DETERMINING THE TRAJECTORY OF PEDESTRIAN MOVEMENT IN INDOOR ENVIROMENT

Ľ. Ilkovičová, P. Kajánek, A. Kopáčik

Department of Surveying, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovak Republic

Abstract

Nowadays, the topic of the navigation in indoor environment is becoming more and more current and several systems that can substitute GNSS technology are developed. In the presented paper is introduced the method of determining the trajectory of pedestrians in an indoor environment, what constitutes an undisputed basis for navigation of persons in indoor environment of buildings. To determine the trajectory of movement were used data from inertial sensors (accelerometers and gyroscopes), from which was calculated path of the pedestrians with "step detection" method. We have focused on the detection of step from accelerometers measurement. We used first integration of measured acceleration to calculated velocity of movement and after we applied step detection. Each step have orientation (azimuth), which was calculated from gyroscope measurement. During the experiment the accuracy of the trajectory calculated from the smartphone Samsung Galaxy S4 data was tested. The trajectory was determined in the ground plan of an administrative building with known location of fixed points, which are included in the path of the pedestrians.

1 Introduction

Today navigation using a mobile phone or tablet has become a normal part of life. For man is nothing exceptional when it gets to the unfamiliar territory. Each of us was in an unknown environment, where was needed to find some target and device by which this problem is easily solvable are nowadays especially smartphones. In open spaces we can use global navigation satellite system (GNSS). This technology uses clusters of satellites that transmit data from space directly to the device and allows you to view the current location of the user, calculate the route through maps and allows the user to navigate easily from point A to point B. GNSS technology finds application in navigation in outdoor environment, but the problem occurs in situations where the user is located in indoor areas where device has no connection to the satellites. This fact motivates us to search for suitable alternatives to remove this barrier in navigation. The aim of the indoor navigation lies mainly in facilitating the orientation of the user in an unfamiliar environment. Navigation in indoor spaces finds its usage in various shopping centers, underground car parks, school buildings and other various complexes. And as a uniform standard of a navigation system does not exist, therefore it is necessary to examine various options to solve this problem [1].

Paper presents methodology for determination of the trajectory of pedestrian movement in indoor environment, which is basic part of indoor navigation system for pedestrian. Trajectory of pedestrian movement was determined from measurements of inertial sensors (accelerometers and gyroscopes), which was stored in smartphone Samsung Galaxy S4. We used step detection method to calculate change of pedestrian´s position and heading detection to calculate orientation of pedestrian. Results were verified with floor plan of the building and fixed points, which position were known.

2 Realization of the experiment

At first we needed to get measurement data from smartphone. For this purpose we used free mobile application Sensor Tester. This application provides easy access to measured data from accelerometers and gyroscopes. Before measuring we set recording parameters (type of sensor, sampling frequency and range of sensor).

