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Research Article

Wireless IMU-Based Orientation Control for Robotic Systems

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Abstract:

The study investigates the application of Wireless Inertial Measurement Unit (IMU) technology in enhancing the orientation control of robotic systems, specifically focusing on the Denso VP6242 serial robot. The research aims to accurately measure and control the roll, pitch, and yaw angles of the robot using the Xsens MTw wireless IMU, integrating the data with inverse position kinematics to achieve real-time orientation control. The methodology involves the calibration and integration of IMU sensors, data acquisition via Matlab scripts, and the real-time processing and transfer of data to the Simulink environment for simulation and experimental validation. Results from both simulations and laboratory tests confirm the effectiveness of the system in maintaining high precision and accuracy in the robot's movements, with minimal deviations in orientation angles. The study demonstrates the potential of wireless IMU technology to improve flexibility, mobility, and ease of installation in robotic systems, with applications extending across various fields such as industrial automation, healthcare, and autonomous navigation.

1. Introduction

Inertial Measurement Units (IMUs) are integral to applications ranging from consumer electronics to industrial automation. In mobile devices, they enable functions like screen rotation and geolocation, while in sports and health monitoring systems, they support movement analysis and activity tracking. IMUs are crucial in industrial automation for position tracking and control, as well as in spacecraft for determining position and orientation, playing a vital role in space exploration [1, 2].

In robotics, IMUs are essential for tasks such as motion tracking and orientation control, particularly in drones, UAVs, and mobile robots. Integrating IMU data with control systems to enhance robotic orientation accuracy and improve data processing methods is possible [3, 4]. The Xsens MTw system, a wireless IMU, represents advanced sensor technology, offering high-accuracy orientation data, real-time 3D motion tracking, and wireless communication protocols, making it ideal for applications in wearable technology and mobile robots [5-7].

IMU technology has evolved, becoming more compact, accurate, and integrated with AI and data processing algorithms, enhancing system mobility and flexibility [8]. The Xsens MTw system is widely used in fields such as motion analysis, sports performance tracking, and robot control, delivering reliable data even in dynamic environments [9]. Additionally, the advantages of wireless IMU technology over traditional wired systems contribute to effective robotic control methodologies [10, 11].

This research aims to utilize a wireless IMU to accurately measure and control a robot's orientation (roll, pitch, yaw) in real-time. By integrating IMU data with inverse kinematics, the study seeks to achieve precise and rapid orientation control in simulation and experimental environments. The transfer of data from the IMU sensor to the Simulink environment after real-time processing has been a problem for researchers. A solution to this problem has been proposed thanks to the methodology to be presented in this study. The verification process, which includes simulation and experimental studies, is intended to validate the proposed system's effectiveness through both simulation outcomes and laboratory-based investigations. Another secondary goal of this study is to demonstrate the contribution of wireless IMU technology to robotic control methodologies, specifically by enabling effective and adaptable position control mechanisms. The study aims to guide future applications by providing valuable insights for practitioners and researchers developing innovative solutions for precise spatial positioning. Experimental studies have been developed based on results from research conducted on the Denso VP6242 robot in the laboratory, with the aim of assessing and improving the performance of the wireless IMU in real-world applications.

2. Methodology

This study focuses on integrating the Xsens MTw wireless IMU with the Denso VP6242 robot to enhance real-time orientation control through data processing and simulation. Initially, the IMU sensors have been mounted away from the robot and calibrated using the MT Manager application or an already existing Matlab script to ensure accurate data acquisition. The Xsens MTw sensor has provided real-time orientation data, processed with advanced algorithms to reduce noise and improve accuracy. This data was then integrated into the robot's control system via Matlab Simulink, enabling precise orientation control.

Simulations have been conducted in Matlab Simulink to evaluate the impact of IMU data on robot performance. Real-world tests followed to validate the system's accuracy and reliability. A MATLAB script facilitated seamless data transfer to the Simulink environment, allowing real-time monitoring and adjusting of the robot's movements. Control algorithms, including PID, were used to maintain the desired orientations with high precision. Experimental studies in the Mechatronics Laboratory confirmed the effectiveness of this system, demonstrating the potential of wireless IMU technology for improving robotic orientation control.

