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Simple Three-Dimensional Motion Measurement System using Marker-IMU System

Kunihiro Ogata[1] Hideyuki Tanaka[1] and Yoshio Matsumoto[1]

***Abstract*— Image-based motion capture system have a limited measurement range, and the inertial motion capture system cannot directly acquire the position information . In addition, simple and robust measurement is required in the realization field, but it is difficult with the conventional motion capture system. Therefore, in this research, we constructed a system that robustly measures human movements by combining images and IMUs. High-accuracy visual markers were used to measure the position and orientation by images. By combining this with an IMU, we have established a robust measurement method even for hiding. In addition, by using the environmental reference marker, it is possible to acquire the absolute position even if the camera moves. In fact, we measured the movement and walking movements of human upper limbs, and realized continuous and smooth movement measurement by this method.**

I. INTRODUCTION

Several methods for measuring human movement have been proposed. Optical motion capture system is a typical motion capture system.

This is a method in which multiple cameras are fixed, a large number of reflection marker are attached o the body of the measurement target, and the three-dimensional position of these reflection markers is acquired. In recent years, a method of estimating the posture of the whole body by a machine learning method has been developed by using a color images as an input without requiring a reflection markers [1]. In a motion capture system that uses these image informations, there is a problem that the data is lost because the reflection marker goes out of the measurement range or is hidden.

On the other hand, an inertia motion capture system that measures motion by attaching an inertia measurement unit(IMU) to the whole body has been proposed. The whole body movement is estimated based on the posture information obtained from each IMU and the human kinematic model. Since no camera is used, the measurement range is not limited, and there are merits such as continuous measurement indoors and outdoors. However, since the joint position is calculated indirectly based on Kinematics, errors are likely to occur.

There are advantages and disadvantages to measuring position and orientation with images or IMUs. Although the position of the image can be acquired with high accuracy, it is vulnerable to hiding and continuous measurement is difficult. On the other hand, although the IMU can acquire the attitude with high accuracy, it is difficult to calculate the position directly.

II. PURPOSE OF THIS STUDY

Image measurement and IMU measurement have completely weaknesses. Therefore, a position and orientation calculation methods that combines images and IMUs have been developed.

A. Previous studies

The systems consisting of vision and inertia information were developed in previous studies. Tao developed the system that can measure the motion of human arm using camera and inertia sensors [2]. This system needs image and inertia information to measure the human arm, thus cannot complement missing image information with inertia information. The system that can measure the movement locus of human using camera and inertia sensor was developed [3]. To measure the movement locus of human, many visual markers were pasted on the ceiling, and the device consisting camera and inertia sensor was used. Neges et al. was developed the algorithm that could estimate the locus of human based on the position and orientation of the natural markers (e.g. exit signs) and the acceleration information, and the route could be estimated using only the camera and IMU mounted on tablet PC[4]. The body suit that was mounted many visual markers and IMUs was developed [5], and the whole body motion of worn subject was estimated based on the markers, IMUs, and human kinematic information.

B. Purpose of this study

In many previous studies, it is often applied to estimate the movement path of a person or an object, and there are a few examples of using it for motion measurement. Our research group has developed a robust position and orientation measurement method that combines a high-precision marker and an IMU [9]. Therefore, the purpose of this study is to apply this method to human motion measurement. Moreover, in the optical motion capture system, it is necessary to fix the camera, and the measurement space is fixed. In this research, we aim to continuously measure human movement while moving without fixing the camera.

III. PROPOSED ALGORITHM

In this study, we aim to robustly estimate the position and orientation by combining a high-accuracy marker and an IMU. In addition, by applying this method, absolute position and orientation measurement can be realized even if

[1]Human Augmentation Research Center, National Institute of Advanced Industrial Science and Technology (AIST), 6-2-3 Kashiwa-no-ha, Kashiwa-shi, Chiba, Japan ogata.kunihiro, hideyuki-tanaka, yoshio.matsumoto@aist.go.jp

the measurement target person and the measurement camera move at the same time. A device that combines this marker with an IMU is called "Marker-IMU".

A. High Accuracy Visual Markers

We use visual markers like those in Fig. 1, consisting of a 2D code and four reference points. The relative location and orientation of the visual marker can be measured based on the relative position of four reference points [6]. Each marker can be identified by its 2D code. In order to estimate the orientation with high accuracy, we developed two types of patterns and mounted them on the markers [7][8].

