MIMICKING HUMANOID ROBOT GAIT USING HUMAN MOTION DATA FROM IMU

EMANUEL MUNTEAN[1], MONICA LEBA[2]

Abstract: This paper presents a new method for mimicking the gait of a humanoid robot using data obtained from Inertial Measurement Unit (IMU) sensors placed on a human body. The proposed framework benefits from the capabilities of IMU sensors to capture detailed motion data, including acceleration and angular velocity from various parts of the human body. The IMU sensors are strategically placed on the both feet to ensure comprehensive gait analysis. The collected data is processed using 2 Arduino UNO that send PWM signals to control the robot's Servo Motors in order to replicate human-like walking patterns. The methodology involves several key steps: data acquisition, preprocessing, feature extraction, and gait synthesis. During data acquisition, IMU sensors record the human subject's gait in real-time. The effectiveness of the proposed method is validated through a series of experiments, where the humanoid robot successfully mimics the human gait on flat surfaces. The results demonstrate that the IMU-based gait imitation framework achieves high fidelity in replicating human walking patterns, offering significant improvements in the robot's stability and adaptability. This research contributes to the field of humanoid robotics by providing a robust and efficient approach to gait imitation, with potential applications in rehabilitation, assistive robotics, and human-robot interaction. Future work will focus on refining the control algorithms and exploring the integration of additional sensory data to further enhance the robot's gait performance.

Key words: Humanoid robot, IMU sensors, gait imitation, signal processing, gait analysis, human-robot interaction.

1. INTRODUCTION

In recent years, the field of humanoid robotics has seen significant advancements, particularly in the development of bipedal locomotion systems. Mimicking human gait in humanoid robots is a complex task that requires precise control and coordination of multiple joints and actuators. This paper presents a new method to replicate the gait of a bipedal humanoid robot using data from four IMU sensors strategically placed on the human's legs. Specifically, two IMU sensors are mounted on the thigh and tibia of each leg, providing comprehensive motion data. The IMU sensors capture critical gait parameters such as acceleration, angular velocity, and orientation, which are essential for accurate gait analysis and replication. The data collected from

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these sensors are processed by two Arduino Uno microcontrollers, which serve as the central processing units for the system. The Arduino Uno microcontrollers analyze the sensor data in real-time and generate control signals for the servomotors. To achieve precise control of the servomotors, the system employs two PCA9685 16-channel 12-bit PWM Servo Drivers. These drivers are capable of controlling up to 16 servomotors each, allowing for scalable and flexible motor control. In this setup, four servomotors are used to actuate the joints of the humanoid robot, enabling it to perform bipedal walking motions.

The integration of IMU sensors with Arduino microcontrollers and PCA9685 servo drivers provides a robust and cost-effective solution for humanoid gait replication. This method not only enhances the robot's ability to navigate complex environments but also improves its interaction with human tools and surroundings. The proposed system demonstrates the potential for advanced humanoid robots to achieve more natural and efficient bipedal locomotion, paving the way for future developments in humanoid robotics.

This paper will detail the design, implementation, and testing of the proposed gait replication system, highlighting the advantages and challenges associated with using IMU sensors and Arduino-based control for humanoid robots.

2. LITERATURE REVIEW

The main focus of paper [1] is to generate stable gaits for small-sized humanoid robots using geometric methods for kinematic analysis. The paper employs a 3D linear inverted pendulum model to determine the trajectory of the robot's center of mass, which, combined with foot positions, is used to solve the Denavit-Hartenberg (D-H) matrix. The goal is to find a computationally efficient solution to the inverse kinematics problem, enabling the robot to walk forward, turn left, and turn right in a stable manner. The paper also discusses the implementation and testing of these gaits on a 17-degree-of-freedom humanoid robot named TONY.

Paper [2] is focused on overcoming the sim2real gap for humanoid robots, specifically the HRP-5P humanoid robot, by utilizing current feedback from actuators and training policies in a simulation environment with degraded torque-tracking. The authors propose a method to address the discrepancies between simulated and real-world environments, which often result in poor performance when transferring policies trained in simulation to real hardware. They achieve this by simulating poor torque-tracking during training and incorporating current feedback from the actuators into the observation space of the reinforcement learning policy. This approach allows the policy to compensate for inaccuracies in torque application, leading to successful deployment of bipedal locomotion policies on the real HRP-5P robot.

