Pedestrian Trajectory Determination in Indoor Environment

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SUMMARY

The topic of the navigation in indoor environment becomes nowadays more and more actual and several systems that can substitute GNSS technology are developed. The paper presents the method for pedestrian trajectory determination in indoor environment as an undisputed basis for navigation of persons in indoor environment of buildings. Data from inertial sensors (accelerometers and gyroscopes) available in smart phones and the calculated trajectory by “step detection” method were used for determination of the pedestrian trajectory. The developed method isn’t able to identify the absolute position in the building but provides the information about the relative position. The accuracy of the trajectory calculated from the smart phone Samsung Galaxy S4 data was tested during the experiment. The trajectory was determined in the ground plan of an administrative building with known location of the reference points which are included in the path of the pedestrians. The algorithm for data processing was created in Matlab software, parallel with the algorithm for calibration of smart phone sensors. Matlab function “*findpeaks*“ was used for step detection and determination of changes in sensor orientation. The main algorithm implemented to the smart phone produces dynamic plot of the current position of pedestrian on the floor plan displayed on the smart phone in real time.

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1. INTRODUCTION

Today navigation used in a mobile phone or tablet has become a normal part of our life. For a man there is nothing exceptional when it gets into the unknown territory. Each of us was in an unknown environment where it was necessary to find some target and devices by which this problem is easily solvable present nowadays especially smart phones. In open space we can use global navigation satellite systems (GNSS) but the problem occurs in situations when the user is located in indoor areas where the used device has no connection to the satellites. This fact motivates the developer to search for suitable alternatives to remove this barrier in navigation. Navigation in indoor space finds its usage in various shopping centres, underground car parks, hospitals, school buildings and other various complexes. To find an optimal design of navigation system for indoor environment, it is necessary to examine various options on this way [1].

This paper presents one of the possible methods for determination of the trajectory of the pedestrian movement in indoor environment which is an indisputable basis for navigation of people in indoor space. Data from inertial sensors embedded in the mobile phone Samsung Galaxy S4 (acceleration sensors and gyroscopes) were used to determine the trajectory. The step detection method and the adaptive step length estimation were also used to calculate the trajectory. The proposed algorithm was developed to achieve higher accuracy in the estimation of the walking distances.

2. RELATED WORK

There is evident huge increase in activities aimed at automating processes and services in recent years. Their integral part is a creation of an "intelligent environment" in which vehicles, machines and people are navigated. Nowadays there are lots of proposals of navigation systems for indoor navigation, mainly due to the increasing interest in these technologies. Among others, for example, inertial measurement systems [2], which via sensors (accelerometers and gyroscopes) provide information about the orientation and position in 3D space. Another possibility is a system based on WLAN network [3], which great advantage is especially the flexibility and the high coverage. Operating system based on Bluetooth [3] was originally designed for the short-range connection for personal devices but its usage can be applied also in the methods of indoor navigation based on the triangulation method using received signal strength. Another solution is to use UWB (Ultra Wide Band) [3] when the radio signals penetrate inside buildings also through a very full environment. However, its disadvantage is the very short range. The often used method is also positioning by ultrasound, RFID (radio frequency identification) [3], and also the system based on scanning barcodes. Simple characteristics and advantages and disadvantages of many of these systems are described in [3].

In [4], [5] is described an Indoor Navigation System based (INS) on the capabilities of a typical modern smart phone equipped with accelerometers, compass, camera and internet

connectivity. The user initially takes a photo of a geo-referenced 2D-bar code in order to acquire the map of the building and the initial position.
Foot-mounted INS which uses combined method of calculation used by ZUPT (zero-velocity-update) is described in [6]. ZUPT method is also used in [7].
In [8] there is used the smart phone's video camera to identify known and geo-referenced key points in the building map.
In [9] there is developed a map aided navigation solution. This research develops an aiding system that utilizes geospatial data to assist the navigation solution by providing virtual boundaries for the navigation trajectories and limits its possibilities only when it is logical to locate the user on a map. The algorithm develops a Pedestrian Dead Reckoning (PDR) based on smart-phone accelerometer and magnetometer sensors to provide the navigation solution.
Our experiments were focused to the usage of the step detection method and the adaptive step length estimation. Previous step detection algorithms based on accelerometers and gyroscopes in cooperation with Kalman filter were presented in [10], [11], and [12]. In [13] there is developed the indoor navigation system based on PDR (Pedestrian Dead Reckoning) using various sensors in smart phone using the Artificial Neuron Network to recognize the walking status such as stop, walking and running and to estimate the step length.
Adaptive step length estimation using optimal parameters is also used in previous work [14] and [15] where the movement status awareness was used. In [16] there is calculated the variable amplitude threshold for current position of the user.
In this paper there are proposed a few simple rules to determine very precise orientation of the movement instead of complicated calculation algorithm. This approach limits the ability to move only in perpendicular directions but significantly refines the resulting trajectory through an exact orientation adapted for movement inside the building. In this paper there are also presented results of adaptive step length estimation which increase the accuracy of the step length determination using the walking frequency and acceleration variance.

