Evaluation of Leap Motion Controller with a High Precision Optical Tracking System

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Abstract. The paper presents an evaluation of the performance of a Leap Motion Controller. A professional optical tracking system was used as a reference system. 37 stationary points were tracked in 3D space in order to evaluate the consistency and accuracy of the Controller's measurements. The standard deviation of these measurements varied from 8.1 μm to 490 μm, mainly depending on the azimuth and distance from the Controller. In the second part of the experiment, a constant distance was provided between two points, which were then moved and tracked within the entire sensory space. The deviation of the measured distance changed significantly with the height above the Controller. The sampling frequency also proved to be very non-uniform. The Controller represents a revolution in the field of gesture-based human-computer interaction; however, it is currently unsuitable as a replacement for professional motion tracking systems.

Keywords: Leap Motion Controller, motion capture system, consistency, accuracy

1 Introduction

Gesture-based user interfaces in combination with the latest technical advances, incorporating accurate and at the same time affordable new types of input devices, offer new opportunities for specific application areas such as entertainment, learning, health and engineering [1]. One of the latest technological breakthroughs in gesture sensing devices is Leap Motion Controller [2]. The device, approximately the size of a matchbox, allows for precise and fluid tracking of multiple hands, fingers or small objects in free space with sub-millimeter accuracy. With its enhanced interaction possibilities, the Controller could trigger a new generation of much more useful 3D displays and possibly complement the mouse as a secondary input device [3].

An interesting study of the Controller in [4] shows its potential for gesture and handwriting recognition applications. The acquired input data are treated as a time series of 3D positions and processed using the Dynamic Time Warping algorithm. The authors report promising recognition accuracy and performance results.

Professional optical motion capture systems are also often used in the domain of human-computer interaction for motion detection and gesture recognition. An example of their application is presented in [5], where the authors focused on an adaptive

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gesture recognition system while developing a gesture database to eliminate the individual factors that affect the efficiency of the recognition system. In particular, hand gestures were investigated.

The motivation for the research presented in this paper is to analyze the accuracy and consistency of the Controller with the aid of a professional optical motion capture system Qualisys [6]. The major goal of the study was to determine the Controller's suitability for a possible replacement of a professional motion tracking system. We were primarily interested in the following aspects:

- the consistency of the measurements at fixed spatial positions (spatial dispersion of measurements through time),
- the accuracy of the measured position in relation with its spatial position (the spatial dependency of accuracy), and
- the uniformity of data sampling.

The rest of the paper is organized as follows: Following the introduction, technical setup and measurement methodology are presented in Chapter 2. The detailed results are presented and analyzed in Chapter 3. Finally, key conclusions are discussed in Chapter 4.

2 Experimental Design

2.1 Technical Setup

Due to patent and trade secret restrictions, very few details are known about the Leap Motion Controller's inner structure and its basic operational properties. It is, however, clear that infrared imaging is used for object tracking.

According to the official specification [2], the Controller's sensory space is in the shape of an inverted pyramid positioned at the central point of the device. The Cartesian and spherical coordinate systems used to describe the tracked positions are shown in Fig.1. Cartesian coordinate system consists of the x axis running along the longer Controller's side (the length). Height is measured above the Controller and described as the y axis. Finally, the depth runs along the shorter Controller's side and is described as the z axis.

Our pre-experiment trials determined the Controller's useful sensory space, which is approximately within the boundaries of -250 mm $< x < 250$ mm, -250 mm $< z < 250$ mm and 0 mm $< y < 400$ mm.

The spherical coordinates consist of radius (r), azimuth (φ) and elevation (θ). In our case, the azimuth angle is defined under the assumption of the symmetry in the Controller's performance over x and z axes. The angle is therefore measured from the x axis (and not from the z axis as it is a common practice) to the line connecting the coordinate origin and the projection of the measured location in the x-z plane.

