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Adjusting the Movements of the Robotic Platform Through Inverse Kinematics

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***Abstract*— The paper presents an approach to the development of a control system for a quadruped robotic platform using inverse kinematics. The solution enables accurate movement of the robot's legs to achieve stable motion and balancing under uncertain terrain conditions. The kinematic model is calculated using FreeCAD tools and implemented in a control code through the transformation of joint angles into PWM signals for servo drives. A simulation model in MATLAB Simulink was created to test the stabilization algorithm. The obtained results demonstrate the ability of the system to correct the robot's posture and maintain balance in real time, even under significant external disturbances.**

Keywords*— *Quadruped Robot, Inverse Kinematics, PID Control, MATLAB Simulink, Robotic Balance, Freecad Simulation, Robotics, Industry 5.0.

I. Introduction

Research in the field of robotics is one of the promising areas in the development of mobile robots aimed at timely and successful implementation of search operations in various potentially dangerous and unfavorable conditions for people, such as heterogeneous disasters, natural disasters, incidents of local or individual scale, etc. [1].

Currently, the number of robots designed to search for victims of natural and man-made disasters is growing sharply. Basically, such are based on the need to overcome obstacles for which rescuers, search animals and flying drones would be less effective [2]. Very often, such robots are based on methods of movement from both living creatures and mechanisms already created in the past. It is also important to note the growing popularity of collaborative robots that are designed to ensure human safety in the working area of robots [3]. Thus, in the context of the growing demand for autonomous and stable mobile platforms, algorithms that ensure precise positioning of robot limbs and adaptation to environmental changes are of particular importance [4]. The use of inverse kinematics allows not only to implement movement in a complex environment, but also to create the prerequisites for the implementation of balancing algorithms that contribute to increasing the efficiency of the mobile platform.

II. Platform adjustment

To facilitate users in moving the end member of the robot limbs to specific positions, geometric measurements and the inverse kinematics method [5-8] are required. This method uses input position coordinates in the form of X, Y, and Z. The output of inverse kinematics is the angle formed at the joint.

In Figure 1 (where the initial values measured by FreeCAD tools for calculating inverse kinematics are listed in Table 1), the quadruped robot has 3 joints on each leg. The angle is formed by the joint, i.e. there is a pelvic angle (A_0), a thigh angle (A_1), and a lower leg angle (A_2).

In the control code itself, the values of these angles are converted into PWM values to move the servo via the servo driver.

The inverse kinematic functions, which will be used for calculations, require the input of the X, Y, and Z coordinate axes in the following form: the X axis represents the robot's forward and backward movements, the Y axis represents the robot's right and left movements, and the Z axis represents the robot's up and down movements.

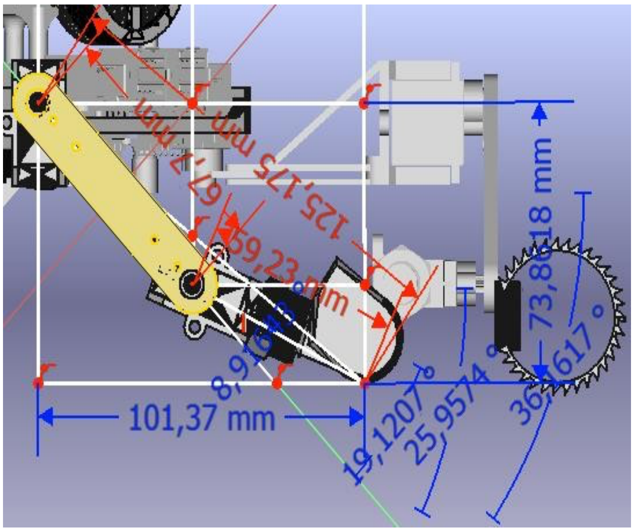

Figure 1. Side view of the plane common to the hip and shin joints of the robot leg, which regulate the platform inclinations

