TIPTEKNO'24 MEDICAL TECHNOLOGIES CONGRESS
10-12 October 2024
Yasmin Bodrum Resort, Muğla, Türkiye

Quantifying the Impact of Integrating the HTC Vive Tracker with the Awinda Motion Capture System in Minimizing Positional Drift

Elie Chebel
Department of Computer Engineering
Bahcesehir University
Istanbul 34353, Turkey
elie.chebel@bahcesehir.edu.tr

Yara Corky
Department of Bioengineering
Bahcesehir University
Istanbul 34353, Turkey
yara.corky@bahcesehir.edu.tr

Omar Kassem
Department of Computer Engineering
Bahcesehir University
Istanbul 34353, Turkey
omar.kassem@bahcesehir.edu.tr

Burcu Tunc
Department of Biomedical Engineering
Bahcesehir University
Istanbul 34353, Turkey
burcu.tunc@bau.edu.tr

***Abstract*—Inertial measurement unit (IMU) based systems are considered a very attractive solution for human motion capture. However, these systems suffer from significant drift when it comes to positional tracking due to the nature of the IMU technology. This study aimed to quantify the positional accuracy of the MVN Awinda motion capture system after its integration with a single HTC Vive tracker. The integration aims to leverage the strengths of both systems, enhancing accuracy, precision, and adaptability in motion capture technology. Our experimental protocol focused on evaluating the drift under two conditions: performing an in-place repetitive motion such as squatting and performing a repetitive walking-based task while circulating in between specific checkpoints. Our findings revealed a significant positional error reduction ($p < 0.001$) in terms of walking-based tasks after integrating the Vive tracker. The positional drift with the assistance of the tracker had an average of 56.27 mm while the exclusion of the tracker yielded an average drift of 218.64 mm. On the other hand, the inclusion of the tracker in the in-place task did not lead to any improvement in terms of positional drift, but rather showed that the inclusion of the tracker in such tasks is not advised.**

***Index Terms*—IMU Motion capture, Awinda system, HTC Vive, Positional drift**

I. Introduction

Motion capture technologies play an important role in capturing human motion. These technologies have many applications in important industries, including film [1], entertainment [2], sports analysis [3], and biomechanics research [4].

Optical systems are considered the most trusted form of motion capture and are regarded as the gold standard. These systems mainly rely on video cameras and reflective markers to accurately capture motion from multiple angles.

979-8-3315-2981-9/24/$31.00 ©2024 IEEE

Inertial based motion capture systems, on the other hand, rely on sensors attached to the body to detect motion, and track subjects in different environments. Xsens is a renowned provider of inertial motion capture systems, offering MVN suits equipped with Inertial Measurement Units (IMUs) to capture and analyze movement and orientation data.

The Xsens Awinda system samples signals at 1000 Hz internally and outputs at 60 Hz using 17 IMU sensors for motion capture. It offers real-time data streaming for immediate motion visualization and analysis. However, it suffers from positional drift, which is the accumulation of inaccuracies in sensor locations due to issues like incorrect calibration or changes in calibration parameters, notably related to integrated magnetometers, leading to biases and noise buildup causing drift [5].

Recent versions of the MVN software include the optional integration of HTC Vive trackers for positional assistance. With this function, the HTC Vive position tracking is combined with the Motion Tracker data from the Motion Capture System (Awinda) to enhance the overall position.

The HTC Vive tracking system, is a piece of hardware that HTC created for their virtual reality headset, the HTC Vive. This tracker works on the known inside-out concept, which eliminates the need for external cameras. Rather, this tracking system makes use of Lighthouse base stations that generate infrared laser beams [6].

A study by [7] combined IMU and Vive tracker systems to analyze human-robot interactions. They found that IMU technology provides smooth motion but has noticeable drift, while Vive trackers offer high stability during rapid moves. By combining both systems, more robust motion is possible. The main issue with HTC Vive is jitters and occlusions,

while MVN systems suffer from drift. IMU-based technology creates smoother motion profiles, advantageous for physical interaction and human-robot collaboration..

Another important study by [8] determined how different static and dynamic movements affected the Base of Support (BoS) on the MVN platform. Data was gathered using the MVN BIOMECH motion capture equipment and MVN Studio software. Participants completed a variety of experimental tasks, and different measurements were used to assess the accuracy of the MVN-based BoS. They showed that various tasks significantly affected the relative error of the BoS area, especially during squatting motions.

To our knowledge, the literature does not provide any research exploring the relationship between Xsens MVN Awinda and HTC Vive systems in terms of minimizing the positional drift. Therefore, in this study we aim to offer valuable insight into the prospective benefits of this integration, by investigating the positional drift under two conditions: performing an in-place repetitive motion, specifically a squatting task, and a repetitive walking-based task involving movement between specified landmarks.