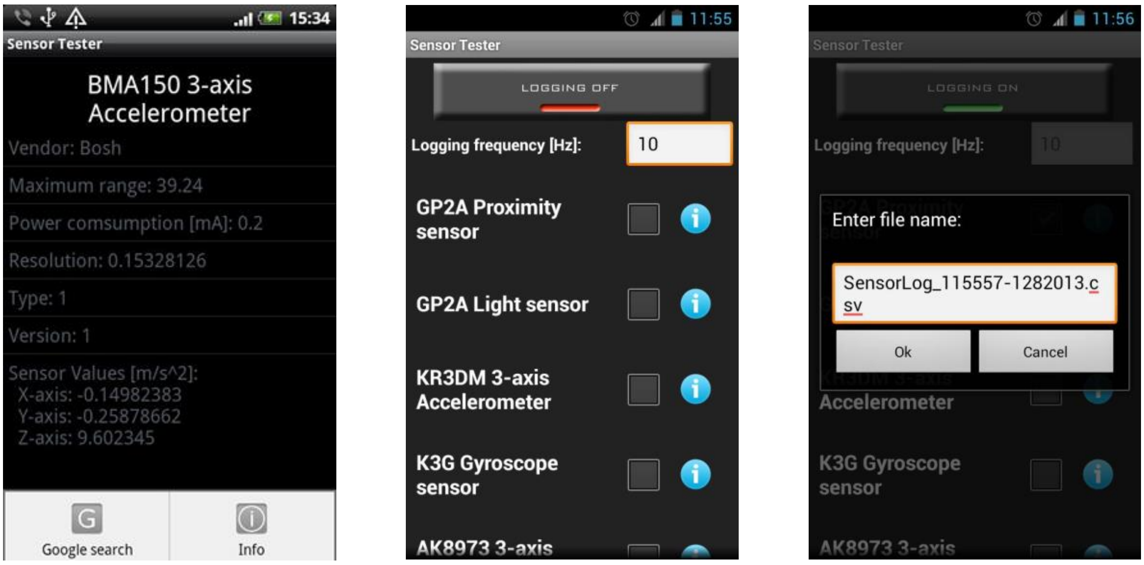

Figure 1. Preview of the mobile application environment Sensor Tester (source GooglePlay)

Measurements from inertial sensor are stored in the phone memory as coma separated value (CSV) and this format is supported in Microsoft Excel. Data include time, acceleration (for x, y, z axis), angular velocity (for x, y, z axis) and other measurements (which we choose before measurement). Accelerations are provided in $m.s^{-1}$ and angular velocity is provided in $rad.s^{-1}$. The sampling frequency was chosen as 25 Hz (time interval 0,04 s).

	A	B	C	D	E	F	G
1	TimeStamp[ms]	AccX[m/s^2]	AccY[m/s^2]	AccZ[m/s^2]	GyroX[rad/s]	GyroY[rad/s]	GyroZ[rad/s]
2	1.39634E+12	0.495001	0.481833	10.748769	-0.123700	-0.153938	-0.105069
3	1.39634E+12	0.307655	0.974440	9.537302	0.011606	-0.006109	-0.023213
4	1.39634E+12	0.236427	1.180940	9.441534	-0.047647	-0.009468	-0.056810
5	1.39634E+12	0.575806	1.045668	9.628283	-0.061392	-0.015882	-0.071471
6	1.39634E+12	0.222062	1.598728	9.272144	-0.018326	0.090408	-0.032376

Figure 2. Preview of the output record from mobile application Sensor Tester

3 Calibration of inertial sensors

Calibration of inertial sensors is important part of processing of inertial measurement. If we want correct results (position, velocity and azimuth) from inertial measurement, we have to correct the errors that affect accuracy of position and orientation of a moving object. It is understood that every measurement system has errors, which are transferred to measurement and if we neglect impact of errors, it causes rapid degradation of result. In processing we used double integration of acceleration to calculate displacement and integration of angular velocity to calculated orientation of object. Secondary effect of integration is rapid accumulation errors in results. So we need to use optimal calibration method [2], [4].

Main error sources of inertial measurement are bias, scale factor and non-orthogonality. In processing these errors occur in wrong position, wrong velocity and wrong azimuth. We can remove this effect with using special calibration method, because these errors are deterministic. Accuracy of inertial measurement system significant decrease with total travelled distance, so we often use combination inertial measurement system with other navigation technique [2], [4].

In our experiment we used six position calibration method to estimate deterministic sensor errors such as bias, scale factor and non-orthogonality.

4 Step detection

Human´s walk is specific kind of mechanic movement. It is natural movement, which consists from steps, while there is a regular alternation of one and other leg. Measured acceleration varies depending on the current phase step, especially in toe off phase (begins as toes leave the ground) and heel strike phase (heel touching a ground). We used acceleration in step detection method to calculate number of steps, each step had also time information, which we used for determination of azimuth [1].

The advantage of this positioning method based on step detection is fact, that we do not use double numerical integration of the acceleration, thus there is no accumulation of errors in the integration process. This is main reason why we decided for the application step detection method, because this method prevents the accumulation of errors of inertial measurement in processing.

During experiment we assumed that the user holding the smartphone in hand and mobile device screen is upward, what means that direction of Z axis is approximately same as the direction of gravity. This assumption is not requirement, because we can use step detection method for experiment with any orientation of smartphone.

Based on the above assumption we was interested in an acceleration measured along the axis Z. This acceleration best describes the motion of the user. In the Figure 3 we can see periodically repeated acceleration, which related on phase of the walk.

