Localization of Walking or Running User with Wearable 3D Position Sensor

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Abstract

This paper describes a new method of measuring position of running user for location-based services in wide indoor environments, such as augmented reality navigation system with wearable computer. Conventional localization methods usually employ a hybrid approach in which user's position is estimated by combining positioning infrastructures and a pedometer. Since the installation cost of infrastructures increases when the area expands, the measurement method of user's relative position with high accuracy is required. Although a number of methods using a pedometer have been developed to improve the estimation accuracy, these methods generally can handle only usual walking behavior of a user. This paper proposes a new real time localization method for both walking and running users by using a wearable electromagnetic tracker and an inertial sensor. The proposed localization method estimates a moving distance in the period when both legs do not ground by estimating a velocity of waist when user's leg leaves. Experiments have been carried out using a prototype system to evaluate the accuracy of user localization with the proposed method.

Keywords: Localization, Wearable computer, 3D position sensor

1. Introduction

Location-based information services which measure user's position with wearable computer and sensors and provide users with information have been developed [1, 2, 3]. One of examples of such applications is navigation system by using augmented reality technology with wearable computers[4, 5, 6, 7, 8]. Since these services need user positioning system with high accuracy in wide area, many localization sensors have been proposed in these years. Especially indoor environments, because Global Positioning System (GPS) which is typical measurement approach in outdoors cannot be used, localization methods with various approaches are investigated. The indoor localization methods can be divided into two approached: absolute position measurement with positioning infrastructures and estimation of relative distance by using wearable sensors such as dead reckoning system [9]. Recently, some hybrid methods which combine these two approaches have been also proposed.

To measure a user's position using a positioning infrastructure, visual markers [10, 11, 12, 13], infrared becomes [14, 15] or IC tags are generally used. The approach can estimate an absolute position of the user. However, the larger the area of positioning infrastructures is, the more the installation cost is increased since the infrastructures usually need electric power. On the other hand, a major method of the dead reckoning approach is to use a pedometer and an electronic compass[16, 17, 18, 19]. The methods can measure a relative distance of the user in any place essentially because walking steps of the user are counted. However, it is easily to accumulate the error of moving distance due to difference of length of user's step or miscount of user's steps by noise of sensors.

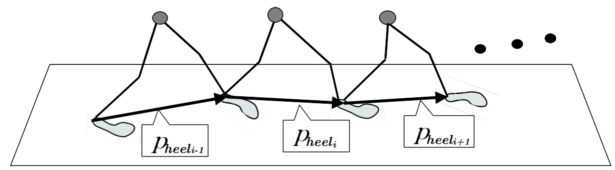

Figure 1: Illustration of summing up step vectors of walking user.

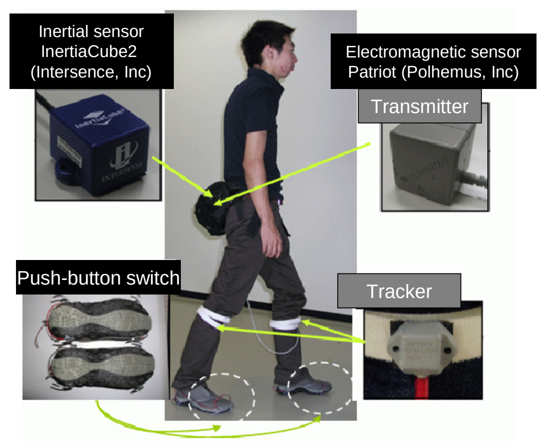

Figure 2: User's equipments in the proposed method.