TABLE I. Initial values measured in FreeCAD

Specification	Marking	Value
Length of the first leg link	L_0	91 mm
Length of the second leg link	L_1	67.7 mm
Length of the third leg link	L_2	59.2 mm
The first leg of a right triangle with the hypotenuse from the joint point A_0 to the edge point of the step in a vertical view	X	30.9 mm
The second leg of a right triangle with the hypotenuse from the joint point A_0 to the edge point of the step in a vertical view	Y	121.1 mm
Default second joint tilt	A_1	45°
Default third joint tilt	A_2	25°

First, the values of the coordinates X Y and Z are placed. To get all three angles at the joint, it uses an algebra and geometry approach. The first calculation is to find the value of the pelvis angle (A_0):

$$A0 = arctan(\frac{Y}{X}) = 75° \quad (1)$$

Next, the values of the resulting quantities X and Y are found using the equation:

$$\overline{XY} = \sqrt{X^2 + Y^2} \quad (2)$$

The calculations use the displacement L_0 – the distance from the pelvic joint to the femoral joint, i.e. the length of the first leg link.

The following calculations contain the values of R and Z that are necessary for the equations for finding the updated values of the angles A_1 and A_2 in the balancing and stabilizing corrections:

$$Z = L1 * sin(A1) + L2 * sin(A1 + A2) \quad (3)$$

$$R = \overline{XY} - L_0 \quad (4)$$

R can also be found by the equation:

$$R = L1 * cos(A1) + L2 * cos(A1 + A2) \quad (5)$$

According to the simplifications of calculations from the source [36], to implement adjustments, the hip and shin angles are calculated using the following formulas:

$$\mathrm{A1} = \arctan(\frac{Z}{R}) - \arctan \frac{l_2 \sin(A_2)}{l_1 + l_2 \cos(A_2)} \quad (6)$$

$$A2 = arccos\left(\frac{R^2+Z^2-L_1^2-L_2^2}{2L_1L_2}\right) \quad (7)$$

III. Development of a Control System for Balancing

To implement calculation formulas into the robot control code, it is necessary to develop an application part for applying the calculations.

Figure 2 shows a simplified representation of the balancing system using a block system in MATLAB SIMULINK.

The virtual block system includes:

– sinusoidal-noise generator of extreme tilt values from the gyroscope along the X and Z axes each, approximately from (-55)° to 55°;

– exponential filters to remove noise from signals entering the assembly with target zero slope values for further verification;

– block of the algorithm for selecting stabilization actions relative to current slopes;

– blocks for selecting the initial values of the degrees of the correction angles relative to the commands from the stabilization algorithm;

– PID controllers that are configured for the system and provide the degree values of the correction angles to the limiter values from (-60)° to 60°, which then provide the correction values to the summation over the data stream of the slopes being checked;

– displays of values of initial influence slopes, correction slopes and result slopes.

Figure 3 shows the parameters of PID controllers. Figure 4 shows the algorithm of actions for each of the iterations of calling the robot balancing subsystem. Figures 5-7 show the results of the block system simulation in the form of graphs. teams capable of self-organization, adaptation and effective interaction with humans and other technical agents.

