N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
PHYSICO-MATHEMATICAL SERIES
ISSN 1991-346X **https://doi.org/10.32014/2019.2518-1726.33**
Volume 3, Number 325 (2019), 140 – 152

Wojcik Waldemar[1], S.A.Kulmamirov[2], Zh.M.Alimzhanova[2], L.M. Alimzhanova[2], A.M. Akhmetova[2], V.I. Karyukin[2]

[1]The Lublin University of Technology;
[2]Kazakh National University al-Farabi

STUDY OF THE STABILITY OF THE REGULATOR BALANCING ROBOT NI MINDSTORMS

Abstract. The article presents the results of studying the steady state of a balancing robot when the control is carried out in a closed state. The synthesis of the controller's coefficients was carried out by estimating the root of the characteristic equation and the linear quadratic regulator. Under the action of the PID controller, algorithms for controlling the robot servos were compiled. The results of the experimental studies allowed us to construct transient characteristics in a closed robot control system while balancing the state of the robot in a steady state and in motion.

Evaluation of the stability of the robot. The control system of the balancing robot is asymptotically stable if its steady-state value at the time of its movement or at the moment of stopping will tend to zero regardless of the initial conditions, in the absence of input influences: $\lim_{t\to\infty} x(t) = 0$.It is assumed that the movement of the robot is described by a standard equation of the form: $\dot{x}(t) = Ax(t) + Bu(t)$ [1].In order for the robot to be asymptotically stable, it is necessary and sufficient that the real part of all the eigenvalues of the matrix be negative [2-6].

Feedbacks object state control. Let us consider that the robot under the study of a control object is a closed system, the block diagram of which is shown in Figure 1. The feedback control action is determined by the product of the proportionality coefficient K and the difference between the desired values and the measured values.

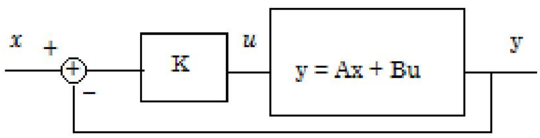

Figure 1 Feedback control

The control action and the status of SIS threads shown in Figure 1 describe the following equations:

$$u(t) = -K(y(t) - x(t),$$
$$\dot{x}(t) = (A - BK)y(t) + BKx(t). \quad (1)$$

It is necessary to maintain the system under the study of a steady statem by dividing by thecount value of the matrix *K*. Changing these valuesentails a change of b-governmental numbers of the matrix *(A – B *K)*. For sustainable regulation of a closed robot system, it is necessary for it to be controlled. The system will be controllable if the rank of the matrix *M* coincides with the rank of the matrix *A*. Here $M_c = [B, AB, \dots, A^{n-1}B]$ you can use the ctrb command to determine manageabilityinthe ControlSystemToolbox environment. There are 2 main methods for calculating feedback coefficients:

1) Calculation of the desired roots. The method describesthecalculation of the coefficients *K* with the creation of the desired eigenvalues of the matrix *A – B * K.*Inthe ControlSystemToolbox for the calculation, you can use the place function.

Example 1. K coefficients are describedin the first communication system with closed CONCRETE and GOVERNMENTAL parameter values A = [0,1; -2; -3] and B = [0;1]. Pole values are [-5, -6].

$$\begin{bmatrix} \gg A = [0,1,-2,-3]; B = [0,1]; \\ \gg poles = [-5,-6]; \\ \gg K = place\ (A, B, poles) \\ K = 28{,}0\ \ 8{,}0 \end{bmatrix}$$

2) Linear square regulator M is received by calculating the coefficients of the matrix K on the basis of minimizing the value of the functional J calculated in the following form: $J = \int_0^{\infty} (x\,(t)^T Qx(t) + u(t)^T Ru(t))dt$. Parameters are adjusted by selecting the weight matrices of the state Q and the input action R, which are selected on the basis of the physical nature of the processes. The ControlSystemToolbox application can use the lqr functions to calculate a controller.

Example P 2. A = [0,1; -2, -3], B = [0; 1], Q = [100, 0; 0, 1]; R = 1.

$$\begin{bmatrix} \gg \lambda = [0,1,-2,-3]; B = [0,1]; \\ \gg Q = [100, 0; 0, 1]; R = 1; \\ \gg K = lqr\ (A, B, Q, R) \\ K = 8{,}198\ \ 2{,}137 \end{bmatrix}$$

The control of the servos of the robot is carried out to generate the desired movement of the robot. For this purpose, the PID controller is most often used [16], i.e. a device in the feedback circuit used by an open-loop control system to generate a robot control signal. The PID controller generates a control signal which is the sum of 3 terms, the first of which is proportional to the input signal, the second is the integral of the input signal and the third is the derivative of the input signal.

The purpose of the PID controller is to maintain a given value x0 of a certain value x by changing another value of u. The value of x0 is called the "setpoint", and the difference e = (x - y) is called the "non-residual" or mismatch. The output signal of the regulator u is determined by three terms:

$$u(t) = P + I + D = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de}{dt}, \quad (2)$$

where K_p, K_i, K_d, are proportional, integral and differential components of the regulatorrespectively.