2.1 Robotic System and Kinematics

The Denso VP6242 robot which is a six-axis serial manipulator is given in Fig. 1. Table 1 shows its Denavit Hartenberg (DH) parameters to derive the kinematics of the Denso robot arm. Known for its compact design, the robot features a load capacity of 2 kg, a reach of 432 mm, and repeatability within ±0.02 mm. The robot's kinematics were analyzed using forward and inverse kinematics, with the latter posing challenges due to the nonlinearity and interdependence of equations. Forward and inverse kinematics analysis of the Denso VP6242 robot can be examined in [12].

Figure 1. *Denso VP6242 robot.*

Table 1. *DH parameters of the Denso robotic arm.*

Joint i	θ_i	d_i	a_i	α_i
1	q_1	d_1	0	π/2
2	q_2	0	a_2	0
3	q_3	0	$-a_3$	-π/2
4	q_4	d_4	0	π/2
5	q_5	0	0	-π/2
6	q_6	d_6	0	0

where d_1 = 0.125m, a_2 =0.21m, a_3 =0.075m, d_4 = 0.21m and d_6 = 0.07m.

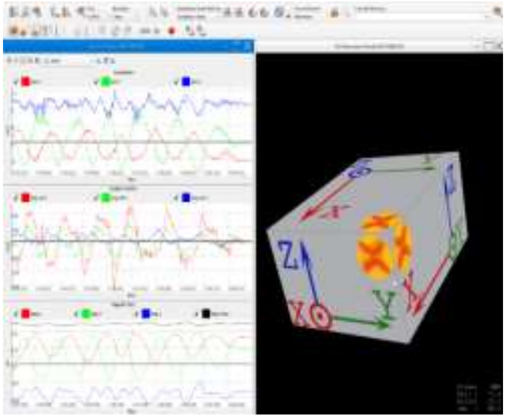
2.2 Integration of XSENS MTw with the Robot

The Xsens MTw sensor has been assembled away from the Denso VP6242 robot and has been ready to collect and process real-time orientation data. Calibration has been performed using the MT Manager application to minimize sensor error. The processed data, including roll, pitch, and yaw angles, have been integrated into the robot's control system via Matlab Simulink, allowing precise control. Simulations and real-world tests have assessed the impact of IMU data on robot performance, focusing on sensitivity, accuracy, and stability. The sensor and dongle are illustrated in Fig. 2.

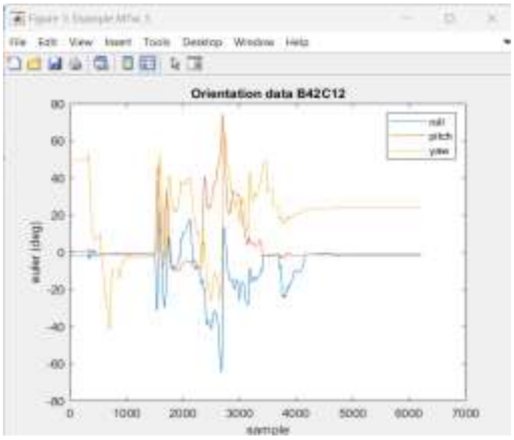
Figure 2. *IMU sensor and its dongle.*

2.3 Acquiring Orientation Data from Xsens MTw

Data from the Xsens MTw is processed using a software called MT Manager, a custom programming interface (API) as shown in Fig. 3 (a). Data can be recorded and saved in different formats. It is also possible to monitor the data via a Matlab script that is already available. It is given in Fig. 3(b). The sensor captures orientation data, which is transmitted wirelessly to a control unit at a configurable frequency. This data is processed using advanced filtering algorithms, like the Kalman filter, to enhance accuracy.



(a)



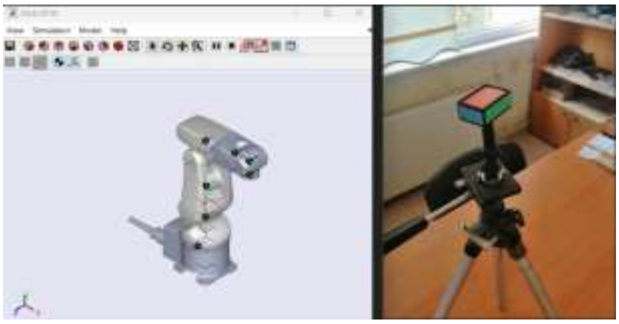
(b)

