the quality of the output results through investigating the matching residuals along the sequence, and give theoretical standard deviations. Therefore, the whole multi-source fusion filtering performance get improved significantly.

For the problem of heavy maintenance of the positioning fingerprint database, this thesis designs an offline user trajectory recovery algorithm based on sparse landmark correction. It makes full use of the advantages of the continuity and smoothing algorithm of the strapdown PDR, combined with the position correction of sparse signal landmarks of opportunity, to reliably output the user's high-precision position trajectory. The smartphone user offline trajectory recovery algorithm can enable the crowdsourced update of the fingerprint database, which makes the real-time multi-source fusion positioning scheme proposed in this chapter more feasible.

Chapter 6 summarizes the work of this thesis and suggest the future works.