An Improved Dead Reckoning Algorithm for Indoor Positioning Based on Inertial Sensors

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***Abstract*—Location based service (LBS) became more and more popular. The core technology of LBS is positioning. For indoor positioning, the GPS (Global Positioning System) receiver can't provide accurate results and even fails in positioning. This paper raises a method by using inertial sensors to realize a continuous indoor positioning. The method used Pedestrian Dead Reckoning (PDR) algorithm, which utilized accelerometers and gyros to determine step, stride and heading. In common PDR algorithm, the step is counted when the measured vertical impact is larger than a given threshold value. Sometimes steps are miscounted because the vertical impacts are not correctly calculated due to inclination of the foot. This paper proposes a new method for step detection and stride estimate: The stride is not constant and changes with speed, so the step length parameter must be determined continuously during the walk in order to get the accurate travelled distance. The new step detection method uses pattern recognition which proposed from the analysis of the vertical and horizontal acceleration of the foot while walking. A stride estimate method is also obtained by analyzing the relationship between stride, step period and acceleration. Heading is output from gyros and magnetic compass. Experiments showed that the result of new method is more effective and reliable.**

Keywords-indoor positioning; step detection; stride estimate; heading determination

I. INTRODUCTION

When the building with complex structure was on fire, firefighters were difficult to find the trapped person and guide them to evacuate quickly. Because the GPS didn't work indoor, firefighters often felt confused about where they were and where to go. Some widely used indoor positioning technologies, such as WLAN (Wireless Local Area Network), ultra wide band (UWB), mobile cellular networks, RFID (Radio Frequency Identification) etc. need extra infrastructure (hotspot, router or signal projector etc.) and a fingerprint database to position Fallah et al [1]. These infrastructures are hard to pre-arranged in the scene of fire accident and limited to apply to the emergency rescue. A self-contained sensors indoor positioning system based on dead reckoning (DR) algorithm is of interest. It only contained a Micro-Electro-Mechanical System (MEMS) which consists of a 3-axis accelerometer, a 1-axis gyroscope, a magnetic compass and 16-bit microprocessor. Mar and Leu proposed the Dead Reckoning method in a car navigation system in 1996. Thomas H.Walters proposed pedestrian dead reckoning combined with GPS to achieve integrated navigation system. Giinther Retscher studied the integration of a variety of navigation technology, such as GPS, digital compass and barometer, in order to achieve a seamless indoor and outdoor positioning. The indoor positioning errors of common dead reckoning method are about ten percent, which means deviating several meters from the destination. Also firefighters wearing the heavy fire equipments couldn't walk as usual, the common dead reckoning algorithm couldn't suit the situation. This paper proposes new step, stride and heading determination methods for indoor positioning, which is more reliable especially in emergency rescue.

II. THE PRINCIPLE OF DEAD RECKONING

The principle of dead reckoning is according to the pedestrians walking distance and heading of the walking period to reckon current position of pedestrian from a known previous position (Figure 1) *Judd and Levi* [2]. Assuming the previous position is $(E(t_1),N(t_1))$, the current position is $(E(t_n),N(t_n))$, heading during the walking period is $\theta(t_i)$, the distance is $S(t_i)$, the relation of the positions (eqn. 1) is as follows:

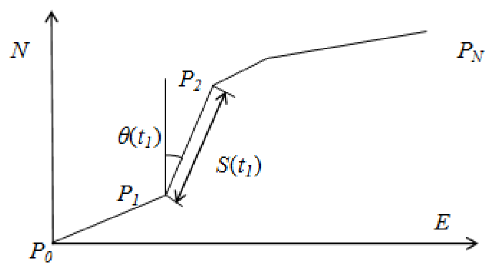

FIGURE I. THE PRINCIPLE OF DEAD RECKONING

$$E(t_n) = E(t_1) + \sum_{0}^{n-1} S(t_i) * \sin(\theta(t_i))$$

$$N(t_n) = N(t_1) + \sum_{0}^{n-1} S(t_i) * \cos(\theta(t_i)) \qquad (1)$$

The accuracy of the position depends on the accuracy of initial position and the accuracy of walking distance and heading in the reckoning process. Initial position information can be obtained by a GPS receiver, and the accuracy meets the needs. The count of steps is combined with the stride to obtain the walking distance. In addition, gyroscope is used as a heading sensor *Harle* [3].