In order to overcome the problems of the approaches, a hybrid approach is proposed [5, 20]. The hybrid approach can eliminate the accumulation error of the relative distance estimation by detecting the absolute position of the user with the positioning infrastructures. In addition, since user's position can be estimated complementally by continuously estimating the relative distance of userfs movement with a dead reckoning sensor, the alignment density of positioning sensors as the infrastructures beacons low and the installation cost of them decreases. Therefore, if a relative distance measurement sensor with high accuracy is developed, the cost for positioning infrastructures can become lower.@

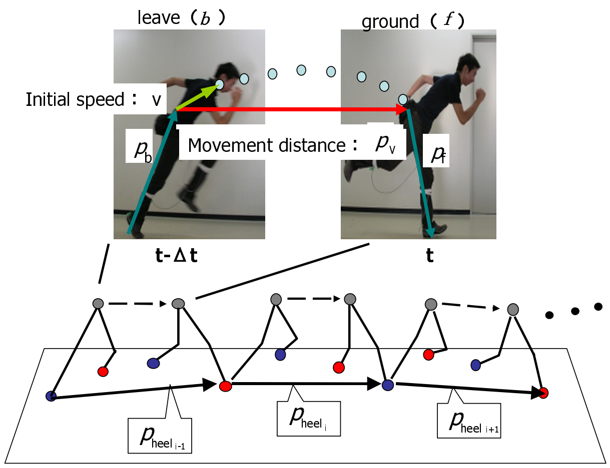

Figure 3: Illustration of summing up step vectors of running user.

To accurately estimate a relative distance of the user's movement, some studies directly measure the distance of a step with accelerators attached to user's toe [21] instead of a pedometer. A user localization method with a wearable electromagnetic sensor has been also proposed [22]. The method can estimate user's position even if user walks along various paths such as curve or stairs. These methods calculate the relative distance by summing up step vector which is the relationship between left and right feet when the both legs are grounded as shown in Fig. 1. Therefore, the methods cannot correctly measure the relative distance of a running user which there is a period when both legs do not ground, because a distance of the user's movement cannot be estimated in the period. In this paper, a new localization method for both walking and running users by using a wearable electromagnetic tracker and an inertial sensor is proposed. The proposed localization method measures a moving distance in the period when both legs do not ground by estimating a velocity of waist when user's back leg leaves from ground.

This paper is structured as follows. Section 2 describes the proposed localization method for running user with wearable electromagnetic tracker and orientation sensor. In Section 3, experimental results with a prototype system are described. Finally, Section 4 summarizes the present work.

2. Localization of Running User

2.1. Overview of the proposed localization method

This section describes the proposed localization method with an electromagnetic tracker, inertial sensor and push button switches. A user equips an electromagnetic sensor (Polhemus Inc.: Patriot), an inertial sensor (Intersence, Inc.: inertiaCube2) at user's hip, and push button switches attached to user's both heels and toes, as shown in Fig. 2. Trackers of the electromagnetic sensor are fixed on cnemis of both users' legs, A weight of the system is about 1.8 Kg. By attaching these sensors to user's hip, leg, and heel, the relative position of the left and right legs and absolute orientation of user's hip are estimated continuously. The proposed localization method estimates a moving distance

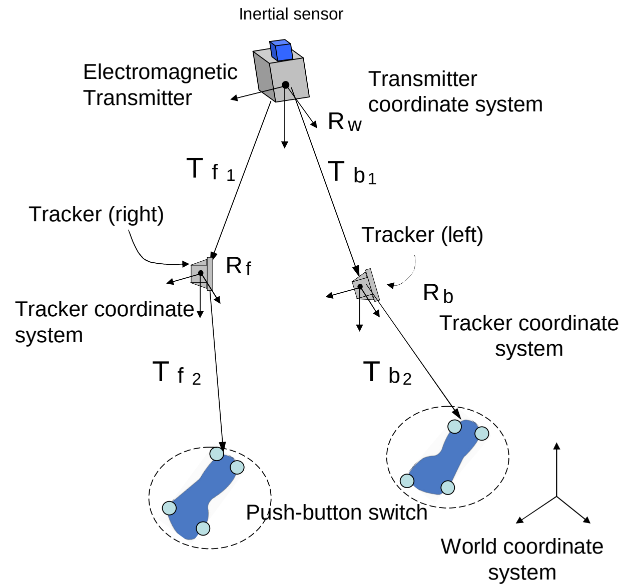

Figure 4: Coordinate systems of the proposed localization method.

in the period when both legs do not ground by estimating a velocity of waist when user's leg grounds. Therefore, the proposed method can measure the distance of user's movement even if there is a period when both legs do not ground. In other words, when the user walks, runs or jumps, the relative distance of the user's movement can be estimated.

