Pedestrian Trajectory Determination in Indoor Environment

Ľubica Ilkovičová
Pavol Kajánek
Alojz Kopáčik

Indoor navigation technologies

- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities, shopping malls,...) – GNSS signal can’t be used, only outdoor

- WiFi - principle based on wireless network WLAN and received signal strength
  - Radio Frequency
  - Pseudolites
  - Visual techniques
  - Inertial navigation
Indoor navigation technologies

- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can’t be used

- WiFi

- Radio Frequency - electromagnetic communication between RF reader and tag

- Pseudolites

- Visual techniques

- Inertial navigation

---

Indoor navigation technologies

- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can’t be used

- WiFi

- Radio Frequency

- **Pseudolites** - use of the navigational signal similar to GNSS, supplement of the GNSS signal (tunnels, indoor environment)

- Visual techniques

- Inertial navigation
Indoor navigation technologies

- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can’t be used

- WiFi
- Radio Frequency
- Pseudolites

- **Visual techniques** – localization is provided by evaluation of the reference objects placed on the characteristic places in the building

- Inertial navigation

---

Indoor navigation technologies

- Increasing need of the navigation systems in indoor environment (hospitals, rescue services, universities,...) – GNSS signal can’t be used

- WiFi
- Radio Frequency
- Pseudolites

- **Visual techniques** – localization is provided by evaluation of the reference objects placed on the characteristic places in the building

- Inertial navigation – trajectory determination provided by the measurements from the inertial sensors (accelerometer, gyroscope)

- IPIN - International Conference on Indoor Positioning and Indoor Navigation (organized every year since 2010)
Determining the path of pedestrian movement in indoor environment

- The use of inertial sensors built in the smartphone to determine the trajectory of pedestrian movement
- Smartphone – basic equipment all of us

Advantages of inertial sensors usage:
- Availability
- Independence (no need for information from external sources)
- Price

Disadvantages of inertial sensors usage:
- Relative position determination
- Need to know the initial position and orientation of the device
- Accuracy of the position rapidly decreases with time measurement (accumulation of errors in the integration process)

- Trajectory determination - base for the navigation in indoor spaces (step detection method), smartphone – low cost solution, expected accuracy 1m

System architecture

- WiFi
- MATLAB
- External web server
Data acquisition:

- Matlab- Android support (version 2014a)
- Automated acquisition of the measured data

Inertial sensors used in the calculation:
- Accelerometers (linear motion)
- Gyroscopes (rotation)

Double integration

- Trajectory determination using double integration → error accumulation

\[ s = \int \int a \cdot dt \]

\( s \) trajectory
\( a \) acceleration
\( dt \) time difference

![Graph showing distance over time with error accumulation](image)
Step detection

**Principle:**
- Step – specific type of mechanical movement
- Changes in the acceleration
- Based on the measured acceleration, steps can be detected (benefit - double integration is not used)
- Orientation of the device - determined from the angular velocity (gyroscopes)
- Direction of the +Z axis - down (identical to the direction of gravity)
- Movement of pedestrian - a periodic character

Options of step detection:
- from the acceleration magnitude
- from the residues of the acceleration norm
- from residues of acceleration in the Z axis direction
- velocity of movement along the axis Z
The principle of calculation of the pedestrian trajectory by step detection

- Step detection from peaks, length determination - use of a known averaged step length (acquired by previous experiment)
- Threshold (limit search of peaks)
- Minimal time difference between two steps (0.2 s)

\[ s = N \cdot \bar{d} \]

\( s \) trajectory
\( N \) number of detected steps
\( \bar{d} \) average step length

Calculation of the pedestrian orientation (orientation of the steps):
- Calculation of the Euler angle \( \text{yaw} \) (rotation around the Z axis) by the numerical integration of the angular velocity,
- Movements restricted to 4 main directions - 0°, 90°, 180°, 270° (rectangular arrangement of corridors)
- Orientation refers to the initial orientation of the pedestrian (resp. smartphone)
Determination of the trajectory – average step length

- Average of user’s step length, acquired by the previous experiment for the specific user
- Initial position and orientation

Location of pedestrian determined by the polar method:

\[
X_{(t)} = X_{(t-1)} + \text{step}. \cos(\text{azimuth}_{(t)}) \\
Y_{(t)} = Y_{(t-1)} - \text{step}. \sin(\text{azimuth}_{(t)})
\]

- \text{step} - step length
- \text{azimuth} - orientation of the step (4 main directions)
- \text{t} - number of step
Adaptive step length estimation

Disadvantages of proposed algorithm (averaged step length)
- Constant step length
- Different step length for each user
- Length difference of the whole trajectory (203.80 m) → 6.20 m

