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INDIVIDUAL MOBILE NAVIGATION SYSTEM OF WAY COUNTING

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Abstract**—***The problem of step counting has been considered for personal navigation while walking and using mobile sensors with low accuracy. Three primary approaches to computing the acceleration vector magnitude in time domain have enabled step counting. When analyzing data from mobile phone sensors for various pedestrian kinds, environmental factors, and their mobility patterns, several methodologies were compared. Except for the approach of normalized auto-correlation based step counting, which only processes short distances, the walking trajectories have been chosen to be long enough (at least 100 meters) to produce statistically representative results. The specifications for a specific step counting system have been developed.*

Index Terms—Pedestrian dead reckoning; autocorrelation function; thresholding; peaks detection; zerocrossing, global route.

I. INTRODUCTION

The issue of pedestrian dead reckoning (PDR) falls within the category of unique navigational issues [1]. The usage of satellite navigation is a typical mobile phone fix (GPS, GLONASS, Galileo, etc). However, a satellite's signal can occasionally be purposely blocked or lost because of obstructions in an urban area. The user localization issue with PDR is also fascinating when it comes to interior environments like huge garages and urban malls.

Micro-Electro-Mechanical Sensors (MEMS) technology is now used for smartphones' instrumentation, which includes a standard set of Inertial Measurement Unit (IMU) components, including accelerometers, gyroscopes, magnetometers, and pressure sensors.

Accelerometers may be used to measure distances as well as detect step occurrences. However, it is susceptible to factors like walking pace and road slope, leading to erroneous findings when determining stride length. Like any dead reckoning method, PDR is susceptible to accumulated inaccuracy. As a result of the location estimate's constant calculation using the prior outcome, the mistake multiplies with time. This indicates that ongoing rectification updates are required.

For instance, the error in calculating the step length has less of an impact on the estimation of the location than the error in determining the direction.

The course may be determined using the magnetometer and gyroscope measurements. However, the gyroscope has a drift issue, which causes the reading inaccuracy to grow over time, and the magnetometer is exposed to electric current and environmental metals. In addition, tilting the smartphone may cause it to turn away from the user's direction of travel. The precision of a course is also increased by smartphone postures, which must be taken into account in practice.

How to use IMU measurements to identify steps is a significant issue. There are several distinct approaches and procedures [2]: step counting based on normalized auto-correlation, peak detection, zero crossing, etc.

The threshold approach [3] counts the steps by detecting when sensor readings surpass a threshold (usually accelerometers). However, the threshold value varies depending on the sensor type and the pedestrian's gait style. Although the threshold approach is the simplest, it largely relies on empirical methodologies because there isn't a single threshold that works in every situation, especially when using a smartphone in an unrestricted way.

The number of peaks in the accelerometer vector magnitude is used to compute steps in the peak detection algorithm [4]. Although more adaptable, it experiences interference peaks brought on by outside sounds and sporadic disruption. There are many other ways to modify a technique, including low-pass filtering to eliminate interferences, restricting the duration between two peaks, and using vertical acceleration data to place restrictions on where a smartphone may be placed.

Based on the identification of zero points in the accelerometer vector magnitude, the zero-crossing technique of step counting [1] is used.

Unrestricted smartphone holding is a concern for both zero crossing and peaks detection approaches. The normalized auto-correlation based step counting approach [5], [7] is the most intriguing since it directly exploits the periodic character of walking.

II. PROBLEM STATEMENT

All smartphone sensors operate in a body-fixed (or sensor) coordinate system that is connected to a navigation frame called NED or ENU and can be translated into latitude and longitude coordinates (Fig. 1).

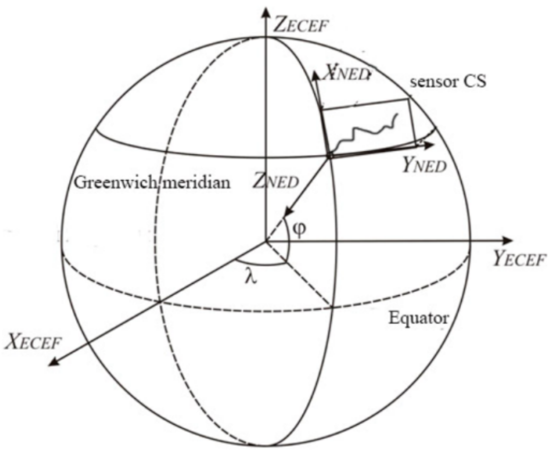

Fig. 1. Coordinate systems

The following data are used for further analysis and processing assuming the standard set of IMU sensors in mobile phones.