III. Improved Dr Algorithm

A. Step Detection

Common method to detect a step is to detect the peaks of vertical acceleration, which correspond to the step occurrences because the vertical acceleration is generated by vertical impact when the foot hits the ground Foxlin [4]. If the vertical impact is larger than given threshold, it is considered as a step. The threshold is not reliable for step detection. Moreover the error is occurred by an oscillation of body in walking behavior. This paper presents a step detection method based on pattern recognition which performed better in the scene of fire accident. To analyse the variation of vertical and horizontal acceleration of the foot during walking, the signal pattern of walking behaviors is known.

B. Step Behavior Analysis of Pedestrian

A complete human walking motion is composed of two parts: standing and swing Lee and Mase [5]. The swing motion divided into two phases. In the 1st swing phase, the foot is behind of gravity center of human body. And the foot is located on front of gravity center of human body in the 2nd swing phase. The step detection means to distinguish the different status. When human change his status, it will be subject to his gravity center. The acceleration in the process of walking is composed of vertical and horizontal components as shown, where a, h, g means horizontal and vertical acceleration, gravity force, respectively.

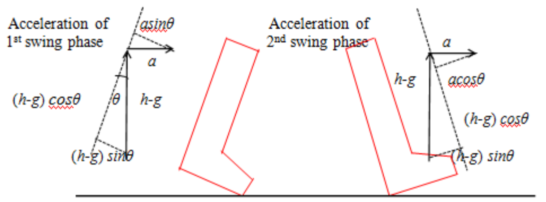

FIGURE II. ACCELERATION OF SWING STATUS

The horizontal direction acceleration and vertical direction acceleration during the swing phase is denoted in the equation, where θ (t) is inclination angle of the leg at time t.

$$A(t)_{\mathrm{Horizontal}} = (h-g)\sin\theta(t) + a\cos\theta(t)$$

$$A(t)_{\mathrm{Vertical}} = (h-g)\cos\theta(t) - a\sin\theta(t) \qquad (2)$$

In many researches, a step is counted when the measured $A(t)_{Vertical}$ is exceed the threshold. But the $\theta(t)$ according to characteristics of walking which is different from each person, it is hard to determine the exact value of threshold of $A(t)_{Vertical}$. Also the acceleration augment caused by unavoidable vibrations in walking may exceed the threshold. The steps miscounted when wrongly predetermined threshold is applied. By using the signal pattern of acceleration, this problem can be solved. Typical signal pattern of acceleration is obtained from the function of the acceleration. $A(t)_{Vertical}$ is a cosine function and $A(t)_{Horizontal}$ is a sine function as follow:

$$A(t)_{\mathrm{Horizontal}} = \sqrt{(h-g)^2 + a^2}\,\sin[\theta(t) + \phi] \quad \tan\phi = \frac{a}{h-g}$$

$$A(t)_{\mathrm{Vertical}} = \sqrt{(h-g)^2 + a^2}\,\cos[\theta(t) + \phi] \quad \tan\phi = \frac{a}{h-g} \qquad (3)$$

According to $A(t)_{Horizontal}$ and $A(t)_{Vertical}$, we obtain the signal pattern of one step. The actual variation of the vertical acceleration (figure 3) proved the theoretical analysis.

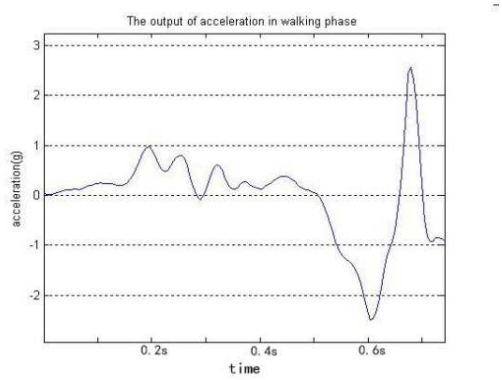

FIGURE III. REAL HORIZONTAL ACCELERATION SIGNAL

1)Algorithmic process

Step detection algorithm process as follows:

(1) Detecting the swing state: recognize horizontal acceleration signal pattern;

(2) Filtering a slight vibration: set up a trading range;

(3) Updating dynamic threshold: predict the threshold based on the maximum and minimum acceleration of last step;

(4) Setting the time window: take the human normal swing speed for consideration;

