

Wearable Electromyography Sensor Based Outdoor-Indoor Seamless Pedestrian Navigation Using Motion Recognition Method

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Abstract— Navigation and position applications are now becoming standard build-in features in smart phone. However, locating a mobile user in GNSS unfriendly and denied environments such as urban canyons and indoor environments ubiquitously is still a challenging task. Several self-contained sensors, such as accelerometer, digital compass, gyroscope and barometer, have been adapted as assistant augmentation technologies to a GPS receiver to make a seamless outdoor-indoor seamless pedestrian navigation. Since the indoor environment is more complex than an open signal-environment, such GNSS signal-degraded areas are typically also contaminated with disturbance sources that affect sensor measurements, a digital compass can be disturbed significantly by e.g. an elevator that bears magnetic perturbation. And a ventilation facility may cause jumps in the barometer's measurements; not to mention that the indoor attenuate the GNSS signal. In this paper a novel outdoor-indoor seamless solution for pedestrian navigation is introduced, which is based on Electromyography (EMG) sensors. The EMG sensor measures the electrical potentials generated by muscle contractions of human body. Therefore it is immune against the environment disturbance; moreover, it has potential capability to exploit the health situation of the pedestrian, since the EMG sensor has been applied on biomedical field for decades. Five different motions are classified to determine the stride length, including: walking horizontally, walking up alone a slope, stepping upstairs/downstairs and stand still. The stride length is based on a simple empirical module where fix stride length is donated to each classified motion. In order to evaluate the EMG-based PDR solution developed in this study, an outdoor-indoor field test has been carried out. The test results demonstrated that the EMG-based PDR solutions are comparable to the commercial GPS solutions for a period of 9 minutes outdoors, that is equivalent to a walking distance of 695 meters and offer a robust and promising solution indoors.

Keywords — electromyography signal; Pedestrian dead reckoning; outdoor-indoor seamless navigation; motion recognition

I. INTRODUCTION

Navigation applications and location-based services are becoming standard features in smart phones nowadays. GPS has been used in a pervasive way in most open-sky environment applications. However, locating a mobile user ubiquitously is still a challenging task for standalone GNSS technology, especially in GNSS degraded and denied environments such as urban canyons and indoor environments.

Electromyography (EMG) signal is a typical kind of bio-signal that measures electrical currents generated in muscles during its contractions without any other references to the external environment. When a pedestrian is walking, the EMG signals measured from the legs are changing periodically and reflect the occurrence of each step. Therefore, it can be used to count the steps. [1][2][5]

EMG-based technologies, provides researchers with a significant opportunity to capture human locomotion by directly sensing and decoding muscular activity. Such technologies are widely applied in medical diagnosis, rehabilitation and human-computer interaction (HCI). Moreover, there is a positive relation between force exerted by the legs and the motion type. To be exact, the motion type determines the strength of leg muscle contraction. The EMG signal amplitude could reflect the exerted strength, which makes it possible to recognize the motion with EMG signals.

In this paper, motion recognition assisted PDR algorithm is proposed using wearable EMG sensors to measure walking strides and classify the motion type. There are two major improvements demonstrated in the paper: the first one is the pedestrian motion recognition, which is not only to improve that step detection rate, but also improve position accuracy. The other is a simple empirical stride length module with fixed stride length for corresponding motion is applied for calculating position, which is convenient for being transplanted into embedded system in future.

The work presented in this paper is the consecutive step of some former pilot studies [1][2][5] in further developing a novel and robust PDR solution using wearable EMG sensors to measure walking steps.

Since the indoor environments are typically contaminated with significant error sources that disturb the measurements of the digital compass [3][4]. The purpose of this paper is to discuss the performance and feasibility of EMG signal for indoor PDR. To simplify the discussed problem, the heading output of Novatel SAPN is used as azimuth for PDR solution.

II. METHOD AND ALGORITHM

A. Stride Detection

The Algorithm of stride detection is not based on the signal from a single EMG channel, but rather based on the smoothed signal, for precise information about the algorithm please review paper [1] [2].

B. Motion Recognition

Motion recognition algorithms are based on the following assumptions

- The exerted force by the leg has positive relation with motion type.
- The step mode is different between free walking and walking along the stair.

