Balancing System For A Zoomorphic Spot Type Mobile Robot Development Using An Accelerometer MPU 6050(GY-521)

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***Abstract*—Currently, the areas of use of robots in general and zoomorphic ones in particular are very diverse. They are used in various fields: from research to social support for elderly and sick people. When creating such robots, scientists face a number of problems. This paper considers the problem of maintaining balance in a four-legged, Spot type robot. A block diagram for balancing a zoomorphic mobile robot of the Spot type has been developed. We have created a balancing system and carried out studies, which show promising results and a quick response to disturbances. As a result, the robot restores balance after all applied disturbances.**

Keywords—mobile robot, manufacturing innovation, accelerometer, balancing, zoomorphic robot.

I. Introduction

In today's world, robotics plays a vital role in various fields such as industry, medicine, education, and entertainment [1-8]. One of the most promising areas in robotics development involves creating zoomorphic mobile robots that can imitate animal movements and behavior [9,10]. Balancing is one of the key aspects in the mobile robots development, especially for four-legged robots like Spot, which must ensure stable movement. In this context, the relevance of the research lies in the creation of an effective balancing system for the Spot robot using the MPU 6050 (GY-521) accelerometer. Thus, the balancing system for a zoomorphic Spot type mobile robot development using the MPU 6050 accelerometer is of high practical significance and can significantly improve the functionality and stability of the robot in real operating conditions.

II. Related Research

Currently, many scientists are developing zoomorphic robots. They solve issues of creation, simulation, as well as various details of movement, including balancing. Let us look at just a few of them.

Let us begin with the work [11]. Here the authors propose their zoomorphic robot design and development. They have made 3D printing robot. And for it researchers determined the kinematics solutions. In order to control robot's locomotion and legs positioning scientists used an Arduino application.

The study [12] proposes a quadruped zoomorphic robot with 8 degrees of freedom. It is controlled remote and monitored via an IoT interface. And in this work there is described a mathematical model of its kinematics. To balance this robot and to correct the center of mass position there are developed corresponding equations. Authors have made a conclusion that in order to prevent loose of balance it is necessary to move one limb in a diagonally-crossed manner.

Scientists in [13] note that mobile bases with three or four-wheeled designs are rather stable. But they have lack of maneuverability. And vice versa if the robot has great maneuverability its stability is poor. They used RL-based controllers and founded that they are more robust against changes in initial conditions of the robot.

III. A Balancing System Development for a Zoomorphic Mobile Robot

A balancing system development for zoomorphic mobile robots, including Spot, using a Raspberry Pi 3 and an MPU 6050 accelerometer is a complex engineering process. Key features include the integration of an accelerometer module to sense the robot's acceleration and tilt, and the use of a Raspberry Pi 3 as a central control device [14,15]. To ensure balance, continuous determination of the robot's spatial position and correction of its movements is vital. This is achieved by analyzing data from the accelerometer and accepting the appropriate control commands. As part of these studies, the following structural diagram of balancing a zoomorphic Spot type mobile robot was developed, which is presented in Fig. 1.