2.2. Measurement of moving distance of running user

In this study, the localization method [22] for various walking actions with a wearable electromagnetic sensor is improved for a localization of running user. In [22], to estimate the user's position, the distance between left and right legs is summed up when the pivoted leg is changed as shown in Fig. 1. Here, let us call this amount of one step movement $\mathbf{p}_{heel}$ in Fig. 1 a step vector. The step vector of walking user can be calculated by using parameters acquired from electromagnetic tracker and inertial sensor shown in Fig 2. Let $\mathbf{p}_f$ and $\mathbf{p}_b$ be a relationships between user's hip and heels of the front and back feet in the world coordinate system, respectively. The step vector p_{heel} is defined by Eq. (1).

$$\begin{aligned}\mathbf{p}_{heel} &= \mathbf{p}_f - \mathbf{p}_b \\ &= \Big(\mathbf{R}_w(\mathbf{T_{f1}} + \mathbf{R}_f\mathbf{T}_{f2}) \\ &\quad -\mathbf{R}_w(\mathbf{T_{b1}} + \mathbf{R_b}\mathbf{T_{b2}})\Big), \qquad (1)\end{aligned}$$

where

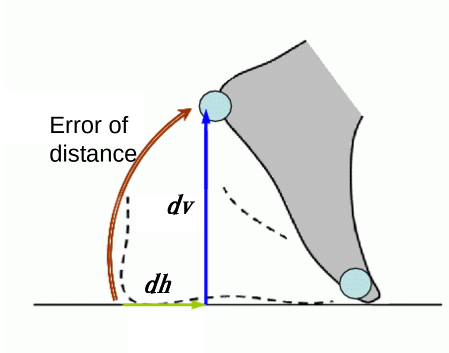

Figure 5: Error of distance when the back leg leaves from ground.

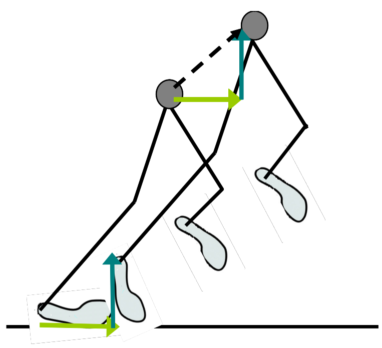

Figure 6: Error of hip velocity estimation by the heel height error.

$\mathbf{p}_{heel}$: step vector in the world coordinate system,
$\mathbf{R}_w$: absolute orientation of hip in the world coordinate system,
$\mathbf{T}_{f_1}, \mathbf{T}_{b_1}$: position of cnemis (position of electromagnetic tracker) in electromagnetic sensor coordinate system,
$\mathbf{R}_f, \mathbf{R}_b$: pose of cnemis in electromagnetic sensor coordinate system,
$\mathbf{T}_{f_2}, \mathbf{T}_{b_2}$: distance between cnemis and heel (constant).

Fig. 4 illustrates a relationship among coordinate systems of the proposed localization system. Here, f and b mean front and back side legs, respectively. Fig. 1 illustrates the process of estimating user's position. The estimated distance is defined by Eq. (2).

$$\mathbf{Distance} = \sum_{i=1}^{n} \mathbf{p}_{heel_i} \ . \qquad (2)$$

In this paper, in order to adjust the method mentioned above to localization for a running user, we attempt to improve the calculation method of the step vector (Eq. (1)). The proposed method measures a moving distance in the period when both legs do not ground by estimating a velocity of hip when user's back leg leaves from ground. Here, Note that $\mathbf{p}_f$ and $\mathbf{p}_b$ are vectors which mean relationships between a hip and front and back feet in the world coordinate system, respectively, and $\mathbf{p}_V$ is a moving distance for a period both logs do not grounded as shown in Fig. 3. The step vector of a running user is defined by Eq. (3).