II. Methods

A. Participants

This study included five healthy young participants (mean age: 23 ± 2 years) with no restrictions on physical activity and no recent self-reported musculoskeletal issues to avoid the effects of those impairments on the results. The experiments were approved by the Research and Publication Ethics Board of Bahcesehir University and performed at Bahcesehir University Biomedical Engineering Laboratory in Istanbul. All procedures were conformed to the Helsinki Declaration, and all the subjects provided their written consent.

B. Experimental Protocol

Before starting the experiment, we set up a 2.5 x 2.5 m square experimental area by placing the four base stations as shown in Fig.1. The Vive system requires that each one of the base stations to be within the range of all the others. The maximum range which can be covered by the four base stations is a 10 x 10 m square. The setup of this experimental area also included the placement of a 1 cm gridded A3 sized paper exactly at the middle. This paper serves as a reference for the feet positions while the subject performs an in-place task.

After setting up the area, the 17 Awinda IMUs are then placed on the subject at their respective body landmarks such as the head, shoulders, upper arms, forearms, hands, sternum, pelvis, upper legs, lower legs, and feet, while following the detailed instructions provided by the system's manual. Following the IMUs placement, the HTC Vive tracker is then placed on the lateral side of the right lower leg, specifically one-third from the ankle to the knee as instructed by the Awinda user manual. Afterwards, the subject's body dimensions are manually measured and entered into the MVN software prior to the initiation of the calibration process.

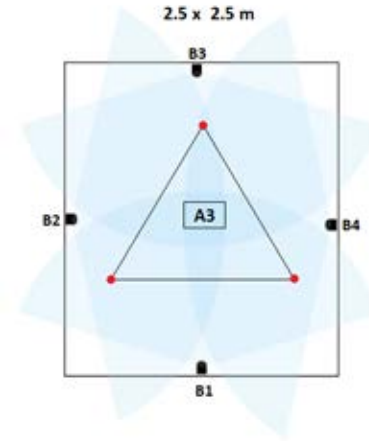


Fig. 1. The four VR Base stations combined to define a 2.5 by 2.5 m "play area" for the tracker. The three red dots construct the checkpoints on which the subject has to repetitively tap while walking. The rectangle placed in the middle represents the A3 paper used to mark the feet placement while performing the in-place task.

The final step before initiating the data collection is ensuring that the system is well calibrated. The MVN's calibration process includes standing still for three seconds in a upright static posture referred to as the N-pose [9], followed by two walking tasks, the first being used to calibrate the IMUs to segments placement, and the second is used to calibrate the Vive tracker with the MVN system. It should be noted that during the calibration process, the subject maintained the same foot position as indicated on the A3 paper that is placed on the ground.

C. Data collection

The reference or ground truth for all BoS-related measurements was determined by taking direct hand measurements of each participant's feet and footprints. Awinda's data were collected and saved using MVN Analyze in a proprietary file format (*.mvn) and later exported to ".c3d" format to be used in the Motion Kinematic and Kinetic Analyzer (Mokka, version 0.6) program. The feet landmarks position data were retrieved from the c3d files, more specifically the horizontal coordinates of the landmarks pLeftToe (LT), pLeftHeelCenter (LH), pRightToe (RT) and pRighttHeelCenter (RH). Those particular coordinates were used to define our BoS area.

In attempt to minimize the occurrence of unwanted drifts prior to data collection, at each recording, an axis reset was applied, followed by a calibration of the Vive tracker. For us to ideally compare the effect of the tracker integration, we only took the recording with the Vive tracker included, and later compared the data with the reprocessed recordings in which we eliminated the Vive integration through the software.

D. Designed tasks

The subjects were asked to perform two different experimental tasks that mainly focuses on lower body motion, and

one calibration task. The experimental tasks were designed as follows:

1) First task - In-place repetitive motion: In this task, each subject performed three sets of eight full-range squats on marked paper indicating initial and measured foot positions. An axis reset was done after each set to correct foot position drift. Markers were placed in MVN Analyze after each squat to compare the position shift with the original reference position.

2) Second task - Repetitive walking: In the second task, participants walked from a marked 'x,' tapping their right toe on it three times, then moved to the next 'x' and tapped once. The three 'x' points formed an equilateral triangle with 1.5 m sides. A lap was completed when returning to the starting point. Each participant did eight laps, with the first lap serving as the reference for toe position at each 'x'.

E. Statistical Analysis

For statistical analysis, we first conducted the Shapiro-Wilk test to determine the normality of the data distribution. For normally distributed data, we performed a repeated measures ANOVA to evaluate the effects of integrating the HTC Vive tracker on the positional drift in both the in-place and walking-based tasks. For non-normally distributed data, the Friedman test was employed to assess significant differences in positional drift. By setting the p-value at 0.05, we aimed to determine the impact of integrating the Vive tracker on minimizing the positional drift while considering both normal and non-normally distributed data. All tests were applied using the SPSS (IBM ® SPSS ® Statistics 25, IBM Corp., USA) software.

