Localisation using Accelerometer and Magnetometer

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***Abstract*—This paper explores methodology for quantifying pedestrian localisation and orientation utilising sensor technologies in portable devices. By analysing vertical acceleration, the research identifies the starting point and the finishing point of the step, recording the steps taken. Furthermore, the magnetometer values are used to determine the user's orientation like a compass.**

I. INTRODUCTION

In recent years, the need for accurate and real-time localisation techniques has become important, especially with the rapid advancement in robotics, autonomous vehicles, and augmented reality applications. This research aims to perform localisation and orientation accurately, employing advanced methodologies in sensor technology. The LSM303AGR sensor is used for this project. This report focuses on employing an accelerometer to accurately detect step motions and a magnetometer to determine the user's directional orientation, leveraging the sensitivity of Earth's magnetic field. By utilising the vertical oscillations captured by the accelerometer, the starting point and the finishing point of the steps are determined accurately. Furthermore, the data from the magnetometer is used in determining the user's orientation relative to magnetic north, a critical component for navigational applications. Moreover, the research acknowledges the potential errors in sensor readings, especially those from the magnetometer. To address these, the methodology designed to diminish the effects of magnetic disturbances, is incorporated.

In the subsequent section of the paper, a structured presentation of the research journey and experimental findings are provided. Section 2 offers a review of related works, setting the foundation and context. In section 3, the implementation stages are outlined. Moving to Section 4, the experimental results and the limitations are detailed. Section 5 concludes the report by summarising the experiments and discoveries.

II. RELATED WORKS

There has been a lot of research on step-detection methods for localisation. Three notable works, [1], [2], and [3], leverage Inertial Measurement Units (IMU) sensors to identify human steps for this purpose.

A. *Step detection and IMU sensor fusion*

[1] introduces an algorithm that combines accelerometer, magnetometer, and gyroscope data from an IMU sensor to estimate position.

In [1], pitch and roll values from the accelerometer and gyroscope are estimated using sensor fusion via Kalman filter to integrate data from these sensors, obtaining more accurate pitch and roll estimates. Then, the pitch value derived from the sensor fusion is used for detecting steps and estimating their length. A valid step is detected based on specific peaks (maxima and minima) within the pitch data. If the maximum or minimum peaks exceed a noise threshold, the step count is increased with predefined thresholds to avoid false detections. After detecting a step, how far each step travels is determined. The model uses the difference in pitch values (between the highest and lowest peaks) to estimate the step length via a linear regression model. Then the direction (heading) of a person is estimated using magnetometer and gyroscope data, and to address sensor inaccuracies, a Kalman filter is applied to provide a more precise orientation measurement. Upon determining the step length and heading, the algorithm calculates an individual's position. This is achieved by multiplying the step length with the total number of steps taken and then aligning this result according to the estimated direction (heading). One of the notable strengths of the algorithm is that the strengths of each sensor are combined, mitigating their weaknesses. For example, while the gyroscope provides short-term accuracy but drifts over time, the accelerometer provides reliable long-term data but can be noisy in the short term. By fusing data from these sensors, the proposed algorithm aims to provide accurate indoor position estimates.

B. *PILoT System*

Similarly to how [1] incorporates a Kalman filter to combine data from the accelerometer, gyroscope, and magnetometer readings, the PILoT system in [2] also employs a Kalman filter for merging data from accelerometer and gyroscope. This assists in estimating pitch, roll, and heading. This study also emphasises that the Kalman filter approach provides a better estimation over individual sensor data. While [1] detects steps by only analysing pitch maxima and minima derived from the sensor fusion, the PILoT system in [2] utilises the Continuous Wavelet Transform.

C. *Refined step detection and stride estimation*

The system in [3] emphasises the limitations of the traditional PDR, which detects steps based on threshold values of vertical impact. This approach may need to be revised due to foot inclination. While [1] and [2] propose a comprehensive algorithm combining data from accelerometers, magnetometers, and gyroscopes to estimate position including techniques such as sensor fusion, step detection, and step length estimation, [3] focuses on improving step detection and stride estimation by analysing the vertical and horizontal acceleration of the foot while walking.