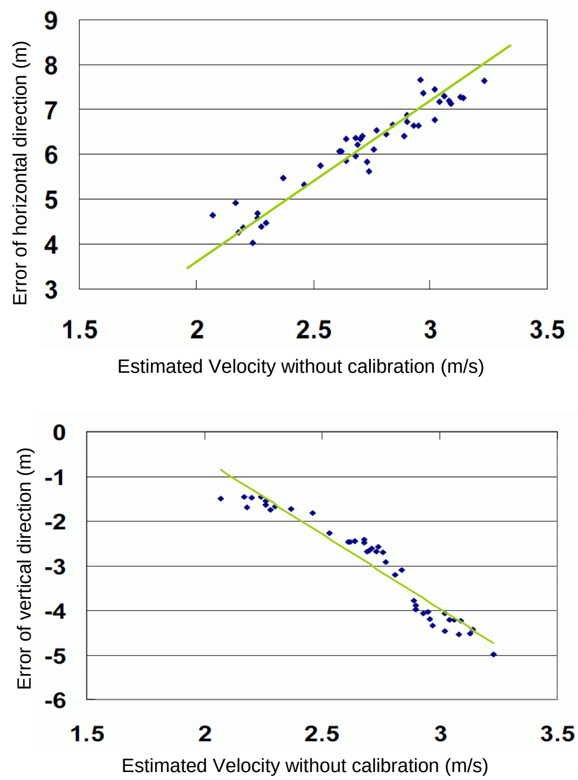

Figure 7: Measurement results of error of distance and velocity of the trials (30m straight line).

$$\begin{aligned} \mathbf{p}_{heel} &= (\mathbf{p}_f - \mathbf{p}_b) + \mathbf{p}_V \\ &= \Big(\mathbf{R}_{wt}(\mathbf{T_{f1}} + \mathbf{R}_f \mathbf{T}_{f2})_t \\ &\quad - \mathbf{R}_{w(t-\Delta t)}(\mathbf{T_{b1}} + \mathbf{R_b T_{b2}})_{t-\Delta t}\Big) + \mathbf{p}_V \quad (3) \end{aligned}$$

where,

Δt : Time of period which both legs do not ground

$\mathbf{p}_V$: Moving distance of hip for period both logs do not ground

horizontal direction : $\mathbf{p}_V = \mathbf{v}\Delta t$

vertical direction : $\mathbf{p}_V = \mathbf{v}\Delta t - \frac{1}{2}\mathbf{g}\Delta t^2$

By assuming that the user's hip moves under a parabolic motion, the distance of hip movement $\mathbf{p}_V$ while both legs do not ground can be calculated from an initial velocity $\mathbf{v}$ of hip when the back foot leaves from ground. The initial velocity $\mathbf{v}$ of hip is estimated from adjacent hip positions when the back foot leaves from ground.

The difference from conventional methods for a walking user is to consider times of leaving of back leg and grounding of front leg. In the method[22], since there is no period when both legs do not ground, it assumes that times of leaving of back foot and touching of front foot are same time. This means that Δt in Eq. (3) is 0. In this case, Eq. (3) is same to Eq. (1) which is step vector for walking user. Therefore, since the method can detect whether

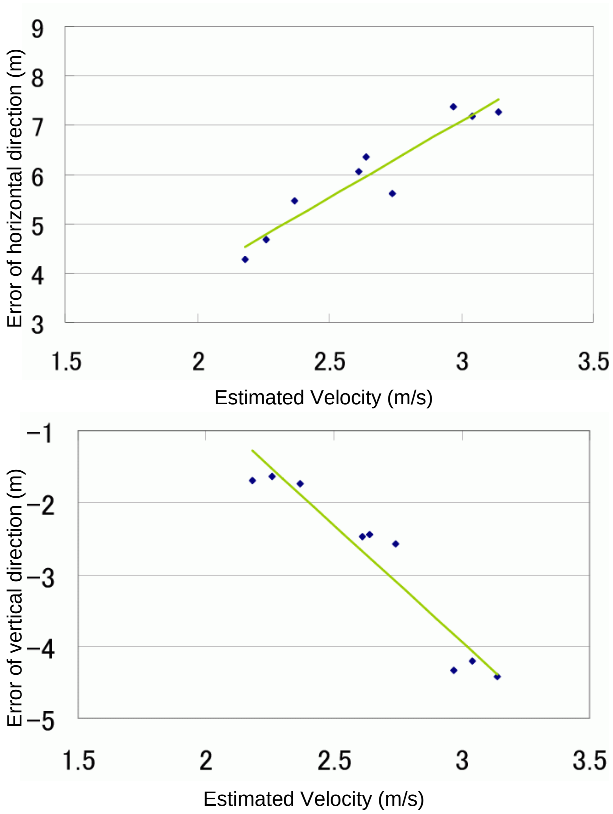

Figure 8: Relationship between error and velocity of nine trials.

