Gait analysis using inertial sensor and vision

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Abstract: In this paper, a novel method is proposed to analyze the gait using inertial sensor and vision technique. An indirect Kalman filter is used to estimate step length and foot angles. The vision technique provides us vision information which is used to update the Kalman filter. A measurement unit including a camera and inertial sensors is mounted on a shoe. The vision information including position and attitude of a shoe is estimated based on a simple planar landmark system which consists of thousands of markers and be easily expandable. Experiments verify our proposed system is quite accurate, especially in step length measurement. This proposed system is suitable for long distance applications.

Keywords: gait analysis, image processing, inertial sensors, position estimation.

1 INTRODUCTION

Gait analysis [1] involves the measurement of temporal/spatial characteristics (step size and walking speed), kinematics and kinetics. Gait analysis is used for medical purpose, sport analysis and also for entertainment.

In this paper, a new gait analysis system is proposed. A measurement system consisting of a camera and inertial sensors is installed on a shoe. Fiducial markers [2] are printed on paper and placed on the floor. Fiducial markers are used mainly in virtual reality systems. There are many types of markers. Since there are no concerns that complicated backgrounds are mistakenly recognized as markers, we used simple markers in this paper.

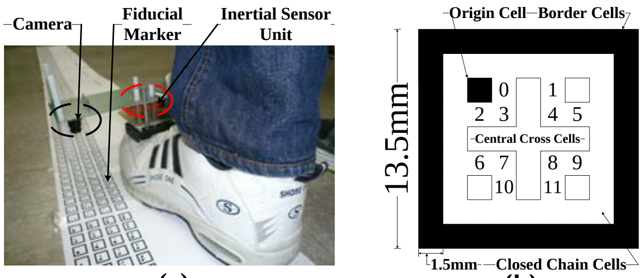
When a foot is on floor, the movement is estimated using a camera. When a foot is moving, its movement is estimated using inertial sensors. In an inertial-based foot estimation system, Kalman filters are usually used to estimate foot measurement. For better accuracy, a smoother [3] is used to combine vision data and inertial sensor data.

The paper is organized as follows. In Section 2, formulation problem of the proposed system is given. In Section 3, experimental results are given. Conclusion is given in Section 4.

2 FORMULATION PROBLEM

2.1 Gait analysis system

The gait analysis system consists of a sensor unit on a shoe and fiducial markers on the floor (**Fig. 1. (a)**). A sensor unit consists of a camera (point grey Firefly MV FFMV-03MTM) and inertial sensors (XSens MTi inertial measurement unit).



(a) **(b)**

Fig. 1. Gait analysis system and marker's structure

A fiducial marker is similar to ARTag markers [2] and its structure is shown in **Fig. 1(b).** The marker is a nine by nine grid of quadrilateral cells of 1.5 millimeter edge including origin cell, border cells, central-cross cells and closed-chain cells. The marker has twelve bits digital coding system inside. The code bits are distributed along the quadrilateral central-cross in the order from left to right, and from top to bottom. A planar landmark system is generated by N fiducial markers which are composed of a four by M grid of markers as in **Fig. 2.** make it be easily expandable. The marker ID is encode from 0 to $\left(N-1\right)$.

2.2 Coordinate frame assignment

There are four coordinate frames in this paper. The world frame is located at the first marker of the planar landmark system. Positions of a foot are expressed in this frame. The navigation frame is used in an inertial navigation algorithm. It has the origin as same as that of the world frame. The camera frame is placed at the pinhole of the camera, where the Z axis perpendicular to the image plane. The last frame is body frame which has three axes coincide with those of inertial sensors. In this paper, it is assumed that three axes of the camera frame and the body frame are the same.