3. CALIBRATION OF INERTIAL SENSORS

The knowledge of correct sensor parameters is important information for the signal processing when inertial measurements are used. Systematic errors that affect the accuracy of the position and the orientation of moving object should be eliminated (extracted) to achieve correct position, velocity and orientation (azimuth) by inertial measurements. Usage of sensors without the knowledge of their correct parameters causes the rapid degradation of result, mainly they accuracy. The data (signal) processing is based on the double integration of acceleration and integration of the angular velocity which is used to calculate the object orientation. To eliminate this systematic effect of the integration and the rapid accumulation of errors in results, we need the optimal parameters of sensors which could be determined by calibration [17], [18].
The main error sources of inertial measurement are the deflection, the scale factor and the non-orthogonally relative position of sensors. These errors occur in wrong position, velocity and azimuth determination in data processing. In respect of deterministic character of these errors, it is possible to describe this problem by parametric function defined by special calibration methods. The six position calibration method was used to determine the function parameters and on the base of this the deflection, the scale factor and the non-orthogonality of

the used sensors were determined. The accuracy of inertial measurements is significantly decreasing with time or total travelled distance [17], [18].

4. STEP DETECTION

The human´s walk is specific kind of mechanic movement. It is natural movement which consists from steps, where is a regular alternation of both legs. Measured acceleration varies in dependence 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 the acceleration signal in step detection method to calculate the number of steps. Using the average step length is generated the distance information for trajectory calculation [1].
The advantage of this method is that we do not apply the double integration of the acceleration, thus there is no accumulation of errors in the data processing. This is the main reason why we have decided for the application of step detection method. During the experiment we assumed that the user holds the smart phone in a hand and the mobile device screen is upward, it means that direction of Z axis is approximately the same as the direction of the gravity vector. Based on the above assumption we were interested in an acceleration measured along the axis Z because this acceleration describes the motion of the user in the best way. In the Fig. 1 we can see the periodically repeated acceleration which is related to the phase of the walk.

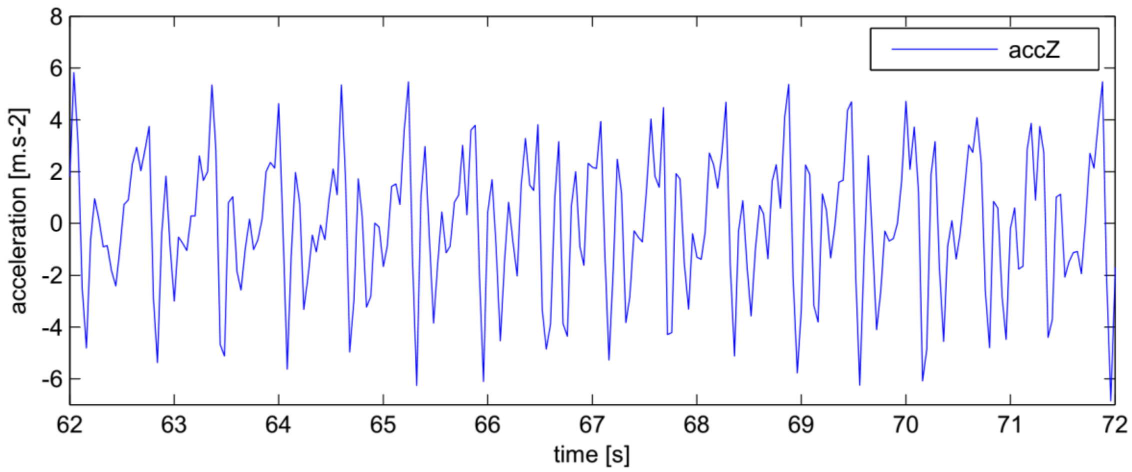

Figure 1 Preview of the calibrated values from the acceleration sensor corresponding to the Z axis while walking

The basic principle of the step detection consists in the utilization of periodic character of the human walk. By monitoring the inertial sensor signal, we can identify steps as peaks in the record. A person during normal walking makes one step less than one second. If we identify two peaks with small time interval, we know that it cannot be two different steps. The basic principle of the step detection consists in searching peaks but we need to define two important value as:

- threshold,
- minimum distance between two peaks.