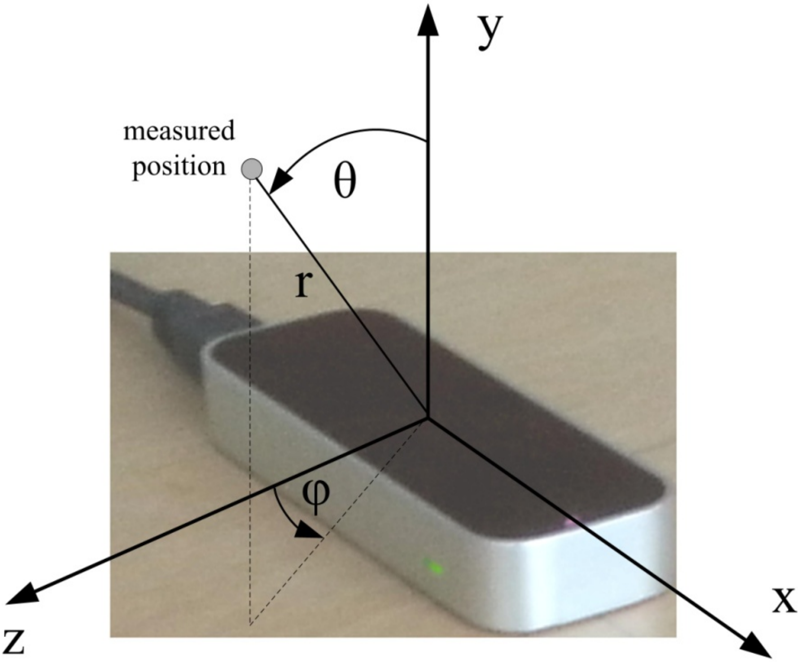

Fig. 1. The Cartesian and spherical coordinate systems used to describe positions in the Controller's sensory space

Programmatically, the Controller can be accessed through various Application Programming Interfaces. For the purpose of this study, a special real-time data acquisition and logging software has been developed in Python programming language. Each measurement of the Controller was logged with the corresponding timestamp. The latter enabled us to determine the exact time gap between two sequential samples and to calculate the corresponding sample frequency. Data processing and analysis was performed in Matlab.

A high-precision optical tracking system Qualisys [5] was used as a reference system. It consisted of eight Oqus 3+ high-speed cameras and the Qualisys Track Manager software. Such systems are widely used for fast and precise tracking of various objects in industrial applications, biomechanics, and media and entertainment applications. The tracking precision depends on the number of cameras used, their spatial layout, the calibration process, and the lighting conditions.

2.2 Methodology

The Controller's performance was evaluated through two types of measurement scenarios. In the first scenario, 37 stationary points in space were tracked for a longer period of time in order to evaluate the consistency and uniformity of the measurements. The locations of the stationary points were chosen systematically through the entire Controller's sensory space.

Fig. 2. Experimental environment showing the static measurement scenario setup. One of the cameras of the motion tracking system is visible in the background.

The tracked object was a passive reflective marker, attached to the middle finger of a plastic hand model. The marker was tracked by the Controller and by the reference optical motion tracking system simultaneously. The experimental setup is shown in Fig. 2.

In the second measurement scenario, a constant distance was provided between two points (markers) with the aid of a special V-shaped tool. It consisted of two markers and a supporting rigid structure ensuring constant distance (21.36 mm) between the markers. The exact distance was acquired with the reference system. The tracking accuracy of the Controller was evaluated based on the deviation of the distance between the two markers after moving the V-tool freely around the sensory space. This experimental setup is illustrated in Fig. 3.