The M_f is the first motion recognition discriminator, which is used to describe how strong the force that the measured muscle exerts is.

$$M_f = \begin{cases} 0 & \text{if } \bar{P}_{EMG} < 50000 \\ 1 & \text{if } 50000 \leq \bar{P}_{EMG} < 450000 \\ 2 & \text{if } \bar{P}_{EMG} \geq 450000 \end{cases} \quad (1)$$

The $\bar{P}_{EMG}(i), 1 \leq i < L$ (here, L is the length of the EMG measurement) is the average power feature series of the EMG signals. The classified result of M_f is presented in Fig 1.

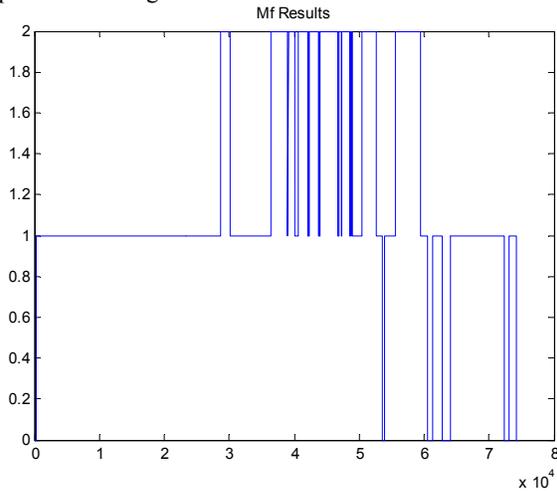


Figure 1. the classification result of M_f based on the average power of EMG signal

M_s is the second motion recognition discriminator, which is used to describe whether pedestrian walks freely or with stairs and the value of epoch P and can be calculate with following criterions:

$$M_s(P) = \begin{cases} 0 & \text{if } Std(S_p) < 0.015 \\ 1 & \text{if } Std(S_p) \geq 0.015 \end{cases} \dots\dots\dots(2)$$

Where the $Std(S_p)$ is variance of the stride period at the epoch of P , and the threshold value of 0.015 for $Std(S_p)$ is empirically selected.

$$Std(S_p) = Std[S(P+k)]_{k=P-w}^{P+w}, P = w, w+1, \dots, N-w \quad (3)$$

A sliding window with window size of $2w+1$ is applied to compute the variance. The classified result of M_s is presented in Fig 2.

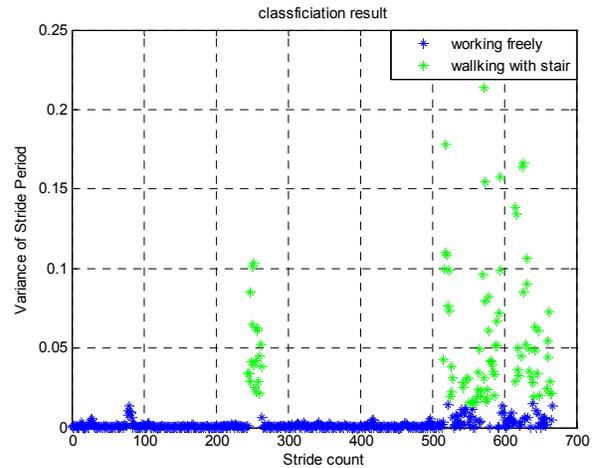


Figure 2. The classification result of based on the variance of stride period

C. Positoing Calculation

Assuming the beginning position of the pedestrian, the present position is calculated with:

$$\begin{aligned} N_{K+1} &= N_K + SL_K \cdot \cos \alpha_K \\ E_{K+1} &= E_K + SL_K \cdot \sin \alpha_K \end{aligned} \quad (4)$$

where N_K and E_K are the coordinate of the North and the East on the map, which represent position when the k -th step occur, SL_K and α_K are the corresponding stride length and azimuth of the k -th stride. Here the SL_K is simply calculate with empirical model that

$$SL_K = \begin{cases} 1.35 & \text{if } M_H(K)=4 \\ 1.30 & \text{if } M_H(K)=3 \\ 0.80 & \text{if } M_H(K)=2 \\ 0.60 & \text{if } M_H(K)=1 \\ 0.0 & \text{if } M_H(K)=0 \end{cases} \quad (5)$$

Where the $M_H(K)$ is motion recognition discriminator in k -th stride, it donates which kind of motion type the pedestrian is and is determined by motion recognition algorithm based on the M_f and the M_s discriminators mentioned in last section according to criterions listed in Table 1. And final recognized motion is present in Fig 3.

