Review on wearable devices using pedestrian death reckoning

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***Abstract*: Pedestrian death reckoning uses wide range of wearable inertial sensors. Typical low-cost PDR systems use sensors attached feet. The recent evolution of smartglasses and smart watches provides an opportunity to use both types of wearable devices for tracking the position. A novel method of utilizing both a smartwatch and smartglasses for PDR is proposed in this paper. The idea is to use the relative angle between head direction and arm swing direction to detect any head-turn motion .This is achieved by using Kalmal Filters, this paper also presents a novel cascaded twostep Kalman filter orientation estimation algorithm. Tilt angles are estimated in the first step of the proposed cascaded Kalman filter. The estimated tilt angles are passed to the second step of the filter for yaw angle calculation. A complete PDR solution it includes step length estimation, step detection, head-motion detection and dead reckoning. This is achieved by using smartwatch and smartglasses that are widely used in current market.**

I. INTRODUCTION

In recent years the wearable technology has taken over the consumer market rapidly. Wrist-worn devices such as Android Wear-based watches, Fitbit, Apple Watch, Microsoft Band and Garmin GPS watches are the most famous wearable devices. Nowdays the emergence of smartglassess like Eye Tap, SOLOS AR and Recon Jet provides an extra dimension in non-coverable body locations.

Why glasses and watches????

Based on an online research database the number of wearable devices available in today's market, out of 434 wearable devices listed, 204 (47.0%) are wrist-worn devices and 79 (18.2%) head-worn devices[1].This gave an idea of fusing these two wearable devices for the betterment of positioning accuracy in bad Global Navigation Satellite System (GNSS) areas. GNSS solution has a demerit in indoor environment and in outdoor areas with tall buildings due to multipath error and signal blockage. In this case the pedestrian dead reckoning (PDR) systems are used for the improvement of absolute positioning by refering the position from a previously known position.

On the other hand, the reason of choosing a wrist or head-worn device in the form of glasses or a watch is because of its user-friendly and acceptable compared to a foot or waist-worn device.As PDR system has put more effect in the field of fitness applications such as walking, jogging and running, one can easily locate the cyclic nature of natural arm swing motion during these activities. Arm swing during human locomotion is a natural motion that is related to lower body motion. It is suggested that movement of the arm during locomotion contribute to the entire gait stability of human locomotion.PDR can usually be categorized as self-contained and aided navigation[2].The self-contained navigation, which is based on only inertial sensors, changes over a period of time. This change is due to the integration of uncompensated time-varying bias of the low-cost, consumer grade MEMS inertial sensors. Thus, this navigation is aided by an absolute positioning system for practical long-term usage.For aided PDR, GNSS[3] and cellular networks are typically used for outdoor navigation, while Wi-Fi[4][5]Bluetooth, ultrawideband (UWB) or even ultrasonic ranging are used for indoor navigation.if there is available of Building Map Information, it can also be used for map-matching purposes[6][7].The main contribution of this paper is to present a algorithm that exploits the cyclic nature of arm swing during walking and running, combined with head-worn and wrist-worn sensors to improve the accuracy of the PDR system.This also includes pedestrian death reckoning for indoor also.It uses the a navigation system based on a combination of foot-mounted inertial sensors and ultrasound beacons.[8].Sec.II The architecture of the proposed dead reckoning system is presented. Sec. III.describes the data collection. And this followed by the experimental test and result which is discussed in Sec. IV. Finally, Sec. V gives the conclusion of this paper.Many researches and techniques are taken place for outdoor positioning which depends on wireless infrastructure[13].In availability of GPS signal absolute positions within few meters is obtained. The future mobile communication systems service differentiation and personalization. Relative as well as absolute positioning are considered as primary factors. Many depend on the presence of indoor data network base stations,such wireless WLAN access points or Bluetooth(BT) node. Where others depend on specialized transponders which is designed specifically for positioning,such as GPS "pseudolites"[14] or Ultra-Wideband(uwb) beacons.

Figure 1

Figure 2

II. SYSTEM ARCHITECTURE

The overall block diagram of the proposed head-wrist pedestrian dead reckoning (HWPDR) system is shown in Fig. 3. The following subsections describe each sub-block of the system in detail.