Threshold specifies the limited value above which the peaks are searchable. Minimum distance between two peaks defines the time interval between two steps. The minimum distance between two peaks is important because the algorithm without this requirement identifies fictitious steps.
There are four different methods for step detection:

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

Our focus was given on step detection from the velocity in direction of the Z axis because there is a maximum velocity in each step. At first we needed to remove long-frequency component from the time series of velocity signal because it represents the trend which causes the accumulation of the errors in integration process. After this, we can apply the condition to find-out peaks in time series (Fig. 2).

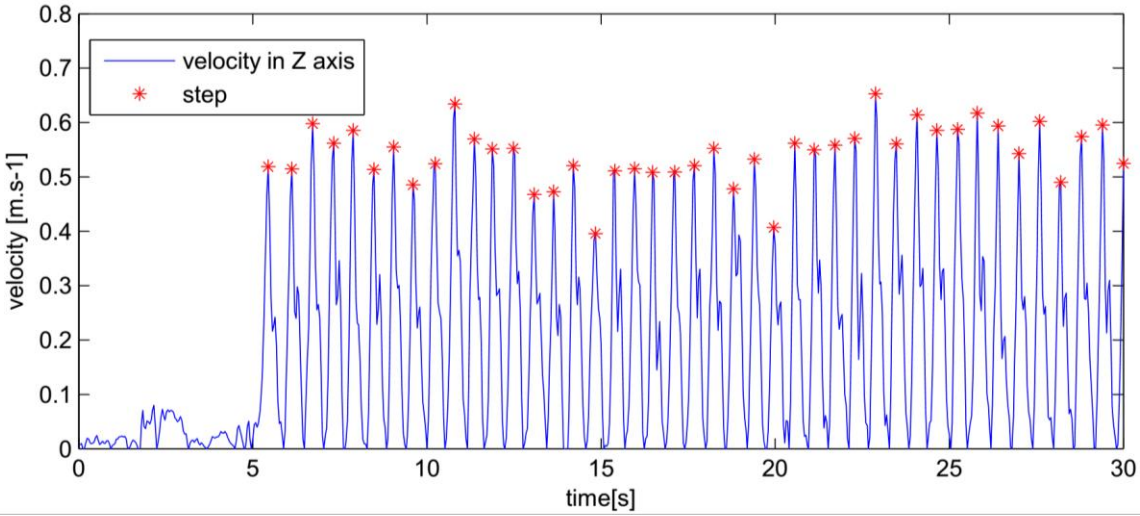

Figure 2 Result of the step detection using the velocity signal

5. PEDESTRIAN MOVEMENT ALONG PREDEFINED TRAJECTORY

We decided to realize experiment with the known trajectory to check the quality of the developed algorithm. During the experiment the user with smart phone in his hand walked along a predefined trajectory. The trajectory consists from reference (fixed) points situated in those places where the trajectory changes the direction. These points are signalized on the floor and distance between these points was measured. Before data processing, the inertial sensors were calibrated by using the multi-position test.
The trajectory of pedestrian movement can be divided to the steps with orientation (azimuth). At first we applied the step detection algorithm on the velocity signal measured in the direction of the Z axis. In the second phase of data processing the azimuth for each step is calculated. The azimuth of the step is calculated as a result of the numerical integration of the angular velocity measured by gyroscope. Using the integration of the angular velocity there are calculated the Euler angles roll, pitch and yaw, which represent the rotation of the smart

phone around the x, y, z axis. For the determination of the trajectory the yaw angle is necessary which represents rotation angle around the Z axis. It was necessary to remove the drift from the yaw angle signal and after this the points of maximal changes of the yaw angle were searched by using the residuals. These points represent the places of azimuth (direction) changes of the user movement (Fig. 3).