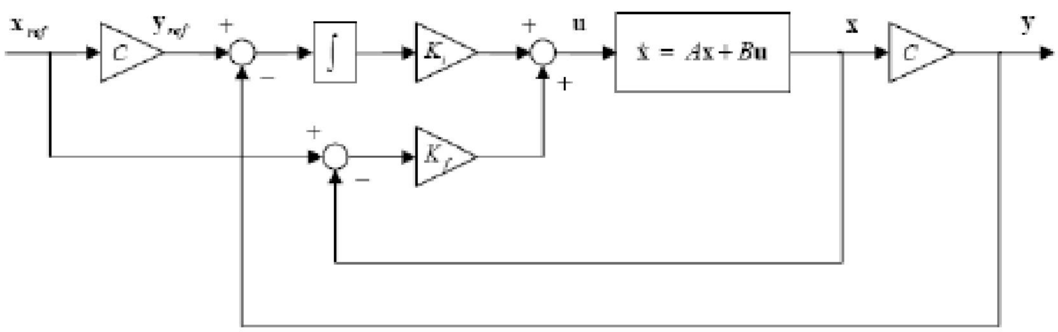

Figure 2 - PID controller

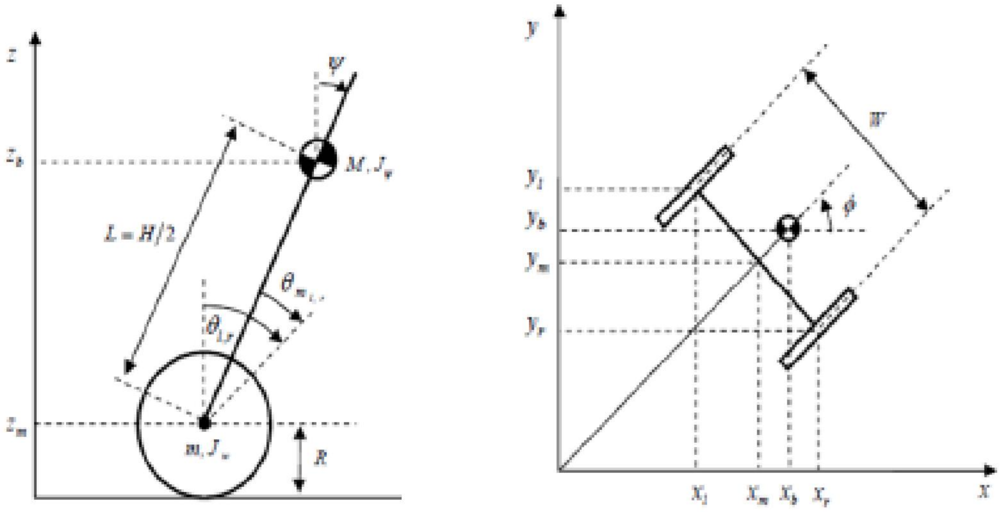

Figure 3 Model Parameter Designation

Figure 3 shows the model parameters indicated for robots: mobile robots of the “Motobot” type [2] and a balancing robot of the “Segway” type [3]. For use in specific studies below are the values of their parameters:

g = 9.81 (m / s2) acceleration of gravity;
m = 0.03 (kg) wheel weight;
R = 0.035 (m) wheel radius;
Jw = mR2 / 2 (kgm2) the moment of inertia of the wheel;
M = 0.6 (kg) body weight;
W = 0.14 (m) body width;
D = 0.04 (m) body thickness;
H = 0.144 (m) body height;
L = H / 2 (m) distance to the center of mass from the axis of the wheels;
JΨ = 2 (M * L) / 3 (kgm2) the moment of inertia of the body is tilted;
Jφ = M (W2 + D2) / 12 (kgm2) rotational moment of inertia;
Jm = 10-5 (kgm2) the moment of inertia of the engine;
Kb = 0.468 (V * s / rad) is the counter-emf constant;
Kt = 0.317 (N * m / A) is the motor torque constant.

Now we know everything to compile the source code of the program for organizing the movement of the robots. Let's call this program “Segway”. First of all, we compose the main control circuit of the robot. The diagram shown in Figure 4 reflects the main window of the program. The key blocks of the program are described above when they conducted an experimental study on assembling a Motobot robot. The rest of the schemes are contained in the nxtway_appblock.

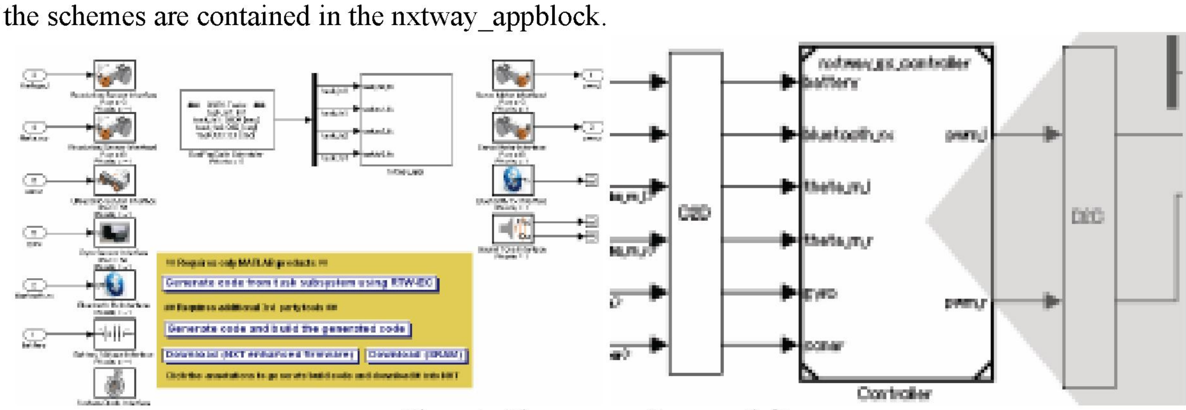

Figure 4 - The program «Segway» (left)
for the organization of the movement of the robot with the controller (right)

Figure 5 shows a general diagram of the model with all adjustable registrable inputs/outputs. Shown here are the signals that transmit data on the record, which is conducted via Bluetooth protocol.

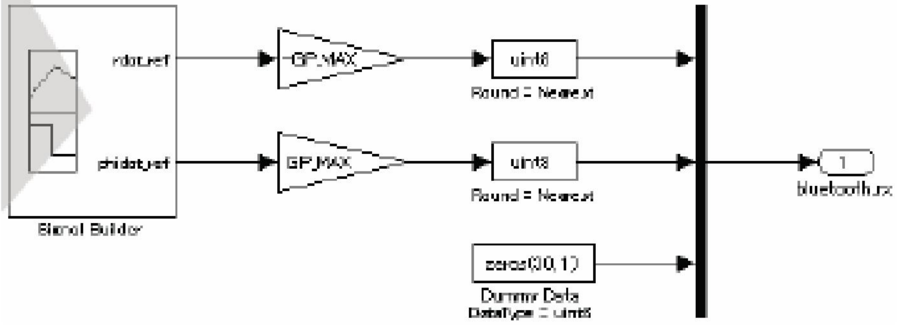

Figure 5 - Control generator diagram

The results of the study made it possible to examine some of the constituent blocks of the robot model in details. ReferenceGenerator is a unit that transmits and limits control actions on the controller. The "Controller" shown in Figure 4 is the block designating the NXT controller. On the left side there are blocks that serve to receive data from sensors, encoders and Bluetooth.On the right side there are blocks that serve to transmit signals to the engines and Bluetooth (Figure 6). The controller unit operates in the discrete time system, and the model unit operates in continuous time mode; therefore, it is necessary to convert the transmitted values.

Figure 7 shows the "NXTway-GS" subsystem, consisting of sensors, drivers, and a linearized model of the robot. It converts the type of input data signals into real values. The subsystem calculates the dynamics of the robot, and displays the recorded data of the results after performing the data sampling procedure. This subsystem defines the parameters of the environment of the robot.