SOLUTION

ADAPTIVE STEP LENGTH
(linear combination of the walking frequency and the acceleration variance)

- Variable step length
- Change in the step length during natural walk
- Better accuracy

OFFERS

Adaptive step length estimation

- Variation determined by the linear combination of the walking frequency and the acceleration variance from the several series of measurements

\[ SL = \alpha \cdot WF + \beta \cdot AV + \gamma \]

\( \alpha, \beta, \gamma \) - parameters of the adaptive step length estimation, individual for each user

\( WF \) - walking frequency,
\( AV \) - acceleration variance,

\[ WF = \frac{1}{k_{n} - k_{i}} \]
\[ AV = \frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \]
Trajectory

Achieved results

<table>
<thead>
<tr>
<th>Section</th>
<th>Actual</th>
<th>Detected</th>
<th>Actual length</th>
<th>Average step length</th>
<th>Adaptive step length</th>
<th>Average step length</th>
<th>Adaptive step length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 2</td>
<td>21</td>
<td>21</td>
<td>18,40</td>
<td>16,80</td>
<td>17,14</td>
<td>1,60</td>
<td>1,26</td>
</tr>
<tr>
<td>2 - 3</td>
<td>4</td>
<td>4</td>
<td>2,40</td>
<td>3,20</td>
<td>3,12</td>
<td>-0,80</td>
<td>-0,72</td>
</tr>
<tr>
<td>3 - 4</td>
<td>2</td>
<td>2</td>
<td>1,60</td>
<td>1,60</td>
<td>1,40</td>
<td>0,00</td>
<td>0,20</td>
</tr>
<tr>
<td>4 - 9</td>
<td>77</td>
<td>76</td>
<td>64,00</td>
<td>60,80</td>
<td>63,31</td>
<td>3,20</td>
<td>0,69</td>
</tr>
<tr>
<td>9 - 10</td>
<td>38</td>
<td>38</td>
<td>32,00</td>
<td>30,40</td>
<td>31,77</td>
<td>1,60</td>
<td>0,23</td>
</tr>
<tr>
<td>10 - 11</td>
<td>12</td>
<td>12</td>
<td>9,60</td>
<td>9,60</td>
<td>9,50</td>
<td>0,00</td>
<td>0,10</td>
</tr>
<tr>
<td>11 - 12</td>
<td>5</td>
<td>5</td>
<td>3,50</td>
<td>4,00</td>
<td>3,88</td>
<td>-0,50</td>
<td>-0,38</td>
</tr>
<tr>
<td>12 - 13</td>
<td>61</td>
<td>59</td>
<td>48,70</td>
<td>47,20</td>
<td>49,70</td>
<td>1,50</td>
<td>-1,00</td>
</tr>
<tr>
<td>13 - 14</td>
<td>6</td>
<td>5</td>
<td>4,20</td>
<td>4,00</td>
<td>4,16</td>
<td>0,20</td>
<td>0,04</td>
</tr>
<tr>
<td>14 - 15</td>
<td>12</td>
<td>12</td>
<td>8,10</td>
<td>9,60</td>
<td>9,65</td>
<td>-1,50</td>
<td>-1,55</td>
</tr>
<tr>
<td>15 - 1</td>
<td>14</td>
<td>13</td>
<td>11,30</td>
<td>10,40</td>
<td>11,19</td>
<td>0,90</td>
<td>0,11</td>
</tr>
<tr>
<td>Suma</td>
<td>252</td>
<td>247</td>
<td>203,80</td>
<td>197,60</td>
<td>204,82</td>
<td>6,20</td>
<td>-1,02</td>
</tr>
</tbody>
</table>
Conclusions

- Pedestrian trajectory determination using smartphones – low cost solution, available for large part of population
- The advantage of the adaptive step length determination - simplicity of calculation algorithms, reflected specific characteristics of the user’s walk
- Step detection could be applied for pedestrian trajectory determination – accuracy of proposed algorithm 1 m

Future work

- Definition of the control points - correction of the calculated trajectory (e.g. scanning RFID tags with exact position) in the field of possible movement
- Floor plan may be replaced by 3D model of the building

Pedestrian Trajectory Determination in Indoor Environment

Thank you!

Ľubica Ilkovičová
Pavol Kajánek
Alojz Kopáčik, prof., PhD.
lubica.ilkovicova@stuba.sk

Slovak University of Technology in Bratislava,
Faculty of Civil Engineering,
Radlinského 11, 813 68 Bratislava, Slovakia,
Web site: www.svf.stuba.sk

Supported by Comp. Center for SMART Technologies for Electronics and Informatics Systems and Services, ITMS 26240220072, funded by the Research & Development Operational Programme from the ERDF.