the legs ground by using push button sensors attached to user's heels and toes, the proposed method can estimate the position of both walking and running users.

2.3. Calibration of heel height of running user

In the proposed method, it is ideal that both left and right heels are grounded when the back foot leaves and the front foot ground. However, in a human running action, the heel of back foot usually leaves from the ground before the toe of back foot as shown in Fig. 5. Therefore, the error of height accumulates. Especially, a hip velocity when a back leg leaves from a ground can not be correctly estimated because the heel height error affects the adjacent hip positions as shown in Fig. 6. To avoid the problem, we correct the error by estimating the dh and dv which denote the horizontal and vertical distance errors in each step, respectively.

In this research, by assuming that the error of distance is correlated with the velocity of user running, the errors of distance are corrected by using the relationship. In order to confirm a relationship between a running velocity and error of distance, we carried out a pilot study which measures the error of distance from many trials of running action under various speed. Fig. 7 shows measurement results of the trials. From Fig. 7, we can confirm that the relationship between the velocity of running and error of horizontal and vertical direction is assumed to be linier. Thus, the parameters dh and dv are estimated by some trials of running along a path whose distance is known in advance. Since calibration results differ among individuals, a user should try to calibrate the error of distance before the system is used.

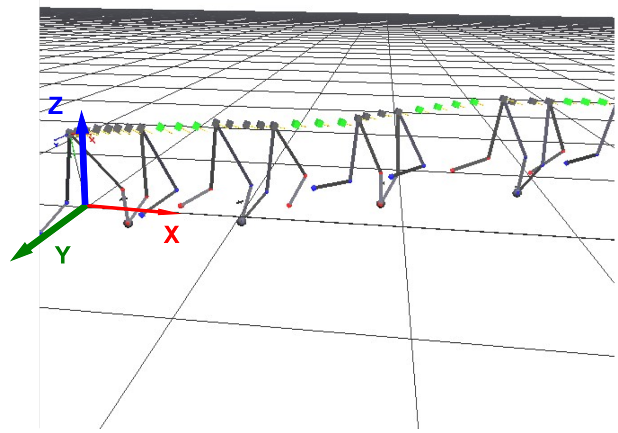

Figure 9: Estimated steps of running along a straight line.

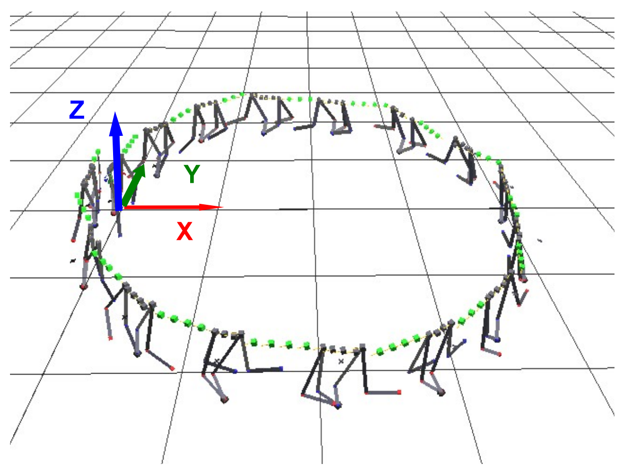

Figure 11: Estimated steps of running along circle.

3. Experiments

In order to confirm the feasibility of the proposed method, we have carried out the experiments. First, to calibrate error of distance caused by a heel height, we measured errors and velocities of nine trials which user runs along 30m straight line. The calibration process should be executed for each person one time in advance. Fig. 8 shows the measurement results of a user. One dot in the figure means the result of one trial. By estimating relationship between velocities of the user's running and error of distance, the measurement error is able to correct according to velocity of the user's running. The line in the figure shows relationships between errors and velocity of user's movement, which are approximately estimated with least square method. The experimental results below use the calibration result.