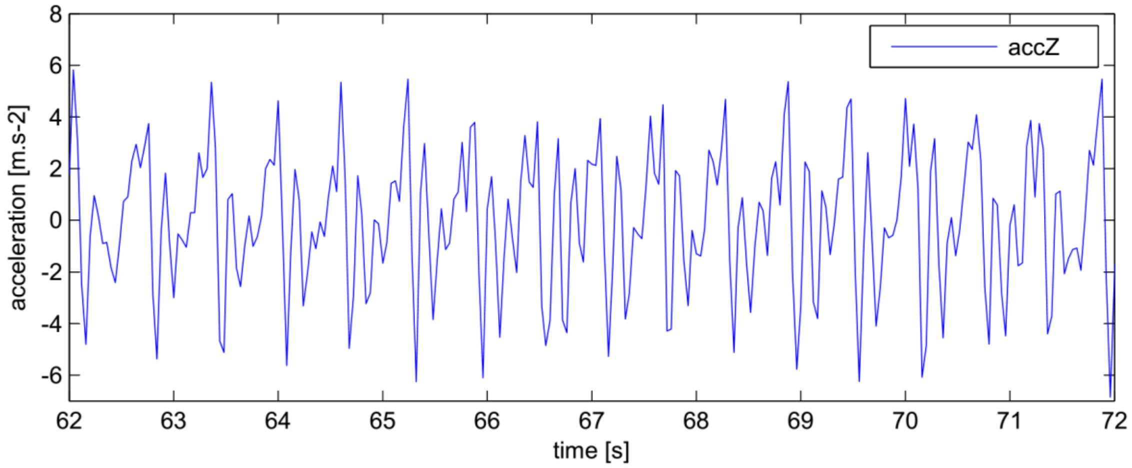

Figure 3. Preview of the calibrated values from the acceleration sensor corresponding to the z axis while walking

The basic principle of the step detection consists in the utilization of periodic character of human walk.

If we look at measurement from inertial sensors, we can indetificated steps as peaks in the record, but normal person can not maked step less than one second. If we identify two peaks with small time interval, we know that it can not be two steps. The basic principle of step detection consist in seaching peaks, but we need to define two important value as:

- threshold,
- minimum distance betwen two peaks.

Threshold specified the limited value above which the peaks are searchable. Minimum distance betwen two peaks define time interval betwen two steps. Minimum distance betwen two peaks is important, therefore algorithm without this requirement identifies fictious steps.

This step detection algorithm was aplied on variours forms of measurement. For step detection we tested four form of measurement as:

- norm of acceleration,
- residuals from norm of acceleration,
- residuals from acceleration,
- velocity in direction of the Z axis (first integration of acceleration).

We focused on step detection from velocity in direction of the Z axis, because there is maximum velocity in each step. First we need remove long-frequency component from time series of speed, because it represent trend, which create accumulation of error in integration proces. After we can apply the condition for finding peaks in time series (Figure 4).

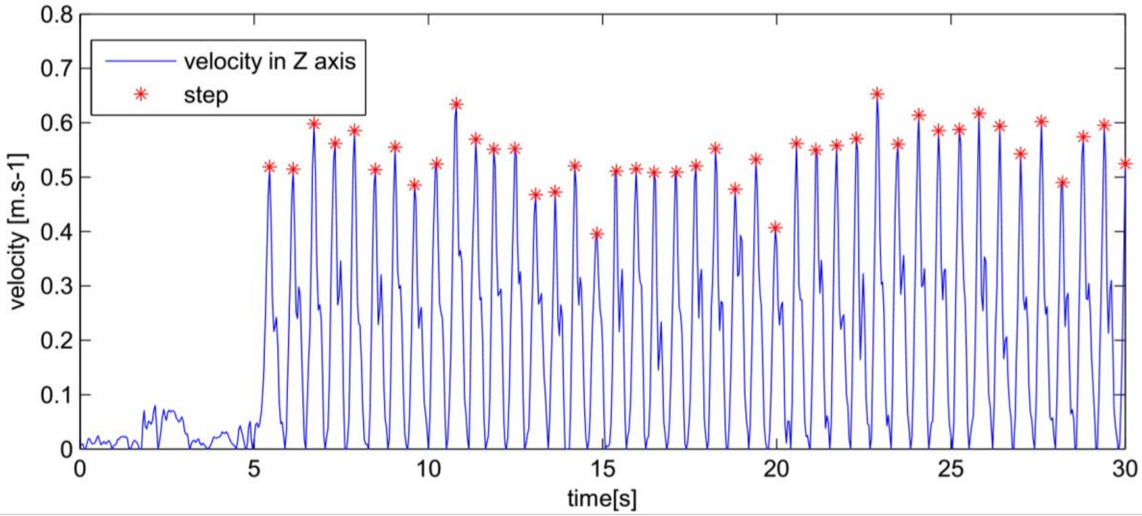

Figure 4. Preview of the step detection from the velocity in direction of the Z axis

5 Pedestrian movement along predefined trajectory

During experiment user with smartphone in his hand walked along a predefined trajectory. We decide for this type of test, because we can easy verification result from experiment. Trajectory consist from fixed points, which were placed on fracture points of trajectory. We signalized fixed point on floor and after we measurement distance between this points. Before processing we calibrated inertial measurement, where we used calibration coefficient from multi-position test.