TABLE 1. THE CRITERION TABLE TO GENERATE THE MOTION RECOGNITION INDEX

M_s	M_f	M_H	Motion
1	1	2	Step down with a stair
1	2	1	Step up with a stair

1	0	0	Stand still
0	1	4	Walk horizontally
0	2	3	Walk up alone a slope
0	0	0	Stand still

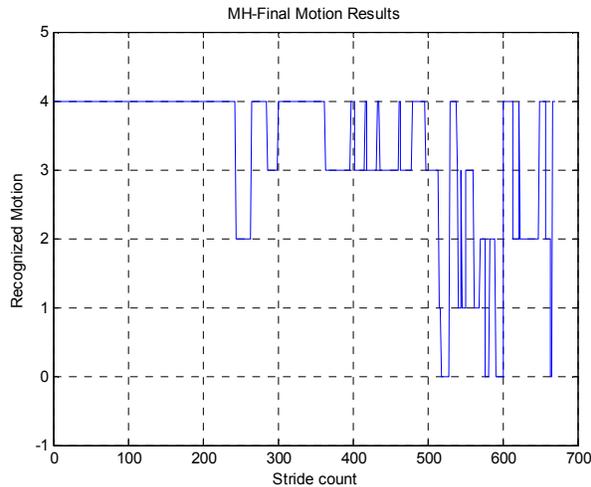


Figure 3. The Classified result of M_H

Since the indoor environments are typically contaminated with significant error sources that disturb the measurements of the digital compass. A unified error model for a certain digital compass for all indoor environments is still not available. The heading error model of a digital compass should be setup case by case according to different environment. The purpose of this paper is to discuss the performance and feasibility of EMG signal for indoor PDR by using motion recognition method. To simplify the discussed problem, the heading output of Novatel SPAN (Synchronized Position Attitude Navigation) system is used as azimuth (heading) for the PDR solution.

III. FIELD TEST

In order to evaluate the performance and feasibility of the proposed EMG based solution, the researchers carried out an outdoor-indoor field test in Oct, 2010. The reference trajectory is based on the measurements of SPAN system. The route of the outdoor test starts from the Masala railway station, steps down from a stair, passes through two tunnels walk along a slope and finally arrives the main entrance of Finnish Geodetic Institute (FGI).

The route of the indoor test, starts from the main entrance of the FGI, step up with stairs from 1st floor to 3rd floor, then take the elevator down to the 1st floor then walk through the corridor of the 1st floor and exits the building from another entrance.

To collect muscles activities during walking, several EMG sensors were attached to muscles of both left and right legs. To be exact,

- CH1-CH4 for left leg
 - CH1 and CH2 for Medial Head and Lateral Head of Gastrocnemius muscles.
 - CH3 for middle of Vastus intermedius
 - CH4 for Soleus

- CH5-CH8 for right leg and the installation position is same position as left leg as shown in Fig 4.



Figure 4. EMG sensor attached on left and right leg

The sample rate for each EMG channel is 1kHz. During the test, A Tester worn both EMG measurement system and a commercial GPS receiver (Fastrax IT03/16), and carried a Novatel SPAN system on the back. Novatel SPAN is a tactical grade GNSS / inertial systems, which tightly couples the GNSS receiver with robust inertial measurement units (Honeywell AG19) to provide continuously measurements including position, velocity and attitude even when the satellite are not available. The trajectory output of the SPAN is used as the reference for final evaluation. The outdoor scenario lasts for 9 minutes with a 663 meters walking distance, and the indoor scenario lasts for approximate 3 minutes with a 117 meters walking distance. All the dataset from different sensors are achieved for post-processing

Meanwhile, for honorably evaluate the performance of the EMG solution; the heading output of SPAN is used as azimuth to calculate the position, because the indoor magnetic disturbance of the main building is still not be modeled yet.

IV. RESULT AND DISCUSSION

The position accuracy of EMG-based PDR solutions are comparable to the commercial GPS solutions for a period of 9 minutes, that is equivalent to a walking distance of 663 meters in a complex route outdoors. The route contains

- normal walking,
- stepping down with stair
- stepping up with stair
- walking up along a slope
- walking down along a slope
- and several intentional stops

The EMG based PDR solution coincides with reference trajectory and offers a comparable solution to a commercial GPS receiver, as Fig 5 shows. In some GPS unfriendly place along the trajectory, for example, two tunnels and a road with dense forest in its south side, the EMG solution demonstrates better robust performance against GPS solution.