The work [3] presents an intelligent motion attitude control algorithm for humanoid robots. This algorithm leverages deep reinforcement learning (DRL) to address issues related to the precision of motion manipulation control and the balance of humanoid robots. The paper proposes an offline pre-training approach for the attitude controller using an identification model as prior knowledge, which helps to overcome the challenges of limited physical training samples and low training efficiency. The effectiveness of the proposed intelligent attitude controller is demonstrated through experiments, showing significant improvements in tracking accuracy and stability compared to traditional control methods like PID, PID + MPC, and MPC + DOB controllers.

Paper [4] improves the walking behavior of a humanoid robot to enable it to walk faster while ensuring safety during the learning process. The paper proposes the use of Safe Reinforcement Learning (Safe RL), specifically the Policy Reuse for Safe Reinforcement Learning (PR-SRL) algorithm, which leverages a safe baseline policy to guide the learning process. This approach aims to achieve fast convergence to near-optimal walking policies while minimizing the risk of falls and potential damage to the robot during training.

Authors of [5] propose and analyze robust control strategies for different models of the linear inverted pendulum, which represent the upper, middle, and lower body of a bipedal walking robot. The paper investigates the performance of one mass, two masses, and three masses linear inverted pendulum models in terms of stability, noise rejection, and set-point tracking to the zero-moment point (ZMP). The study aims to improve the stability and control of bipedal walking robots by using robust control methods and comparing the effectiveness of these models through simulations and experimental setups using an Arduino microcontroller and MATLAB Simulink system.

Paper [6] proposes a trajectory-planning method for biped robots that enhances walking stability and flexibility. The method combines the Linear Inverted Pendulum Model (LIPM) for the Single Support Phase (SSP) and the Linear Pendulum Model (LPM) for the Double Support Phase (DSP). The paper addresses the limitations of existing models that often ignore the DSP, leading to discontinuities in the acceleration of the center of mass (CoM) and negatively impacting walking stability. By incorporating both LIPM and LPM, the proposed method aims to achieve smoother CoM acceleration transitions, improve walking stability, and enable real-time trajectory planning for various walking scenarios, including periodic walking, speed adjustments, disturbance recovery, and walking on uneven terrain.

The work [7] analyzes and compares the optimal control of the zero-moment point (ZMP) for a bipedal walking robot. The study involves both experimental and theoretical approaches to determine the ZMP during the single support phase of the robot's gait cycle. The research utilizes a 17 degrees of freedom bipedal robot made of hard aluminum sheets and employs MATLAB Simulink for simulation. The paper aims to achieve optimal balance control by minimizing the performance index through optimal feedback control gains, and it discusses the principles of ZMP, the methodology for measuring ZMP, and the application of optimal control methods to ensure the stability of the bipedal robot.

Paper [8] is developing a dynamic gait planning method for the NAO humanoid robot to effectively climb and descend stairs. The method involves modeling the NAO robot's kinematics, analyzing its gait characteristics, and planning its movements using a first-order linear inverted pendulum model. The paper also introduces the zero-moment point (ZMP) stability judgment and supporting polygons control to ensure the robot's stability during stair navigation. The feasibility of the proposed gait planning method is verified through simulations and real-world experiments using the Webots platform and the NAO robot.

The work [9] proposes an improved model predictive control (MPC) method incorporating an extended Kalman filter (EKF) to enhance the robustness of humanoid robots' walking capabilities by using a simplified finite-sized foot-pendulum model for gait planning in both single-support and double-support phases, ensuring the robot's center of mass (CoM) converges to the divergent component of motion (DCM), thereby simplifying feedback control and enabling the robot to adjust its step duration to compensate for CoM trajectory errors caused by disturbances, as demonstrated through simulations on flat surfaces, under impact disturbances, and on uneven terrain.