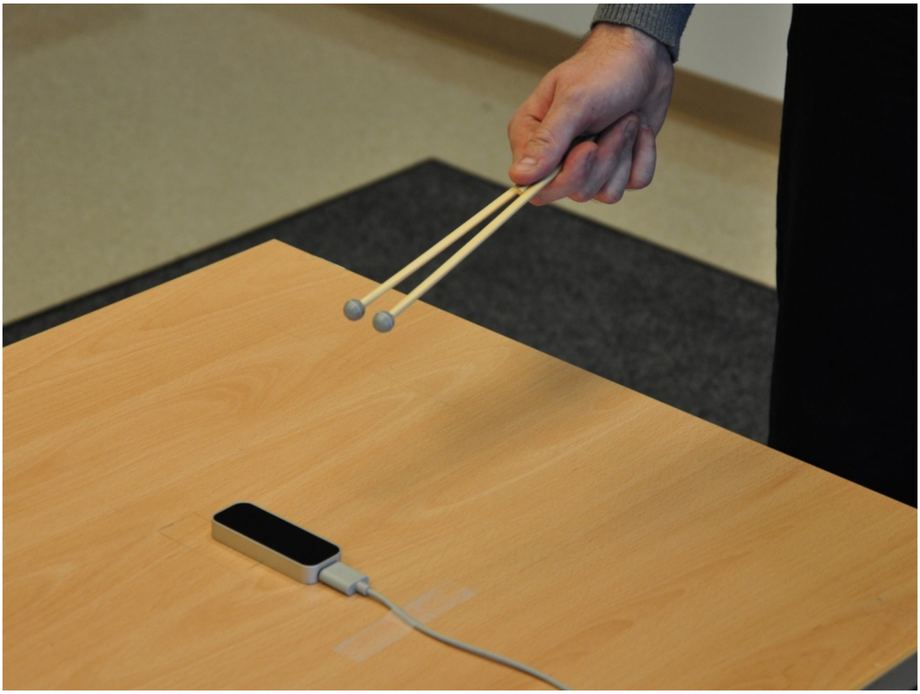

Fig. 3. Experimental environment showing the dynamic measurement scenario setup

3 Results and Interpretation

3.1 Static Measurements

In the static setup, standard deviations calculated for all 37 points varied from 8.1 µm to 490 µm. Generally speaking, the lowest standard deviations were measured in space directly above the Controller, while the highest standard deviations were measured at the leftmost and the rightmost positions.

Fig. 4 shows the probability density of deviation of the measured location from the actual location for the individual axes. The results indicate that, when making a single measurement, a smaller deviation of the location is expected along the x axis (alongside the Controller) compared to the directions away from the Controller (along the z axis) or in height (along the y axis).

Further analysis of the linear correlation revealed that standard deviation increases significantly with the distance from the Controller ($r = 0.34$, $p = 0.044$) and azimuth angle (leftmost and rightmost sides of the Controller, $r = 0.43$, $p = 0.051$). No significant correlation was found when changing inclination of the tracking objects.

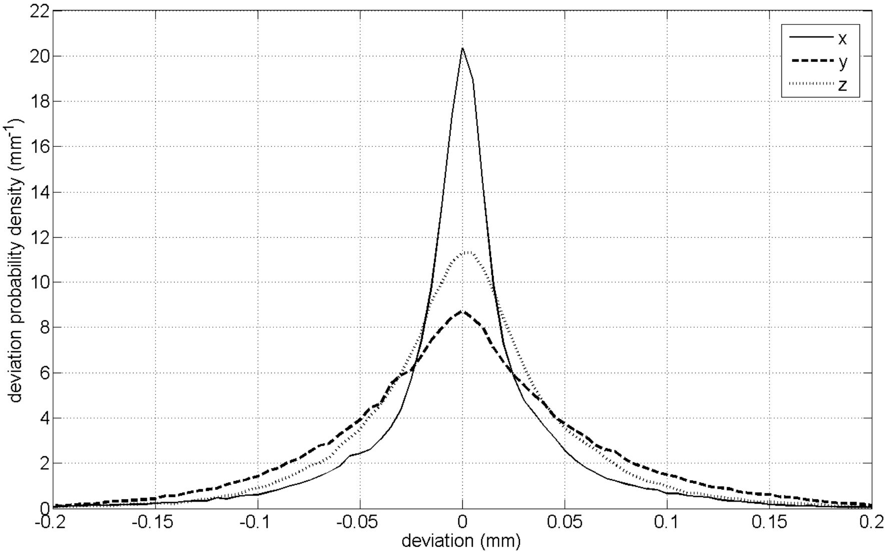

Fig. 4. The deviation probability density for individual axes including all 37 locations