To examine the accuracy of estimated position of running user, four kinds of actions which include a period when the both legs float are evaluated: running along a straight line and a circle, triple jump and repetitive side steps. Here, Position error E_{pos} and position error rate E_{rate} are defined as follows;

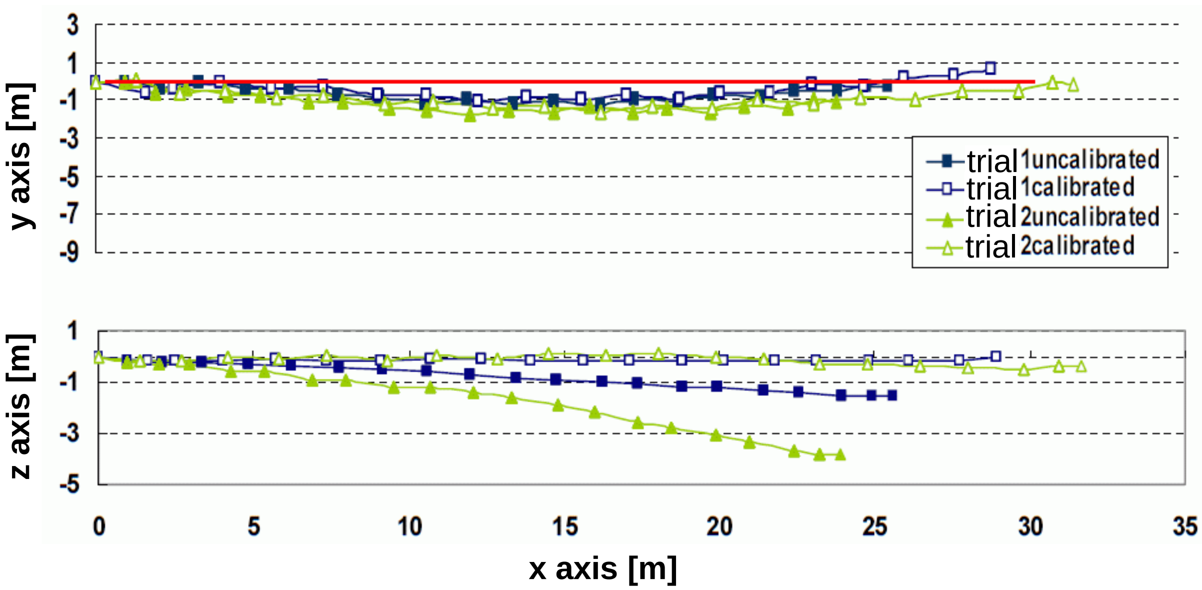

Figure 10: Estimated trajectories of running along a straight line with and -out calibration.

$$E_{pos} = |\mathbf{P_{res}} - \mathbf{P_{truth}}| \quad (4)$$

$$E_{rate} = \frac{E_{pos}}{Dis} \quad (5)$$

where $\mathbf{P_{res}}$ and $\mathbf{P_{truth}}$ are estimated and truth positions, and Dis means a total amount of movement, respectively.

Figs. 9 and 11 show the estimated steps of running along 30m straight line and circle whose diameter is about 6m, respectively. Figs. 10 and 12 illustrate the estimated trajectories of running along a straight line and a circle. In the experiments, we have estimated the error of distance caused by height error in advance from the nine results of user's running along the paths whose distances are known. We can confirm the proposed method can estimate user position accurately. Therefore, we can see that the calibrated results are better than uncalibrated results. The average position error of two trials is 1.054m. Here, the position error rate which is defined as a ratio of the difference between true and estimated positions and the true total amount of movement. The position errors rates in the two paths are 1.4% and 4.6%, respectively.

