**MOTION MONITORING WITH A FOOT MOUNTED INERTIAL MEASUREMENT UNIT FOR PEDESTRIAN NAVIGATION SYSTEMS**

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The field of pedestrian navigation systems have grown in the last years because of the wide spectrum of future applications. Additionally the sensors for such systems become smaller and cheaper. For low cost navigation systems primarily Microelectromechanical System (MEMS) Inertial Measurement Units (IMU) are typically used. The main disadvantage of these sensors is their high bias instability. To achieve a long-term stable navigation solution, generally complementary sensor techniques have to be fused. In most outdoor applications with open sky conditions a Global Navigation Satellite System (GNSS) is used.

Our approach solely requires a foot-mounted IMU to estimate the navigation solution. This deals with the extreme challenging indoor navigation application when no additional sensor is available. For example this is necessary for the scenario of firefighters when they explore a burning building, because other sensors like cameras or Rotating Laser Scanner may fail because of dense smoke.

In this publication a precise classification of different gait phases with a foot-mounted inertial measurement unit is presented. The goal is to increase the accuracy and the robustness of the detected stance phases of the foot compared to state of the art variance based methods. The navigation solution is improved by applying Zero Velocity Updates (ZUPTs) in the classified midstance phases to the Kalman filter. The precise detection of the midstance phases is realized with a finite state machine (FSM) which separates the human gait circle in different sub states. These sub states model gait phases including forward, backward and staircase motion occurring in indoor scenarios.

Transition conditions allow to switch, depending on the current state, between the states. The most descriptive signal for the transition conditions is the angular rate in the sagittal plane. Also other classification features such as the jerk, absolute value and the variance of the acceleration and angular rate are used. We compute the angular rate in the sagittal plane by a transformation from the body-frame to the foot-frame. This transformation is initialized with the aid of two forward steps and updated during the walking sequence. Due to the transformation we are independent of the exact initial attitude of the sensor relative to the foot.

The hardware of the foot-mounted IMU consists of two different inertial sensors. One is the ADIS 16448 from Analog Devices with an in-run bias stability of 14.5°/h. The other sensor is the ultra-low cost MPU 9250 from InvenSense with a worse bias stability than the ADIS. The module can be connected to the processing unit via Bluetooth or USB cable.

To improve the navigation solution we apply additionally to the ZUPTs height and heading constraints to the stochastic cloning Kalman filter. The height constraint powerful prevents the height drift. The difficulty of the unobservability of the heading angle is solved by heading angle constraints during longer stance phases and if applicable pseudo delta heading angle measurements based on a principle building angle.

The accuracy of the detected ZUPTs is evaluated with real sensor data and compared to state of the art variance-based ZUPTs. The difference in the length of the estimated path based on the FSM technique and the variance approach are compared on 100m straight forward walks. Errors are noticeably smaller with the FSM based approach than the variance based technique due to earlier motion recognition. In further field tests backward motions are analyzed and the advantages of the motion classification with the FSM are shown. These tests are done for both sensors and the difference of the accuracy of the ultra-low cost MPU compared to the low-cost ADIS IMU are presented.

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