Authors of [10] develop a highly efficient motion planner that generates stable center-of-mass (CoM) trajectories for legged robots, specifically for walking, running, and jumping motions, by leveraging the 3D-Divergent Component of Motion (3D-DCM) framework, which was previously used for walking, and extending its application to include running and jumping; the key contributions of the paper include: introducing a unified formulation for the CoM and DCM waypoints at the start and end of each motion phase, making the framework extensible and enabling efficient waypoint computation, proposing a highly efficient algorithm for computing DCM and CoM waypoints for a general sequence of motion phases, including stance, flight, and transition phases, implementing transitions between different modes of motion (standing, walking, running, and jumping) within the 3D-DCM framework, and demonstrating the feasibility of the generated reference trajectories through extensive whole-body simulations with the humanoid robot TORO, aiming to show that the 3D-DCM framework retains its validity and coherence during flight phases and can be used for planning complex locomotion tasks involving arbitrary contact sequences and time parametrizations.

Research from [11] improves the fast and stable walking ability of humanoid robots by proposing a gait optimization method using a Parallel Comprehensive Learning Particle Swarm Optimizer (PCLPSO) algorithm, with key aspects including the selection of key parameters affecting walking gait based on the natural zero-moment point (ZMP) trajectory planning method, decomposing gait training tasks in a parallel distributed multi-robot environment using the RoboCup3D simulation platform, employing a layered learning approach to enhance turning ability, and experimentally validating that the PCLPSO algorithm achieves quick, optimal solutions for a fast, steady gait and flexible steering, emphasizing the use of intelligent algorithms to balance speed, stability, and flexibility in humanoid robot walking.

In paper [12] is developed a robust and efficient gait controller for the humanoid robot NAO by integrating a Particle Swarm Optimization (PSO) technique with a Proportional-Integral-Derivative (PID) controller to enhance the robot's stability and navigation capabilities [13], emphasizing gait planning and stability using the Linear Inverted Pendulum Model (LIPM), implementing a PSO-tuned PID controller to optimize the parameters for better obstacle avoidance and stability, validating the approach through simulations and real-world experiments, and demonstrating through comparative analysis that the PSO-tuned PID controller significantly outperforms other techniques in terms of stability and efficiency.

3. MATERIALS AND METHODS

To develop a method to imitate the walking of a bipedal humanoid robot, we used a robot created by Youbionic [Figure 1], 3D printed from PetG material. The robot, named Ionut, has the appearance of a kindergarten child but with the personality of a teenager. He is 110 cm tall and weighs around 40 kg. The robot is equipped with various servomotors, which allows it to easily perform various tasks, including walking on a straight surface, at the request of the user. We focused on making the movement on both legs of the robot.