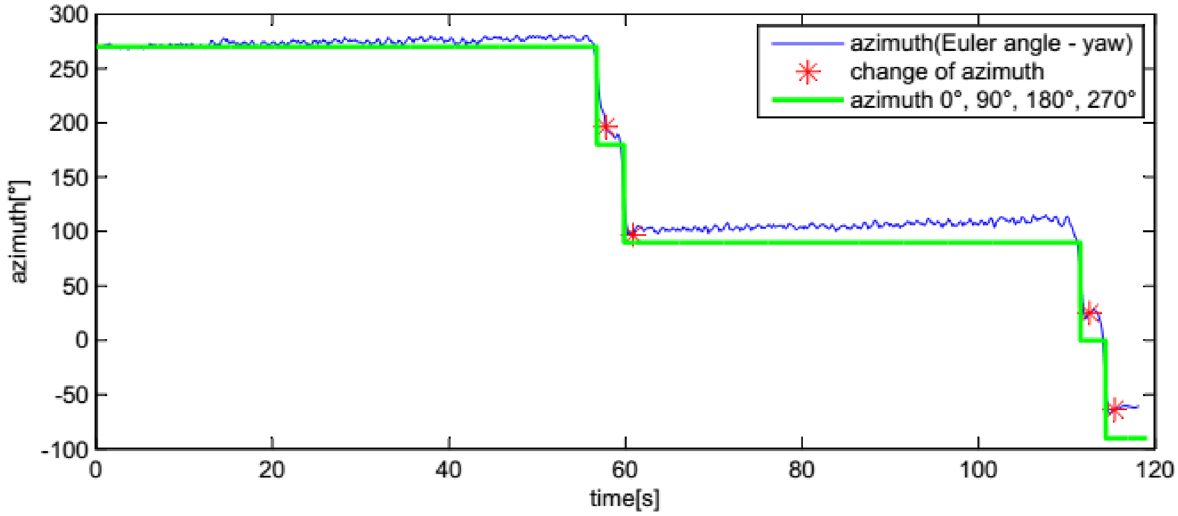

Figure 3 Orientation limited to four basic directions when moving in a rectangle

In azimuth detection, we decided to restrict the pedestrian movement in the four basic directions (with azimuth 0°, 90°, 180°, 270°) because we considered a rectangular arrangement of corridors. For this purpose we created the Matlab function which adds the basic direction (0°, 90°, 180°, 270°) to the current azimuth. Fig. 4 shows steps which are divided to four main directions.

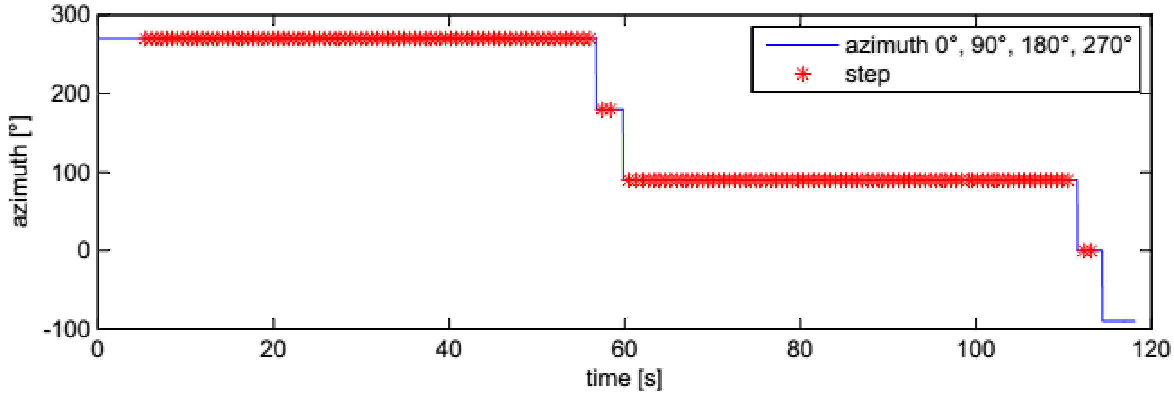

Figure 4 Steps in the orientation limited to four basic directions

There are combined the step detection and the azimuth determination to get a final trajectory. At first the initial condition should be defined (initial position, initial velocity and initial azimuth) when we used inertial measurement system. The start point of the trajectory is defined on the floor plan by coordinates X, Y in a local frame of the building and initial azimuth based on the initial azimuth of the device (smart phone). Next we had to define the stride length which is necessary for transformation of the number of steps to the travelled distance. Each user has different stride length therefore we have to determine the average stride length for each user at first. For this purpose the user walked along the straight trajectory with known distance and the average stride length was calculated from travelled distance and number of steps.

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

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

where

$X_{(t)}$, $Y_{(t)}$	- current position,
$X_{(t-1)}$, $Y_{(t-1)}$	- previous position,
step	- average step length,
azimuth	- azimuth of the steps divided to four main directions (0°, 90°, 180°, 270°).