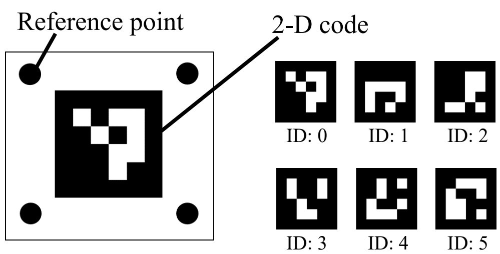

Fig. 1. High-accuracy visual marker.

B. Marker-IMU Algorithm

Our research group has developed a method for robustly estimating the position and orientation by fusing high-accuracy markers and IMU information. [9] The outline is shown in Fig. 2.

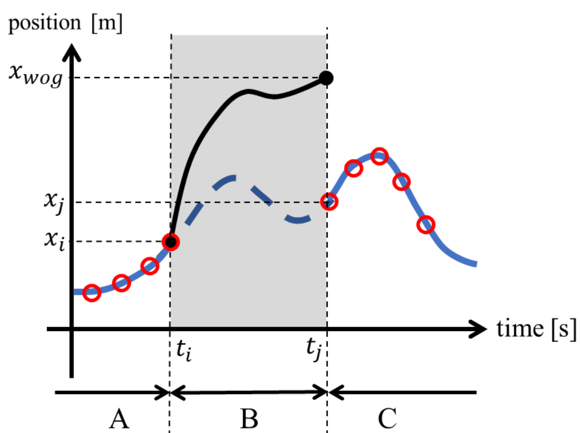

Fig. 2. Overview of Marker-IMU algorihtm that can interpolate missing position information.

The position and orientation of the marker can be obtained in the section A and C in Fig. 2, but not in B. Therefore, in order to calculate the position in the B, the IMU accelerometer is integrated. However, if the value of the accelerometer are integrated twice as shown in Fig. 2, the calculation result will diverge. Therefore, bu using the information in the boundary conditions (a and b) between each interval, the divergent effect of the integral can be identified, and the appropriate trajectory can be estimated by removing the error.

In this study, it is possible to robustly measure the whole body movement by calculating each Marker-IMU attached to each part of body.

C. Motion measurement with a moving camera

In the method in the previous section, the camera needs to be fixed. When the camera is fixed, the measurement area becomes narrow, which impairs the benefits of the IMU. Therefore, we aim to measure motion even with a moving camera.

The high-accuracy marker calculates the position and orientation with the camera as the reference coordinates. When the camera and marker move at the same time, the absolute position cannot be obtained. Therefore, by installing a reference marker in the environment, it is possible to obtain the absolute position of the measurement target person even when the camera and the markers attached to the body move at the same time. The relationship between the camera, the marker for motion measurement, and the reference marker is shown in Fig. 3.

$$ {}^{W}p_M = {}^{C}R_W^{-1}\left({}^{C}p_M - {}^{C}p_W\right) \tag{1} $$

${}^{C}R_W$ is the reference marker's rotation matrix with respect to the camera coordinate system.

From Eq.(1), it is possible to measure human movement even when the camera moves. In addition, by mounting the IMU on the camera, the algorithm in the previous section can be applied, even if the reference coordinates are temporarily invisible. It is possible to measure continuous human movement. In the way, the Marker-IMU algorithm can robustly measure human movement.

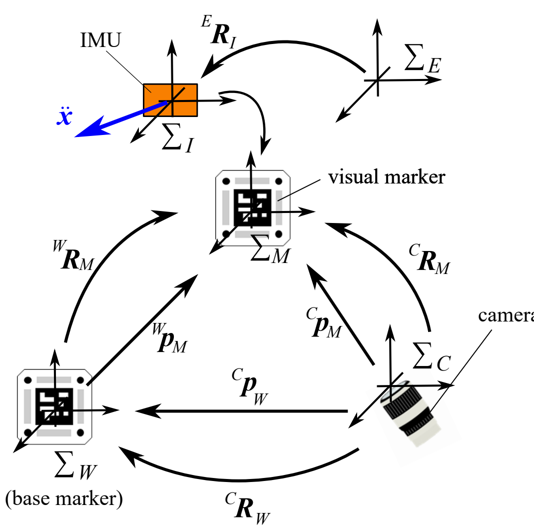

Fig. 3. Coordinate system between visual markers, camera and IMUs.

