ISMAR03 in Tokyo, Japan, pp.260-261

A Wearable Augmented Reality System with Personal Positioning based on Walking Locomotion Analysis

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Abstract

In this paper, we present a wearable Augmented Reality (AR) system with personal positioning based on walking locomotion analysis that allows a user to freely move around indoors and outdoors. The user is equipped with self-contained sensors, a wearable camera, an inertial head tracker and display. The system is based on the sensor fusion of estimates for relative displacement caused by human walking locomotion and estimates for absolute position and orientation within a Kalman filtering framework. The former is based on intensive analysis of human walking behavior using self-contained sensors. The latter is based on image matching of video frames from a wearable camera with an image database that was prepared beforehand.

keywords : personal positioning, pedometer, human walking analysis, sensor fusion

1 Introduction

In this paper, we have aimed at developing a wearable Augmented Reality (AR) system that allows the user to move freely around a large-scale environment that also receives location/orientation awareness services.

We took the approach of combining the measurement of relative displacement by analyzing human locomotion on foot and several other methods of absolute positioning within a Kalman filtering framework. First, we attached self-contained sensors to the user's torso (the pelvis) to detect and measure his displacement achieved by analyzing patterns of the acceleration vector and angular velocity vector caused by walking behavior. The sensors were composed of 3-axis accelerometers, gyro-sensors and magnetometers. Thanks to advanced Micro-Electro Mechanical System (MEMS) technologies, these sensors were very tiny and inexpensive and were able to be packaged into a single package that was as small as a typical cellular phone.

Clinical studies of human movement have revealed that the pattern of movement and applied force to the center of gravity (COG) of the human body (COG is located near the pelvis) while walking is almost deterministic and undisturbed by individual characteristics [2]. We can thus detect and measure human walking behavior by analyzing a time sequence of the acceleration vector and angular velocity vector without introducing a learning mechanism to absorb individual differences. Second, we can use a wearable camera and an inertial head tracker to determine absolute positioning and head orientation. The wearable camera is attached to the user's head and aligned to match his direction of sight. A set of images taken at several points in the environment are stored beforehand as a database that is associated with the position and orientation of capture. We matched the image from the wearable camera with that in the database through frame-to-frame image registration [3]. If image matching was successful, we acquired the direction of the user's head and his absolute position. This information are fused into a single statistically consistent estimate of the user's position and orientation within a Kalman filter framework. Figure 1 is the system diagram for the Kalman filter described in the literature [4].

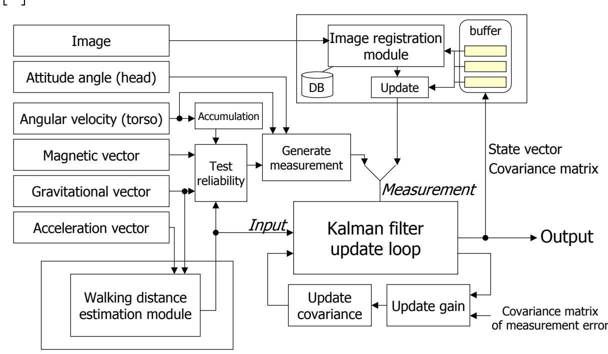

Figure 1: System diagram of the Kalman filter.

2 System

We developed a prototype wearable system with the wearable visual interfaces, that we called *Weavy* [1]. The system is composed of an inertial head tracker, a wearable camera and display, and self-contained sensors that detect and measure human walking locomotion, and a processing unit.

