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Accuracy measurement of HoloLens2 IMUs in medical environments

Abstract: As augmented reality devices become more available, collaborative work in the augmented space is expected to increase. Knowing the position of participants allows for realistic interaction rather than passive participation. The HoloLens 2's camera and IMUs fuse data to locate the device. In this paper, accuracy and repeatability of the HoloLens2 position finding was analysed to provide a quantitative measure of pose repeatability and deviation from a path while in motion. Deviation from a circular path was found to be below 5 mm per 628 mm travelled.

Keywords: HoloLens2, AR, Pose repeatability, Patient tracking, Telemedicine, Staff tracking, Position finding

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1 Introduction

The Microsoft HoloLens2 augmented reality headsets (henceforth abbreviated as HL2), while currently bulky and heavy, introduce a wireless device which broadens the scope of digital assistance and interaction. Especially in the medical field, where clinicians can benefit from personalized digital support, the HL2 offers contactless input capabilities through speech, hand gestures, and eye tracking, as well as speakers and compact displays that are calibrated to the users eyes. WiFi 5 allows for wireless data streaming to and from the device, facilitating unobstructed mobility while remaining connected to a wireless network.

In a clinical setting such as in operating theatres or in pre-hospital emergency treatment in an ambulance, the HL2 can be deployed at a moment's notice and support medical

personnel in their decision making processes. Furthermore, the HL2 can connect to external experts through telemedical applications. Currently, collaborative work is limited to video teleconferences and is realized in a way that the external expert is presented with the point of view of the HL2 wearer, while simultaneously being projected as a 2D hologram.

Future applications will expand and innovate telemedical applications, by allowing three-dimensional immersion for all participants with augmented reality headsets. To achieve vivid interactions with multiple users in an AR environment, a realistic positioning of all participant is essential, so that the corresponding avatars can be projected at the correct location. Further benefits from knowing the AR headset location can be explored, such as guidance of rescue workers to an accident site or aiding patients in rehabilitation[1]. While current research investigates hologram position stability[2], quantifiable data on the position finding accuracy of the HL2 headset is scarce[3].

In this paper we aim to investigate the accuracy and precision of the HL2 position finding capabilities and quantify the pose repeatability as well as the deviation of the device from a known trajectory. The approach chosen minimized the impact of the camera and maximized the effect of the IMU on position tracking.

2 Methods

Using Unity and Visual Studio 2019 an application was implemented in C# to record the current position $P\{x\ y\ z\}$ of the HL2. Additionally, orientation and current frame rate were recorded. The HL2 was firmly attached to a KUKA LBR iiwa 7 R800 robot (henceforth abbreviated as KUKA) via a custom-made mount, 3d printed in an Ultimaker S5. Reference position data was acquired from the KUKA at 100Hz. All data was analysed in MatLab.

Two scenarios were performed to obtain data, with the first serving as reference to investigate potential time related position deviation.

- scenario 1: HL2 at rest for 2 minutes
- scenario 2: HL2 moved on circular paths

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2.1 Intended data analysis

This investigation intended to analyse how accurate the HL2 determined its own location when repeatedly brought to the same position and furthermore, what the perceived deviation from the defined path was. Testing was analogous to ISO9283 “Manipulating industrial robots - Performance criteria and related test methods”, fulfilling the minimum requirement of 30 repetitions and five different motion sets.

Scenario 1 was used to quantify the deviation over time of the HL2 at rest. The main investigation focused on scenario 2, aiming to analyse:

- the deviation d of the HL2 was defined as the distance between the measured position of the HL2 and the closest point on the predefined path.
- the deviation from the defined path while in motion
- the recorded path length when reconstructing motion from position measurements.
- The dependency of deviation due to movement speed, orientation, and direction of motion

The deviation d from the path is the distance between points P and K . P is the actual position. K is located on the path. For a circle with centre C and radius r , the point Q is the projection of P onto the plane containing the circle, hence:

$$K = C + r \frac{Q - C}{|Q - C|} \quad \text{and} \quad d = |P - K|$$

This deviation d defines a volume which contains the coordinate data points. In the case of circular motion, this will be a series of tori which represent the probability distribution of the position measurement.

The HL2 position recording software initiates data recording before KUKA motion begins. To match the start of motion between HL2 and KUKA data, the first change in position which exceeds the mean rest position $\pm 3\sigma$ will be chosen. Measurements are provided in mm unless otherwise stated.

