Development of a Pedestrian Navigation System

Using Low Cost Accelerometer, Magnetometer and GPS

Master Thesis

by

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03.12.2007

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Goal of the Work
Providing a user’s current position relative to an initialization point by blending data from shoe mounted sensors with GPS data

Overview of the Presentation
1. Introduction & Review of Pedestrian Navigation Techniques
2. Hardware Implementation
3. Step Detection
4. Stride Length Determination
5. Azimuth Calculation with Tilt Compensation
6. Position Estimation by Sensor Fusion
7. Field Tests
8. Future Outlook
A Pedestrian Navigation System is needed for:

- Guidance in unfamiliar environments (for both civil and military use)
- Location based services
- Context-aware applications
- Tracking of users operating in high-risk environments
- Guiding the visually-impaired in urban cities
Available positioning techniques for different levels of accuracy

- Global Navigation Satellite Systems: GPS, DGPS, AGPS, HSGPS
- Local Radio-based Positioning Systems: WLAN, RFID, GSM Networks
- Dead Reckoning Systems
- Computer Vision-based Navigation Systems
- Sensor Fusion
Development of a Pedestrian Navigation System

1. Introduction & Review
2. Hardware
   - ADXL202 2-axis Accelerometer
   - HMC1052L 2-axis Magnetometer
   - dsPIC30F3013
   - BlueNiceCom3 Bluetooth Transceiver
3. Step Detection
4. Stride Determination
5. Azimuth Calculation
6. Sensor Fusion
7. Field Tests
8. Summary & Future Outlook

- GPS Receiver
- Laptop PC with MATLAB

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Fachgebiet Elektronische Mess- und Diagnosetechnik
Typical walking cycle and corresponding accelerometer outputs:

PHASE | STANCE | SWING
---|---|---
PERIOD | 1st DOUBLE SUPPORT | SINGLE LIMB SUPPORT | 2nd DOUBLE SUPPORT | INIT | MID | TERMINAL

EVENT | FOOT STRIKE | OPPOSITE TOE-OFF | OPPOSITE FOOT STRIKE | TOE OFF | FOOT CLEARANCE | TIBA VERTICAL | FOOT STRIKE
---|---|---|---|---|---|---|---
% of CYCLE | 12% | 50% | 62% | 100%

Typical walking cycle:
- Begin Stance
- Opposite Foot Strike
- Toe Off
- Terminal Swing
- Foot Strike

Graph showing:
- Acceleration (g)
- Percentage of a Stride (%)
3. Step Detection

Block Diagram of Step Detection Algorithm

- $Z_{acc}$
- $Y_{acc}$
- [ZxY]
- $\text{Var[ ]}$
- Moving Average
- $Z_{acc}$
- $Y_{acc}$
- Low Pass Filter
- Peak-Detection
- $T_{Toe-Off}$
- $T_{Foot-Strike}$

- Acceleration Signals
- Variance of Product
- Detected Peaks in Filtered Accelerometer Signal
- Moving Average Output

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Stride Length Determination by Linear Regression

\[ \text{Stride Length} = a_1 + a_2 \times \text{Freq} + a_3 \times \text{Var} \]

- **Freq**: Actual step frequency
- **Var**: Variance of the Y-axis accelerometer signal during one step

LR parameters \(a_1\), \(a_2\) and \(a_3\) determined by least squares fit:

![Graph showing the relation between step length, frequency, and accelerometer variance.](Image)
Neural Networks as an Alternative Approach:

Comparison of LR-Model with NN-Model:
The Need for Tilt Compensation

- Compass horizontal to earth’s surface → Hx and Hy can be measured accurately → Accurate heading determination
- Walking on surfaces with inclination → Hx and Hy can’t be measured correctly → Wrong heading determination
- Solution: Roll and Pitch angles must be measured!
Tilt Compensationed Azimuth is determined by:

- Reading the magnetometer, when the foot is resting on the ground
- Using the accelerometer outputs to determine the pitch and roll angles

Tilt Compensation in a Static Test:
Sensor Fusion using an Optimal Estimation Technique

- DD2 Filter is chosen for this purpose
- Resembles the Extended Kalman Filter, yet the implementation is simpler

Design of the Optimal Estimator

\[
\begin{align*}
N_k &= N_{k-1} + \ell_k \cdot \cos (\psi_k + \varepsilon_k^\psi) \\
E_k &= E_{k-1} + \ell_k \cdot \sin (\psi_k + \varepsilon_k^\psi)
\end{align*}
\]

\[
z_k = h(x_k, w_k) = \begin{bmatrix} N_k^{GPS} \\ E_k^{GPS} \end{bmatrix}
\]

State Model
Observation Model
Development of a Pedestrian Navigation System

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Block Diagram of the PNS Algorithm
Field Test 1
Development of a Pedestrian Navigation System

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Field Test 1

- Graphs showing Easting [m], Northing [m], Heading [Grad], and Estimated Stride Length [m] plotted against Step No.
Development of a Pedestrian Navigation System

Field Test 2

7. Field Tests
Field Test 2

1. Introduction & Review
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Development of a Pedestrian Navigation System
Field Test 3
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Field Test 3

1. Introduction & Review
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8. Future Outlook

Suggestions for further study:

- Improvement of the DR performance by an additional gyro
- Smaller package for sensor module
- Other additional movement classifiers
- Usage of a cell phone as the computer module
Thank you!
Any questions?