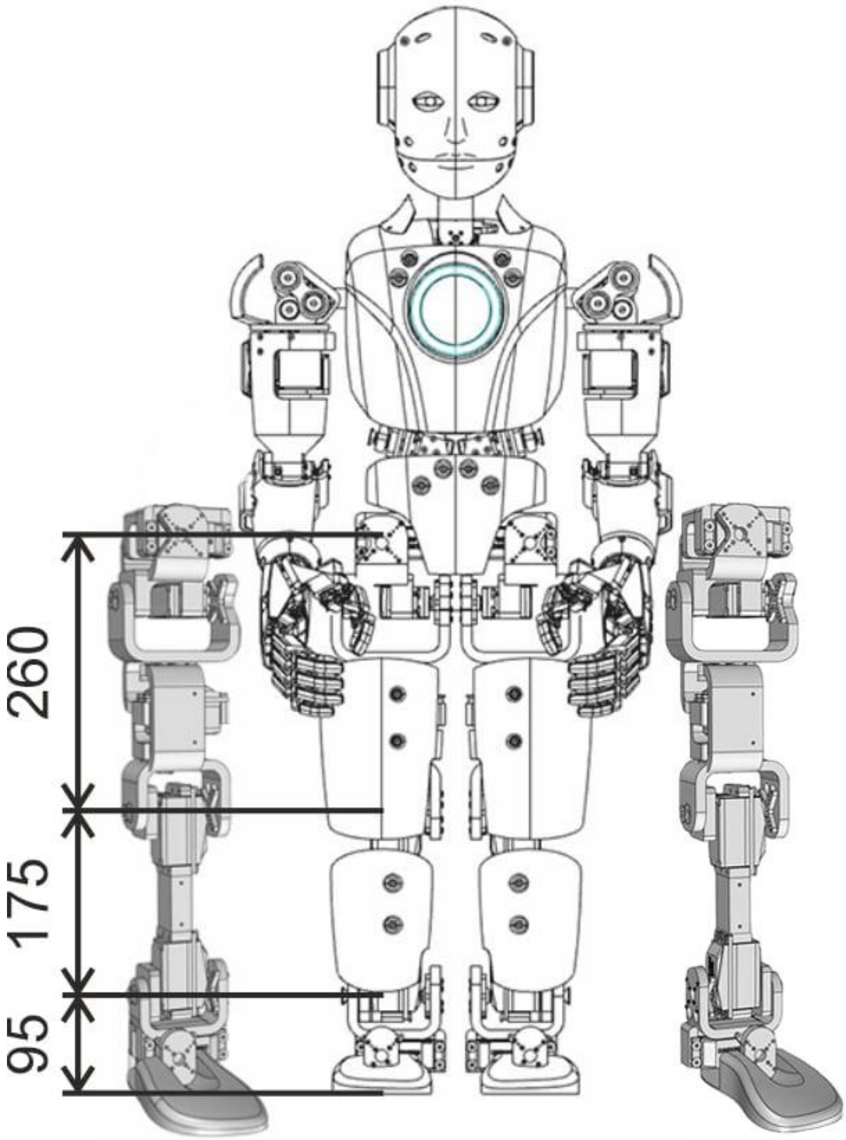

Fig.1. Humanoid robot scheme with accent on both legs (reproduced with written approval from Youbionic)

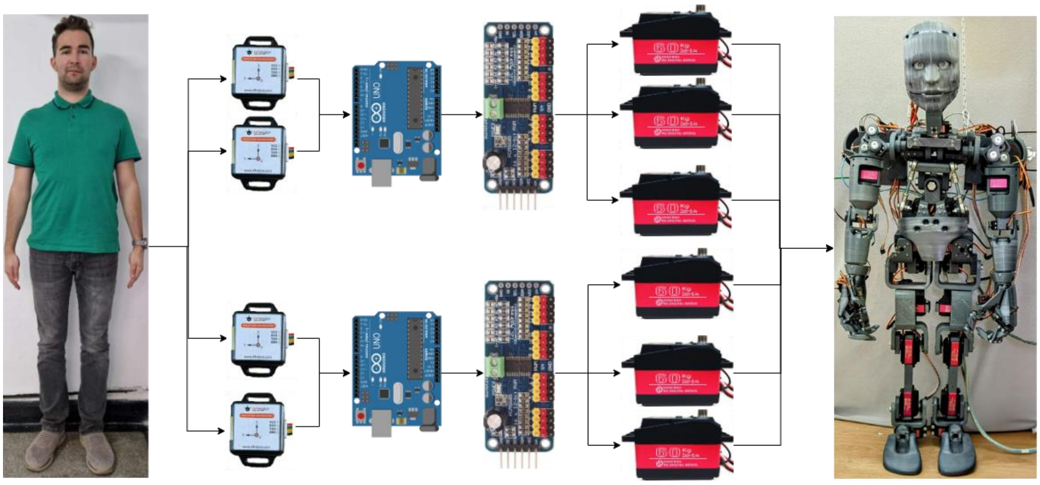

Fig.2. Hardware Block Diagram of the humanoid robot legs control system

To build the physical system, we used four IMU [14] sensors distributed two on each leg, located on the calf and leg bone. As the main microcontrollers, we used two independent Arduino UNO boards, along with two PCA9685 PWM motor drivers and six servo motors, each capable of a power of 60 kg depending on the received supply voltage, as seen in Figure 2.

4. EXPERIMENTAL RESULTS

To improve lower limb coordination during walking you have to stand tall with good posture by keeping the head up, eyes forward, shoulders back and down, and core engaged; start with a heel-to-toe step, striking the ground with the heel first, rolling through to the toes and pushing off to start the next step; take appropriately sized steps, avoiding overly long strides and letting the back leg provide power; keep the hips level to avoid swaying side-to-side; swing arms naturally in opposition to the legs with slightly bent elbows; maintain a steady rhythm with evenly timed steps at a comfortable pace; practice on different surfaces, starting on flat ground and progressing to uneven terrain; focus on balance by keeping the body centered.