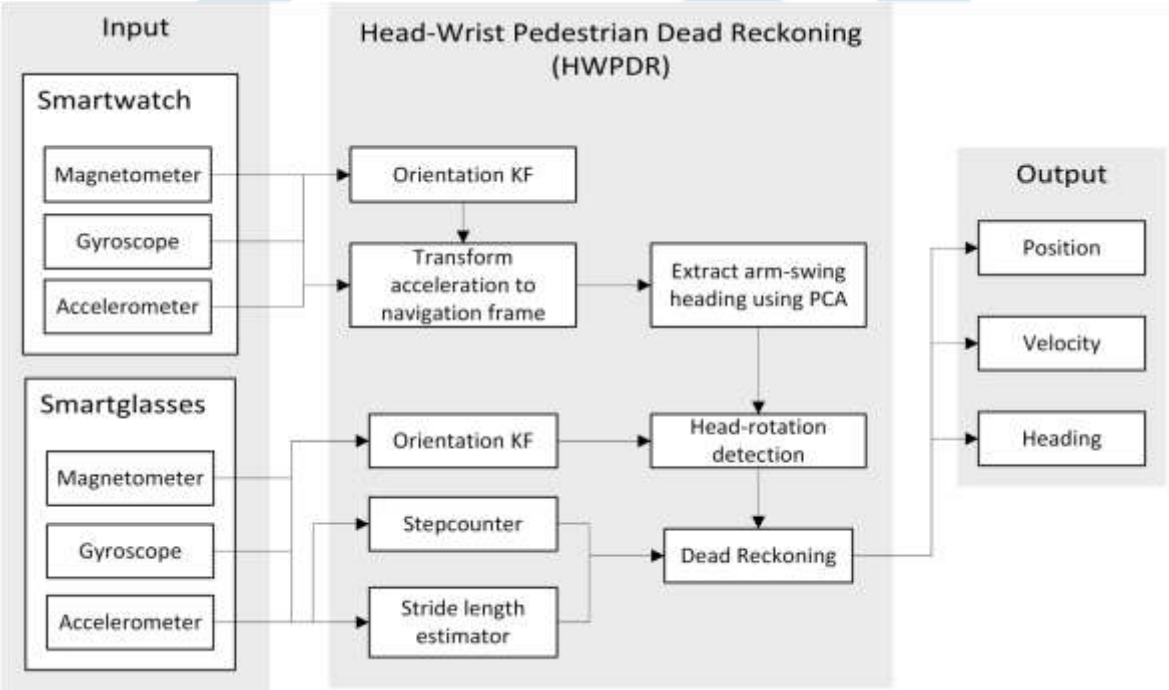


Figure 3

A. ORIENTATION KALMAN FILTER

This orientation uses tri-axial accelerometer, gyroscope and magnetometer. which are referred from[9]and[10].

The rotation matrix from sensor frame (*s*-frame: a coordinate system attached to the inertial sensor) to the navigation frame (*n*-frame: a local level coordinate system with its *x*-, *y*- and *z*-axis pointing to the East, North and Up direction, respectively), ${}^{n}_{s}R$, is obtained from the orientation Kalman filter (KF) and used to estimate the acceleration in the *n*-frame:

$$\begin{bmatrix} a_{east} \\ a_{north} \\ a_{up} \end{bmatrix} = {}^{n}_{s}R \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} \quad (1)$$

where a_{east}, a_{north} and a_{up} are the East, North and Up components of the wrist acceleration in the *n*-frame; and a_x, a_y and a_z are the measured acceleration components from the tri-axial accelerometer in the *s*-frame.

B. PCA-BASED WRIST-SWING DIRECTION ESTIMATION

The wrist heading estimation is carried out in a same way to previous works that use Principal Component Analysis (PCA) on a cellphone in a pocket or in multiple carrying mode.[11]the PCA is applied on wrist acceleration from the smartwatch's sensors to determine its heading direction.The PCA is applied to every 2-second window of the horizontal acceleration in the *n*-frame (East and North components of the acceleration). The wrist swing direction is then simply the first component from the PCA.