IV. EXPERIMENTS

Human motion was measured by multiple Marker-IMUs. Here, data is measured under two types of conditions: measurement when the camera is fixed and when the camera is moving. It was confirmed whether the Marker-IMU could complement even if the marker position information i missing.

A. Experimental Conditions

Fig. 4 shows an overview of the markers, IMUs, and cameras used in the experiment. In this experiment, markers with and without a lenticular lens were used. The monocular camera was a Point Grey (GS3-U3-23S6M) and the IMU was a MTw device (Xsens) that can wirelessly connect to a PC. The MTw can calculate orientation data with high accuracy using a real-time Kalman filter. Since the sampling rate of the IMU (about 5 ms) is shorter than that of the visual marker (about 75 ms), sensing data were obtained using multithreaded processing, allowing the IMU to obtain more sensor data than the visual marker. Camera and IMU information were simultaneously measured by a laptop computer (CPU: Intel Core i7-8750H(2.2GHz), GPU: NVIDIA Quadro P1000, memory: 16GB).

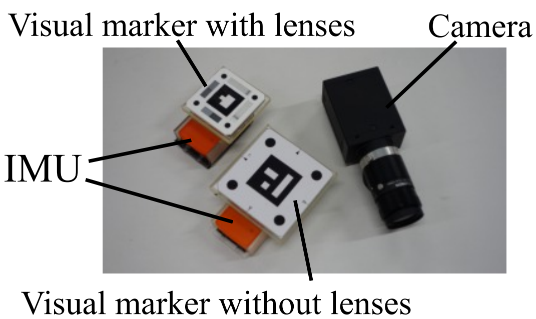

Fig. 4. Marker-IMUs and monocular camera.

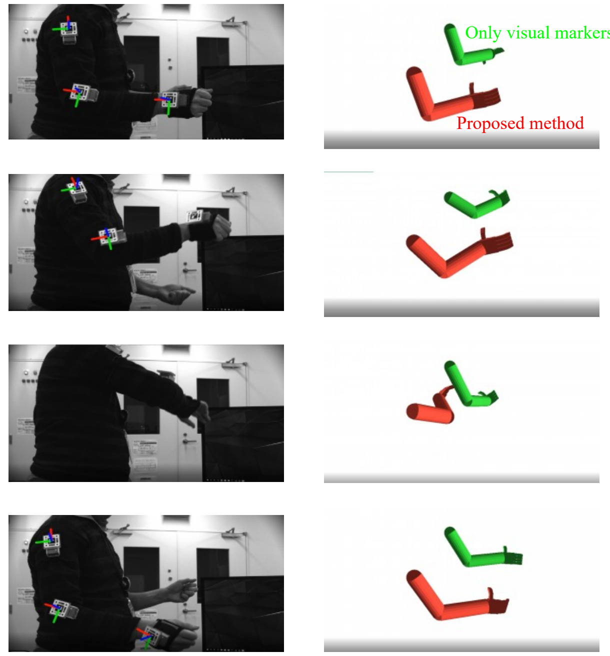

Fig. 5. Experimental results of upper limb movement.

B. Results and Discussion

First, we measured the movement of the upper limbs of a person. Marker-IMUs were attached to the hands, forearm(near the elbow), and upper arms(near the shoulder). The experiment results are shown in Fig. 5. The left side of Fig. 5 is the actual image, and the right side of Fig. 5 is the visualization result based on the estimation result. Red is the proposed method, and green is the visualization result of only the markers. As shown in Fig. 5, when the arm moves dynamically, it can be seen that the movement of the arm cannot be tracked by the marker alone. On the other hand, the Marker-IMU can properly estimate the movement of the arm.

Next, the movement of the walking person was measured, When continuously measuring walking motion, the camera alone can measure only a limited number of steps. However, with this method, motion can be measured while moving the camera. In this experiment as well, the motion measurement was performed while moving the measurement camera so as to keep the relative distance to the measurement target person constant. The experimental results are shown in Fig. 6 and 7.

