



POLITECHNIKA ŚLĄSKA

WYDZIAŁ AUTOMATYKI, ELEKTRONIKI I INFORMATYKI

KIERUNEK AUTOMATYKA I ROBOTYKA

Rozprawa Doktorska

Zastosowanie czujników bezwładnościowych w nawigacji osób pieszych

Autor: mgr inż. Paweł Iwaneczko

Promotor: prof. dr hab. inż. Aleksander Nawrat

Promotor pomocniczy: dr inż. Roman Koterak

Gliwice, 2019

Application of inertial sensors in pedestrian navigation

mgr inż. Paweł Iwaneczko

The subject of dissertation is the application of inertial sensors in pedestrian indoor navigation system. Navigation, named in the dissertation subject, concerns the determination of position with use of dead reckoning algorithms based on double integration of acceleration. Inertial measurement unit (IMU) was used during experimental verification. IMU is a sensor composed of three accelerometers, three gyroscopes, and three magnetometers integrated with microprocessor employing extended Kalman filter (EKF). The overall system provides accurate orientation estimation.

The following thesis has been formulated in the work: *It is possible to create a pedestrian navigation system that works in real time and uses: inertial sensors, force sensing resistors, odometry algorithms, information about the building structure which positioning accuracy is less than one metre.*

Essential technology used in the presented research, are inertial sensors. Particularly the accelerometers and magnetometers are very sensitive to the excitation. During the positioning process, extensive error is being accumulated due to the employment of double integral algorithms and magnetic field disturbances. The reduction of such positioning error, has been made based on a number of tweaks. First of all, the force sensing resistors (FSR) was used to detect the step phase. Secondly, the information about building structure was used to limit the growth of the area of positioning error. All tested routes have been compared with previous measurements in terms of root mean squared error (RMSE) and accuracy of the positioning algorithms using the absolute of mean error (AoME). The inertial sensor was mounted on the outside of a shoe, while the FSR sensors was placed on the inside shoe insole. Tests have been performed both: inside and outside of the building. The presented work is independent of the human walking model as well as positioning methods based on the steps counting. The scope of the dissertation is focused on the odometry algorithms and deals with problems related to methods of precise steps detection.

Proposed algorithm of indoor pedestrian navigation combines acceleration with estimated orientation in order to translate IMU axes to local tangent plane of the Earth's surface. After this process, position accretion can be calculated with double integrate of reoriented acceleration. The integral is updated until the step is detected with the use of FSR sensors. During the position calculation zero velocity update (ZUPT) algorithms are used to eliminate position drift (zero error). At the end optimisation algorithms have to be applied to limit the area of determined position, according to the building structure. This information was measured manually or have been determined using online maps like i.e. OpenStreetMap (OSM). Step is detected in the two steps loop using analysis of data aquired from five FSR sensors located on the inside shoe insole.

Presented doctoral thesis describes in details the following experiments (all tests have been performed outside and inside of the building of the Silesian University of Technology):

- analysis of eight step detection algorithms for three routes outside and two inside of the building,
- results comparison from the three routes performed outside of the building for maximum of two optimisation algorithms (for five step detection methods),
- results comparison from the two routes performed inside of the building for maximum of four optimisation algorithms (for six step detection methods),
- detection of the disturbances of the earth's magnetic field for three routes,
- analysis of the results performed inside of the building with the use of an additional IMU sensor mounted on the belt,
- comparison of collected data for many complementary filters,
- analysis of repeatability of results and comparison with other IMU sensors.

In the first experiments it was difficult to obtain satisfactory results of determining the position outside of the building without using any optimisation methods. This have been particularly noticeable for one of the analysed routes, for which the accuracy was not much greater than the accuracy of GPS systems. Therefore, according to the author's conclusion, it is justified to use inertial navigation outside the building only in fusion with satellite systems.

Based on the presented research, in field of inside building positioning, it can be concluded that it is possible to obtain the positioning accuracy of less than one metre only when optimisation methods are used. For the linear route of 711 metres long, it was enough to use the heuristic heading reduction (HHR) algorithm, which uses quantisation of the angle ψ with 90° quants. However, for a more complex routes, e.g. 3077 metres long that took about 45 minutes of walk, HHR optimisation turned out to be insufficient. However, the use of the builing's structure outline (BSOUT) method, which is based on limiting the determined position using the external building model (i.e. obtained from online maps), allowed to achieve the accuracy of 0.6 metres. The test results presented in this work, for routes performed inside of the building, can be improved by using a second inertial sensor located on the belt in the centre part of the body. It has been verified, that experiments with other IMU sensors and with other complementary filters have not improve the results. Finally, it can be concluded that the research presented in the dissertation is sufficient to confirm the formulated thesis.