Micromechanical System for Pedestrian Attitude Estimation

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***Abstract*—This paper describes the shoe-mounted MEMS-based system enabling pedestrian attitude estimation. Despite the large amount of publications devoted to pedestrian navigation, development of the accurate pedestrian attitude estimation system is still quite challenging. Such system can be useful in GPS-denied environments for emergency services and military personnel.**

***Index Terms*— inertial navigation, microelectromechanical systems (MEMS), pedestrian navigation.**

I. Introduction

SINCE the 80s years to present, there has been increasing interest in research and development of compact, reliable and cost-effective inertial systems for motion parameters control [1-7]. Besides such traditional applications as strapdown inertial system (SINS) of small robots and unmanned aerial vehicles, MEMS inertial sensors becoming very attractive for personal navigation applications. Potential users of personal navigation systems (PNS) are: firefighters, emergency and security services. Ordinary users (pedestrians) also need such position estimation systems. Moreover of great interest is using of personal navigation equipment for military purposes. Personal navigation equipment enables to carry out continuous monitoring of personnel actions in absence of satellite communications, as well as performing "friend or foe" identification function. Solving these tasks requires the use of appropriate sensors meeting the requirements for size, weight and power consumption. Development of special navigation algorithms that will take into account features of human motion is also required.

II. Inertial measurement unit

A. Principles of operation

There are two ways to implement PNS or personal dead-reckoning (PDR): strap-down inertial navigation scheme for PNS and the second one is based on a pedometer for PDR [1].

SINS calculates the orientation parameters (rotation matrix $\mathbf{C}(t)$) of an object by integrating the gyroscopes signals. Once the orientations parameters are calculated coordinate transformation is performed and the accelerometers signals $\mathbf{a}_b$ can be expressed in the global frame of reference:

$$\mathbf{a}_G(t) = \mathbf{C}(t)\mathbf{a}_b(t) \tag{1}$$

Then the measurements should be integrated over the time in order to determine the speed $\boldsymbol{\upsilon}_G(t)$ and position $\mathbf{s}_G(t)$ of the pedestrian. At the same time the result of this integration should be combined with the previous position and velocity estimates:

$$\begin{aligned} \boldsymbol{\upsilon}_G(t) &= \boldsymbol{\upsilon}_G(0) + \int_0^t (\mathbf{a}_G - \mathbf{g}_G)\,dt, \\ \mathbf{s}_G(t) &= \mathbf{s}_G(0) + \int_0^t \boldsymbol{\upsilon}_G\,dt, \end{aligned} \tag{2}$$

where $\mathbf{g}_G$ is acceleration due to gravity in the global frame of reference.

MEMS inertial sensors used in personal navigation systems, meet the size, weight and power consumption requirements. In addition, inertial sensors are the only sources providing position and heading information when GPS signal is not available (buildings, urban canyons, dense forests). However, MEMS inertial sensors cannot provide high position accuracy since the position errors grow over time after integration and double integration operations. That's why MEMS inertial sensors are usually combined with GPS receivers. The accuracy of such combined systems is higher than the accuracy of individual systems.

In case of PDR algorithm the positioning information comes from a step-counter and step-length estimator. The length of the step can be calculated from direct integration of accelerometer measurements. Since the length of each step is determined separately, the error does not increase with time, but with distance (or number of steps).

A ZUPT (Zero velocity UPdaTe) algorithm reduces the errors of position estimates. The concept of the ZUPT algorithm is to periodically compensate the bias drift of MEMS inertial sensors during the stance phase of walking (foot on the ground). The detection of the stance phase is carried out by the accelerometers or gyroscopes. The major disadvantage of the algorithm is inability to correct heading drift errors.

B. Design and implementation

Proposed micromechanical personal navigation system enables continuous determination of the pedestrian position. It consists of the inertial measurement unit (IMU), the control board and a personal computer for data processing (Fig. 1). Three-axis MEMS sensors with digital interface (gyroscope, accelerometer, and magnetometer) were used to obtain an

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acceptable accuracy of the position estimation. 3-axis accelerometer, 3-axis gyroscope and 3-axis magnetometer form a 9-degrees-of-freedom (DOF) IMU. Gyroscope has on-board temperature sensor, which allows for the adjustment of the temperature-dependent bias drift. ATmega32 microcontroller acquires the sensors data, prepares data package and transfers it to computer. Data between the device and the sensors transfers via serial I2C bus. This makes possible to connect all devices in parallel on the same line and thus to reduce PCB size (fig. 2). The collected data is then transferred via UART to Bluetooth module which transmits data via wireless channel to computer. Data received from the sensors processed in MATLAB.