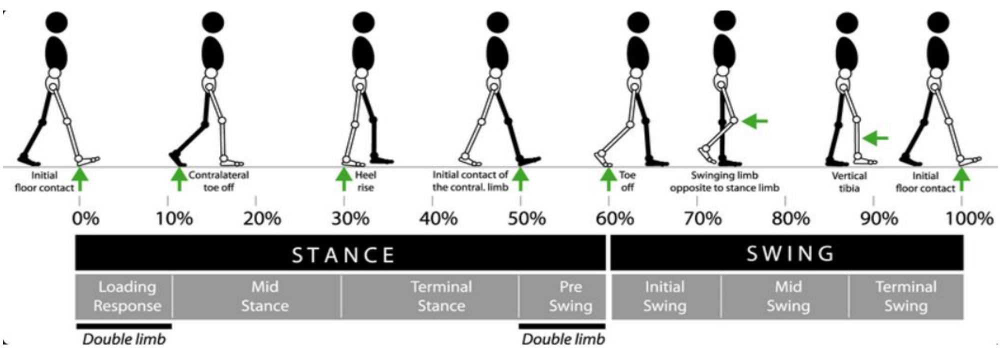

Fig.3. How to make a step [15]

In humans’ case, bipedalism is a mode of terrestrial locomotion in which an organism moves using its two hind limbs or legs. This is a distinctive feature of the human species and its ancestors, which involves walking and running on two legs. To realize a locomotion of the biped robot, we used four IMU sensors, two placed on each leg. We started the first movement with the right foot, focusing on the X-axis. In Figure 4 the left leg serves as the pivot. In this image, a flexion/extension movement is observed: the yellow line represents the sensor located on the knee, which indicates an angle of about 90 degrees and the purple line corresponds to the sensor on the hip leg, which shows an angle of about 40 degrees then when the right leg is tense. The gray and blue lines represent the Y-axis, with values between 0 and 5 degrees. The pivot leg in this case is represented by left leg and the yellow line is 95 degrees, the purple line 90 degrees and the gray and blue line has 0 and 5 degrees.

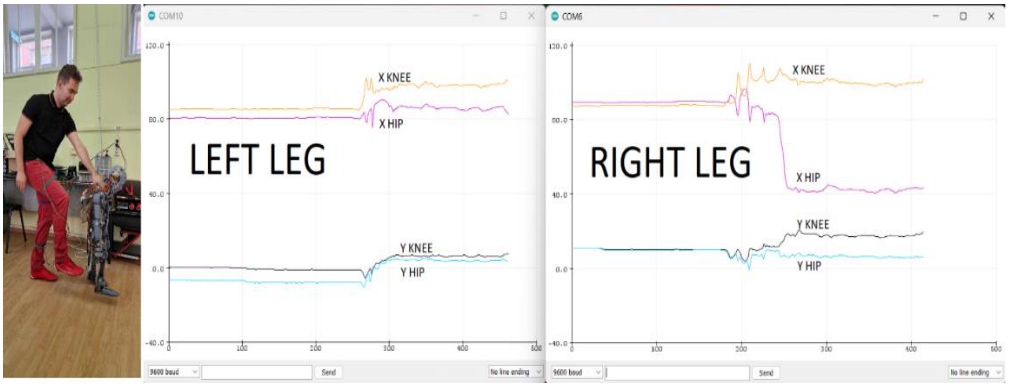

Fig.4. Left leg pivot position and right leg raised

In Figure 5 the left leg is ready to perform the movement on the X axis. The yellow line represents the sensor located on the knee, which indicates an angle of approximately 95 degrees, and the purple line corresponds to the sensor on the hip leg, which indicates an angle of approximately 80 degrees when the right leg is support for movement. The gray and blue lines represent the Y-axis, with values between 0 and -10 degrees. The pivot leg in this case is represented by right leg and the yellow line is 100 degrees, the purple line 80 degrees and the gray and blue line has 5 and 0 degrees.