Trajectory of pedestrian movement can be divided on steps with absolute orientation (azimuth). At first we applied step detection algorithm on velocity in direction of the Z axis. In second phase of processing we calculate azimuth for each step. Azimuth of step was calculated as numerical integration angular velocity from gyroscope measurement. We use integration of angular velocity to calculate euler angle *roll*, *pitch* and *yaw*, which represent rotation of smartphone about x, y, z axis. For determinate trajectory we need *yaw* angle, which represent rotation angle about Z axis. We need remove drift from yaw angle and after we searched maximal change of yaw angle with using residual from yaw angle, because this change represented change of azimuth of user movement (Figure 5).

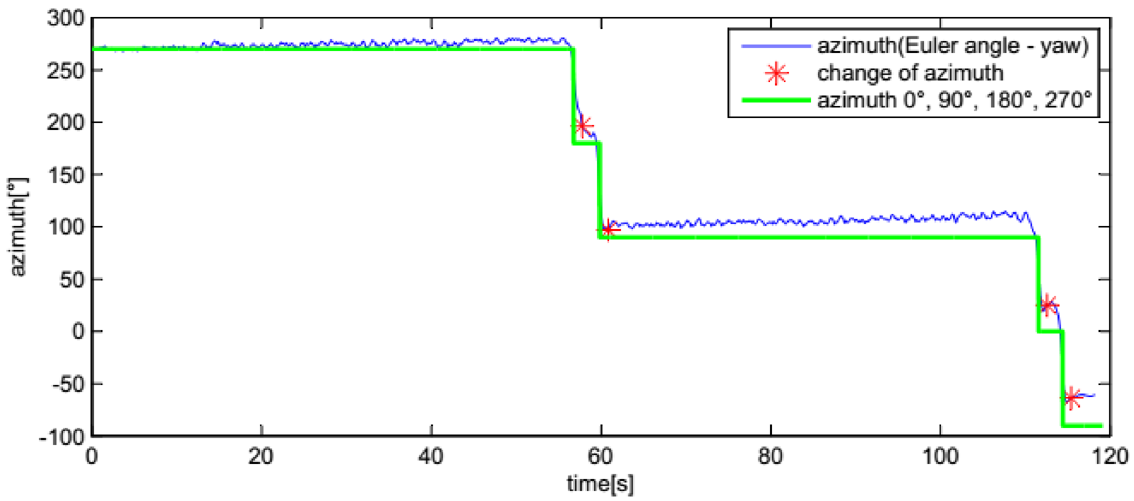

Figure 5. Orientation of pedestrian limited to four basic directions when trajectory is rectangle

In azimuth detection, we decided to restrict the pedestrian movement on four basic directions (with azimuth 0°, 90°, 180°, 270°), because we considered a rectangular arrangement of corridors. For this purpose we created function, which adds basic direction (0°, 90°, 180°, 270°) to current azimuth. Each step has information about time by which it associates the corrected azimuth. In the Figure 6 there are showed steps, which are divided to four main direction.

