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Video-based Gait Analysis with IMU and Industrial Cameras: A Pilot Study

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***Abstract*—In this study, we investigated the validity of using a two-dimensional gait analysis system, which employed industrial cameras and a custom-developed Inertial Measurement Unit system, compared to the gold standard three-dimensional Vicon gait analysis system. Four subjects with a mean age of 26.76 (SD: 0.71) were included in the study, and gait data was collected from their 8 limbs. Correlation analyses examined the relationship between the data obtained from the two-dimensional gait analysis system and the three-dimensional Vicon system. The study's results showed a high correlation for the hip and knee joints between the two systems, but a lower correlation for the ankle joint. This pilot study demonstrated the potential of using industrial cameras and IMU systems for practical gait analysis.**

Keywords— Two-dimensional gait analysis system, Inertial Measurement Unit system, Industrial cameras.

I. Introduction

Gait is the most important activity of human beings, even though the number of steps has decreased today. Observational gait analysis is often used in clinics, but three-dimensional motion capture, a popular technique, is costly, immobile, complex, and data-limited [1]. It is also possible to perform gait analysis with video-based pose estimation using two-dimensional video captured from easily accessible devices (such as smartphones) [2,3]. However, a workflow for performing gait analysis from video is still missing, and further validation of video-based techniques using a dataset of human movement for various gait features requires stepwise progress [4]. Gait analysis system plays a crucial role in clinical and basic research; however, it is expensive and cumbersome. We aimed to find a more accessible and cost-effective system to obtain kinematic data for gait analysis.

II. Methods

A. Participants and Gait Analysis

Four subjects (mean age: 26.76, SD: 0.71) with 8 limbs were included in the study. For the 2-dimensional gait analysis system an industrial Basler camera (acA1440-220uc model, 50 Hz) and a custom-developed Inertial Measurement Unit (IMU) system were used to collect gait data from the subjects during walking. The developed IMU system was placed on the subjects and operated simultaneously with cameras and the gold standard 3-dimensional gait analysis systems (VICON,6x Vantage 5, UK) Retroreflective markers were attached to various anatomic landmarks using double-sided tape. Plug-in gait model [5] bilateral markers were located on the posterior superior iliac spine (SIPS) and anterior superior iliac spine (ASIS), distal 1/3 of the thigh, femur lateral epicondyle, distal 1/3 of the tibia, lateral malleolus, head of Ist metatarsal. (Figure 2)

Then, the patient is recorded in the sagittal plane simultaneously using a Basler camera in a suitable environment. The anatomical landmarks of joints were identified with spacial markers to process the them in recorded videos by open-source MATLAB (R2022) and TRACKER (6.0.x, 2022) softwares to collect the gait kinematic data (joint angles, linear velocity and acceleration, angular velocity and acceleration data) to propose the 2D linked-segment model of individuals.
Five markers were placed on the greater trochanter, lateral femoral epicondyle,calcaneus, lateral malleoli and first metatarsal .The patients were asked to walk as independently as possible. The coordinates of the lower extremity's joints (hip, knee, ankle) were collected in X and Y axes by TRACKER software in a specific walking cycle.These

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coordinates are transfered to an Excel file and the coordinates of the 5-point markers are read from Excel with MATLAB. After defining these points in MATLAB, 3 kinematic data (angle, angular velocity, and angular acceleration) are measured in all 3 joints in the sagittal plane using some formulas and their graphs are drawn (Figure 3). Each patient's 3 different leg data graphs are shown by referencing the average graph of healthy individuals. After obtaining these data, 2-dimensional modeling is done with MATLAB. Each individual's walking analysis data is reduced to an equal number of points and graphs showing the deviation of sick individuals from the average are drawn by referencing the data of healthy individuals. The graphs show the comparison of the data obtained with statistical methods in different phases of individuals' walking and all of them. The data obtained from the industrial cameras were processed using MATLAB and TRACKER applications.Synchronized data was collected and compared with the 3D gait analysis system.

B. Development of IMU Systems

The IMU system consists of a Raspberry Pi-based server and a total of 7 IMU units. The IMU units are composed of ESP8266MOD microcontrollers and 6-axis IMU sensors. The sensors transmit each unit's angular position data in three axises (X, Y, Z) and timestamp to the server using the Message Queuing Telemetry Transport (MQTT) protocol in JavaScript Object Notation (JSON) message format. The server design shares similar specifications with Yapakçı's industrial Internet of Things (IoT) server design, utilizing ThingsBoard, Node-Red, and Mosquitto software [6]. Additionally, our server can create its wireless network and functions as a DHCP server, providing IP addresses to connected devices. This way, while sharing the internet through its local network, the server can still access the internet via its Ethernet port. As a result, users can access both the system interface and database while maintaining an internet connection [7]. A Raspberry Pi is shown in Figure 1.

The IMU system is integrated with Internet of Things architecture which was built on a server infrastructure that enables the utilization of live sensor data alongside online image processing data, leading to the creation of a gait analysis system that can offer immediate visualization and fast analysis outcomes. This architecture embodies the convergence of IoT, sensor technology, and advanced data processing, with profound implications for biomechanical analysis and healthcare innovation.

Synchronized data was collected and compared with the 3D gait analysis system.