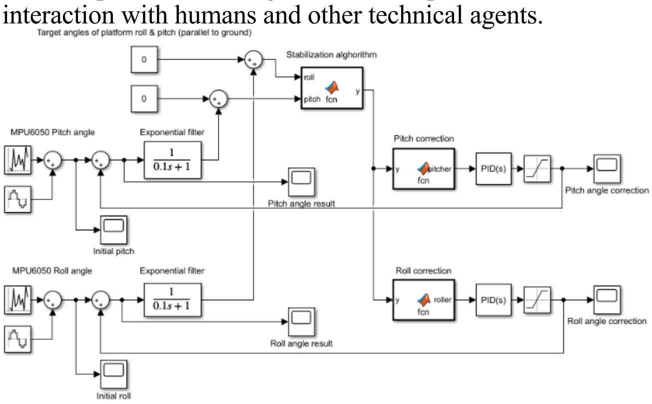

Figure 2. Balancing block system

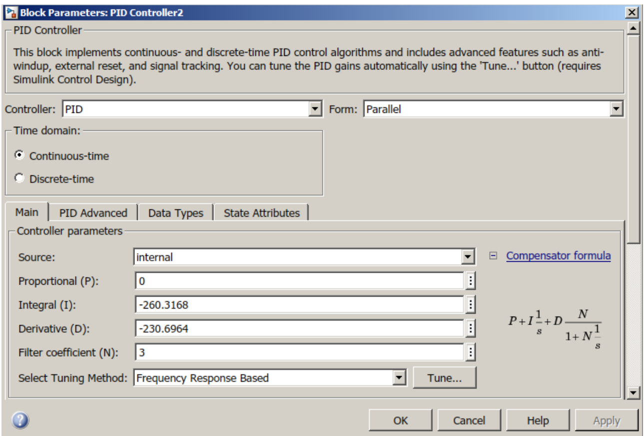

Figure 3. Results of PID controller tuning

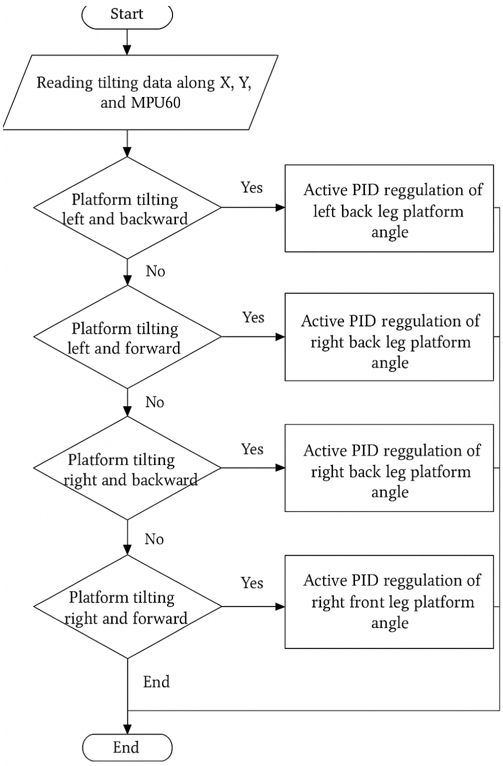

Figure 4. Developed balancing algorithm

The algorithm is designed to stabilize a platform using PID control based on tilt data received from an MPU60 sensor along the X and Y axes. It continuously reads the tilt data and determines the direction of the tilt. Depending on the tilt direction (left-backward, left-forward, right-backward, or right-forward), it activates PID regulation for the corresponding leg of the platform. This helps to adjust the platform angle and maintain balance. The process repeats in a loop to provide real-time stabilization.