Accelerations. Three acceleration vector components are provided by MEMS accelerometers. The measurements from accelerometers can optionally be calibrated and thermal noise-filtered before being used.

$$a_m = \sqrt{a_x^2 + a_y^2 + a_z^2}. \quad (1)$$

Orientation. MEMS-gyroscopes produce angular rates in the sensor coordinate system of x, y, and z. Roll, pitch, and yaw attitude angle calculations are incorporated into the majority of mobile phones (again, in sensor coordinate system).

Depending on the type of walking, inertial measurement unit readings need to be evaluated.

Typically [6] the change in acceleration goes hand-in-hand with the transmission between walking phases (Fig. 2). The majority of step detection and counting techniques therefore rely on processing the acceleration vector magnitude (1).

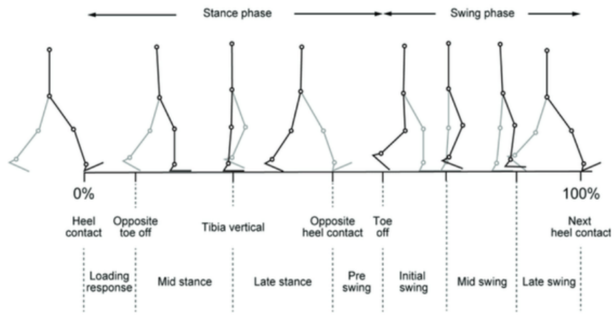

Fig. 2. Walking phases by [6]

The periodic pattern is evident here, just as it is on the accelerometer measurements (Fig. 3).

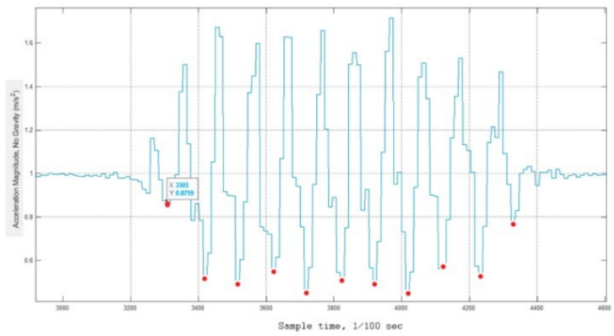

Fig. 3. Accelerometer readings for idle and walking

To remove gravity components, the magnitude of the acceleration vector must be preprocessed

$$a_{ng} = a_m - g$$

and low-pass filtered using a cut-off frequency that corresponds to the update sensor rate to remove unpredictable sounds. The moving average window may be used to implement the filter:

$$a_{filtered}(i) = \frac{1}{T} \sum_{j=-(T-1)/2}^{(T-1)/2} a_{ng}(i+j),$$

where T is the moving window's size [8].

The following is a proposed representation of the autocorrelation function used in the step calculation.

The metrics of similarity for the autocorrelation function will fall within the range [–1, +1] because it is normalized. The issue raised in [7] has to do with determining the ideal time lag value.

Humans typically walk at a frequency of roughly 1 Hz. The time lag in Fig. 3 with a sensor update rate of 100 Hz ranges from 91 to 127. By changing its value in an extra computation loop, the ideal time lag may be determined, but the processing efficiency will suffer.

The erroneous counting of steps in idle mode or phone jittering are further issues related to the autocorrelation approach. Once more, Fig. 3 shows the cyclic nature of the acceleration value from 3000 to 3200 random samples where the pedestrian is not moving.

Because of this, the autocorrelation approach is used in conjunction with other methods like thresholding. Standard deviation determines the simple threshold, for instance, determining whether the device is in idle mode.

$$\sigma(a_m) < 0.01. \qquad (2)$$

The autocorrelation function (ACF) is not computed in this instance. Whether requirement (2) is not met, walking mode is assumed, and ACF is checked to see if it exceeds threshold. If so, the number of steps is increased by one.

This thresholding is seen in Fig. 4, where 0.7 is used as the ACF step value.

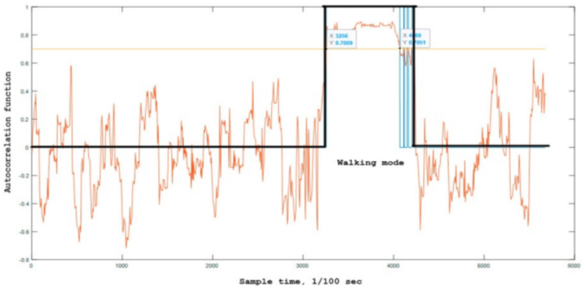

Fig. 4. Detection by ACF of walking and idle modes

Another issue with the autocorrelation approach is that it must deal with extended sequences, which requires either offline data processing or a delay in step counting when operating in real-time modes.

Additionally, the method's computational capacity is less than that of peak detection or zero crossing techniques.