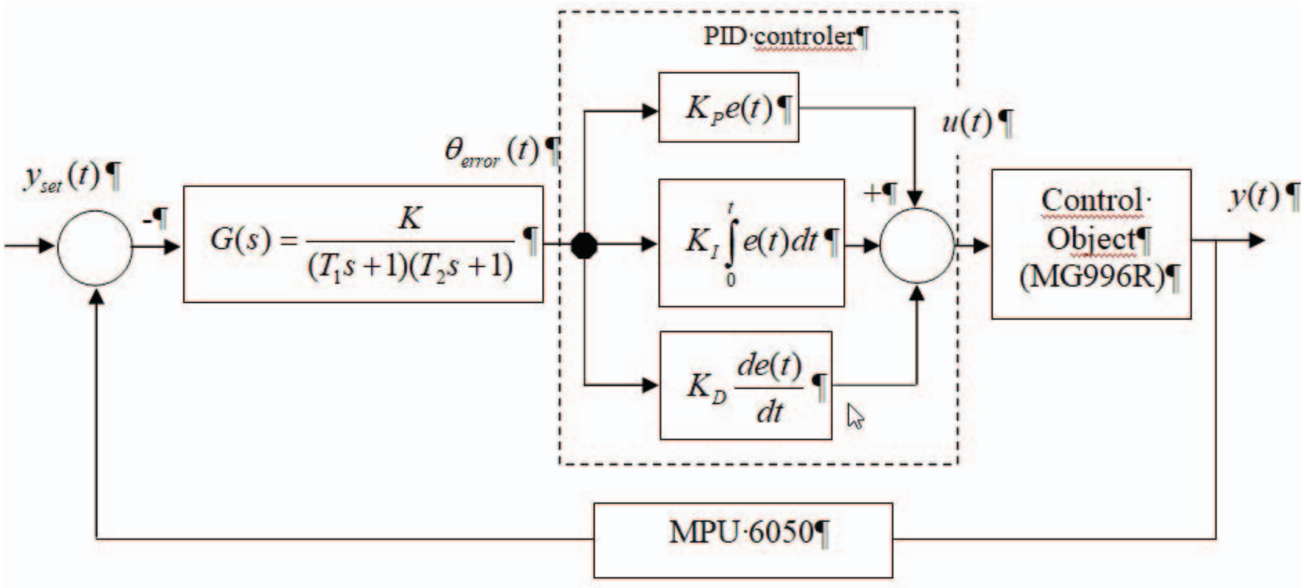


Fig. 1. Balancing a Zoomorphic Spot Type Mobile Robot Block Diagram.

$G(s)=\frac{K}{(T_1 s+1)(T_2 s+1)}$ - transfer function (second order) for the control system (K - amplification factor; T_1, T_2 - time constants);

$y_{set}(t)$ - specified value of the installation parameter;

θ_{error} - robot tilt angle error;

$u(t)$ - control actions (control signal for servomotors);

$y(t)$ - adjustable parameter;

Control Object (MG996R) – MG996R servo motor transfer function $G(s)=\frac{K}{Ts+1}$ (K - amplification factor; T- time constant); each limb has 3 servomotors.

K_p, K_I, K_D - coefficients of PID controllers.

The transfer function of a nonlinear sensor, such as the MPU 6050 feedback accelerometer, is not described in the usual way as it is for linear systems. Instead, to work with accelerometer data, they usually use a model that maps acceleration to a physical quantity (m/s^2).

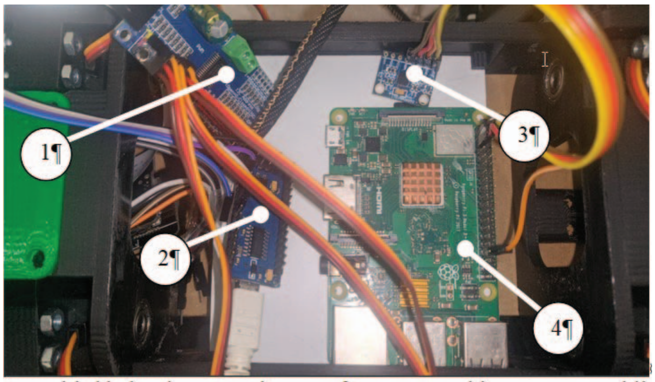
Based on the developed balancing scheme for a zoomorphic Spot type mobile robot (Fig. 1), the balancing equation ($\ddot{\theta}$) for this control system will have the following form:

$$\ddot{\theta}=K_P\theta_{error}+K_i\int\theta_{error}dt+K_D\frac{d\theta_{error}}{dt}$$

where: θ_{error} - robot tilt angle error;

K_p, K_I, K_D - - coefficients of PID controllers.

Fig. 2 shows the assembled balancing control system for a zoomorphic Spot type mobile robot. A Servo module with an I2C interface on PCA9685 is used to control the 12 servo motors, comprising a 16-channel 12-bit PWM.