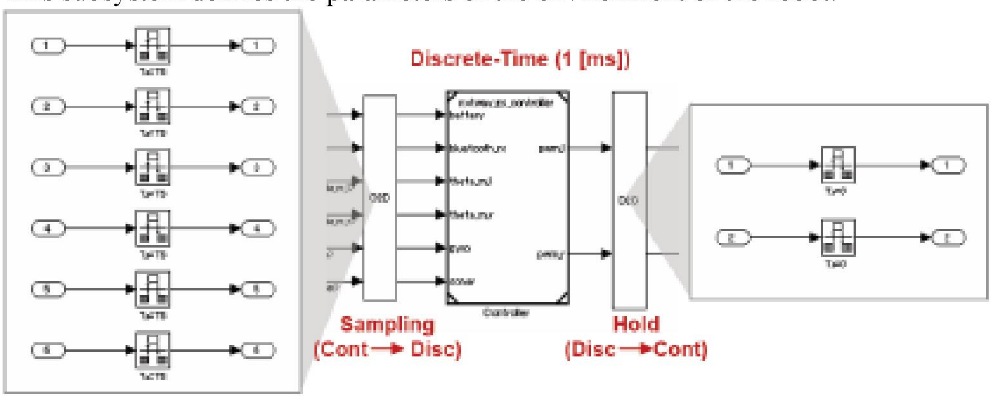

Figure 6 - Circuits of ADC and DAC blocks in models for signal conversion

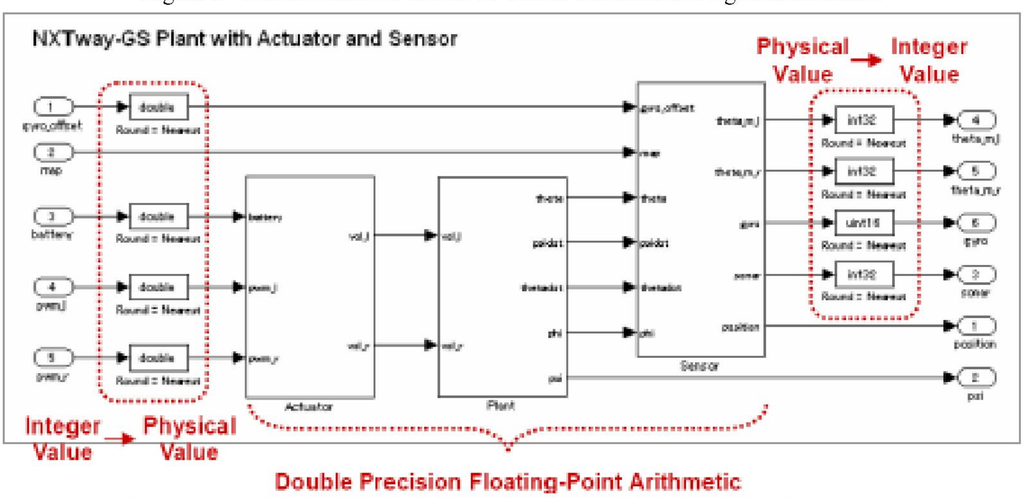

Figure 7 - Scheme servo control depending on the testimony sensors development

The block shown in Figure 7 “Actuator” is a subsystem that converts the power set by the controller to the voltage supplied to the motors. Designated block «Plant» is the model described by equations of double inverted pendulumtaking into account the calibration of the gyroscope.

The “Sensor” block converts the values obtained on the state of the model into the output signals of the sensors. Additionally, the distance to obstacles obtained from the ultrasonic distance sensor is calculated. This information may be used for detecting obstructions and avoid collisions with them.

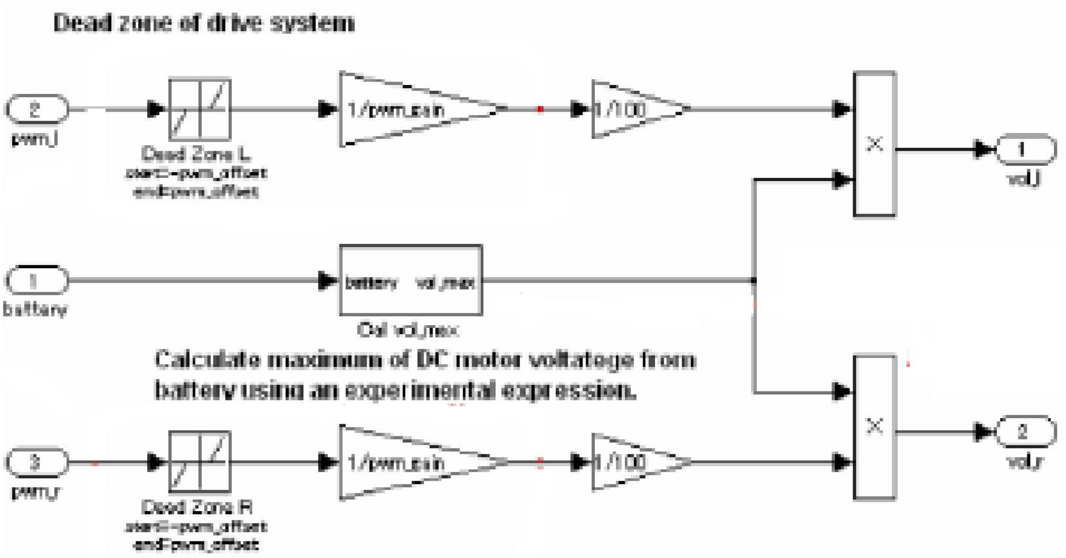

Figure 8 - Drive subsystem

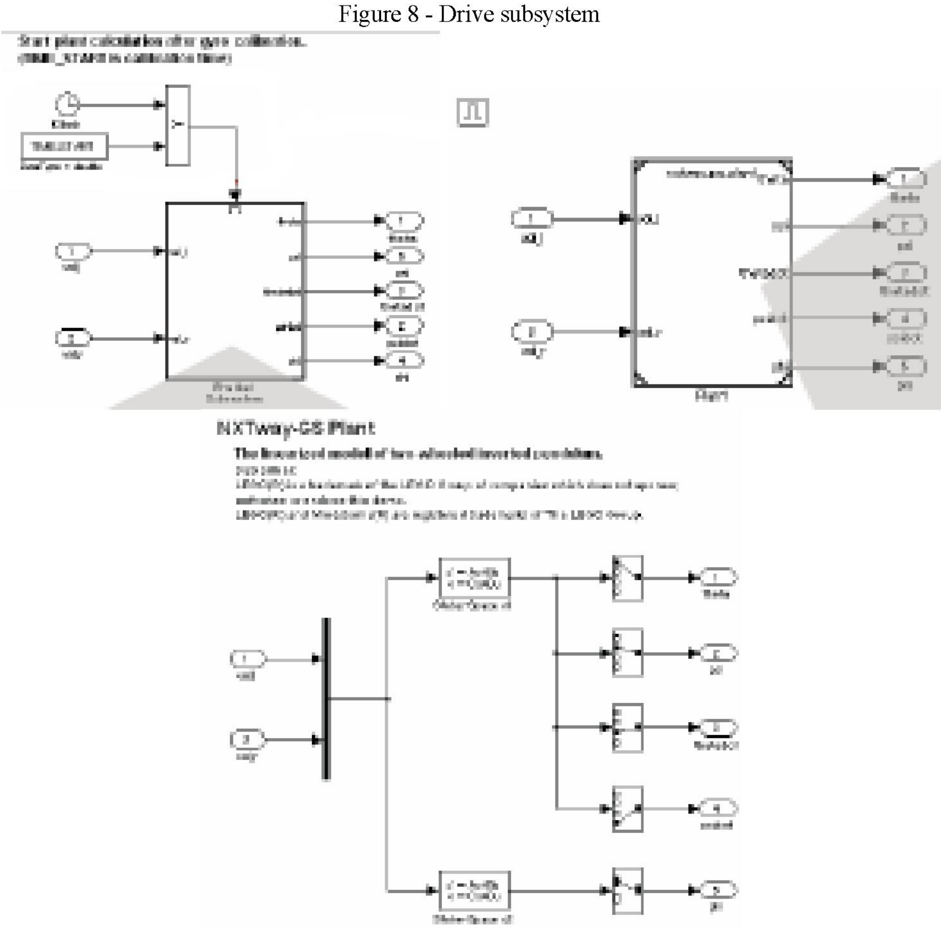

Figure 9 - Model Subsystem

The “Data”, “Store”, and “Memory” blocks are used as general blocks for distributing data between subtasks. Block “task_ts2” is responsible for detecting obstacles of Corollary robot and evading them.The “task_ts3” block is responsible for counting the time and checking the battery level of the robot.