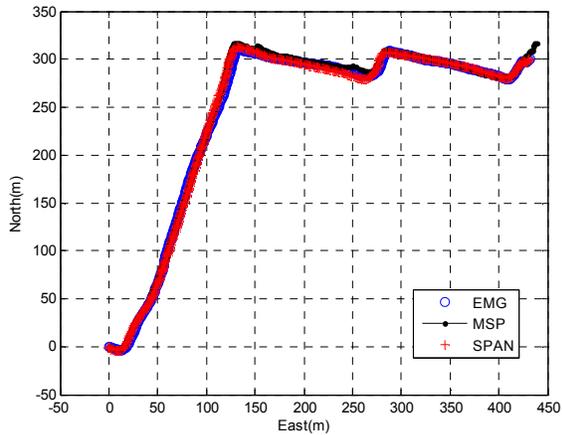


Figure 5. Trajectory of EMG PDR vs commercial GPS receiver (with reference trajectory of SPAN) for outdoor scenario in a local coordinate

For indoor scenario, the EMG based PDR still offers a robust result, the major error source is from the mis-detection on elevator down from the 3rd floor to the 1st floor, the elevator stopped in the 2nd floor during the test, which made the tester to exert the force to keep balance during the stop and the start, and such exerted force introduced “extra” noise for the stride detection algorithm and the average EMG power calculating algorithm. Thus the standing still motion was been mis-detected as walking down with stair as the magenta dots in Fig 6. The EMG sensor could not correctly detect such motion which is not listed in five classified motions. Meanwhile the nature of the EMG signal limits the possibility to detect this motion with single sensor solution. However, the error of EMG PDR could be mitigated if an extra sensor such as a barometer could be integrated into the system to detect the height information. [3]

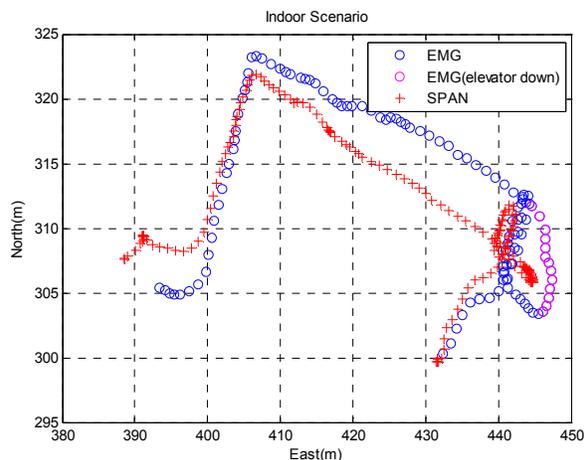


Figure 6. The trajectory of EMG PDR vs the reference trajectory of SPAN for indoor scenario in a local coordinate

To evaluate the performance of proposed motion recognition algorithm, a trajectory of the EMG based PDR with fixed stride length is also be calculated, the result is presented in Fig 7.

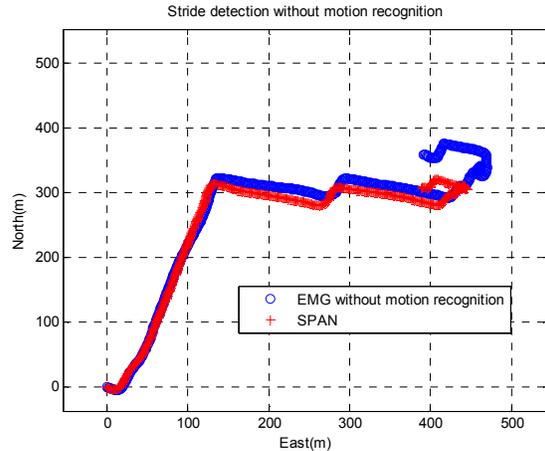


Figure 7. Trajectory of EMG PDR without motion recognition vs the reference trajectory of SPAN

V. CONCLUSION AND FUTURE WORK

The EMG based PDR solution presents promising results in the outdoor-indoor seamless test even with a very simple stride length module; however, only five motions including walking horizontally, walking up alone a slope, stepping upstairs/downstairs and standing still are considered as the classifiable pedestrian activities in this study. Actually, a more complex motion module should be investigated for practical application. Meanwhile, new algorithms for exploring the heading or turning from EMG sensor is essential to setup a gyroscope-free solution.

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