[3] proposes an improved step detection using pattern recognition derived from the vertical and horizontal acceleration of walking. By analysing the walking patterns, they can recognise steps more reliably. For step recognition, while [1] and [2] counted a step whenever a certain

acceleration threshold was exceeded, [3] highlights that individual differences and external vibrations can lead to errors. Their proposed alternative solution uses an acceleration signal pattern to accurately determine when a step has occurred. Differing from other studies that depend on step frequency for stride calculation, which can be influenced by various factors like obstacles or visibility issues, [3] suggests a method that correlates stride directly with acceleration rather than walking frequency. Their findings indicate a relationship between stride length correlates and the amount of vertical force experienced during a step, which can be measured through acceleration. In terms of determining direction (heading), instead of solely depending on gyroscopes which can drift off or contain biases over time, it combines gyroscopes with magnetic compasses. The gyroscope corrects the compass's inaccuracies, while the compass adjusts the gyroscope's drift, providing an initial orientation.

III. Implementation

The project implementation involves data preparation from the LSM303AGR sensor and the use of an accelerometer and magnetometer values to determine localisation and orientation.

A. *Data interpretation*

After waiting until the acceleration data is available, the acceleration data for the X, Y, and Z axes are captured from the accelerometer by retrieving both the least significant byte (LSB) and the most significant byte (MSB), each comprising 8 bits. These two bytes are then combined to form a complete 16-bit integer that represents the full precision of the measurement. A similar approach is employed for processing the data from the magnetometer.

Following data retrieval, the raw acceleration values are converted to the 'mg' unit, representing milli-gravitational force, where 'g' is the standard gravitational force approximately equal to 9.81 m/s². The unit 'mg' is utilised for a display of data on the terminal for debugging purposes.

The raw magnetometer data are converted to the unit milli-Gauss using the conversion factor. The conversion factor is calculated by the maximum range of the magnetometer in Gauss (50) / maximum positive value a 16-bit signed integer can hold (32767). Similar to acceleration data, the unit 'milli-Gauss' is used for printing purposes.

After converting the data into different units, five data are sampled and averaged to reduce the random noise and obtain a more stable and consistent reading. This is because it is essential to ensure that the data is stable and not subject to rapid fluctuations for accurate localisation and orientation. The results of the sensor reading are shown in Fig. 1.

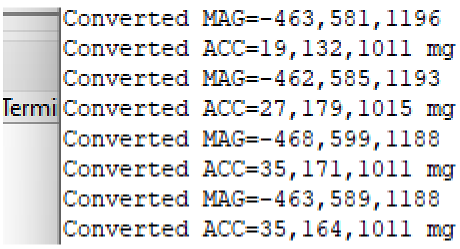

Fig. 1. Magnetometer and accelerometer readings printed out.

B. *Step Detection Methodology*

To identify steps, accelerometer data is utilised. Specific thresholds are set to indicate the starting point and the finishing point of a step, focusing on the Z-value of the accelerometer. The reliance on the Z-value, rather than the combined magnitude of X, Y, and Z, is due to its significant representation of the vertical walking motions. It provides a rhythmic pattern indicative of these actions, as demonstrated in Fig.2.

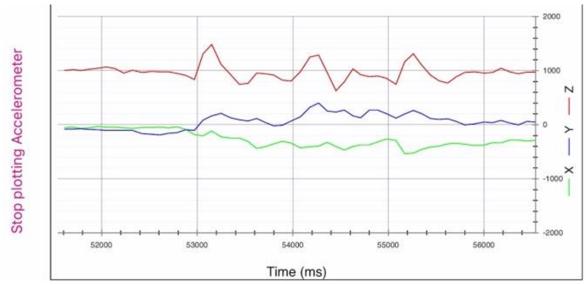

Fig. 2. Accelerometer graph when one step performed.