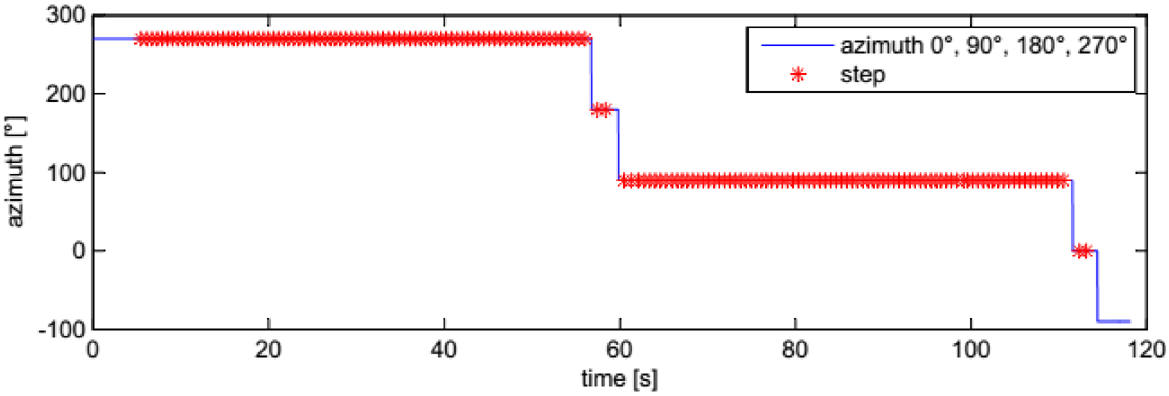

Fig. 6. Steps in the orientation limited to four basic directions

Principe of navigation is determining the trajectory of pedestrian movement. For this purpose we need combine step detection and azimuth detection to final trajectory. When we use inertial measurement system, first we need define initial condition (initial position, initial velocity and initial azimuth). On the floor map, we define start point of trajectory by coordinates X, Y in local frame of building. Initial azimuth was defined based on initial azimuth of device (smartphone). Next we had to define stride length. It is important value, because we need it for the transfer of the number of steps to traveled distance. Each user has different stride length. Therefore at first we must determine average stride length for each user. For this purpose user walked along straight trajectory with known distance. Average stride length was calculated from travelled distance and number of steps.

Finally we applied polar method to calculate the trajectory of user movement. Current position of pedestrian $X_{(t)}$, $Y_{(t)}$ was calculated by using a previously determined position, average stride length and current azimuth.

$$\begin{aligned} X_{(t)} &= X_{(t-1)} + step.\cos\left(azimuth_{(t)}\right) \\ Y_{(t)} &= Y_{(t-1)} + step.\sin\left(azimuth_{(t)}\right) \end{aligned},$$

where

$X_{(t)}$, $Y_{(t)}$ - current position,

$X_{(t)}$, $Y_{(t)}$ - previous position,

$step$ - average stride length,

$azimuth$ - azimuth of steps divided to four main direction (0°, 90°, 180°, 270°).

In second formula is used sign of minus, because coordinate system of floor map is right-hand. Finally we plotted trajectory of pedestrian movement on floor plan of building. In the figure 7, trajectory of pedestrian movement is red line and fixed points are green circles. Start point of trajectory is point with number 1.

