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硕士学位论文

基于 MEMS 传感器的高精度行人导航算法  
研究

Research of High-accuracy Pedestrian Navigation  
Algorithm Based on MEMS Sensors

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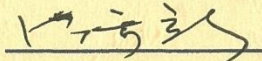
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## 摘 要

伴随微电子技术迅猛发展,导航技术的应用领域已渐渐从军事化转向了商用化。近几年,室内导航技术得到了大力发展,受到了越来越多企业和民众的重视。但现有的室内定位系统多是基于基础设施实现,其缺点非常明显:需要提前在需要导航定位的环境中安装大量外部设备,投入成本不菲,且精度仍有待提高。本文拟设计一种基于自身传感器的行人导航系统来解决上述缺陷。

捷联式惯性导航技术不仅可以避免需要外设、投入高等缺陷,并且在短时间定位精度相当高,但随着时间的推移,其存在累积的漂移误差。针对这一点,本文基于卡尔曼滤波设计出一种有效补偿累积误差的算法。首先,通过捷联式惯性计算模块对惯性测量信息进行积分解算,由角速度积分求解出姿态信息,通过四元数法对加速度进行坐标转换,而后积分求解出速度信息,再二次积分求解出位置信息;然后,由零速检测模块通过三条件判断法对行人步行时的“零速度”阶段进行检测,当检测到“零速度”时触发卡尔曼滤波模块;最后,将捷联式惯性计算后的速度向量作为量测值,使用卡尔曼滤波来估计系统状态误差,通过求解出的速度估计协方差,对状态误差估计进行分段,融入后向固定区间平滑技术,进一步调整状态误差估计及其协方差矩阵,前向反馈校正行人位置、速度和姿态信息;同时,扩充了卡尔曼滤波状态模型,加入加速度计和陀螺仪的零偏误差信息,通过反馈校正惯性测量信息,进一步消除系统漂移误差,最终实现了室内环境的行人定位导航。

在上述误差补偿算法的基础上,本文设计了一种行人导航系统,通过多组实验仿真验证,在 500 m 路程内,该行人导航系统收敛在稳定状态,定位精度保持在 1 m 之内,实现了高精度的定位目标。

本文设计的行人导航系统,为基于自身传感器的室内定位提供了一种简单而有效的方法,可以进一步融合完善,并推广应用到智能家居、火场救援、超市购物、车库停车等诸多场景之中。

**关键字:** 捷联式惯性导航; 卡尔曼滤波; 固定区间平滑





## Abstract

With rapid development of microelectronics technology, the application area of navigation technology gradually shifted from military to the public. Indoor positioning technology is developing dramatically in recent years, attracting more and more attention from enterprises and the public. However, the disadvantage of currently existing indoor positioning system is obvious. Because most of these systems are based on infrastructure implementation, a large number of external devices should be installed in advance in navigation environment resulting in a high initial cost. In the meanwhile, the precision of these systems are waiting to be improved. In order to solve these problems, this paper will design a kind of inertial navigation system based on its sensors.

Strap-down inertial navigation technology not only can avoid the defects mentioned above, but also can greatly improves the accuracy of positioning. Nevertheless, as time goes on, the system would generate an accumulated drift error. Adjusting this problem, this paper designs a kind of algorithm to effectively compensate the accumulated error based on Kalman filter. First of all, the system uses strap-down inertial calculation module to calculate the integral of inertial measurement information, meaning that the system gets attitude information from the integral of angular velocity, and transforms the coordination of acceleration through quaternion method, and gets velocity information from the integral of acceleration, and then using quadratic integral to get the position information. Secondly, the system uses the zero-velocity detection module to detect whether the pedestrians are under the zero-velocity phase through three-condition judgment method. The Kalman filter module is triggered when detects the zero-velocity phase. Finally, the system uses velocity vector calculated in the strap-down inertial calculation as measurement value and calculates the estimation of system state error by Kalman filter, then uses the covariance of the

velocity estimation through forward Kalman filter to segregates the state error estimation, and further adjusts state error estimation and its covariance matrix with the backward fixed-interval smoothing technique. In the end, the system adjusts the position, velocity and attitude information of pedestrians by forward feedbacks. In addition, the author expanded Kalman filter state model by adding the zero-bias information from the accelerometer and gyroscope. This improvement further eliminated system drift error because of the feedbacks and adjustments of the inertial measurement information. After that, the system achieves the pedestrians positioning and navigation in the indoor environment.

On the basis of the above error compensation algorithm, this paper designed a pedestrian navigation system, it converge to a stable state and its position accuracy is less than 1 meter within 500 meter-long road through the experimental simulation. This system achieves the positioning target of high precision.

Pedestrian navigation system designed in this paper provides a simple and effective method to the indoor positioning based on sensors, which can be further integrated, improved, and applied in environments like smart home, fire rescue, shopping mall, and parking in the garage.

**Key words:** Strap-down Inertial Navigation System; Kalman Filter; Fixed-interval Smoothing

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