III. Results and Discussion

After data collection, the evaluation parameters of each tasks are then computed. The parameters used in the in-place drift quantification are the BoS centroid drift and the BoS area relative error (RE) which is calculated according to Eq. 1, as the percentage of change of the new area (NA) with respect to the original BoS area (OA) that is calculated manually on the A3 paper. It should be noted that the BoS in this study is defined as the area of the quadrilateral formed by the great toes and heels coordinates. As for the repetitive walking task, the euclidean distance between the right toe position and the checkpoints was calculated. All parameters were calculated using MATLAB (R2023a, MathWorks Inc.)

$$RE = \frac{NA - OA}{OA} \times 100\% \quad (1)$$

The graph shown below presents the centroid drift during the squatting task in both standing and bending phases, with and without the inclusion of the HTC Vive tracker.

Those findings indicate that the centroid positional drift was not affected by the Vive tracker's assistance in standing phase of this task (p=0.671). On the other hand, the centroid deviation presented a significant reduction during the squatting phase as the statistical test reported a significant difference after the removal of the tracker's assistance ($p = 0.003$). These

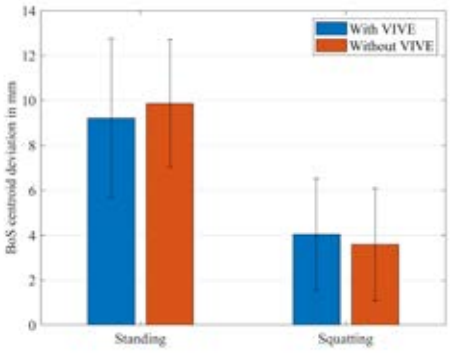


Fig. 2. Mean and standard deviation of the BoS centroid deviation during the two squat phases.The figure displays the results of both conditions with and without Vive assistance

results indicate that in this case the inclusion of the Vive tracker had an adverse effect on the quality of the Awinda's BoS estimation.

Another important parameter used is the RE. The calculated values of the RE during the squatting task are summarized in the Fig. 3 shown below.

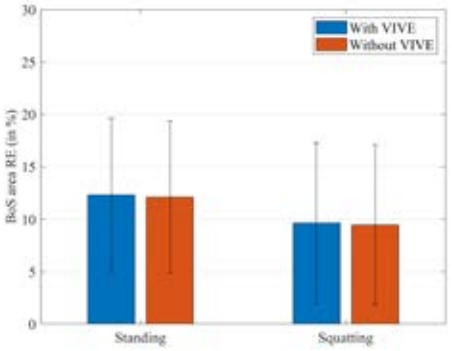


Fig. 3. Mean and standard deviation of the BoS RE during the two squat phases.The figure displays the results of both conditions with and without Vive assistance.

Similar to the results of the centroid, the RE revealed that the Vive tracker did not contribute to enhancing the BoS area change during squats. Conversely, those results indicated that the RE was significantly higher when the tracker was included ($p < 0.001$). In addition, those results highlighted another interesting finding, which is the fact the BoS RE and centroid deviation were significantly improved ($p < 0.001$) as the subject reached their maximum squatting position. A probable cause for such results could be attributed to Awinda's feet positioning algorithm that might tend to prioritize the joints mechanical restrictions over the data acquired through the external assistive data such as the ones received from the Vive tracker. Such an interesting finding requires further detailed investigation.

The final assessment section, takes into consideration the displacement of the person wearing the Awinda system along

with the Vive tracker. This assessment, as previously described, relies on calculating the euclidean distance between the right toe position and the checkpoints marked on the laboratory's floor. The results at each lap for all subjects combined are summarized in the figure below.

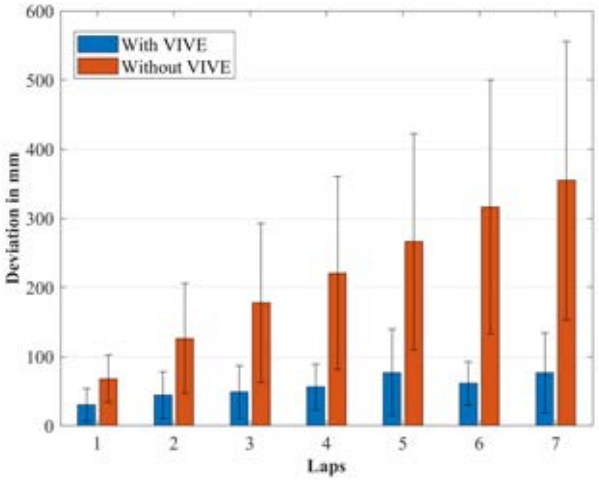


Fig. 4. Mean and standard deviation of the distance of from checkpoints after each lap.The figure displays the results of both conditions with and without Vive assistance

Those findings revealed that the positional error without the integration of the Vive tracker drastically increases with each lap and had an average of 218.64 mm, while on the other hand the Vive assisted positional tracking reveals a significantly lower positional error ($p < 0.001$) with an average of 56.27 mm. Although it is evident that at the 7^{th} lap the error has increased in comparison to the first few laps, it can still be considered to be within an acceptable range (less than 10 cm).