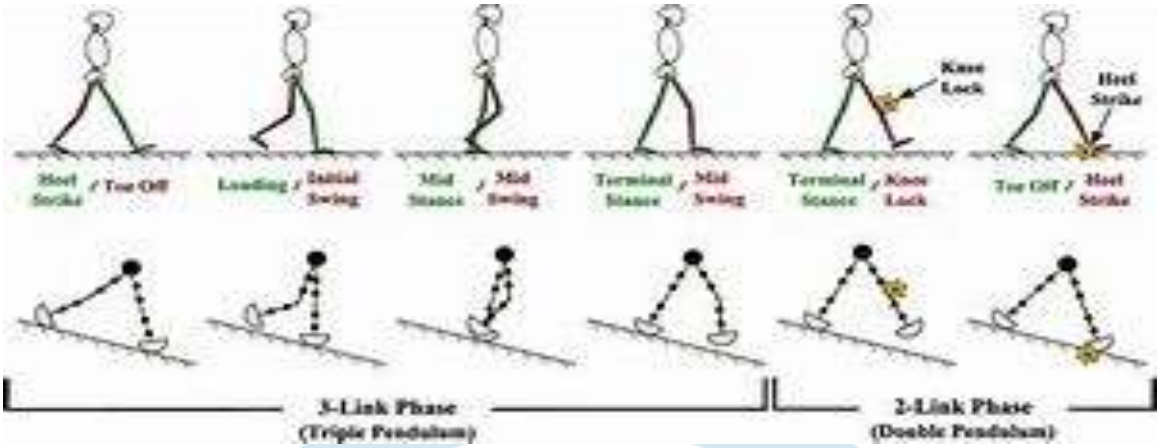


Figure 4

C. STEP COUNTER

The step counter uses the smartglasses' tri-axial accelerometer signals. There are a variety of methods to detect steps based on acceleration signals including: windowed peak detection (WPD), hidden Markov model (HMM) and continuous wavelet transform.[12].The step length, *S*, can then be estimated by:

$$S = K^4 aup,max - aup,min$$

where *S* is the step length, *K* is a scalar constant that has to be calibrated for each individual, $a_{up,max}$ is the maximum vertical head acceleration magnitude, and $a_{up,min}$ is the minimum vertical head acceleration magnitude.

E. DIRECTION OF MOTION ESTIMATION WITH HEAD ROTATION DETECTION

The direction of motion required for dead-reckoning propagation is obtained from the absolute heading of the Smartglasses.

Based on observations, head and body rotations differ during walking and running in a few common scenarios are:

1. While Walking/Running Straight, the Head Stays in Neutral Position
2. While Walking/Running Straight, the Head Rotates to One Side:
3. While Walking/Running Straight, the Head Rotates From Side to Side.
4. During a Turn, the Head and Body Turn at the Same Time.
5. During a Turn, the Head Leads the Body Into a Turn.
6. During a Turn, the body Leads the Head Into a Turn.

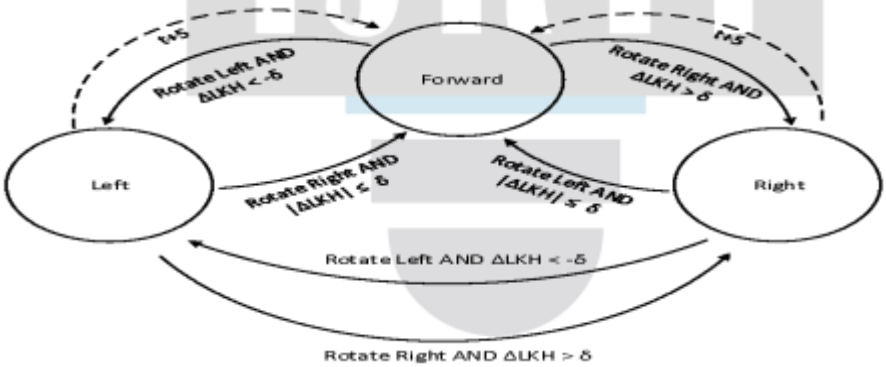


Figure 5

The PDR technique has been applied to the problem of navigation in a number of project[16][17].PDR systems cannot be transferred between users as models are trained with particular individual's walking pattern.

Step model: This is based on our step length estimation algorithm on the method referred in paper[18] and [19].