Block “task_ts1” serves for calibration and balancing the gyroscope and for controlling the sound level and writing data. Balancing and control start after calibrating the Osprey Gear. The calibration time is saved as “time_start”.

Further, in the constructed schemes, the subsystems of balancing and control are presented. In the circuit shown in Figure 17 is a block “DiscreteDerivativeBlock”, which calculates the time constant of reverse differentiation block and “DiscreteIntegratorBlock”, which calculates the time integral by Euler method.

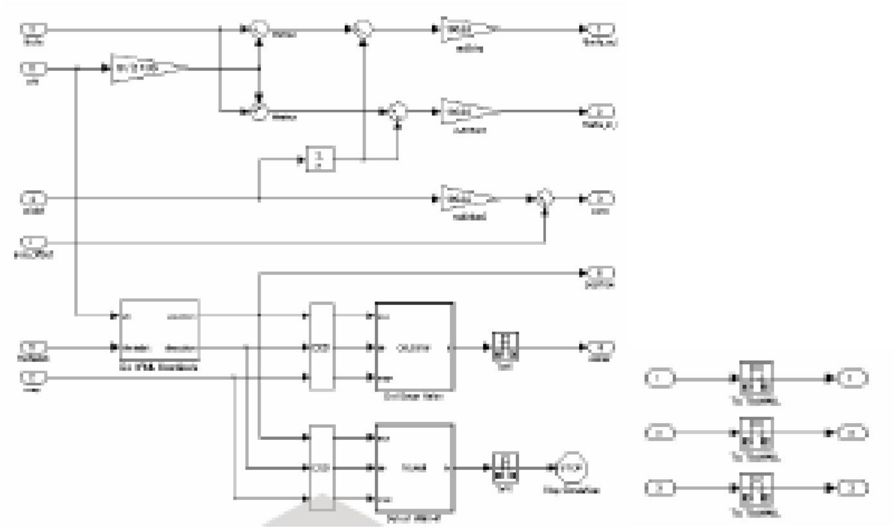

Figure10 - Sensor Subsystem

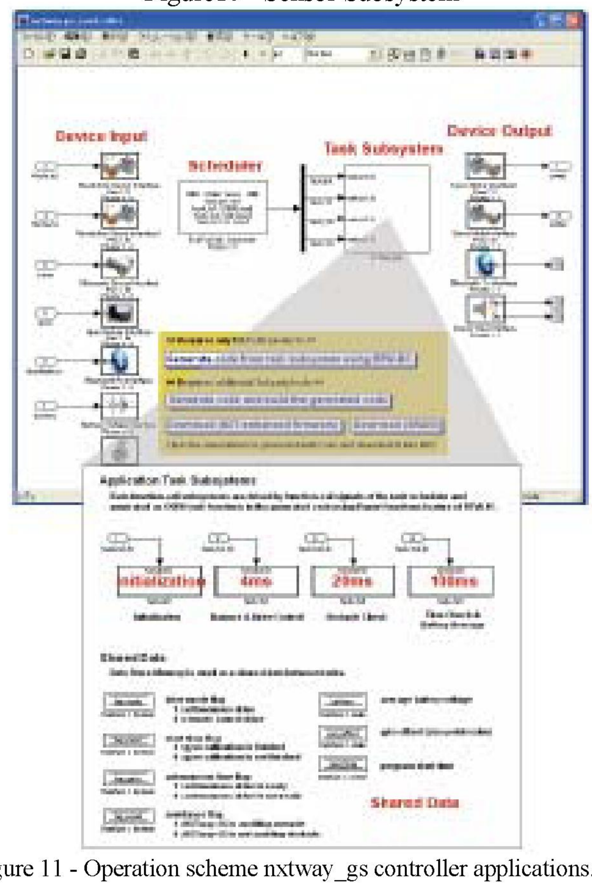

Figure 11 - Operation scheme nxtway_gs controller applications.mdl

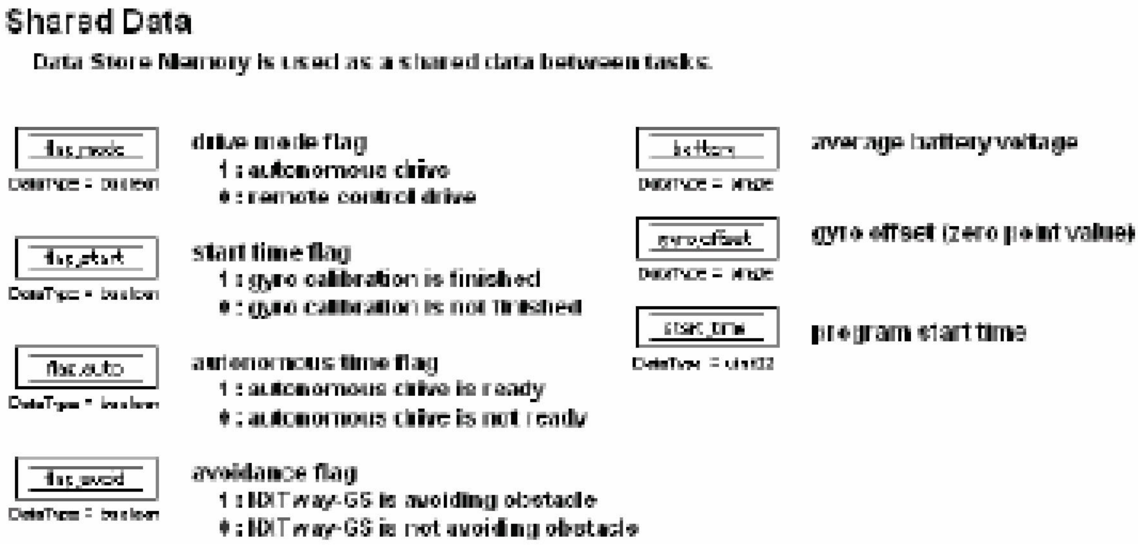

Figure 12 - Distributed data blocks

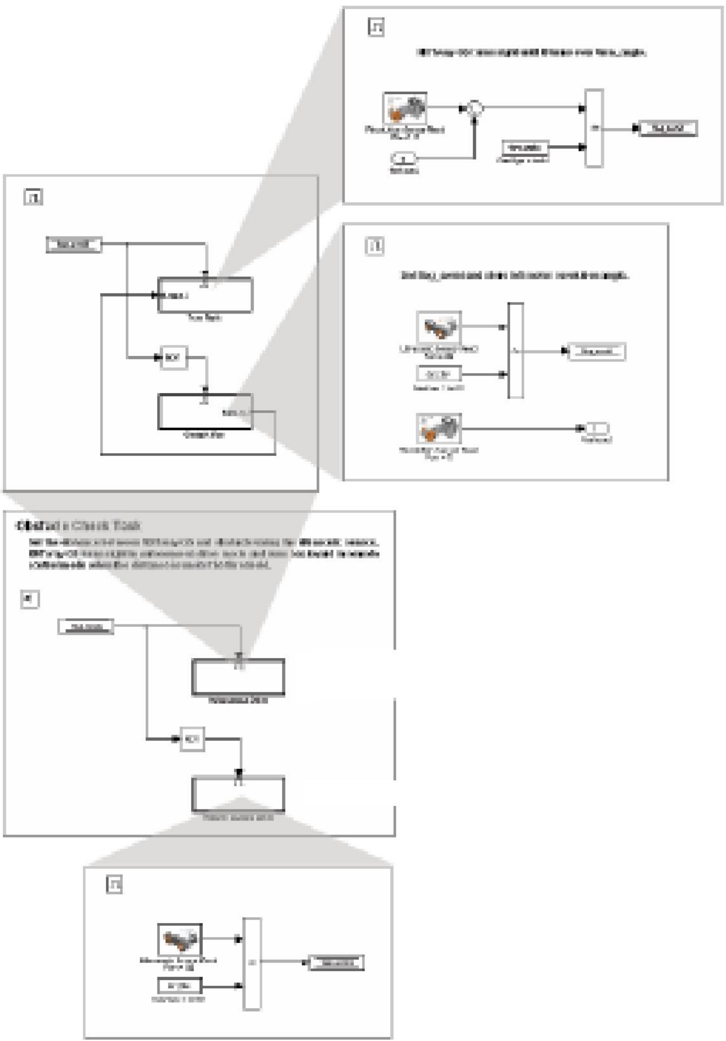

Figure13 - The task_ts2 subsystem responds