III. RESULTS

Correlation analyses were performed to examine whether the data obtained from the 2D gait analysis system we developed and the gold standard 3D gait analysis system showed changes in the gait cycle. According to the results, there is a high correlation between the hip and knee joints, but this is not the case for the ankle. According to the non-parametric Mann-Whitney U test after the Shapiro-Wilk normality test, the results were not significant in the hip ($p=0.726$), while the results were significant in the knee ($p=0.00001$) and ankle ($p=0.00036$).

This pilot study demonstrated the potential of using industrial cameras and IMU systems for gait analysis practically. We can obtain reliable data more quickly with the implementation of this method. Furthermore, we anticipate that further research in this area will enable clinicians to assess individuals who require gait analysis in a more practical and time-efficient manner.

There is a strong correlation found for the hip and knee joints between the IMU gait analysis system and the gold standard 3D system, suggesting that our IMU system accurately captures the movement patterns of hip and knee joints. However, as much as the ankle's correlation was found lower than other joints, it shows similarity with the literature [8].

IV. DISCUSSION

The proportion of participants in the study is its main limitation. A bigger sample size would boost the reliability of the results and provide more reliable statistical power. A smaller sample size may have an impact on the results because there is a greater chance of variability. To ensure that the results can accurately represent the general population, future research should strive to enlarge the number of participants and create a more diverse pool.

The IMU sensors' wired design was another drawback. In addition to adding hindrance to the subject's gait, wireless design may enhance the reliability of the results by allowing smoother walking to the subject and eliminating the risk of loose cable connections. The difficulty of precisely capturing the motion of ankle joints was another research limitation. Since the ankle is located in the distal portion of the leg, it can move faster and with more degrees of freedom than the hip and knee. Enhancing the sensitivity of the ankle sensor and performing more angular computations could potentially yield better results from the ankle sensor.



Figure 1. The Raspberry Pi that used as a server.

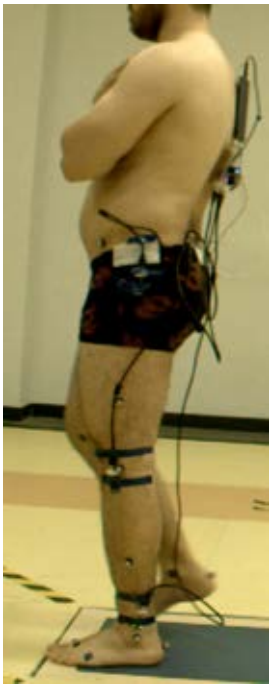


Figure 2. Placement of markers and sensor

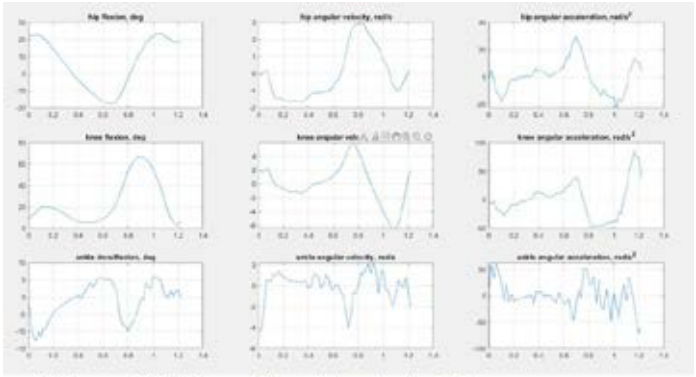


Figure 3.2d kinematic gait analysis data

REFERENCES

[1] Ye, M., Yang, C., Stankovic, V., Stankovic, L., & Kerr, A. (2016). A depth camera motion analysis framework for telerehabilitation: Motion capture and person-centric kinematics analysis. IEEE Journal of Selected Topics in Signal Processing, 10(5), 877-887.

[2] Springer, S., & Yogev Seligmann, G. (2016). Validity of the Kinect for gait assessment: A focused review. Sensors, 16(2), 194.

[3] Abdurrahman, M. R., Dirgantara, T., Mihradi, S., & Mahyuddin, A. I. (2014). Validity of Kinect for Assessment of Joint Motion during Gait. Applied Mechanics and Materials, 660, 921-926.

[4] Stenum, J., Hsu, M. M., Pantelyat, A. Y., & Roemmich, R. T. (2024). Clinical gait analysis using video-based pose estimation: multiple perspectives, clinical populations, and measuring change. PLOS Digital Health, 3(3), e0000467.

[5] Vicon®. (2002). Plug-in-gait modeling instructions. Vicon Manual, Vicon 612 Motion Systems.

[6] Yapakçı, B., Akdağcık, Z., Ayvaz, B., & Ergenç, A. F. (2023, October). Application of Process Mining to Production Lines Using Industrial Internet of Things. In 2023 IEEE 5th Eurasia Conference on IOT, Communication and Engineering (ECICE) (pp. 347-352). IEEE.

[7] Ayvaz, B., İlikçi, H., Bilgili, F., & Ergenç, A. F. (2023, October). IoT Networks and Online Image Processing in IMU-Based Gait Analysis. In International Conference on IoT and Health (pp. 162-177). Cham: Springer Nature Switzerland.

[8] Thomas, J.M., Kollock, R.O., 2022. The Reliability of Three-Dimensional Inertial Measurement Units in Capturing Lower-Body Joint Kinematics during Single-Leg Landing Tasks.