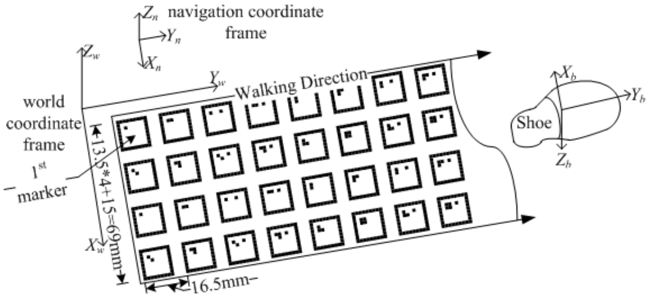


Fig. 2. Planar landmark system and frame assignment

2.3 Position and attitude estimation using markers

When a foot is not moving on the floor, markers in camera image are recognized through an image processing process in which the marker’s ID and its outer four corners coordinates are extracted.

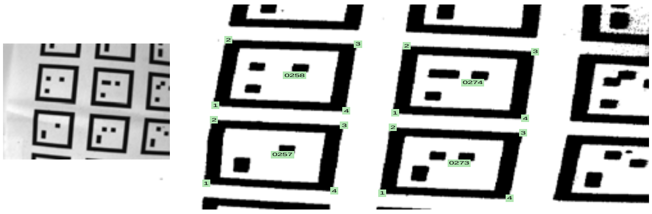


Fig. 3. Origin image and four extracted corners

Position $\left(\hat{r}_{vision}\right)$ and attitude $\left(\hat{C}_{vision}\right)$ of a camera with respect to the world frame are determined using the four corners coordinates and based on the algorithm in [4]. Let r_w be a point expressed in the world frame and r_b be the same point in the body frame. Then the relationship between r_b and r_w is given by

$$r_w = \hat{C}_{vision} r_b + \hat{r}_{vision} \tag{1}$$

2.4 Position and attitude estimation using inertial data

When a foot is moving, position and attitude are estimated using an inertial navigation algorithm. Firstly, zero velocity intervals are detected [5]. An indirect Kalman filter [6] with state vector $x = \left[q_e \quad v_e \quad r_e \right]'$ is used in forward direction and backward direction. Then a smoother is applied to obtain the best accurate estimation of position and attitude.

3 EXPERIMENTAL RESULT

The camera is firstly calibrated to obtain its intrinsic. In our experiments, the sampling rate of camera and inertial IMU sensors are 30fps and 100Hz, respectively. A person who wears the shoe (**Fig. 1(a)**) is required to free walk along a planar marker system path (**Fig. 2**). Through the experiment shown in **Fig. 4,** it is proved that the position are accurately estimated.

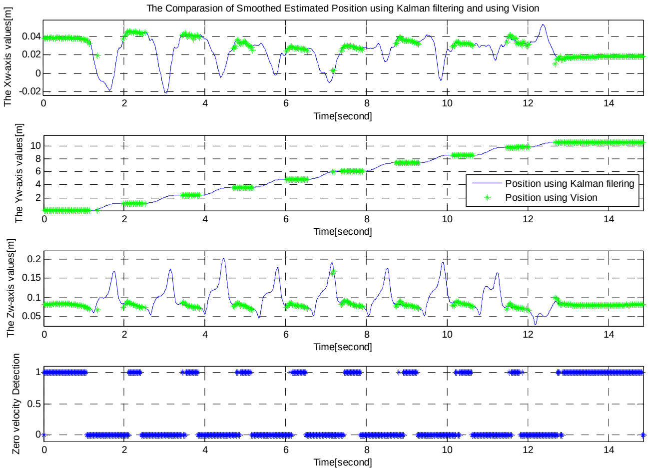


Fig. 4. Position Estimation

4 CONCLUSION

A novel approach was decribed for position and attitude estimation using integration of vision and inertial sensor. In vision, the planar landmark path is easily expandale when longer walking range is need in such application as a clinical gait assessment of patients, parameter estimation of some pedestrian navigation algorithms.

Acknowldegement

This work was supported by Network-based Automation Research Center (NARC) and National Research Foundation of Korea Grant funded by the Korean Government (No. 2011-0002770).

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