2.2 Data acquisition

2.2.1 Scenario 1: HL2 at rest

The HL2 was mounted onto the KUKA and position, orientation and frame rate were recorded for two minutes. To minimize sources of vibrations, the KUKA was turned off and no personnel was present in the testing room and recording was started remotely.

2.2.2 Scenario 2: HL2 moved on circular paths

In order to quantify the pose repeatability of the HL2, as well as the deviation from the planned trajectory, multiple sets of circular motions were carried out. Accurate motion was enabled by mounting the HL2 onto a KUKA. It performed a set of 90 circles with a radius of $r = 100$, which was split into 30 circles in the xy -, xz -, and yz -planes respectively (see Figure 2). This simulated movement with 3 degrees of freedom but a fixed orientation:

- xy plane: forward-backward and left-right
- xz plane: up-down and forward-backward
- yz plane: left-right and up-down

The coordinate system of the HL2 defined the x axis extended backward, the y axis to the right, and the z axis upward. Thus, when moving forward and left, negative values in x and y axis are recorded.

Movement speed was chosen as follows: 50, 75, 100 and 150 mm/s. Furthermore each set was repeated with the HL2 pitched at 0° and 45° downward. Apart from varying movement speed, the pitch angle of the HL2 was chosen at 0° and -45° to simulate a physician looking straight ahead or down onto an operating table.

Simultaneously, the position of the KUKA was recorded to provide reference data. To highlight the end of each circle, the KUKA remained in the final position of each circular trajectory for 2 seconds, thus allowing the setup to settle in and measure this position approximately 120 times for the HL2 and approximately 200 times for the KUKA. The HL2 was faced towards a white wall without discernible features. It was postulated, that in this setup, the camera data would provide little to no input for position tracking, forcing the HL2 to primarily rely on IMU inputs, rather than camera plus IMU data. The camera could not be covered, as this resulted in no position data being generated. In total, eight sets of motion were recorded at two different pitch angles and four speeds.

3 Results

The HL2 measured position over time at rest for 2 minutes. The position had a ± 0.2 mm jitter around the starting point without discernible preference in jitter direction. This indicates no significant deviation of the position with time. Pose repeatability of the KUKA was verified as ± 0.2 mm in separate experiments and its deviation from the path did not exceed ± 0.4 mm, even at 150 mm/s.

The main focus was directed at quantifying the HL2 deviation between the start and end of the circular motion. To illustrate how the data looked, Figure 1 shows individual position measurements of 30 consecutive circles performed in the xy plane at 100mm/s by both the KUKA (top) and HL2 (bottom) in a 3d plot. The starting point is within the more dense region of measurements at coordinates (0,0,0). These position measurements were conducted in all 8 sets.

Figure 1: Top: Position of the KUKA (Black) and a circular path (Red). Bottom: Position of the HL2 (Blue) compared to KUKA (Black). Starting position for both at (0,0,0), speed of 100 mm/s.

No definitive correlation between speed and repeatability was seen from the data. However a pitch angle of -45° showed a lower deviation and better repeatability for different speeds. Tables 1 and 2 list the deviation per circular path for -45° and 0° pitch respectively, along with the deviation between the start and end position of the entire set.

Table 1: Mean and std. deviation between end and start point of circular motion with radius = 100 mm, when pitch of HL2 was 0° .

Speed [mm/s]	XY Plane		XZ Plane		YZ Plane		Deviation d [mm]
	$\bar{d}$	σ	$\bar{d}$	σ	$\bar{d}$	σ	
50	4.1	2.6	4.5	3.2	3.9	1.9	49.3
75	0.8	0.5	1.2	0.5	1.9	0.5	29.9
100	2.1	1.2	2.3	1.0	2.7	1.5	30.1
150	3.0	1.7	2.7	1.8	2.4	1.3	32.9

Table 2: Mean and std. deviation σ between end and start point of circular motion with radius = 100 mm, when pitch of HL2 was -45° .

Speed [mm/s]	XY Plane		XZ Plane		YZ Plane		Deviation d [mm]
	$\bar{d}$	σ	$\bar{d}$	σ	$\bar{d}$	σ	
50	1.0	0.41	1.4	0.5	1.3	0.6	39.4
75	0.9	0.36	1.3	0.5	1.1	0.5	17.6
100	1.0	0.46	1.0	0.5	1.2	0.8	43.1
150	0.9	0.50	2.2	1.2	1.2	1.3	8.7

For consecutive circles, the measured position of the HL2 drifted back (+x direction) and down (-z direction) in all samples. Figure 2 shows how the traveled paths look; this example is taken at the speed of 100 mm/s and 0° pitch.