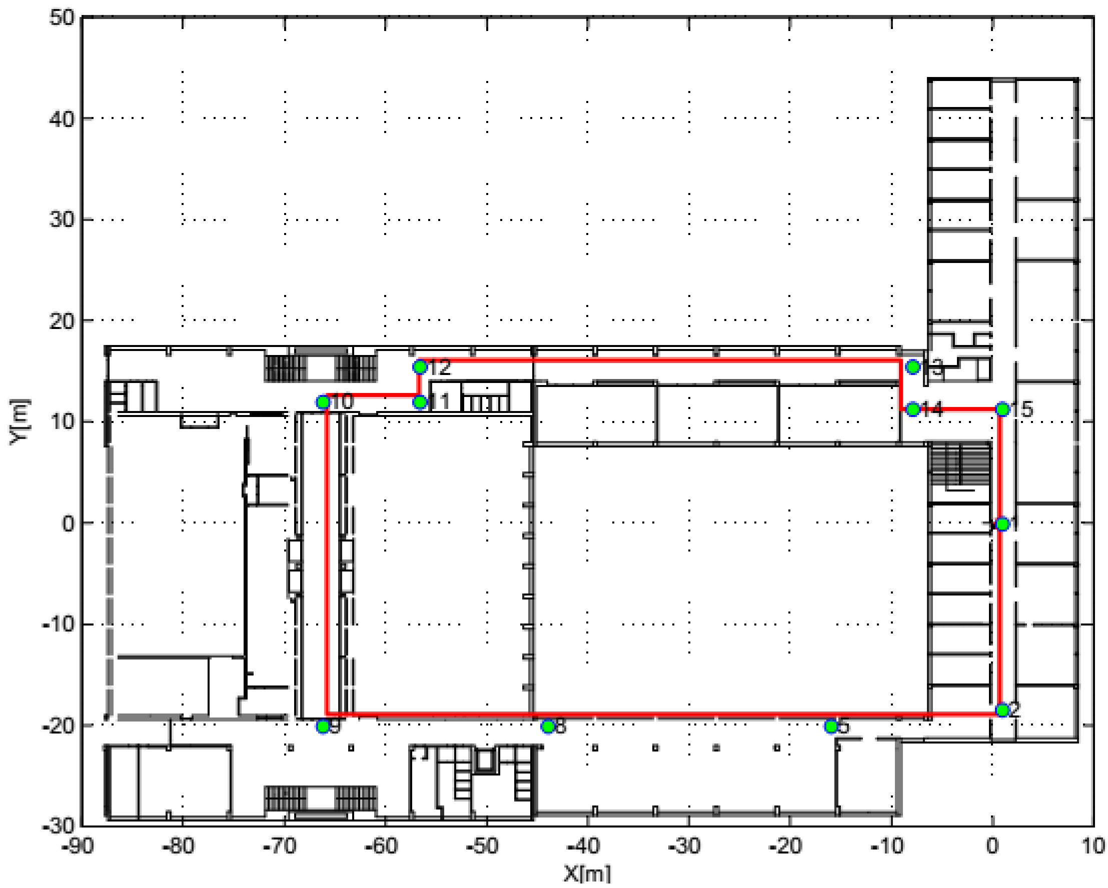

Figure 7. The trajectory of pedestrian movement on the floor plan of the building

Algorithm include dynamic plot of user's position on floor plan of building (figure 8). User's position is marked with red circle, coordinates and actual time.

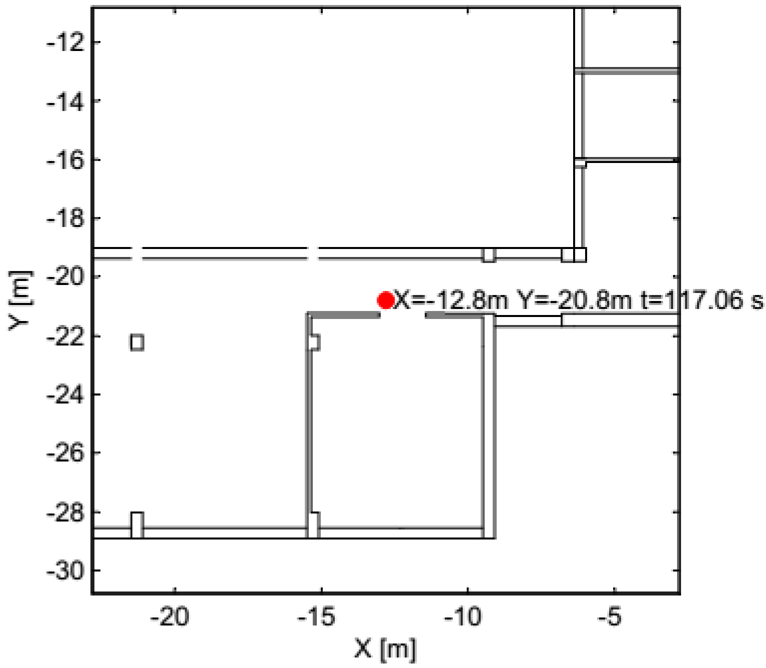

Figure 8. Preview of dynamic plot of user's position

6 Verification of results

Disadvantage of algorithm is using average stride length of user. We used fixed points to verify the accuracy of designed algorithm. Distance between fixed points was measured with measuring tape. After we compared this measured distance with distance determined by step detection. Average stride length of user in our experiment was 0,70 m. Final result of experiment is showed in the Table 1.

Table 1: COMPARISON BETWEEN MEASURED DISTANCES AND DISTANCE DETERMINED BY STEP DETECTION

Part of trajectory	**Measured distance**	**Distance from step detection**	**Residuals**
(fixed points)	*S [m]*	*D [m]*	*S – D [m]*
1 – 2	19,12	18,90	0,22
2 – 9	67,12	65,80	1,32
9 – 10	32,22	31,50	0,72
10 – 11	9,42	9,80	-0,38
11 – 12	3,44	3,50	-0,06
12 – 13	48,52	47,60	0,92
13 – 14	4,33	4,90	-0.57
14 – 15	9,16	9,80	-0,64
15 – 1	11,14	11,20	-0,06
Total:	**204,47**	**203,00**	**1,47**

Table 1 shows that longer distance have lower accuracy than shorter distance. This may be due to the fact that user could not keep average stride length during walk, but stride length was changed (e.g. when pedestrian changed orientation). Determined trajectory of pedestrian does not follow exactly predefined trajectory. It is also caused by using average stride length and azimuth simplified to four main direction. But we can say, that this algorithm can be used for indoor navigation.