Figure 3. *Data monitoring via MT Manager and Matlab*

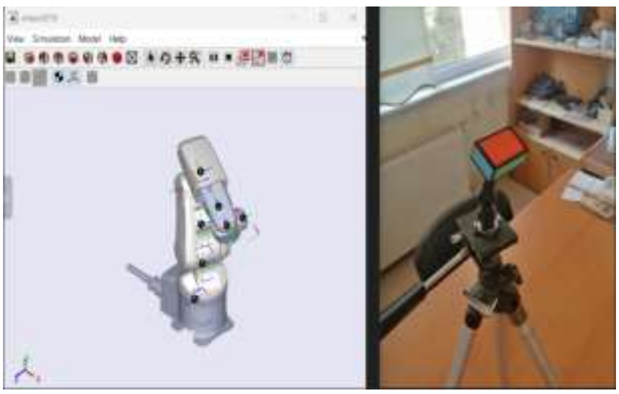
2.4 Transferring Data to MATLAB Simulink for Real-Time Processing

To control the robot within MATLAB Simulink, orientation data from the Xsens MTw is collected and processed in a MATLAB script. This data containing Euler angles (roll, pitch, yaw), is transferred in real-time to Simulink using the set_param command, updating specific blocks that served as inputs for inverse kinematics models. For instance, the command set_param("*****/Constant7", "Value", num2str(rolld)) updates the value of the block corresponding to the roll angle. Similar commands are also used to update the pitch and yaw angles, which are represented in the Simulink model as Constant blocks (Constant8, and Constant9) as depicted in Fig. 4. (*****) is the name of the Simulink model that the orientation angle is sent. The Simulink model, in turn, uses this data to control the robot's orientation. Fig. 5(a-d) depicts the robot's home position and various positions achieved through real-time data transfer in the Simulink simulation. The process ensured effective and flexible robot orientation control. Offline programming may be crucial in industrial operations to estimate the real scenarios [13]. Details of the Denso robot simulation can be analyzed in [14].

Figure 4. *Collecting data in Matlab script and transfer to Simulink Model*

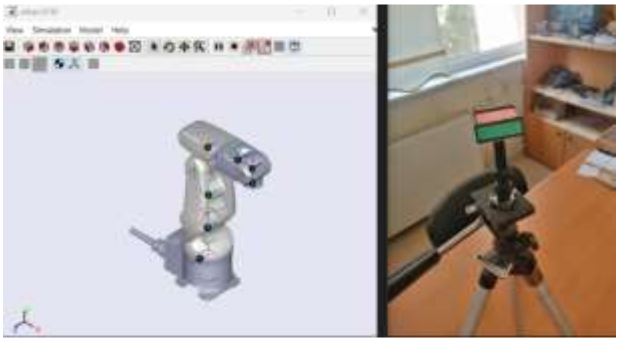


(a) Home position



(b)Roll angle

(c)Pitch angle



(d)Yaw angle

Figure 5. *Denso Robot simulation with XSENS signals by Matlab Simulink*

Since the yaw angle is located in the end effector, the yaw angle changes may not be clearly visible in the Fig. 5(d), but it can be observed in the experiments.

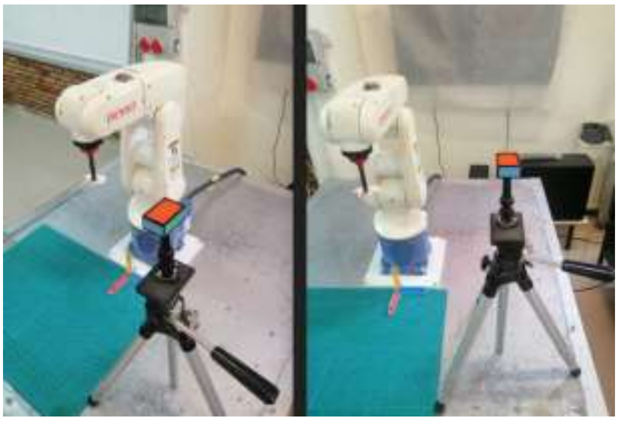
3. Experimental Studies

This section details the experimental studies conducted using the Denso VP6242 robot in the Mechatronics Laboratory of the Mechanical Engineering Department at Gaziantep University. The experiments aimed to test and verify the effectiveness of the developed control algorithms and system models.