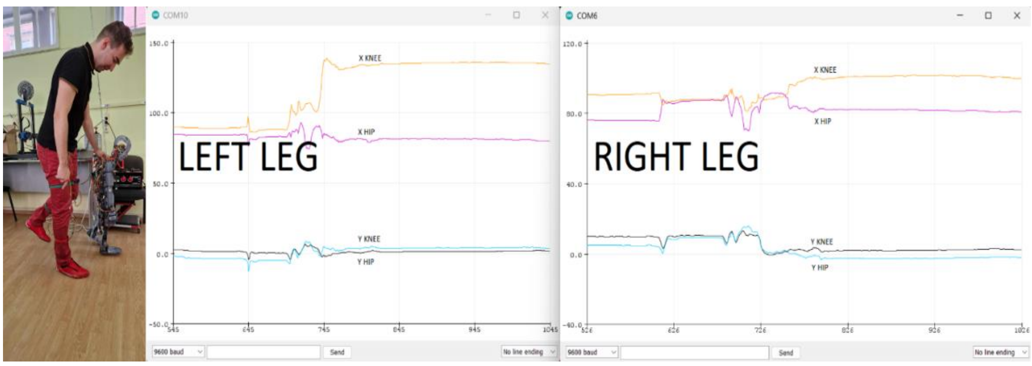

Fig.5. The right leg pivot and the left foot perform the movement

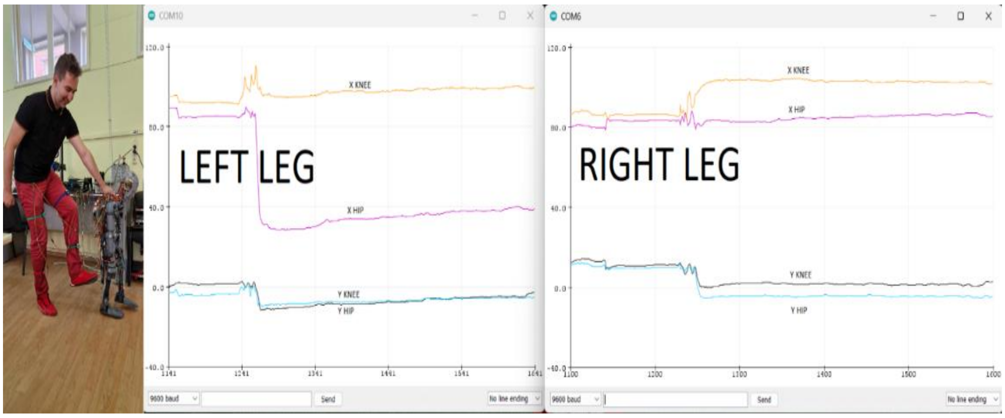

Fig.6. Right leg pivot position and left leg raised

Finally, I finished the movement with the right leg according to Figure 6 as the pivot and the left leg making the final movement on the X axis. The yellow line represents the sensor located on the knee, which indicates an angle of approximately 90 degrees and the purple line corresponds to the sensor on the hip leg, which indicates an angle of approximately 40 degrees.

The gray and blue lines represent the Y-axis, with values between 0 and -10 degrees. The pivot leg in this case is represented by right leg and the yellow line at the shin of 95 degrees, the purple line 90 degrees and the gray and blue line has 5 and - 5 degrees.

5. CONCLUSIONS

In this paper, we have presented a new method for mimicking the gait of a bipedal humanoid robot using data from four IMU sensors strategically placed on the robot's legs. By positioning two IMU sensors on the thigh and tibia of each leg, we were able to capture detailed motion data essential for accurate gait analysis.

The data collected from these sensors were processed in real-time by two Arduino Uno microcontrollers, which generated the necessary control signals for the servomotors.

Our experimental results demonstrate that the proposed system can successfully replicate the gait of a bipedal humanoid robot, enabling it to navigate complex environments and interact more naturally with its surroundings.

This method not only enhances the robot's mobility but also opens up new possibilities for its application in various fields, including assistive robotics, human-robot interaction, and autonomous navigation. While the current system shows promising results, there are still challenges to be addressed, such as improving the robustness of the gait under different terrains and conditions, and optimizing the real-time processing capabilities of the microcontrollers.

Future work will focus on refining the control algorithms, integrating additional sensors for enhanced feedback, and exploring machine learning techniques to further improve the robot's gait adaptation and performance.

In conclusion, the proposed method provides a solid foundation for advancing bipedal locomotion in humanoid robots, contributing to the ongoing development of more capable and versatile robotic systems. The insights gained from this research will be instrumental in driving future innovations in the field of humanoid robotics.

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