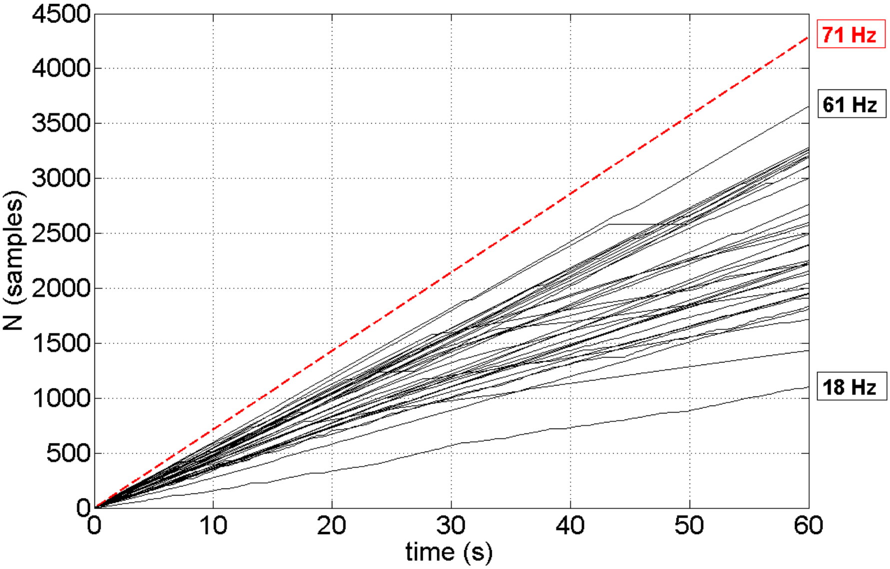

Fig. 5. The sampling performance of the Controller in the static setup

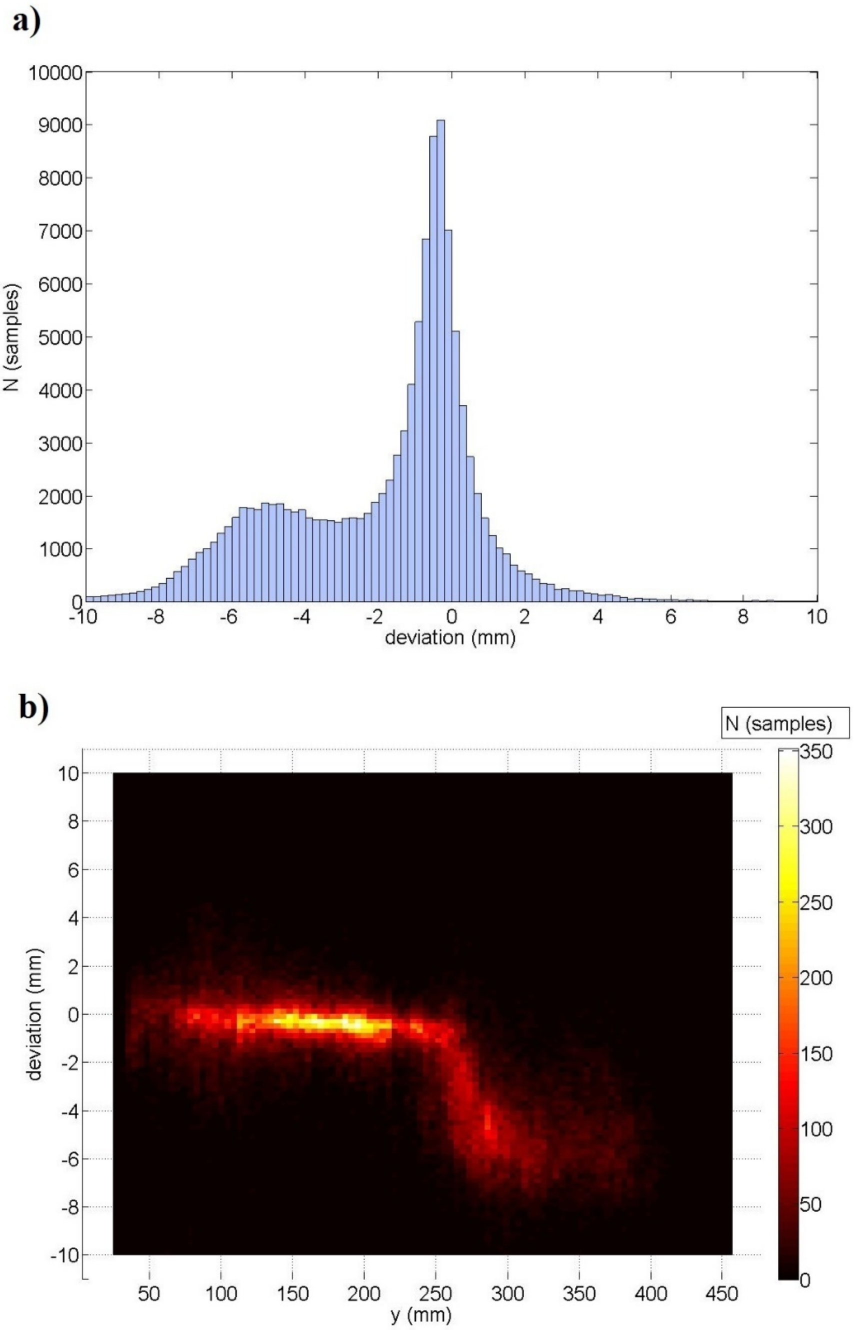

Fig. 6. Distribution of distance deviation between two points: the overall distribution (a) and the distribution on the y axis (b)

Our further investigation was focused on the Controller's sampling performance. Fig. 5 demonstrates the progress of data acquisition in the first minute of measurements at each of the 37 measured positions. The figure indicates very non-uniform sampling as the sampling frequency varies both in space and time. The minimal logged period between two samples was 14 ms, which corresponds to the reference sampling frequency of 71 Hz (indicated with the dashed line in Fig. 5). The actual average sampling frequencies were calculated based on the number of samples acquired in the first minute and ranged between 18 and 61 Hz. The average sampling frequency across all locations was 39 Hz. The standard deviation was 13 Hz.