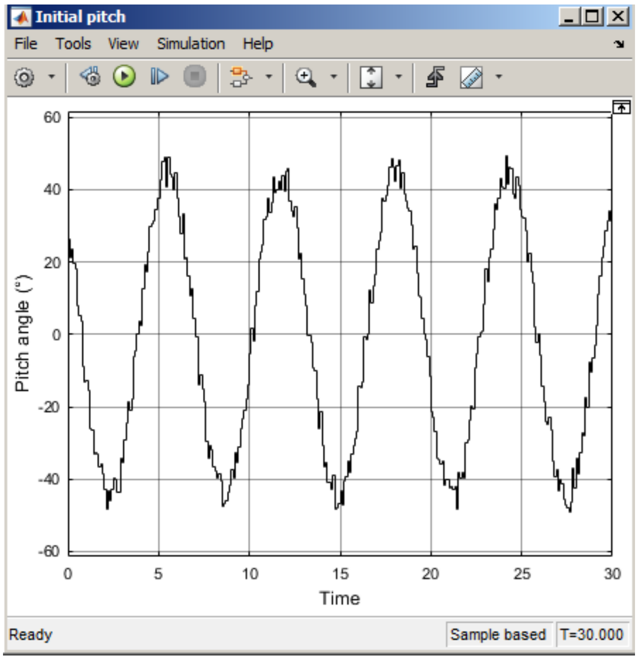

Figure 5 – Graph of initial inclination values from the gyroscope

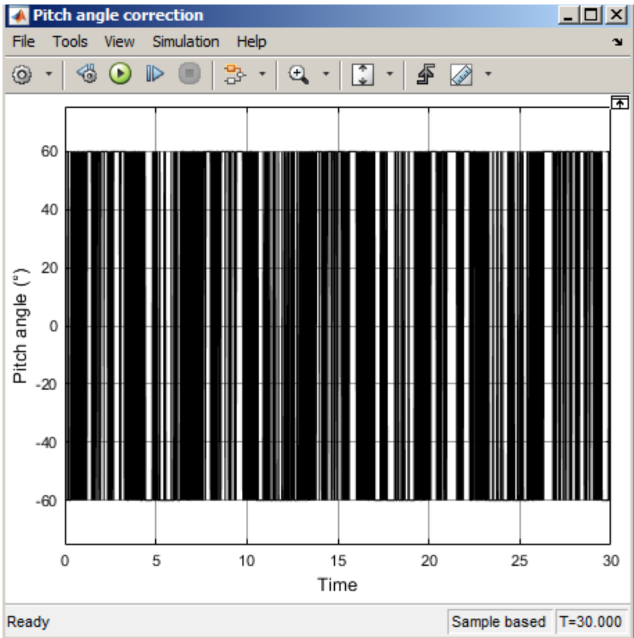

Figure 6. Graph of correction slope values

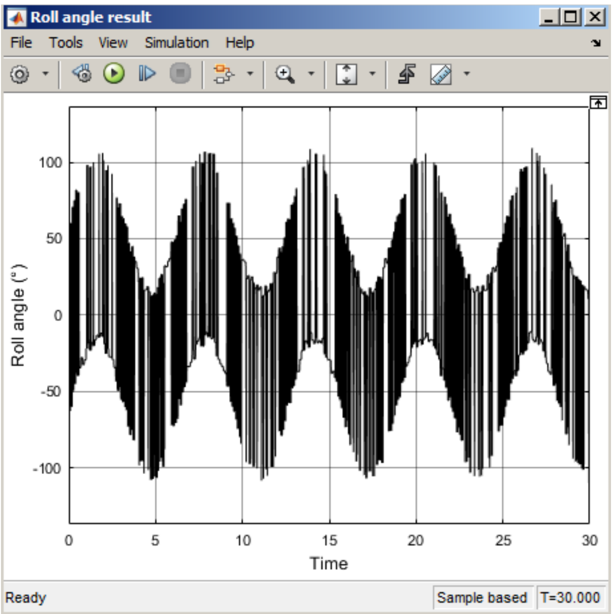

Figure 7. Graphs of correction slope values

IV. CONCLUSION

Despite the disadvantage of the block system in the absence of an ideal simulation of realistic non-extreme physical conditions of platform operation, taking into account inertia and non-momentary deflections of the platform after correction, it can be seen in Figure 7 that the system still corrects the final slope values close to zero.

The results demonstrate the potential of using a decentralized control architecture to ensure stable behavior of a humanoid robot in real time. The integration of inverse kinematics, fuzzy logic, and PID controllers allowed to achieve a high level of adaptability even under limited hardware resources. This confirms the feasibility of using the presented approach in an educational environment and in further scaling to more complex robotic platforms.

Thus, the use of inverse kinematics in combination with a PID control system allows achieving high-precision control of the movement of the limbs of a mobile platform, which ensures the stability of its position under dynamic loads. The model, developed in the MATLAB Simulink environment, demonstrated the ability of the system to effectively compensate for external influences by adjusting the tilt angles. Further research involves improving the model taking into account the inertial characteristics of the real environment and implementing adaptive stabilization methods to expand the functionality of autonomous robotic platforms.

In further research, it is planned to improve the simulation taking into account the dynamics of the platform, implement sensor integration with the vision system, and develop an agent environment for group functioning of robots in the context of Industry 5.0.

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