Figs. 13 and 14 show experimental results of estimating other two actions which include the period of when both user's legs leave from ground. They are sequences of triple jump and repetitive side steps. The Position error rates in the experiments are 1.2% and 3.6%, respectively. We can confirm that the user's positions under not only running action but also other action which there is a period when both legs float are estimated accurately.

4. Conclusions

This paper describes a real time measurement method of position of a running user for location-based services in wide indoor environments. The proposed method can apply to augmented reality systems with wearable computer. The proposed method measures user's orientation and geometrical relationship between user's heel and waist with an orientation sensor and an electromagnetic tracker that are attached to user's body. The proposed localization method estimates a moving distance in the period when both legs do not ground by estimating a velocity of waist when user's leg leaves. Experiments have been carried out using a prototype system to evaluate the accuracy of user localization with the proposed method.

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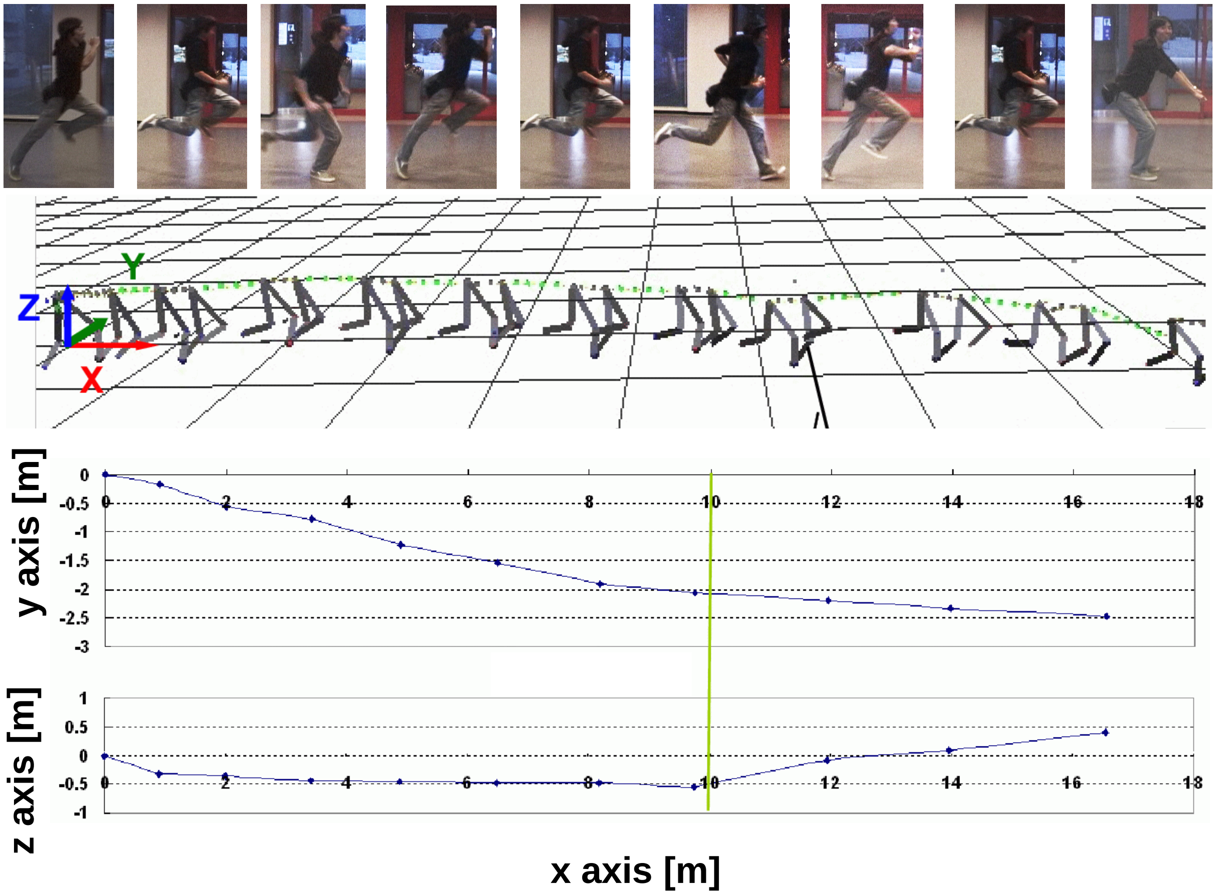

Figure 13: Results of triple jump(hop, step and jump).