Heading Estimation The motion sensor's yaw output (rotated from the sensor-fixed frame to the earth-fixed frame) was used for deriving heading.(that is magenetometer, accelerometer, gyroscope).[20]

II. EXPERIMENTAL RESULTS AND DISCUSSIONS

The data collected on the smartwatch and smartglasses were analyzed using MATLAB.

$$\text{Detection Rate} = \frac{\text{Motion detect}}{\text{Motion performed}} \times 100\%$$

TABLE V
HEAD ROTATION TEST RESULTS

Activity	Walking				Running			
Head Rotate	One side		Side to side		One side		Side to side	
Speed	Slow	Fast	Slow	Fast	Slow	Fast	Slow	Fast
Detected	64/72	65/72	67/72	65/72	72/80	76/80	76/80	74/80
Detection Rate	88.9%	90.3%	93.1%	90.3%	90.0%	95.0%	95.0%	92.5%

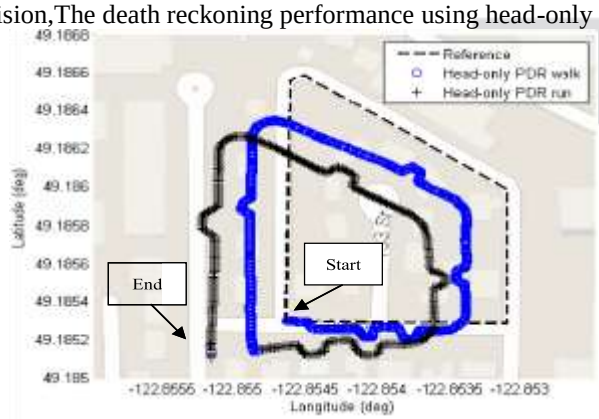
A. Step Counter and Step Length Estimation Test

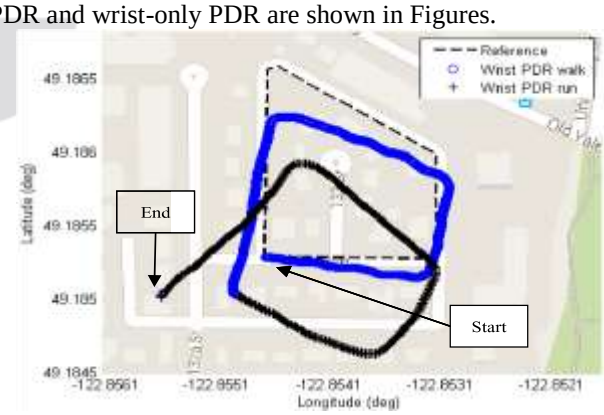
From our observations, using sensors on the head is more robust for step counting than using those on the wrist. This is because the head, while not rigidly connected to the human trunk, exhibits significantly less motion artifacts than the arms.

Step Count Trial		Est.	Actual	Error %
a) Walk	Subject 1	571	573	0.35%
	Subject 2	561	559	0.36%
b) Run	Subject 1	347	346	0.29%
	Subject 2	333	334	0.30%
c) Walk + run	Subject 1	899	901	0.22%
	Subject 2	875	877	0.23%

B. Dead Reckoning Test

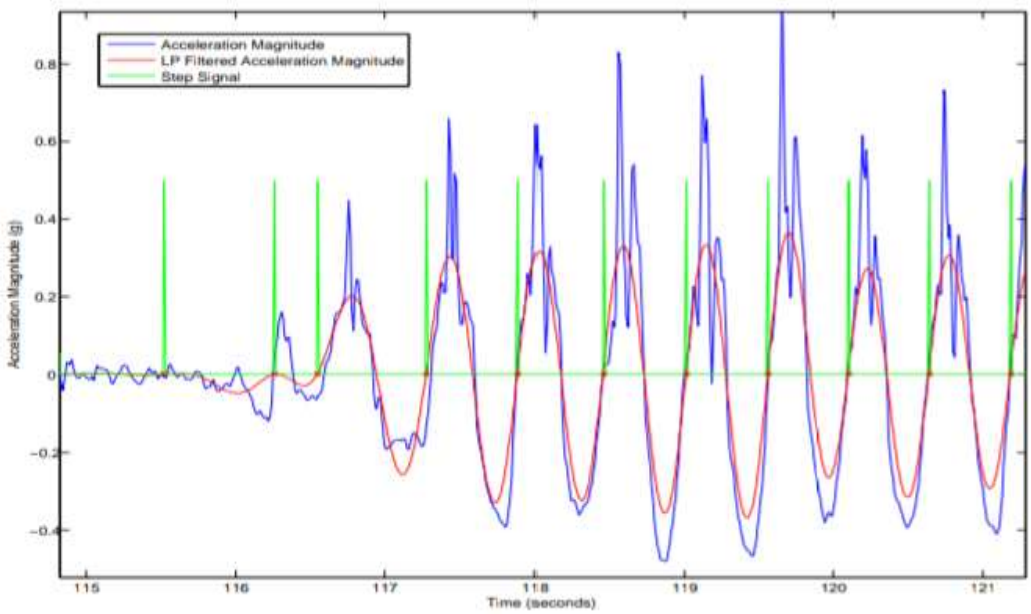
The results for the head-wrist PDR test subject are plotted on google map.to show how it deviates from actual trajectories for comparision,The death reckoning performance using head-only PDR and wrist-only PDR are shown in Figures.