1- Servo module with I2C interface on PCA9685, 16-channel 12-bit PWM;

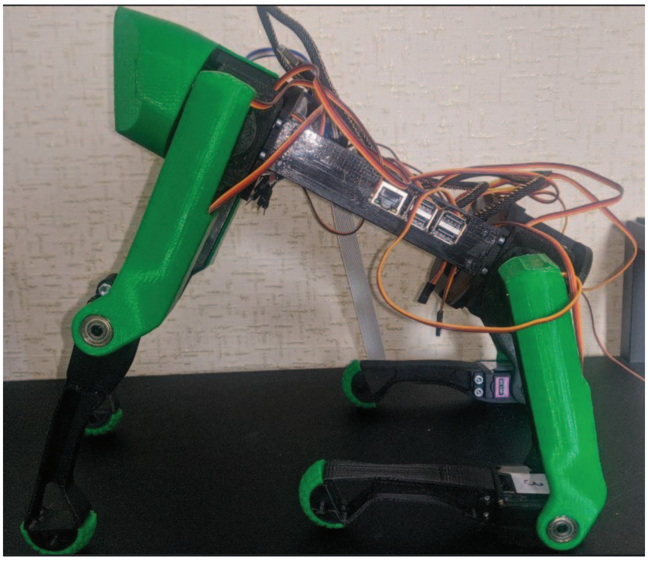
2 – Arduino Nano;

3 - accelerometer MPU 6050 (GY-520);

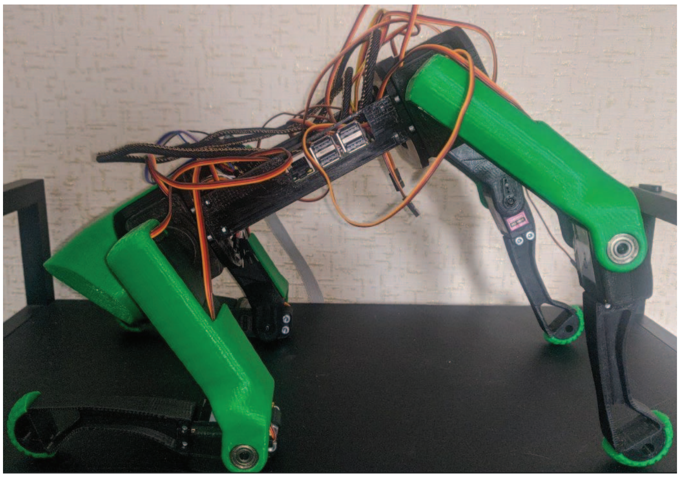
4 - Raspberry Pi 3 model B+.

Fig.2. Assembled balancing control system for a zoomorphic Spot type mobile robot.

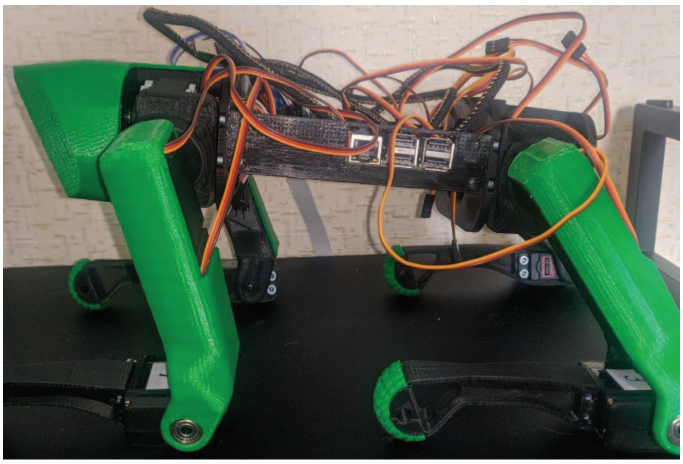
The software implementation for the balancing system for a zoomorphic Spot type mobile robot was developed in Python 3.12 in the Thonny Python IDE on Raspberry OS using the smbus library. It allows us to control the accelerometer via the I2C bus, read data from the accelerometer and send commands to configure its parameters. To conduct the study, three basic commands were chosen: “Guard” (Fig. 3a); “Search” (Fig. 3b) and “Wait” (Fig. 3c), which change the position of the robot in space; the general view of these commands is presented in Fig. 3.