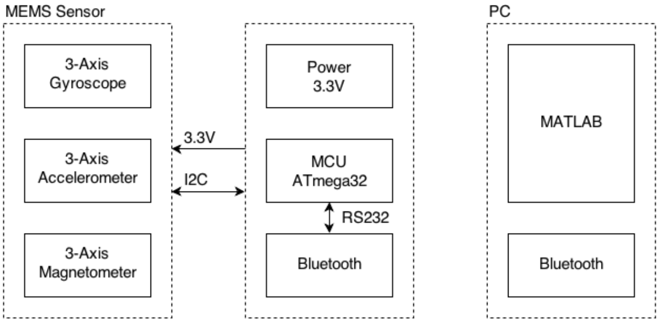

Fig. 1. Block diagram of the system.

The correct operation of the system requires a reliable mounting of the IMU. In addition, the location of the IMU with respect to the pedestrian's body should be fixed. Shoe soles suit well for this purpose.

The 9-DOF IMU data fused together using complementary filter algorithm. Sensors sampled at a 100 Hz rate.

Fig. 2. Implemented sensor module

Future implementation of the system will include the pressure sensor to get altitude information. Also GPS receiver will be used to estimate the sensor errors for compensation when the satellite signal is available.

III. Experiments

Experiments with the proposed personal navigation systems were carried out at an average walking speed. The corresponding IMU readings are depicted on Fig. 3. The peaks on the figure correspond to the step occurrences since the vertical acceleration is generated when the foot hits the ground. Thus every two neighboring peaks correspond to one step.

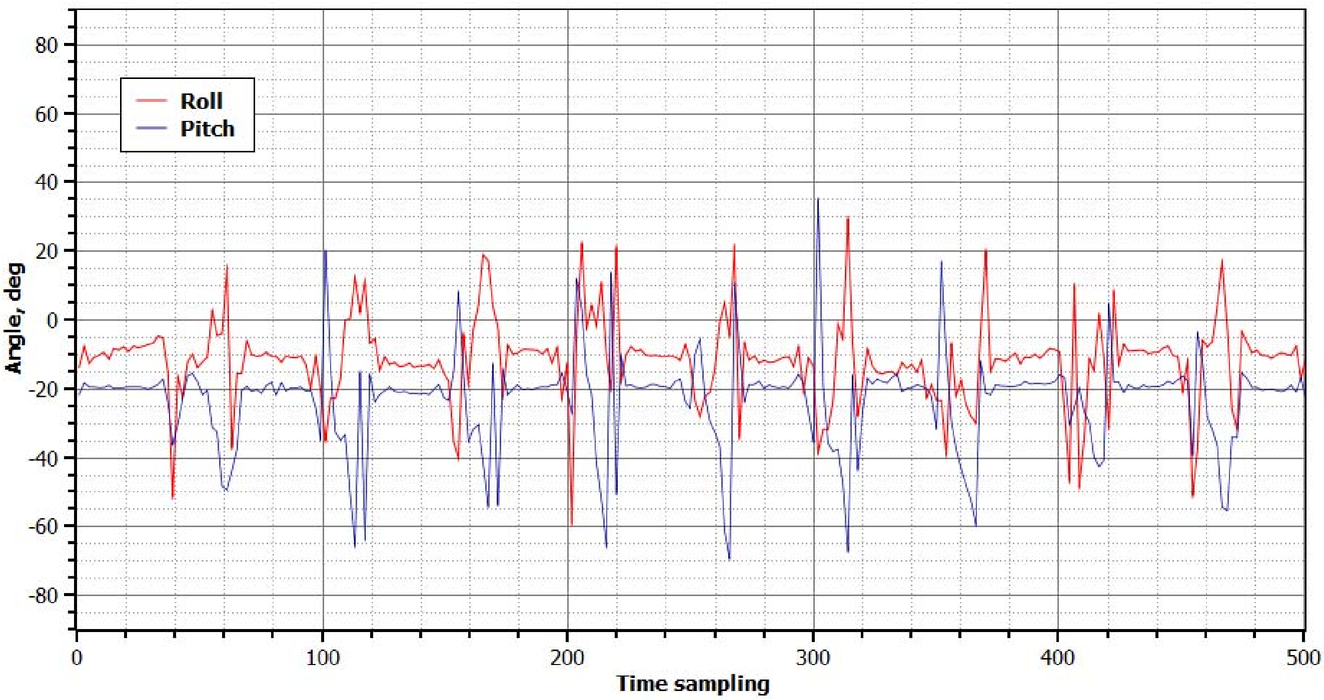

Fig. 3. IMU readings (pitch and roll).

IV. Conclusion

A prototype of the proposed personal navigation system has been implemented. Since the experimental set-up is still being tested only a limited set of experimental results was presented. The future work will be aimed to experimental characterization of the system performance for different kinds of pedestrian motions (walking, running, walking up and downstairs). Sensor calibration and filtering algorithms also should be developed for accurate and reliable position estimation.

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