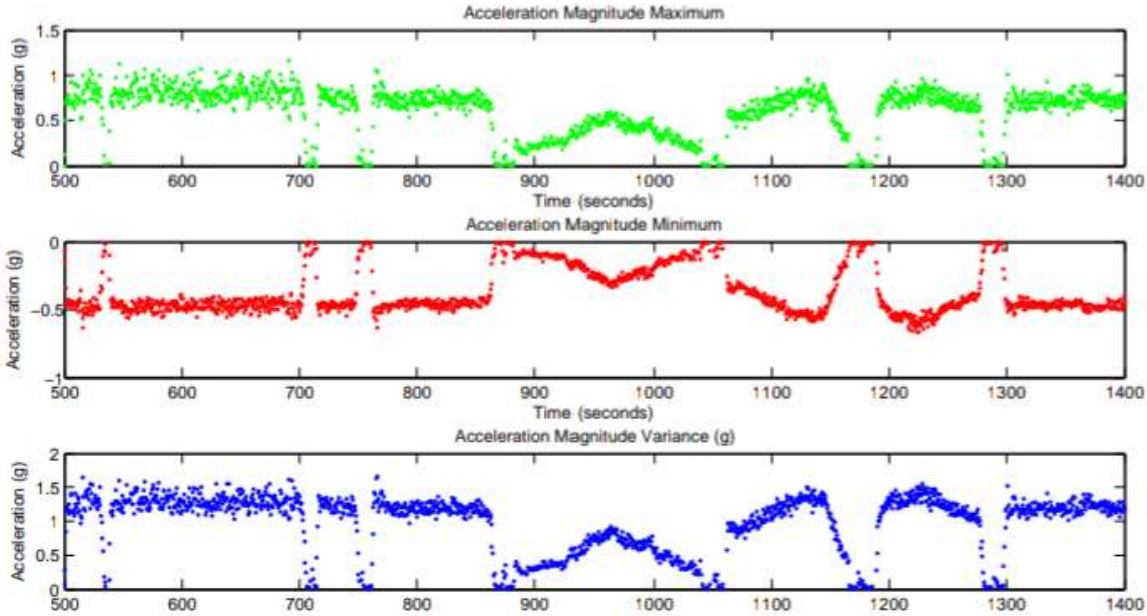


C.ESTIMATED TRACK USING HELMET

Using the magnetic heading information available from the motion sensor, it is possible to calculate an estimated track on the figure below shows this estimated track in comparison to GPS track ground truth outdoor test.



Step acceleration during start: the figure shows the behaviour of step detection algorithm from start to standstill.



Step acceleration analysis: intermediate feature calculated for each step as shown.

V. CONCLUSION

This paper presents a complete pedestrian dead reckoning (PDR) system targeting walkers and runners using both a smartwatch and smartglasses. The shortcomings of using only the smartwatch or the smartglasses alone for PDR are shown in this paper. For the smartglasses, the PDR trajectory is affected by unaccounted head-rotation, while arm swing derived heading does not work as well for running. By combining both types of wearable devices, head-rotation can be detected and correct the heading appropriately. The results show that it is highly feasible to fuse the smartwatch and smartglasses data in an PDR system that would otherwise be hard to implement on just a smartwatch or smartglasses alone. This can be attributed to the developed neural-network-based step-length estimation technique.

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