for detecting and avoiding robbery

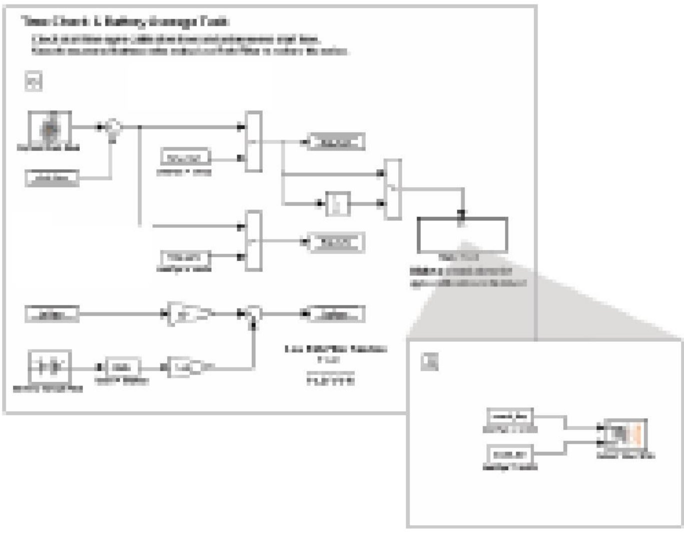

Figure 14 - The task _ts3 subsystem is responsible for counting time. and check the battery level of the robot

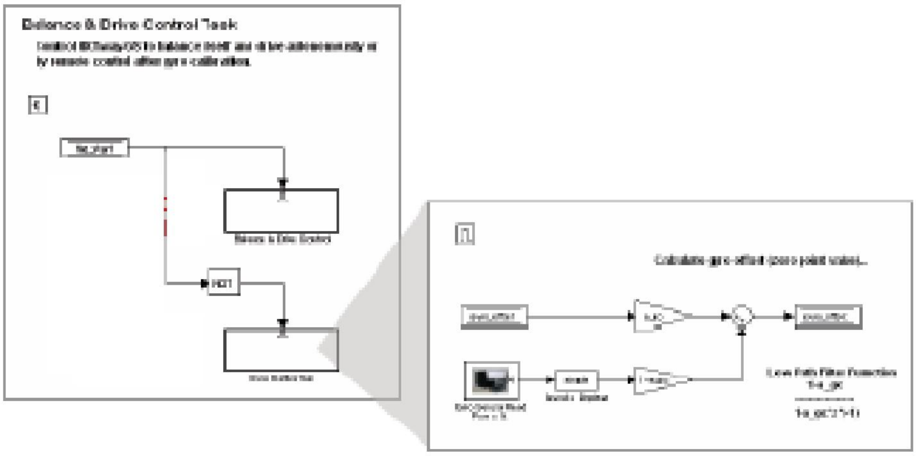

Figure15 - The task_ts1 subsystem is used to calibrate the gyroscope and balancing, as well as for managing and recording data

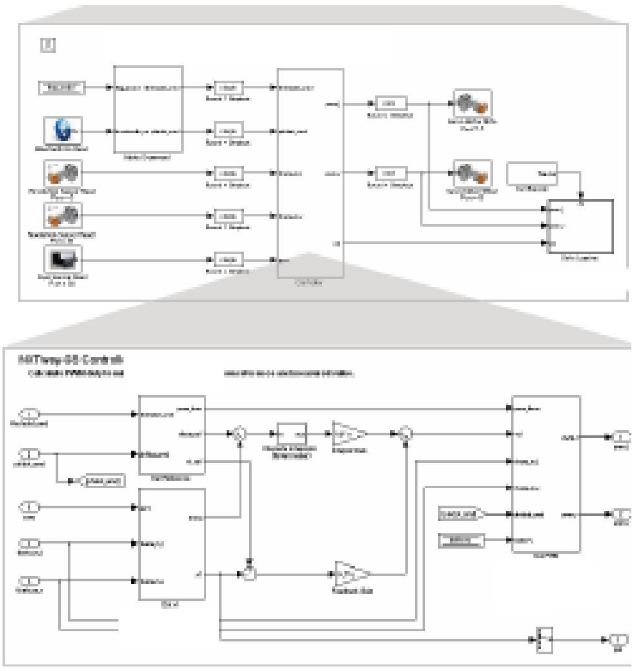

Figure16 - Controller model for control in balance mode

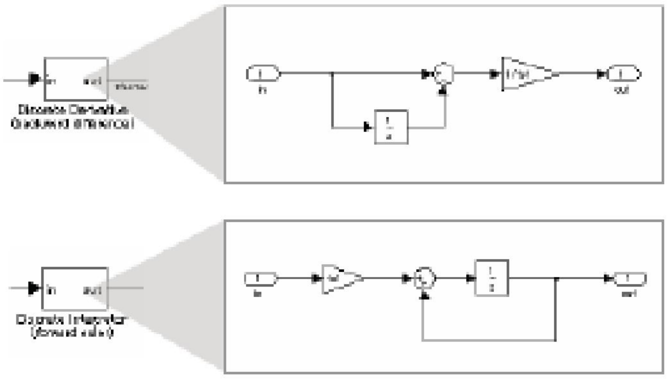

Figure17 - Blocks of the controllers «Discrete Derivative» and «Discrete Integrator Block»

Figure 17 also contains the blocks responsible for the calculation of the signal level, and with the use of a low pass filter for reducing surges caused by abrupt changes in speed of the generated signal. Figure 18 shows the method for calculating the generated controls.