a)



b)

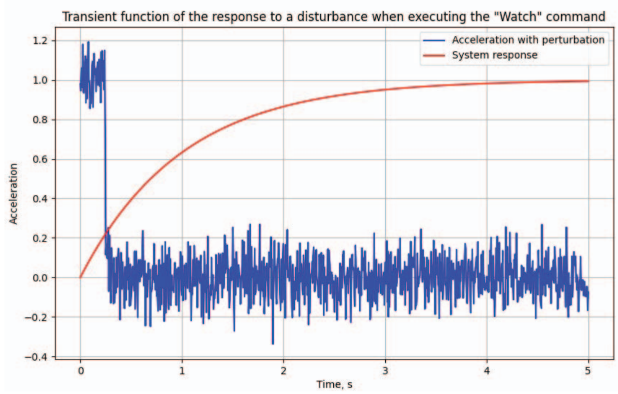


c)

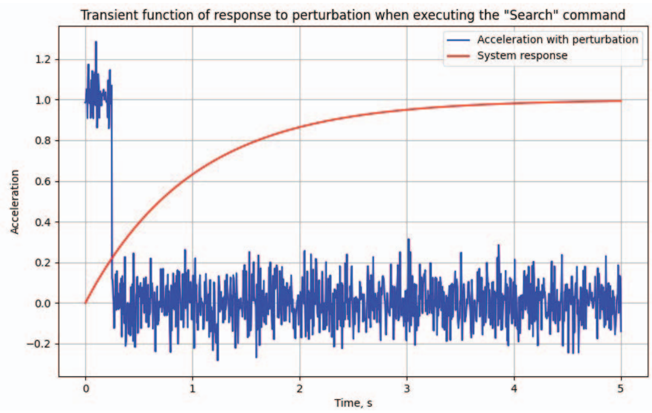
a) "Guard" command; b) “Search” command; c) “Wait”command

Fig. 3. Investigated robot positions for balancing analysis.

The main goal of the experiment is to investigate the transition process of the developed balancing control system for a zoomorphic Spot type mobile robot when executing the "Guard" and “Search” commands from the “Wait” command position. The obtained results of the response of the Spot type robot balancing control system to the disturbance at the beginning and the subsequent change in the robot’s position in space in response to the execution of commands are presented in Fig. 4.



a)



b)

a) the acceleration experienced by the robot in the execution time of the “Guard” command
b) the acceleration experienced by the robot in the execution time of the “Search” command

Fig. 4. The graph shows the acceleration that the robot experiences over the time it takes to execute commands.

This graph (Fig. 4) is a visualization of the response of the balancing control system of a Spot type robot to the disturbance at the beginning and the subsequent change in the position of the robot in space in response to the execution of commands. In this case, the graph shows the acceleration that the robot experiences over time. By analyzing the graphs, the following conclusions can be drawn: the initial acceleration peak corresponds to a disturbance caused by the start of the robot’s movement or an external influence on it; After the disturbance, the acceleration gradually decreases and stabilizes at a level close to zero. This reflects the transition of the control system to steady state after the command is executed. On average, command execution time varies from 3-4 seconds, and depends on battery charging factors and the robot’s position in space.

IV. Conclusions

Based on the presented graphs of the transient response function of the Spot-type robot balancing control system using the MPU 6050 (GY-520) accelerometer when executing commands that change the robot’s position in space, the following conclusions can be drawn. The control system effectively responds to the disturbance at the beginning, which allows you to quickly stabilize the robot's position. After a disturbance, the system quickly returns to steady state, demonstrating high response speed and stability. The response to changes in the robot's position in space occurs smoothly and without sudden fluctuations, which indicates that the control system is well tuned. The transient response function confirms the functionality and effectiveness of using the MPU 6050 accelerometer to determine the position and control the balancing of the robot. The results obtained indicate the possibility of successfully using a control system for balancing a zoomorphic Spot type mobile robot in different conditions and with different teams. In general, the control system demonstrated good response and controllability characteristics, which makes it promising for further application in real conditions.

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