The calculated trajectory was rendered on the floor plan of the building. Fig.5 shows the trajectory of pedestrian movement (red line) and fixed points (green circles) and the start point of the trajectory (point Nr. 1).

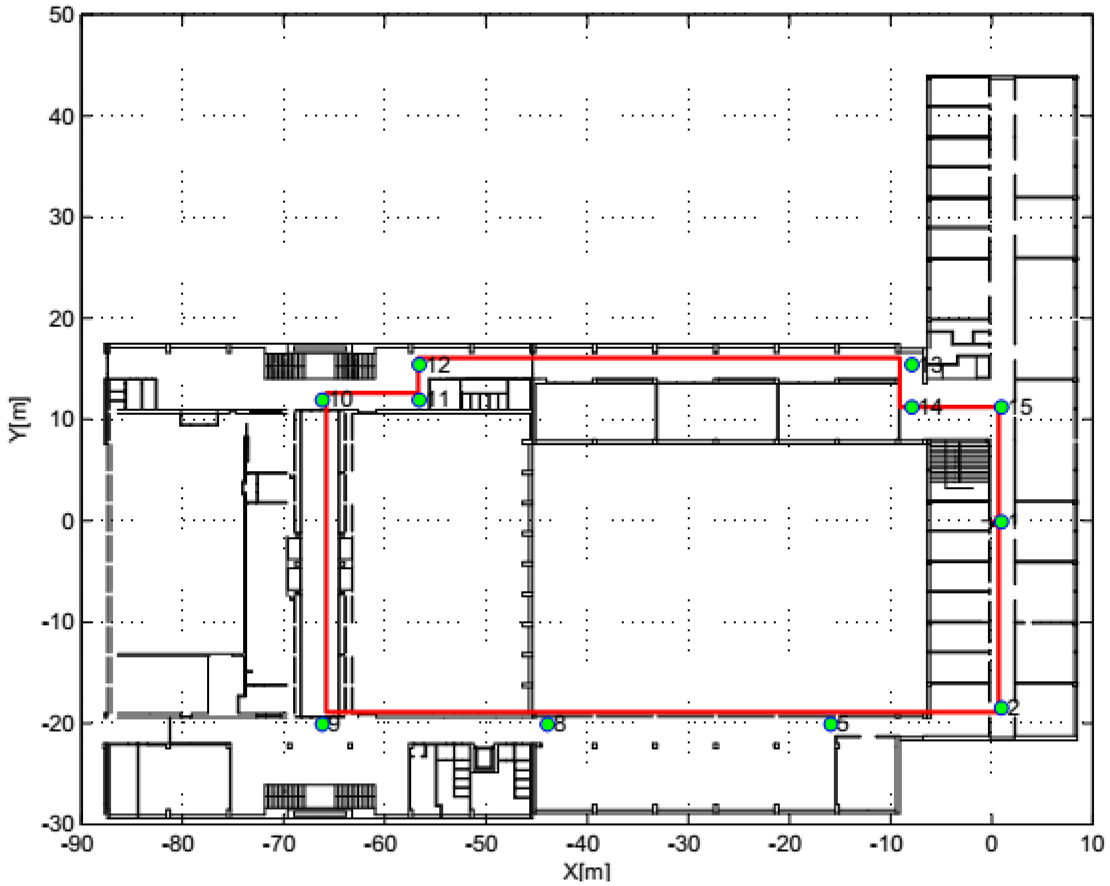

Figure 5 The trajectory of pedestrian movement on the floor plan of the building

The developed algorithm includes also dynamic plot of the user's position on the floor plan of the building (Fig.6). User's position is marked with red point, coordinates and the time of movement.

The disadvantage of the proposed algorithm is the usage of constant step length in the algorithm determining the trajectory. Step length is different for each user, so it is necessary to calibrate it before each calculation of the trajectory. Another problem is the change in the step length during the natural walk. The above mentioned facts are reflected in the results of our experiment and caused uncertainty in the determination of the length, as shown in the Fig. 5 and Tab. 1. After passing the whole trajectory of 203.80 meters there was an error with a value of 6.20 m in the length determination.