2.1 Hardware

We use InterTrax^2 from InterSense Inc. in this research as the inertial head tracker attached to the user's head. We use the 3DM-G from MicroStrain Inc. for accelerometers, gyro-sensors, and magnetometers attached to the user's torso, which integrated these sensors into a single package and enabled us to acquire sensor data with the timestamp of acquisition via a serial port. Within the package, ADXL202JE (3-axis) from Analog Devices Inc. are used for the accelerometers, ENC-03JA (3-axis) from Murata Manufacturing Co. are used for the gyro-sensors, HMC1052 (2-axis) and HMC1051Z (1-axis) from Honeywell Co. are used for the magnetometers. These sensors are very small and inexpensive compared to the sensors integrated in IMU (Inertial Measurement Unit). We use a web image server (YOKOGAWA, IPV) for image capturing and use a card-sized PC (CPU: Mobile Pentium-III

700 MHz, OS: Linux-2.4) from Cell Computing Inc. as the wearable PC. We use Clip-On Display from MicroOptical Inc. for the head-worn display.

2.2 Architecture

Figure 2 is a diagram of the architecture of our prototype of personal positioning system comprised of the hardware described in Section 2.1. All software processing in our method is done on the wearable side. The image database and annotative information including map and annotations are stored in the database server on the infrastructure side and are designed to be fetched from the wearable side via a wireless network compliant with IEEE 802.11b. The system is designed to keep running properly even if the wireless network becomes unreachable anywhere the fetched image database and annotative information are available in the cache storage on the wearable side.

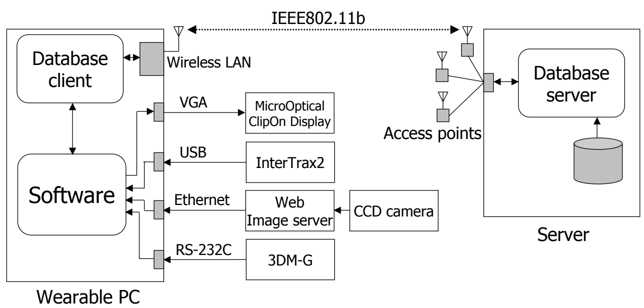

Figure 2: Diagram of personal positioning system.

3 Experimental results

Figure 3 has the subject's trajectory estimated with our method in an indoor environment. Here, the estimated position has been adjusted by image registration and elevator detection at the four locations marked with open circles. This indicates that it can robustly estimate the subject's position and orientation despite in the presence of electronic office appliances such as copiers and CRTs, or building structures which disturb the magnetic field.

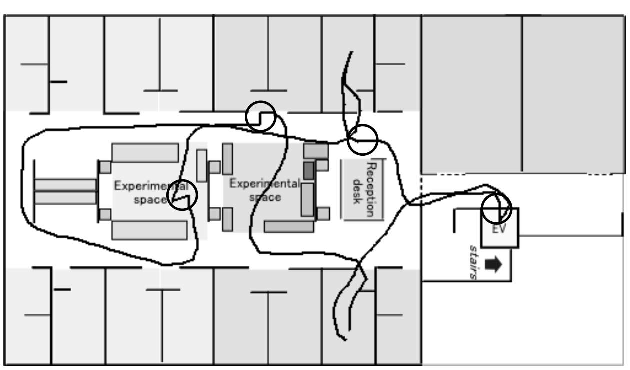

Figure 3: Estimates of trajectory.

Figure 4 has examples of overlaid annotative information on live video frames based on the estimates of the position and viewing direction of the user.

Figure 4: Examples of annotation overlays.(In the top left, two annotations indicate the direction of a presentation hall and a buffet area. In the top right, the annotation informs that a university is in sight. In the middle left, that Weavy presentation is being held. In the middle right, the annotation informs that Weavy research has been conducted in the building. In the bottom left, the overall map has descriptions of each location, and in the bottom right, annotation reminds the user of a meeting with a person in the cubicle.

4 Conclusion

In this paper, we presented a wearable AR system with personal positioning based on walking locomotion analysis and sensor fusion with Kalman filter framework. Experimental results show the effectiveness of the presented system indoors and outdoors.

Acknowledgements

This work is supported in part by Special Coordination Funds for Promoting Science and Technology of MEXT of the Japanese Government and JSPS Postdoctoral Fellowships for Research Abroad (H15).

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