In the second phase of experiment, we wonder how it will change the accuracy with total travelled distance. For this purpose user walked along predefined trajectory twice. After we import measurement data to algorithm, we plotted trajectory on floor plan. We confirmed the fact that accuracy of this method decrease with total travelled distance and time of measurement too. It caused accumulated errors from processing. Error from average stride length are projected into the second transition.

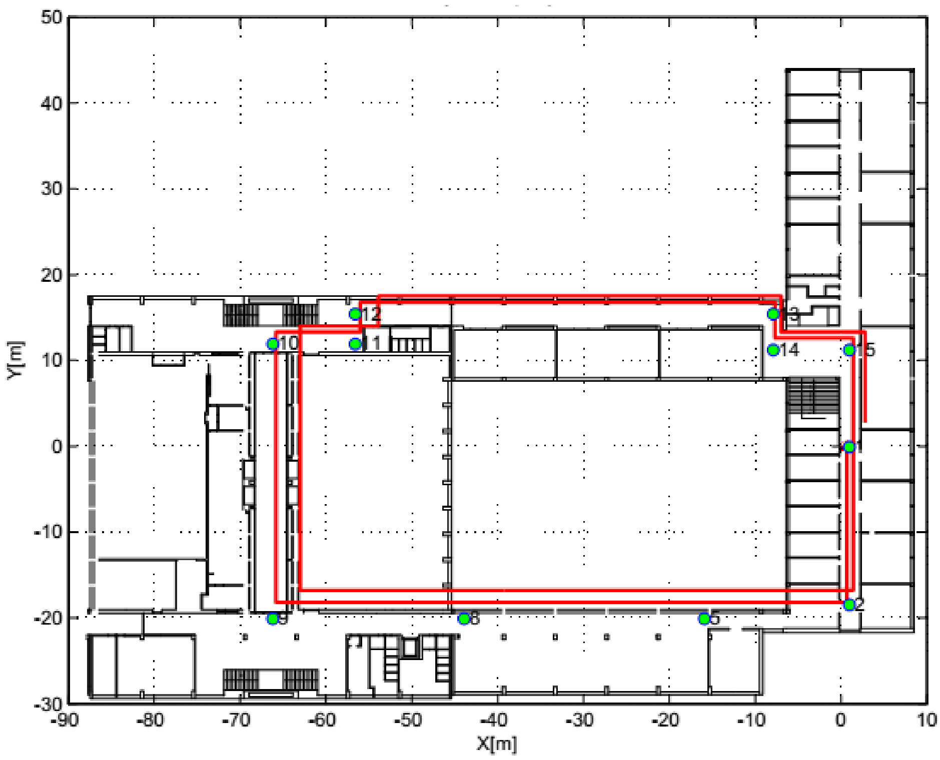

Figure 8. The trajectory on the floor plan of the building traveled twice

Next we interested in accuracy of algorithm in term of azimuth determination. For the reason that algorithm divided azimuth into four main direction, so there are not errors in determined orientation of pedestrian. We need remove drift from time series of yaw angle for correct azimuth detection. When we remove long term component (drift) of yaw angle, after we used function for azimuth detection.

7 Conclusion

Based on result from realized experiment we can said, that main problem of algorithm is average stride length, because stride length of pedestrian change during walking. We can see this disadvantage in figure 7 and 8, where determined trajectory of pedestrian movement crossed over the walls. This disadvantage opens way to improve current algorithm. In future work we want apply adaptive stride length estimation in step detection algorithm. Next we want to use map information from floor plan, where we want to define areas where movement is not possible. These areas will be represent as wall. Further improved algorithm will apply fixed point, which are used to correct trajectory.

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Ing. Ľubica Ilkovičová
lubica_ilkovičová@stuba.sk

Ing. Pavol Kajánek
pavol.kajanek@stuba.sk

Prof. Ing. Alojz Kopáčik, PhD.
alojz.kopacik@stuba.sk