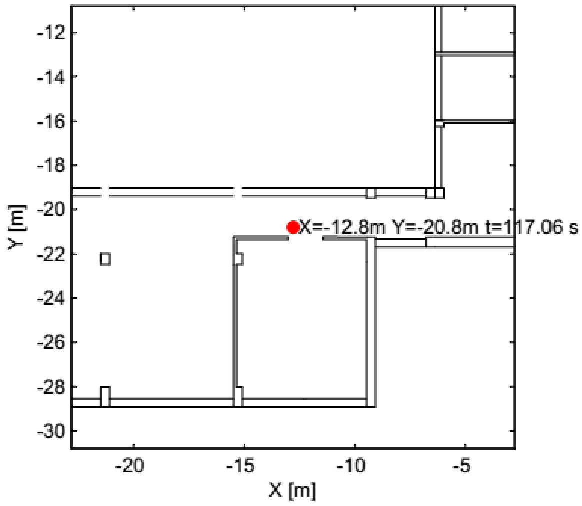

Figure 6 Dynamic plot – actual user's position

6. ADAPTIVE STEP LENGTH ESTIMATION

In the previous experiment the travelled trajectory was determined by a constant step length. However, human walking changes dynamically, this determination is limited. To achieve the better accuracy the adaptive step length estimation was implemented. The variation in the step length can be determined by using of a linear combination of the walking frequency and the acceleration variance [14]. Step length can be calculated by using of linear function

$$SL = \alpha * WF + \beta * AV + \gamma \tag{2}$$

where

α, β, γ - parameters of the adaptive step length estimation, individual for each user.

Walking frequency and acceleration variance were calculated using [14]

$$WF = \frac{1}{t_k - t_{k-1}} \quad , \quad AV = \frac{1}{n-1}\sum_{k=1}^{n}\left(a_k - \bar{a}\right)^2 \tag{3}$$

where

WF - walking frequency,
AV - acceleration variance,
t_k, t_{k-1} - time of detected steps,
$a_k, \bar{a}$ - acceleration in k time, average acceleration.

The average step length and average walking frequency was calculated from several times made walking routes and used for acceleration variance calculation. Fig. 7 shows the relationship between the step length and the walking frequency and the acceleration variance. Slopes of a both straight lines and their shifts determine the coefficients alpha, beta, gamma.

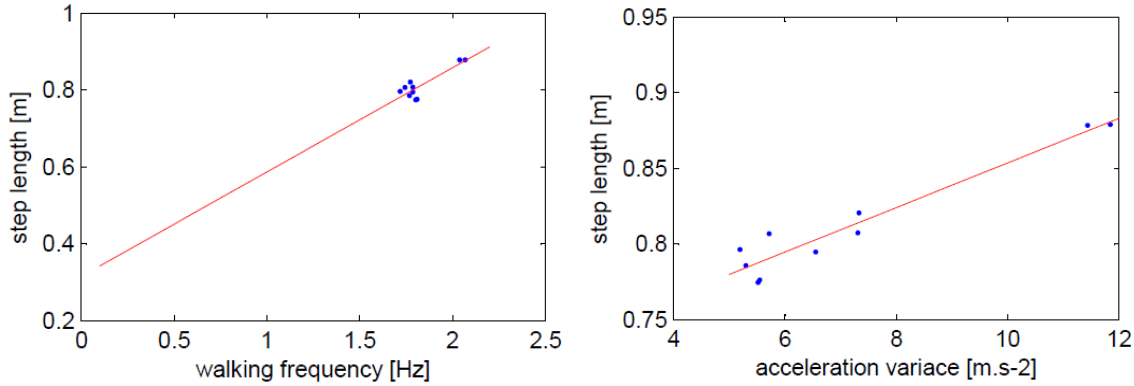

Figure 7 Relationship between walking frequency, acceleration variance and step length

Fig. 7 shows that subject walked eight series with approximately the same step frequency 1.7 Hz and two series faster, with step frequency 2.0 Hz. In order to calculate the step length alpha, beta, gamma coefficients obtained from these measurements were used. The length of the current step SL was calculated by using eq. (2), where the walking frequency and the acceleration variance of the current series were applied. The comparison of both methods and the trajectories determined by simple step detection (red line) and by adaptive step length estimation (blue line) are shown in Fig. 8.