In addition, Fig. 5 presents the pattern drawn while subject 5 was performing 18 consecutive laps in which they step on floor marked checkpoints. The red dots shown in the plots indicate the location in which the subject repetitively tapped the 3 marked checkpoints, which displays the improvement provided by the integration the Vive tracker.

IV. Conclusion

In conclusion, the goal of this study was to evaluate the MVN Awinda motion capture system's positional accuracy after it was combined with an HTC Vive tracker. The results demonstrate the efficiency of this integration by showing a considerable decrease in location drift during dynamic tasks. But for static tasks, the findings revealed that the use of the tracker is not recommended. These results highlight the potential advantages of using the HTC Vive tracker in some motion capture tasks, but they also point to the necessity for more research into the variables affecting positional drift and an evaluation of various motion capture systems. Expanding studies on these areas can lead to improvements in human motion tracking.

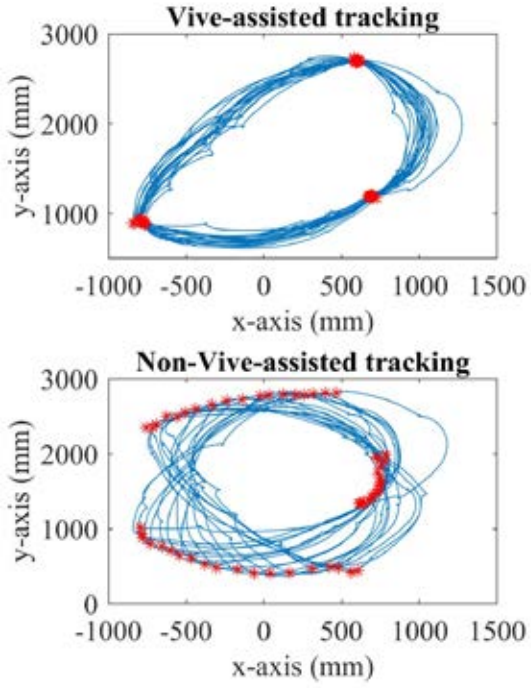


Fig. 5. The difference between a Vive-assisted tracking and a non-Vive-assisted tracking. The red dots indicate the locations in which the subject was tapping on the specified checkpoints.

Acknowledgment

This study was supported the Scientific and Technological Research Council of Turkey (TÜBITAK, Grants No: 121E655 and 119C180).

References

[1] L. Ni, "Application of motion tracking technology in movies, television production and photography using big data," *Soft Computing*, vol. 27, no. 17, pp. 12 787–12 806, 2023.
[2] A. Menache, *Understanding motion capture for computer animation and video games*. Morgan kaufmann, 2000.
[3] B. P. Ortega and J. M. J. Olmedo, "Application of motion capture technology for sport performance analysis," *Retos: nuevas tendencias en educación física, deporte y recreación*, no. 32, pp. 241–247, 2017.
[4] F. Rybnikár, I. Kačerová, P. Hořejší, and M. Šimon, "Ergonomics evaluation using motion capture technology—literature review," *Applied Sciences*, vol. 13, no. 1, p. 162, 2022.
[5] R. G. J. Damgrave and D. Lutters, "The drift of the xsens moven motion capturing suit during common movements in a working environment," in *Proceedings of the 19th CIRP Design Conference–Competitive Design*. Cranfield University Press, 2009.
[6] D. C. Niehorster, L. Li, and M. Lappe, "The accuracy and precision of position and orientation tracking in the htc vive virtual reality system for scientific research," *i-Perception*, vol. 8, no. 3, p. 2041669517708205, 2017.
[7] T. B. Tuli, M. Manns, and S. Zeller, "Human motion quality and accuracy measuring method for human–robot physical interactions," *Intelligent Service Robotics*, vol. 15, no. 4, pp. 503–512, 2022.
[8] L. Guo and S. Xiong, "Accuracy of base of support using an inertial sensor based motion capture system," *Sensors*, vol. 17, no. 9, p. 2091, 2017.
[9] "Xsens Knowledge base — base.xsens.com," https://base.xsens.com/s/article/HTC-Vive-Setup-Guide?language=en$_US$, $[Accessed 24-May-2024]$.