Figure 2: Traveled path of the HL2. XY-Plane (Blue), XZ-Plane (Orange), and YZ-Plane (Yellow) for 100mm/s, $r=100$ mm and starting coordinates of (0,0,0)

During motion, the deviation of the HL2 was defined as the distance between the measured position of the HL2 and the closest point on the predefined path. For 0° pitch it varied between 2.0...5.9 mm with σ 1.7...4.1 mm. This increased to $d=4.9...7.9$ and $\sigma=2.9...6.4$ mm when the pitch was changed to -45° . Furthermore, detected position often jittered back and forth and was clearly visible when plotting position against time. This resulted in errors when calculating the traveled path from position measurements alone. The distance traveled by the KUKA was measured to between 628.4...628.7 mm, compared to the circumference of 628.32 mm of a circle with radius of 100mm. For these motions, the HL2 data that was recorded simultaneously showed distances traveled of 1270.8...1848.8 mm.

4 Discussion

Measurements of pose repeatability and path deviation during motion were conducted. Accuracy of the KUKA reference data was sufficient, deviating less than 0.4mm from the planned path, even during motion, with pose repeatability of <0.1mm.

The HL2 had bad repeatability but good accuracy in measuring its position, often detecting forward and backward motion in alternation for successive measurements. It did not stray far from the trajectory. However the perceived back and forth jitter resulted in a path which was at least double in length when compared to the KUKA reference data. Consequently, the instantaneously detected position was in good accordance with the planned position, however the total distance travelled was completely inaccurate. This could be mitigated and improve velocity interpretations by reducing sampling rate to 30 Hz as performed by Geerse [1].

For determining deviation from the path while in motion, it was presumed that the closest point on the ideal circular path is the coordinate at which the HL2 should be. This poses a risk of evaluating against the same point on the path, especially with stray measurements. A more accurate method would evaluate against coordinates which depend on speed and time so that $d = |P - (f(t, v))|$. This approach would require the synchronization of HL2 and KUKA with accurate time stamps to exactly know when motion began.

5 Conclusion

As with its predecessor [4], the IMU measurements are in good agreement with reference data. Accuracy of HL2 is sufficiently high for interaction between multiple users. The highest recorded deviation from the starting position after moving the HL2 by 5655 mm, was 49.3 mm, which is 0.87% of the travelled path. The acceptance of misalignment of virtual avatars by below 1% in scenarios where participants

are mostly stationary or travel short distances, such as operating theatres or during reanimation of trauma patients, remains to be investigated. Neither movement speed nor the direction of motion appear to influence accuracy of position detection. As trials were conducted with deliberately degraded camera inputs, the quality of position tracking is only expected to improve in scenarios with diverse textures.

Author Statement

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References

- [1] D. J. Geerse, B. Coolen, and M. Roerdink, "Quantifying spatiotemporal gait parameters with hololens in healthy adults and people with Parkinson's disease: Test-retest reliability, concurrent validity, and face validity," *Sensors (Switzerland)*, vol. 20, no. 11, pp. 1–12, 2020, doi: 10.3390/s20113216.
- [2] C. M. Andrews, A. B. Henry, I. M. Soriano, M. K. Southworth, and J. R. Silva, "Registration Techniques for Clinical Applications of Three-Dimensional Augmented Reality Devices," *IEEE J. Transl. Eng. Heal. Med.*, vol. 9, no. July 2020, 2021, doi: 10.1109/JTEHM.2020.3045642.
- [3] A. L. Guinet, G. Bouyer, S. Otmane, and E. Desailly, "Reliability of the head tracking measured by Microsoft HoloLens during different walking conditions," *Comput. Methods Biomech. Biomed. Engin.*, vol. 22, no. sup1, pp. S169–S171, 2019, doi: 10.1080/10255842.2020.1714228.
- [4] R. Sun, R. G. Aldunate, and J. J. Sosnoff, "The validity of a mixed reality-based automated functional mobility assessment," *Sensors (Switzerland)*, vol. 19, no. 9, pp. 1–12, 2019, doi: 10.3390/s19092183.