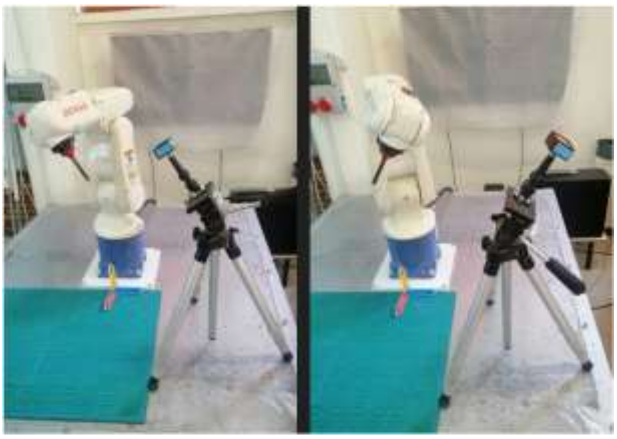
The experimental setup comprised the Denso VP6242 robot, a computer, the XSENS IMU sensor, and Quarc control software. A software platform based on MATLAB and Simulink was used to control the robot. The experiments were designed to assess the robot's performance in various orientations.

3.1 Test Procedure

The robot is initially placed in its home position, and the XSENS sensor is run, as shown in Fig. 6 (a). The sensor's movement data is continuously transmitted to the robot and fed into the Inverse Position Kinematics (IPK) model as inputs for the orientation angles (roll, pitch, yaw). This data is used to calculate the rotation matrix, and the robot's movements are observed across different orientations. For each test scenario, specific target orientations are set, and the robot's accuracy in reaching these targets is examined, as illustrated in Fig. 6(b-d). To enhance the visualization and understanding of the robot's motions, an apparatus measuring 9.8 mm has been attached to the end-effector, necessitating an additional transformation matrix to accurately express the new end-effector position.



(a) Home Position



(b) Roll Angles

(c) Pitch Angles

(d) Yaw Angles

Figure 6. *Experimental Studies with Denso Robot and IMU*

3.2 Experimental Results

The experimental studies have demonstrated that the Denso robot could reach the designated target positions and orientations with high accuracy. The developed control algorithms have effectively managed the robot's movements, exhibiting strong performance in achieving the set goals. The deviations in roll, pitch, and yaw angles, which are controlled using IMU data, were minimal, showing a high degree of compliance with the desired values. These findings confirm the effectiveness and reliability of the proposed system. Consequently, the experimental studies with the Denso robot have successfully validated the developed technique, illustrating its potential for use in robotic control applications.

4. Discussion and Conclusion

This study has focused on enhancing the orientation control of the Denso VP6242 robot using the XSENS MTw wireless IMU. Key findings revealed that the XSENS MTw provided precise orientation control effectively via integration into the robot control system via Matlab and Simulink. Simulations have closely matched experimental results, affirming the model's accuracy. However, challenges like data transmission delays and potential signal loss due to the wireless setup were noted, which could affect performance. This issue can be eliminated with a faster computer system.

Future research can address these limitations by exploring more complex tasks with multiple IMUs, developing sensor fusion techniques, and conducting broader tests in industrial settings. These findings underscore the potential of wireless IMUs for robotic orientation control, offering a solid foundation for further exploration.

The proposed system has diverse potential applications, including industrial automation, healthcare, autonomous transport, and research. In healthcare, it could support patient rehabilitation by accurately tracking movements. The system could also guide autonomous vehicles in logistics and be used in virtual reality or harsh environments like mining and space exploration.

The study demonstrated that real-time control is achievable, with the robot performing tasks with precision and accuracy using IMU data. The successful integration of wireless IMUs into robotic systems and the application of real-time data processing algorithms provide valuable insights for future research.

The study contributed significantly to the field by integrating wireless IMU sensors with a serial robot arm, specifically data transfer from the XSENS MTw to the Simulink environment. The results showed that IMU data could greatly enhance precision in robotic orientation control, providing a reliable example for future applications. The experimental validation further strengthened the study’s applicability.

Future research could explore advanced sensor fusion techniques, AI-based control algorithms, and optimization methods to enhance real-time performance. Testing different robot models, improving system robustness, and developing user-friendly interfaces could broaden the system's applications, contributing to innovations in robotic control.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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