III. EXPERIMENT DESCRIPTION

A set of IMU by BMI160 and K6DS3TR from STM, two smartphone sensors, have been used in experiments. Both of them are low noise 16-bit IMUs that deliver incredibly precise sensor data in real time for mobile applications like indoor navigation.

Figure 5 depicts the walking path used to test the strategies for peak identification and zero crossing. In the studies, different walking speeds (fast / slow) and smartphone holding positions (in hands/in pocket) were used.

The discrepancy between the actual number of steps and the number that was counted determines the step detection method's error. Contains the processed and represented data.

The trajectory used for the autocorrelation step counting approach is significantly shorter, at around 100 steps (Fig. 6).

The times of standing still and walking can be readily observed in the accelerometer measurements (Fig. 7), and the threshold value is established by the standard deviation (std).

The values related to the walking mode are isolated using the thresholding and autocorrelation function (Fig. 8) before being processed.

The autocorrelation method's data have been processed, and shows how they are shown.

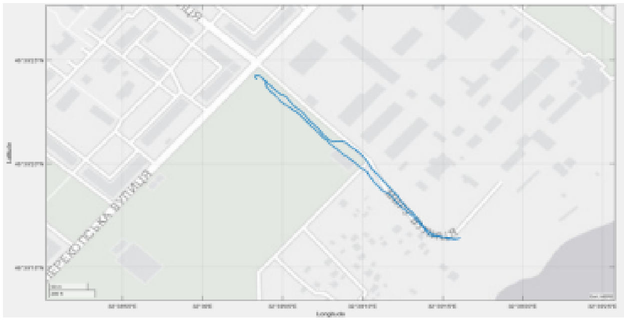

Fig. 5. Trajectory of walking

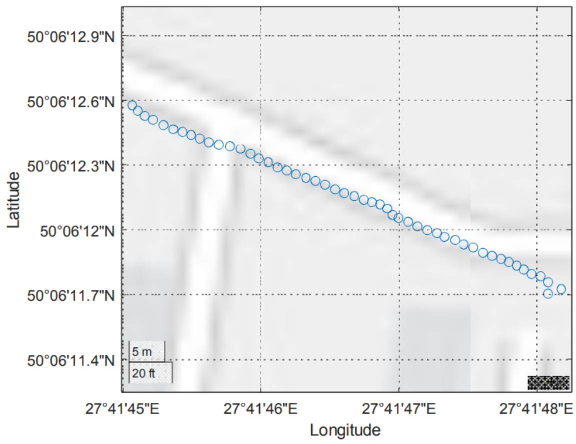

Fig. 6. Testing trajectory for autocorrelation step counting

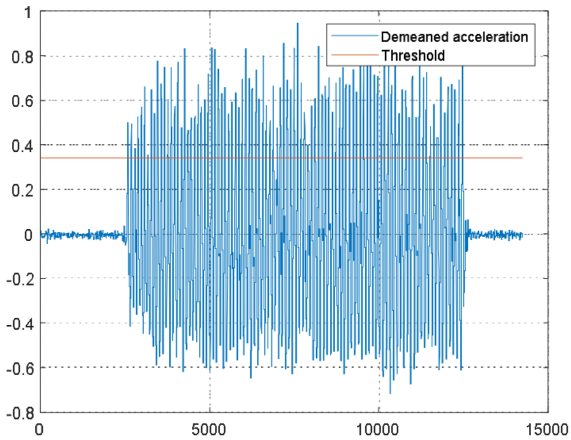

Fig. 7. Accelerometer readings with threshold value

Since thresholds vary greatly amongst devices, the frequency of readings will also be important. When using a continuous frequency that detects one person walking regularly, there is no guarantee that another person's walking will be recognized. Furthermore, there are numerous ways to hold the phone, including in the hands, in a pocket of shorts or pants, or fastened to a belt. Little information is provided, and a lot of the data is duplicate.

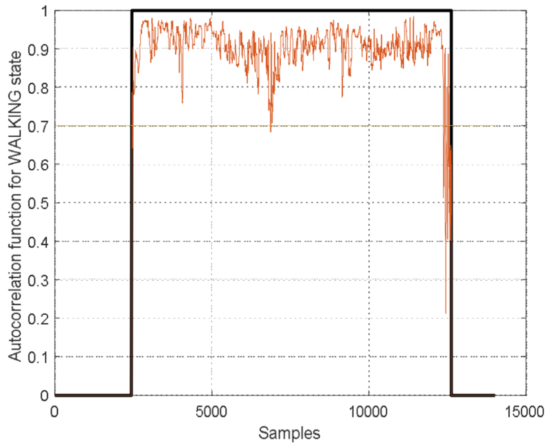

Fig. 8. Accelerometer readings with threshold value

Directional calculation, or angle calculation Taking into account the information gathered from the magnetometer built into the device and knowing the magnetic force of the earth along two axes, the direction can be calculated using the four-quadrant arctangent from the sensor data. This method converts the force into an angle in radians corresponding to the coordinates of the direction a person is walking. converted to a degree measure at last (Fig. 9).