B. Stride Estimate

The stride is a crucial factor in a dead reckoning algorithm. It depends on several factors such as walking velocity, ground, step frequency and height of walker etc. Common stride estimate linear model is only related to step frequency. Yun et al [6] used the equation to calculate the stride. A, B are the regression parameters for the model, SF represent the walking frequency, w is Gaussian noise.

$$\mathrm{Stride} = A + B * SF + w \qquad (4)$$

Fireman wouldn't walk so fast and the stride is random in the scene of fire accident. The stride changed with speed and the step length parameter must be determined according to the acceleration in order to get the accurate travelled distance Godha and Lachapelle [7]. In this paper, we analyse a relationship between stride, step period and acceleration to propose a simple and reliable method of stride estimate. In typical human walking behavior, a short step would cause a slight vibration, a stride becomes larger and the vertical impact becomes bigger as the walking speed increases. The stride only has a direct relation with the acceleration, and no direct relation with walking frequency. Figure 4 show test result of two type strides: 60 cm and 80 cm stride.

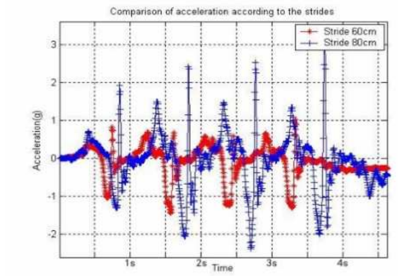

FIGURE IV. THE ACCELERATION SIGNAL OF 60 CM AND 80 CM STRIDE

The tester walks with the fixed stride using ground marks. In the figure, the relation between the acceleration and stride is clearly shown. The figure show the longer stride induces the bigger acceleration. Equation 3 is the experimental equation obtained from several walking tests. The equation represents the relation between measured acceleration and stride, where amax, amin, K means maximum and minimum accelerations in each steps and step length parameter respectively. It is used to calculate the stride.

$$\mathrm{Stride} = \mathrm{K} * \left[(a_{\max} - a_{\min}) + \sqrt[4]{a_{\max} - a_{\min}}\right] \quad (5)$$

Stride estimate algorithm process as follows:

(1) Measuring individual stride parameter K: measure actual walking distance x m and maximum and minimum accelerations in each steps, calculate parameters K. Iterative operation until parameters K unchanging;

(2) Detecting the maximum and minimum accelerations in each steps;

(3) Calculating the stride of each step by the equation.

C. Heading Determination

Heading determination is the most difficult part of dead reckoning, because gyro has unbearable bias and drift error which couldn't be eliminated Meng et al [8]. Even the tactical gyro, its drift error is more than 6 degrees per hour. An optimal and reliable system might be expected by integrating the gyroscopes with the magnetic compass. In the integrated system, the gyroscope can correct the magnetic disturbances, at the same time the compass can compensate the bias of the gyros and determine the initial orientation Ladetto [9].

IV. Experiments

To evaluate the performance of the proposed methods, actual walking test in the indoor environment is conducted. The tester is a male aged 24 with 180cm height. The experiments are done at the 4th floor hallway of the main building, Tsinghua University, Beijing, China. The experimental equipments consist of a sensing module (ADIS16300, Analog device Inc.), a data acquisition system (notebook computer), and a digital magnetic compass sensor (CMPS03, ROBOT Electronics Inc.). The IMU (Inertial measurement unit) was worn on the ankle. Table 1 show the result of the experiments. The result showed the effect of using the improved DR algorithm is better than the common DR algorithm. The experiments show the very promising results: less than 2% step detection error, less than 5% travelled distance error and less than 5% heading error.

TABLE I. THE RESULT OF THE EXPERIMENTS.

Method	**Measured distance**	**Walking distance**	**Error**
Improved DR	66.598 m	68.2m	2.35%
Common DR	61.53 m	68.2m	9.78%
Method	**Actual step number**	**Measured step number**	**Error**
Improved DR	100	100	0
Common DR	100	99	1%

V. Conclusions

This paper proposes an improved dead reckoning algorithm to help firefighters perceive their own location in the scene of fire accident. For accurate distance, we proposed a reliable algorithm to detect step based on the acceleration pattern and estimate the stride online by an efficient algorithm based on the acceleration of the person. The integration scheme of the gyro and magnetic compass is proposed for error compensation of gyro and disturbance rejection of magnetic compass. The experiments using the actual walking tests in indoor shows that the proposed method gives less than 1% steps, 5% travelled distance and 5% heading errors. It is expected that the proposed method will be very useful to emergency rescue.

Acknowledgements

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