Subsystem shown in Figure 19 calculates the state of the system using the sensor output signals. Long gyro data is used to remove "girodrifta" (gidrodreyfa), and a low pass filter is used for removing away move speed signal. The subsystem shown in Figure 20 is responsible for calculating the supply of the required power to the servo drives.

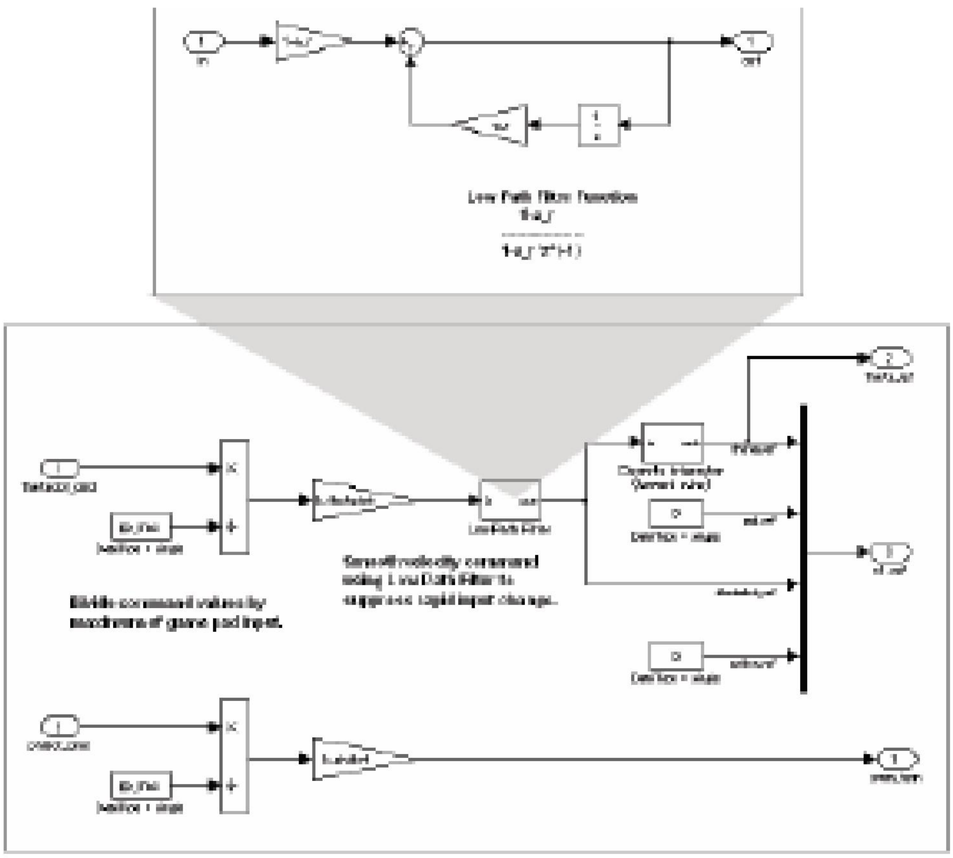

Figure 18 - Procedure for Calculating p and controls generated

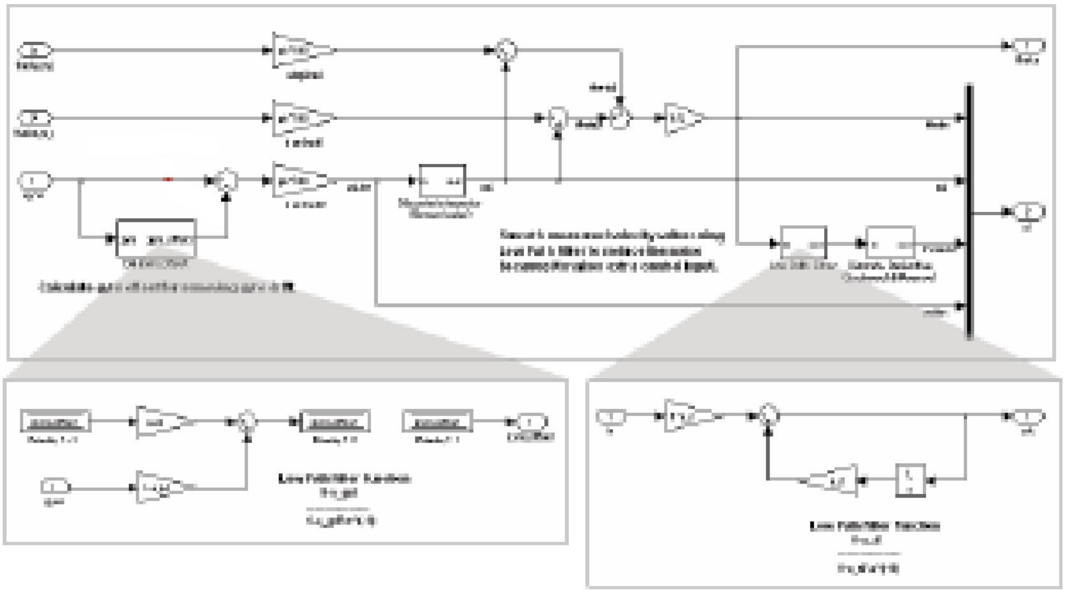

Figure 19 - Monitoring and monitoring the state of the model as a closed system

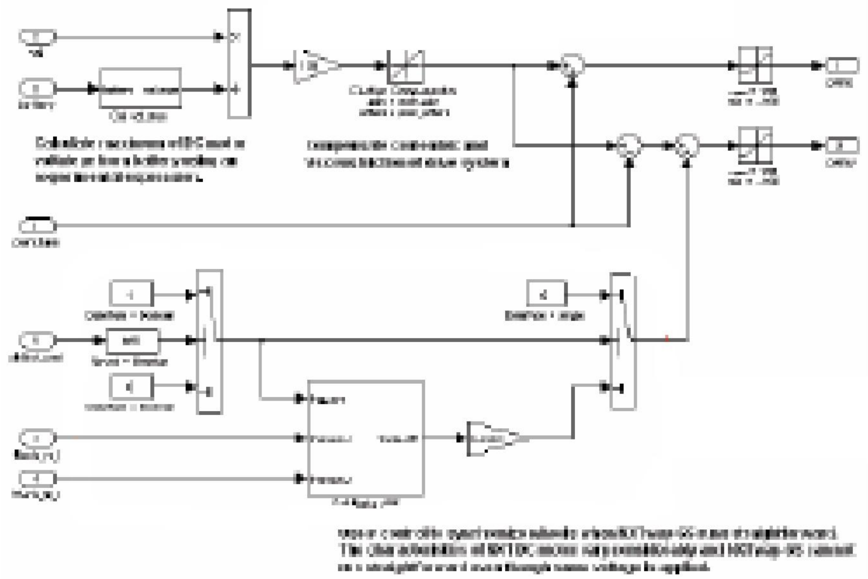

Figure 20 - Procedure for calculating p and the power supplied to the robot servo