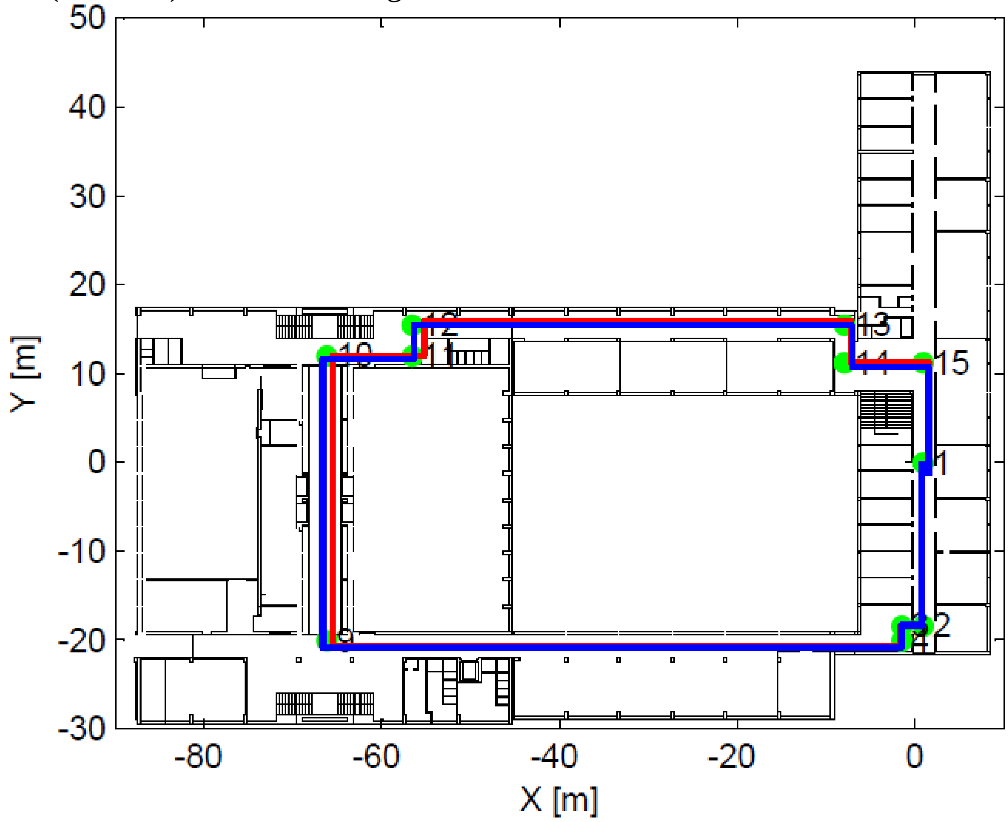

Figure 8 Different trajectories for simple step detection and adaptive step length estimation

Table 1 shows the biggest differences and refinements of the trajectory in the longest sections, between points 4-9, 9-10, 12-13 where the adaptive step length estimation eliminates the systematic errors and the trajectory could be determined with higher accuracy.

	Number of steps		***Length of the section [m]***			***Difference [m]***	
Section	*Actual*	*Detected*	*Actual length*	*Average step length*	*Adaptive step length*	*Average step length*	*Adaptive step length*
1 - 2	21	21	18,40	16,80	17,14	1,60	1,26
2 - 3	4	4	2,40	3,20	3,12	-0,80	-0,72
3 - 4	2	2	1,60	1,60	1,40	0,00	0,20
4 - 9	77	76	64,00	60,80	63,31	3,20	0,69
9 - 10	38	38	32,00	30,40	31,77	1,60	0,23
10 - 11	12	12	9,60	9,60	9,50	0,00	0,10
11 - 12	5	5	3,50	4,00	3,88	-0,50	-0,38
12 - 13	61	59	48,70	47,20	49,70	1,50	-1,00
13 - 14	6	5	4,20	4,00	4,16	0,20	0,04
14 - 15	12	12	8,10	9,60	9,65	-1,50	-1,55
15 - 1	14	13	11,30	10,40	11,19	0,90	0,11
Suma	252	247	203,80	197,60	204,82	6,20	-1,02

Table 1 Differences in travelled length

As you can see from the above mentioned results, the usage of the adaptive step length method refined the calculation of the pedestrian trajectory. There was an error of -1.02 m in the length determination after passing the trajectory with the length of 203.80 m. The advantage of this method is consideration of the natural character of the walking but this is still an approximation of the movement which is the result of the initial calibration. Next the proposed method considers the fact that human movement is not constant. Step length varies naturally with time, walking speed and step frequency. Doors or change of the orientation of the trajectory affect the change of the step length, too. Fig. 9 shows the step length variation due to the changes in orientation of the trajectory (corridors), doors or obstacles. The biggest changes in the step length of the pedestrian are when the orientation of the pedestrian is changing. The most stable step length is on the straight sections of the corridors. These changes in the length are reflected in the determination of the average step length and thus this fact has an impact on the pedestrian's trajectory determination.