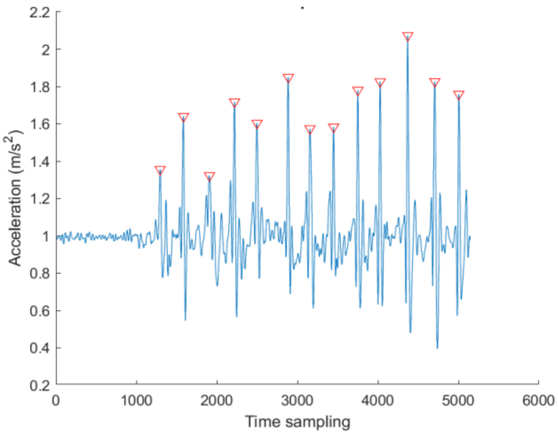

Fig. 9. Highlighted main peaks

The path taken by the pedestrian while the data was being recorded isconstructed using the angles, the direction, the predetermined number of steps, and their placement in relation to the timeline. By switching from a rectangular toa great circus coordinate system and altering the lengths of parallels depending onthe latitude where the test object is located, as per the standards, the displayaccuracy is greatly increased.

Since the inertial system only displays the distance traveled relative to theinitial reference point in meters, and the world direction is preserved relative tothe coordinate axes where the positive *X*-axis is the East direction and thepositive *Y*-axis is the North, West, and South directions, respectively, oppositeeach other, the user has the option to provide his approximate coordinates if he isunable to receive a GPS signal (Table I).

TABLE I. QUALITY OF STEP DETECTION METHODS

Walking type	Zero-crossing	Peak
Slow	$N = 907,\ N_c = 1003$ $Q = 90\%$	$N = 907,\ N_c = 933$ $Q = 97\%$
Slow	$N = 925,\ N_c = 1364$ $Q = 53\%$	$N = 925,\ N_c = 962$ $Q = 94\%$
Fast	$N = 823,\ N_c = 549$ $Q = 67\%$	$N = 823,\ N_c = 780$ $Q = 95\%$
Fast	$N = 810,\ N_c = 777$ $Q = 96\%$	$N = 810,\ N_c = 800$ $Q = 99\%$

IV. CONCLUSIONS

The researched step counting techniques offer precise results for the restricted holding of a smartphone (strictly in hands) and vary in computation speed. Peaks detection and zero crossing both have a quick reaction time and can compute steps in real time for the active pedestrian dead reckoning assignment. The accuracy drastically decreases up to 40–50% when the smartphone is in the hands or bags.

Since the autocorrelation method requires a lot of calculations, it can be used for offline processing. This method shows quality greater than 80% even for unrestricted smartphone usage.

By calculating data from the magnetometer and accelerometer to identify the number of steps and the direction of travel, with diverse behavior patterns, the suggested method enables you to estimate the distance of specific user routes.

Both indoor and outdoor navigation are possible with this application.

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М. П. Василенко. О. А. Лазаревський. Індивідуальна мобільна навігаційна система числення шляху

У роботі досліджено проблему виявлення та розпізнавання кроків і напрямку руху людини. Пропонована система дозволяє вимірювати відстань певних маршрутів користувача, обчислюючи дані з магнітометра та акселерометра, щоб знаходити кількість кроків і напрямок руху, з різними моделями поведінки. Програму можна застосовувати для навігації, як на відкритих майданчиках, так і в закритих приміщеннях. Головною перевагою такої системи є точність визначення місця розташування людини без GPS-навігації. В якості апаратного забезпечення використовується звичайний мобільний телефон. Програму вдосконалено додаванням шаблонів поведінки людини під час руху зі смартфоном. Алгоритм визначає ці моделі та розділяє їх на окремі маршрути для підвищення точності. Калібрування для цього пристрою необхідне тільки під час першого запуску, оскільки різні смартфони мають датчики від різних виробників. Систему також можна використовувати для виявлення аномалій у магнітному поясі Землі, що допоможе у вивченні часткової зміни магнітних полів на окремих ділянках і покращить орієнтування на користувацькій площині. Також проаналізовано фактор використання системи на підприємстві з екранованими стінами для орієнтації користувача у великих приміщеннях, складах, ангарах.

Ключові слова: інерціальна навігація; знаходження піків кроку людини; модуль вектора прискорення; фільтрація; тріангуляція; глобальний маршрут.