The simulation results. The use of the utility “NXT GamePad” can register and record the value of an angle of inclination of the robot of the gyroscope and the robot regarding to the beginning of the movement using the values of the encoder of one of the servomotors. Figures 21 and 22 show the results of experimental research in the form of a graph of the data obtained by balancing the robotin a steady state and in a motion, respectively.

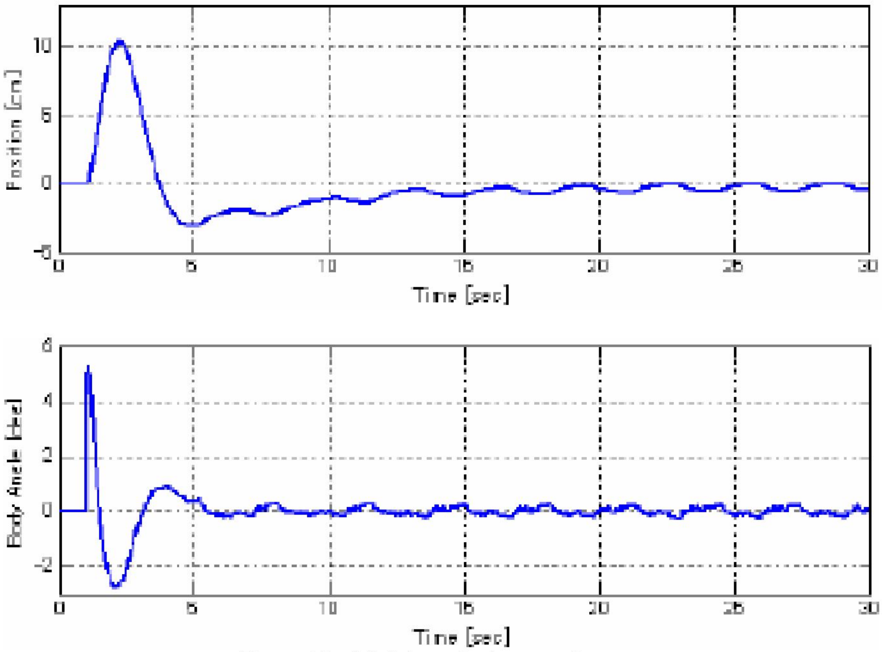

Figure 21 - Model results in a steady state

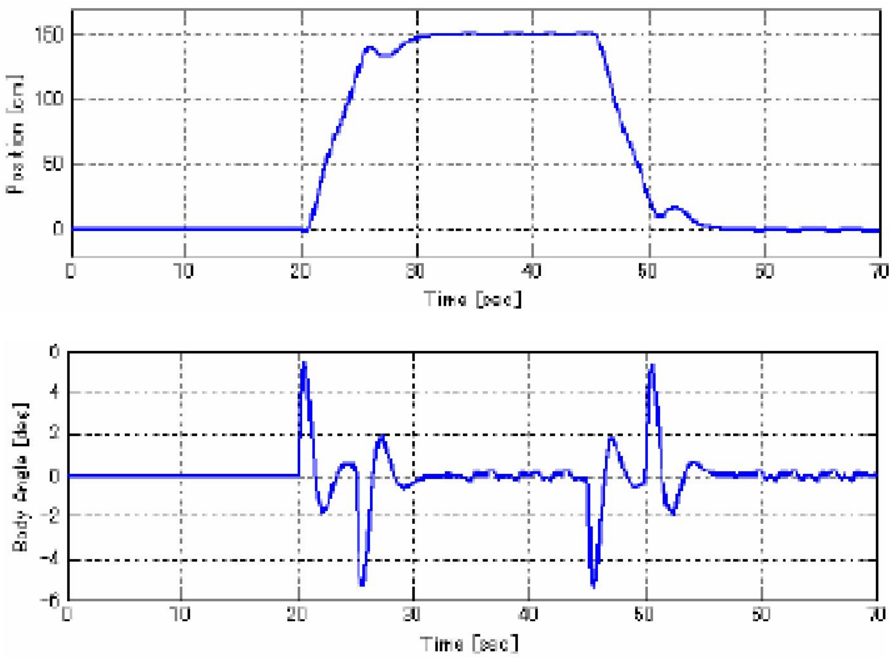

Figure 22 - Simulation resultsinmotion

Findings. The article addresses the problems of stability of a balancing robot in motion in accordance with the laws of TAU. The stability of a closed system on the basis of feedback has been investigated. The coefficients were synthesized using the following methods: calculation by the desired roots and the linear quadratic regulator method. According to the defined parameters of the PID controller, functional diagrams are compiled for controlling the robot servos. The results of experimental studies of balancing a robot in static and dynamic conditions were obtained using the NINXT GamePad utility, taking into account the value of the tilt angle of the robot from the gyroscope relative to the start of movement, using the encoder value of one of the servomotors. Registered statistics for specific values of the parameters of the controller of the robot show the degree of compliance with its stability when the robot moves in the closed state.

[1]Waldemar Wojcik, С.А. Кульмамиров[2], Ж.М.Алимжанова[2], Л.М.Алимжанова[2] , А.М.Ахметова[2], В.И.Карюкин[2]

[1]Люблинский технологический университет;
[2]Казахский национальный университет им. аль-Фараби

ИССЛЕДОВАНИЕ УСТОЙЧИВОСТИ РЕГУЛЯТОРА БАЛАНСИРУЮЩЕГО РОБОТА NI MINDSTORMS

Аннотация. В статье представлены результаты исследования устойчивого состояния балансирующего робота, когда управление осуществляется в замкнутом состоянии. Синтез коэффициентов регулятора осуществлялся оценкой корня характеристического уравнения и линейного квадратичного регулятора. При действии ПИД-регулятора составлены алгоритмы управления сервоприводами робота. Результаты проведенных экспериментальных исследований позволили построить переходные характеристики в замкнутой системе управления роботом при балансировании состояния робота на месте и в движении.