Some studies such as papers mentioned in the related works section, they involved the cumulative magnitude of all three axes as solely relying on the Z-axis could introduce inaccuracies. However, as the device's orientation is kept consistent during the experiments done for this project, I decided only to use the Z-axis value.

When a significant positive acceleration is detected, it is considered the start of a step. Conversely, a significantly lower acceleration indicates the end of a step. These are determined by comparing the acceleration to predefined threshold for the step start and finish values. Setting these two distinct thresholds helped in avoiding double counting for one step and increased accuracy.

C. *Stride Determination*

A stride measurement is an important factor for distance calculation. For this project, the stride determination stage involves using a known distance traversed within a specific number of steps. While theoretical methods such as multiplying the height and conversion factor (0.415 for males and 0.413 for females) exist, for more accurate estimation, total distance with step count was utilised to determine the stride length.

A consistent step pattern was required during the experiment for accuracy. The reliability of stride length in distance measurement is further validated by assessing the total distance covered when walking in a straight trajectory. The stride length used for this project is 0.57m.

D. *Determining heading*

For determining the heading, only the X and Y values of the magnetometer are utilised. This approach is based on the principle that the Earth's magnetic field's horizontal component varies as one changes direction, but the vertical component remains relatively stable. Therefore, the horizontal plane, represented by the X and Y axes, provides sufficient data to accurately ascertain the heading.

For the calculation method, the arctangent (atan2) function is employed. It can compute the arctangent of the quotient of its arguments and it returns results in the full circle (from -pi to pi). This allows for differentiation between all possible directions. The negative values are handled by adding 360 to ensure the range is from 0 to 360. The atan2 function ensures that the calculated heading is reflective of the magnetometer's actual orientation with respect to the Earth's magnetic north. The equation is as follows:

$$currentHeading = (atan2(magY,magX) \tag{1}$$

Where:

- currentHeading represents the calculated heading direction,
- magY indicates the magnetometer reading on the Y-axis, and
- magX indicates the magnetometer reading on the X-axis.

The initial heading is set to zero and the relative heading is updated. The relationship between the current heading value and the relative heading value is shown in Fig.3.

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Heading from Mag = 90 degrees, Relative Heading from Mag = 0 degrees
Heading from Mag = 90 degrees, Relative Heading from Mag = 0 degrees
Heading from Mag = 90 degrees, Relative Heading from Mag = 0 degrees
Heading from Mag = 90 degrees, Relative Heading from Mag = 0 degrees
Heading from Mag = 45 degrees, Relative Heading from Mag = 315 degrees
Heading from Mag = 45 degrees, Relative Heading from Mag = 315 degrees
Heading from Mag = 45 degrees, Relative Heading from Mag = 315 degrees
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Fig. 3. Current heading from magnetometer and relative heading values.

The heading calculation using the sensor was not functioning correctly, with the values getting stuck at either 0 or 270. Consequently, I decided to implement 'hard iron compensation'. The process of 'hard iron compensation' involves determining the constant offset that the hard iron distortion introduces into the magnetometer's readings and then subtracting that offset from the actual readings to get the true magnetic field values. This is calibrating the sensor by taking readings across various orientations and then determining the offset that is present in all readings. For this project, the maximum and minimum readings were taken for X axis and Y axis, and these were added then divided by 2 to get the offset.

E. *Determining position x,y*

Once a step is detected and completed, the system increments a step counter and calculates the total distance travelled based on a predefined stride length. This distance is then used with the previously calculated relative heading to estimate the change in the user's position.

The new position is calculated by resolving the step distance into X and Y components based on the relative heading. The equation used are shown below.

$$positionChangeX = stepDistance \cdot sin(relativeHeading) \tag{2}$$

$$positionChangeX = stepDistance \cdot sin(relativeHeading) \tag{3}$$

Where:

- positionChangeX and positionChangeY represent the changes in position along the X and Y axes, respectively,
- stepDistance signifies the length of one step, and
- relativeHeading denotes the current heading direction relative to a reference point, expressed in radians or degrees, depending on the implementation.