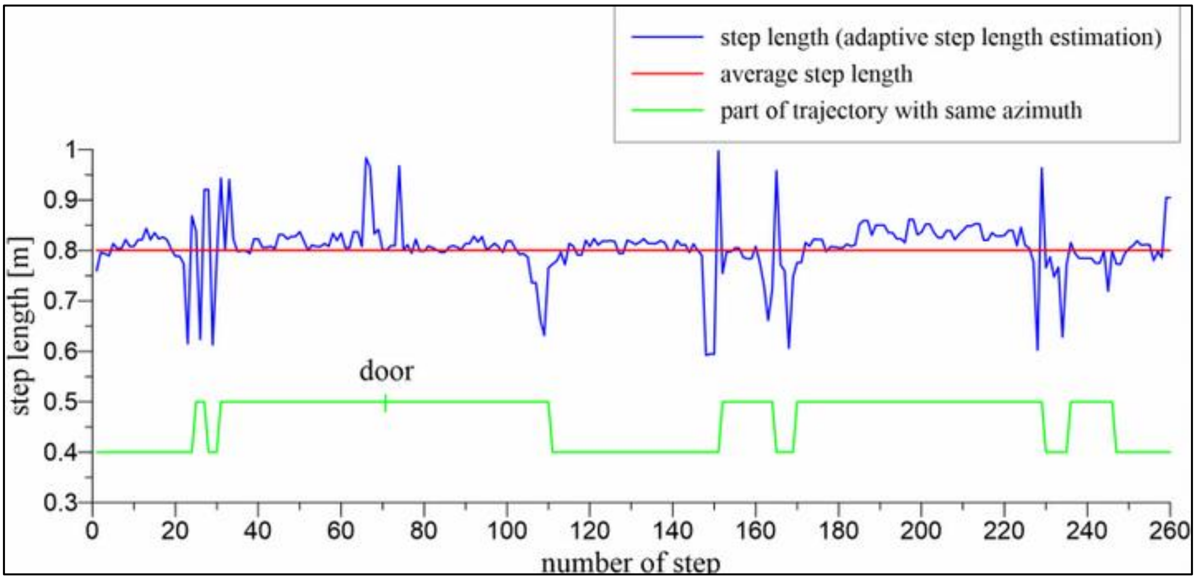

Figure 9 Variation in the step length

The advantage of the proposed method of the trajectory determination for pedestrians is the simplicity of calculation algorithms. With definition of some simple rules of the possible orientation movements, the resulting trajectory became more accurate and reaches the acceptable level for this kind of applications. The orientation calculated by the numerical integration of the angular velocity from gyroscope is burdened with errors, which are cumulated in the integration process. Results of the wrong orientation of the trajectory can be determined which can often completely invalidate the determination of the pedestrian trajectory. The suggested procedure has implemented the external inspection to allow movement only in perpendicular directions (± 90 °) which defines a potential corridor for pedestrians on the floor plan. However, in the most cases (buildings), this restriction is applicable because the hallways (walls) are perpendicular to each other.
After determination of the orientation it is necessary to determine the step length (path elements of the trajectory) and by using of the polar method the current position can be easily calculated. The disadvantage of the step detection method is that the calculation (part of the proposed algorithm to determine the step length) must be calibrated for each user and therefore does not constitute an universal solution for each user. The developed algorithms allow to determinate the relative position only, so the initial position and orientation must be determined at the start of our movement. This could be solved by using other navigation solutions, for example scanning QR-codes with defined coordinates, etc.

7. CONCLUSION AND PLANNED ACTIVTIES

On the base of these results from the realized experiments it is evident that the step detection method could be applied for pedestrian trajectory determination. The presented paper discusses the ability of the usage of two approaches for determination of the pedestrian trajectory using step detection method. The first approach is to determine the step length by the determination of the average step length. The second approach is to determine the step length with the walking frequency and acceleration variance. The nature of the trajectory significantly affects the step length, for example presence of the doors or other obstacles. The proposed algorithm is able to perform the determination of the trajectory with limited accuracy (after passing the trajectory 203.80 m is the length difference -1.02 m). Due to this accuracy it would be appropriate to define areas of possible movement (corridors of the building) and areas where movement would be prevented (walls) in the future. It would also be useful to define the control points that would serve for correction of the calculated trajectory (e.g. scanning QR-codes with exact position) in the field of possible movement. In the future work the floor plan may be replaced by 3D model of the building, so the user has the better spatial imagination of its movement in the building.

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