[1]Waldemar Wojcik, С.А. Кульмамиров[2], Ж.М.Алимжанова[2], Л.М.Алимжанова[2] , А.М.Ахметова[2], В.И.Карюкин[2]

[1] люблюблин технологиялық университеті;
[2]әл-Фараби атындағы қазақ ұлттық университеті

РОБОТ NI MINDSTORMS РЕГУЛЯТОРДЫҢ ТҰРАҚТЫЛЫҒЫН ЗЕРТТЕУ ТЕҢДЕСТІРУ

Аннотация. Мақалада теңдестіру роботының тұрақты күйін зерттеудің нәтижелері келтірілген, ол бақылау жабық жағдайда орындалады. Реттеуші коэффициенттерді синтездеу тәндік теңдеудің түбірін және сызықтық квадраттық реттегішті бағалау арқылы жүзеге асырылды. PID контроллерінің әрекеті бойынша робот серверлерін басқару алгоритмдері жасалады. Эксперименттік зерттеулердің нәтижелері біз роботтың жай-күйі мен қозғалу жағдайын теңестіру кезінде жабық циклдық роботты басқару жүйесінде өтпелі сипаттамаларды құруға мүмкіндік берді.

Information about authors:

Waldemar Wojcik - PhD of informatics and electronics, The Lublin University of Technology,professor;

Kulmamirov S.A. - Associate Professor of the Department "Information Systems", Ph.D., Academician MAIN. Kazakh National University al- Farabi;

Alimzhanova Zh.M. - Associate Professor of the Department "Information Systems", Ph.D., Kazakh National University al-Farabi;

Alimzhanova L.M. - Associate Professor of the Department "Information Systems", Ph.D., Kazakh National University. al-Farabi;

Akhmetova A.M. - Department "Artificial Intelligence and BigData " PhD Kazakh National University. al- Farabi;

Karyukin V.I. - teacher of the department "Information Systems", Kazakh National University. al- Farabi

REFERENCES

[1] Bobtsov A.A., Kapitanuk Yu. A., Kapitonov A. A., Kolyubin S. A., Pyrkin A. A., Chepinsky S. A., Shavetov S. V. LEGO MINDSTORMS NXT technology in studing Dents of the basics of adaptive management // Scientific and Technical Bulletin of St. Petersburg State University ITMO. 2011. No. 1. P.103-108.

[2]Information Control Problems in Manufacturing, V. 1-14.

[3]Bobtsov AA, Pyrkin AA, Borgul AS, Zimenko KA Control Approaches for Com-plicated Self-Unstable Plants with Two-Wheel Mobile Robot Motobot // Preprints of the 9th IFAC Symposium on Advances in Control Education (ACE2012), Nizhny Novgorod, Russia, 2012, pp. 107-111.

[4]Bobtsov AA, Kolyubin SA, Pyrkin AA, Borgul AS, Zimenko KA, Rabysh EY Mechatronic and Robotic Setups for Modern Control Theory Workshops // Precinints of the 9th IFAC, Nizhny Novgorod, Rus-sia, 2012, pp. 348-353.

[5] Bobtsov A. A., Pyrkin A. A., Borgul A. S., Zimenko K. A. Algorithms for managing the autonomous two-wheeled mobile robot “Motobot” // Scientific and Technical Newsletter of St. Petersburg State University ITMO, 2011, # 75, ss . 63–68.

[6] Borgul A. S., Gromov V. S., Zimenko K. A., Maklashevich S. Yu. System and Bolbota Stabilization Algorithms // Scientific and Technical Bulletin of St. Petersburg State University ITMO, 2011, # 75, ss. 58–63.

[7] Korolkova M. A., Krasnova S. A. Using NXTOSEK and EMBEDDED CODER ROBOT NXT for programming the LEGO MINDSTORMS NXT robot // Reports of the Fifth International Conference "Parallel Computing and Control Problems" PACO 2010, Moscow. P.1489-1496.

[8] Luchin R.M. Programming embedded systems: from model to robot // SPb.: Nauka, 2011. 184 p.

[9] LEGO firmware. http://mindstorms.lego.com

[10] leJOS. http://lejos.sourceforge.net

[11] nxtOSEK. http://lejos-osek.sourceforge.net

[12] OSEK. http://portal.osek-vdx.org

[13] ECRobotInstaller. www.mathworks.com/matlabcentral/fileexchange/25207

[14] Explorer. www.nxtprograms.com/NXT2/explorer/index.html

[15] NXT GamePad http://lejos-osek.sourceforge.net/nxtgamepad.htm.

[16] US Navy Academy to Acquire 50 RobotisBioloid Humanoid Robot Kits from KumoTek http://www.azonano.com/news.aspx?NewsID=4498

[17] Programming Bioloid robot in C. http://support.robotis.com/en /software/embeded_c/cm510_cm700.htm.

[18] ROBOTIS BIOLOID http://www.robotis.com/xe/BIOLOID_main_en.

[19] Benedettelli D., Casini M., Garulli A., Giannitrapani A., Vicino A.A. LEGO Mindstorms experimental setup for multi-agent systems // Control Applications, (CCA) & Intelligent Control, (ISIC), 2009 IEEE, pp. 1230-1235.

[20] Brigandi S., Yunfeng Wang, Field J. A LEGO Mindstorms NXT based multirobot system // Advanced Intelligent Mechatronics (AIM), 2010 IEEE / ASME International Conference, pp. 135-139.

[21] Akhtaruzzaman, M., Shafie A. A. Geometrical analysis of humanoid system by BIOLOID humanoid system standing on single leg // Mechatronics (ICOM), 2011 4th International Conference, pp. 1-5.

[22] RoboCup. http://www.robocup.org.

[23] Kalimoldayev, M.N., Pak, I.T., Baipakbayeva, S.T., Mun, G.A., Shaltykova, D.B., Suleimenov, I.E. Methodological basis for the development strategy of artificial intelligence systems in the republic of Kazakhstan in the message of the president of the Republic of Kazakhstan // News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences 6(432), - c. 47-54. - 2018. https://doi.org/10.32014/2018.2518-170X.34

[24] RoboPlus. Software for robot BIOLOID. http://www.wertech.ru/Blog/23-roboplus-bioloid.aspx.

[25]Samigulina, G.A., Nyusupov, A.T., Shayakhmetova, A.S.Analytical review of software for multi-agent systems and their applications // News of the National Academyof Sciences of the Republic of Kazakhstan,Series of Geology and Technical Sciences. - 3(429), c. 173-181. – 2018

[26] Askarova A.S., Bolegenova S.A., Safarik P., Bolegenova S.A., Maximov V.Yu., Beketayeva M.T., Nugymanova A.O. **(2018)** Modern computing experiments on pulverized coal combustion processes in boiler furnaces. N e w s of the National academy of sciences of the Republic of Kazakhstan. Physico-mathematical series Volume 6, Number 322 (2018), Pp. 5 – 14. ISSN 1991-346X https://doi.org/10.32014/2018.2518-1726.11