IV. EVALUATION

A. *Experiment results- Step detection*

For the evaluation, I conducted several experiments, holding the device horizontally to the ground and positioned in front of the body, ensuring the device remained still and did not get tilted. For the step detection, 7 different straight-line distances were measured with the known points. The results are shown in the table below. The stride length used here is 0.57m.

TABLE I. STEP DETECTION RESULTS IN STRAIGHT LINE

Real distance /m	Step Count	Measured Distance (0,y)	Difference /m
2	4	2.28	0.28
5	9	5.13	0.13
6	10	5.70	0.30
7	13	7.41	0.41
8	14	7.98	0.22
8.5	15	8.55	0.05
9	16	9.12	0.12

B. *Heading and position*

The calculation of position (x,y) operated as expected. However, the heading determination failed to obtain accurate results despite the implementation of hard iron compensation. Consequently, a comprehensive evaluation of the entire system, including directional changes, was unfeasible. If I had more time to work on this, my approach would involve experimenting with alternative sensors to figure out the precise issue and exploring other compensation techniques. It's worth noting that when I employed fixed values for verification purposes, the position calculation (x,y) functioned correctly.

C. *Limitations*

Looking at Table 1, one of the notable limitations of this system is the use of a fixed step length, set at 0.57 meters. When the system calculates distance, for instance, a 2-meter walk, the total distance covered does not precisely match the actual distance due to the fixed step length. Since this step length does not evenly divide into common distances, like 2 meters, the system can accumulate rounding errors, leading to inaccuracies in distance measurement over time. Furthermore, the system assumes everyone has the same step size, which is not true because people walk and run differently. Using a one fixed step size ignores the natural differences in how people move and can cause wrong distance estimates. A better way would be to have a step size that changes based on the person's current activity and their own walking or running style, which could make distance tracking much more accurate.

Another key limitation of this method is its reliance on just the Z-axis of the accelerometer to detect steps. This can miss out on capturing unusual or complex movements, especially if the device is not held straight up (e.g. in the pocket) or if the person's movements are not typical walking patterns. This approach might not catch the small differences in each step, leading to errors in both step counting and distance tracking.

V. Conclusion

In conclusion, this project emphasises the significant potential of using accelerometers and magnetometers for the purpose of pedestrian navigation. Through the precise detection of steps using an accelerometer and the determination of orientation via a magnetometer, the system addresses fundamental aspects of human localisation and orientation. However, there are certain constraints, such as the reliance on a single axis for movement detection and a fixed step size for all individuals, which can introduce elements of inaccuracy. Additionally, the challenges encountered with the heading calculation, despite the implementation of hard iron compensation, point towards complexities in magnetic field measurements that require further exploration.

In future developments, I would enhance the system's ability to detect complex motions, potentially through the integration of multi-axis analysis, thus decreasing reliance on the precise orientation of the device. Implementing a dynamic stride length adjustment that considers individual step patterns and current activity context could also significantly improve the system's accuracy.

We suggest that you use a text box to insert a graphic (which is ideally a 300 dpi TIFF or EPS file, with all fonts embedded) because, in an MSW document, this method is somewhat more stable than directly inserting a picture.

To have non-visible rules on your frame, use the MSWord "Format" pull-down menu, select Text Box > Colors and Lines to choose No Fill and No Line.

References

[1] A. Poulose, O. S. Eyobu and D. S. Han, "An Indoor Position-Estimation Algorithm Using Smartphone IMU Sensor Data," in IEEE Access, vol. 7, pp. 11165-11177, 2019, doi: 10.1109/ACCESS.2019.2891942.

[2] M. A. Chattha and I. H. Naqvi, "PiLoT: A Precise IMU Based Localization Technique for Smart Phone Users," 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall), Montreal, QC, Canada, 2016, pp. 1-5, doi: 10.1109/VTCFall.2016.7881166.

[3] Z. Zhou, T. Chen, L. Xu, " An Improved Dead Reckoning Algorithm for Indoor Positioning Based on Inertial Sensors", 2015.