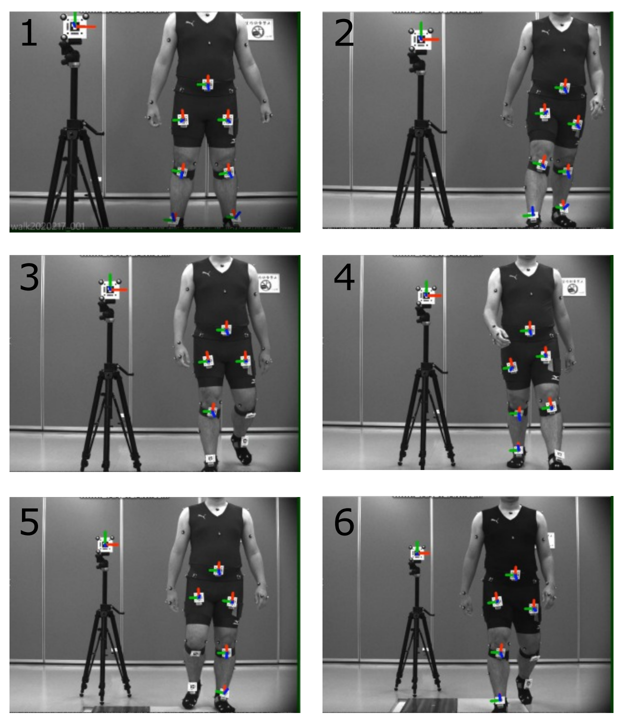

Fig. 6. Experimental results of walking motion.

By using the marker on the left side of each image as a reference marker, the absolute position of the measurement target can be obtained. Here, the coordinate system was set on the floor surface, the z-axis was upward, and the traveling direction of the measurement target was the x-axis. As can be seen from the Fig. 6, the camera is gradually moving away from the reference marker. By measuring while the camera is moving in this way, continuous walking can be measured.

However, it can be seen that the markers on the knees and feet are often lost while walking. Therefore, the lost data was interpolated by the proposed method. The movement trajectory of the knee marker a this time is shown in Fig. 7.

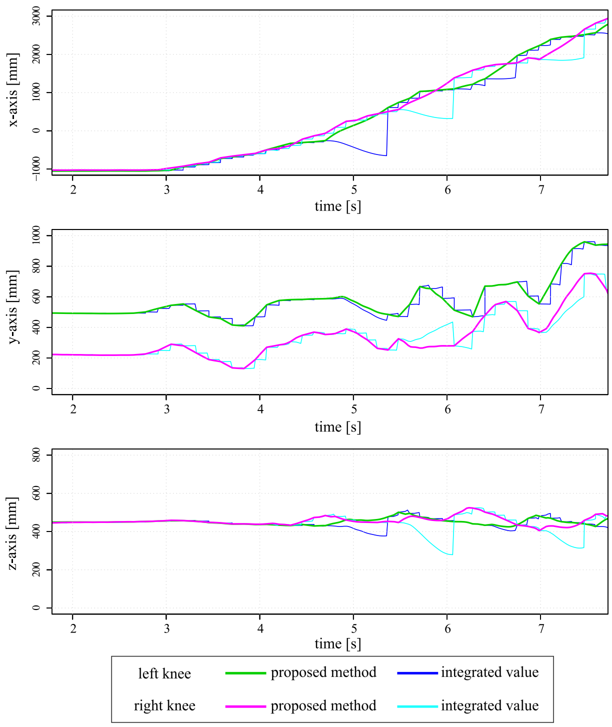

Fig. 7. Left and right knee joint movement trajectories with respect to world coordinate system.

The "integrated value" is just the integrated value without using the proposed method. It can be seen that a continuous and smooth orbit is obtained by the proposed method. In addition, it can be seen that the long distance of 4000 mm is continuously measured. Therefore, it was confirmed that this method can easily and continuously measure a person's gait.

V. CONCLUSION

The purpose of this study is to robustly measure human movement using the Marker-IMU, which is a combination of a visual marker and an IMU. In previous study, we have developed a robust measurement algorithm that combines a high-accuracy markers and an IMU. In this study, we applied this to human motion measurement. Further, by using the reference marker, the motion can be measured based on the absolute coordinate system even when the camera and the measurement target person are moving at the same time. In order to examine whether the measurement by this method is possible, we measured the upper limb movement and walking movement of a person. It was confirmed that the position and orientation could be measured robustly even if the marker was lost. In addition, in the measurement of walking motion, the continuous walking motion of several meters was realized by measuring while moving the camera.

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