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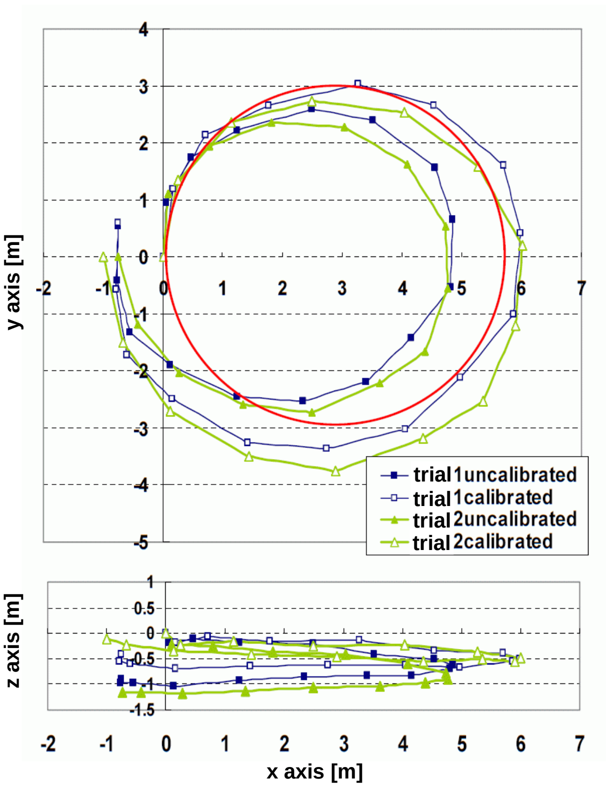

Figure 12: Estimated trajectories of running along circle with and -out calibration.

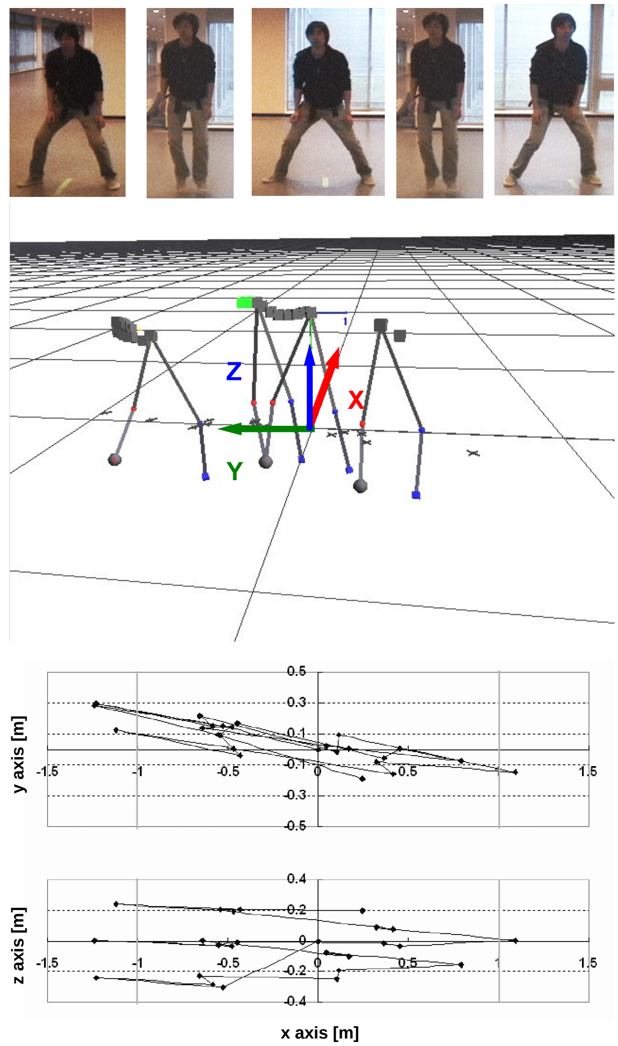

Figure 14: Results of repetitive side step.

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