3.2 Dynamic Measurements

In the dynamic setup, two markers with constant inter-distance were tracked while moved freely in the sensory space. Fig 6a shows the distribution of deviation of the distance between the two tracked markers. The distribution consists of two local peaks, one at 0 mm and one at approximately -5 mm. The latter corresponds to the points located more than 250 mm above the Controller, which can be noted from Fig 6b.

The spatial dependency of the distance deviation was determined by computing linear correlations between the deviation and individual spatial dimensions. The analysis revealed statistically significant moderate negative linear correlations between the distance deviation and the height above the Controller ($r = 0.61$, $p < 0.000$) and the distance from the Controller ($r = 0.60$, $p < 0.000$). The distance deviation was not correlated with other spatial dimensions.

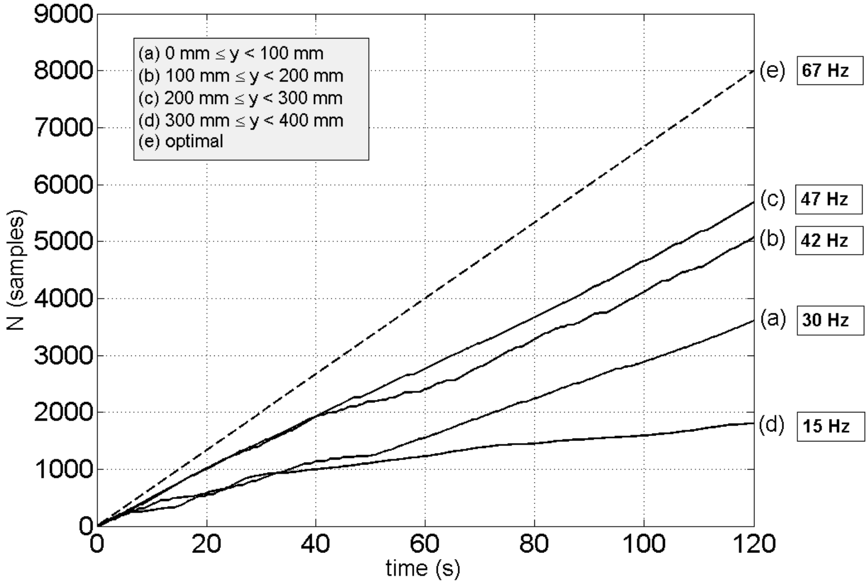

Fig. 7. The sampling performance of the Controller in dynamic scenario

The sampling frequency varied significantly in the dynamic setup as well. Fig. 7 displays the Controller's sampling performance when tracking moving objects in four separate layers in height. The actual sampling performance is compared against "optimal" sampling performance (indicated by a dashed line). The latter corresponds to the constant sampling period of 15 ms, the minimum time interval between two consecutive samples logged in the dynamic measurements.

The figure indicates the best sampling performance between the heights of y = 100 mm and y = 300 mm, while it gets significantly less efficient below and particularly above this height.

4 Discussion and Conclusions

The Leap Motion Controller proved to be very accurate for tracking static points in a predefined sensory space, but less accurate when objects move around. In both cases, the measurement consistency and accuracy varied significantly at different spatial positions. For example, in the static scenario, objects placed directly above the Controller were tracked with the highest consistency (lowest standard deviation) but with a much lower consistency (highest standard deviation calculated) at the leftmost and rightmost positions. In the dynamic scenario, the distribution of deviation of the distance between the two markers increased significantly when tracking higher than 250 mm above the Controller.

Our experiment clearly demonstrated that the Controller's consistency and accuracy are spatially dependent. This fact limits the Controller's suitability for precise tracking of various objects in space. The additional limitations are also a relatively modest sensory space (only approximately one tenth of a cubic meter) and a varying sampling frequency for both static and dynamic measurements. These drawbacks, however, do not influence the Controller's primary purpose which is to be used as an alternative interaction device.

To conclude, the Leap Motion Controller undoubtedly represents a revolution in the field of gesture-based human-computer interaction, but it is currently unsuitable as a replacement of professional motion tracking systems with a sufficient accuracy and sampling uniformity. Based on the insights gained from the study, our future research involving Leap Motion Controller will be focused on using the device in practical applications such as gesture-based interfaces.

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