International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com
June 2023 | Issue 55 | Volume 15 | Number 2 | Pages 23-30

DEVELOPMENT OF ELECTRICAL DRIVE ECOAGROROBOT POWERED BY SOLAR PANELS

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Abstract- A wheeled ecoacrorobot powered by photoelectric panels and carrying out agricultural work has been proposed. The linear motion and maneuverability of ecoacrorobot is achieved by adjusting and reversing the speed of the two leading wheels. The other two wheels are of the "royal" (passive) type and do not generate traction. An algorithm for maneuvering and bypassing of obstacles of ecoagrorobot was developed, calculation of parameters of solar panels and selection of other devices were introduced.

Keywords: Ecoacrorobot, Solar Panel, Smart Village, Frequency Inverter.

1. INTRODUCTION

This article focuses on the development of an ecoagrorobot (EAR) that fed by solar panels and performs agricultural works within the framework of the "smart village" project in Karabakh.

Functional scheme of the proposed EAR shown in Figure 1, where WL1 and WR1 are leading wheels, using which the robot's speed can be changed and its movement direction can be reversed, WL2 and WR2 are "royal" (passive) type wheels, M1 and M2 are alternating current electric motors, and R1 and R2 are reduction.

The I1 and I2 are Frequency Inverters which changes the value and frequency of direct current, IQ1 and IQ2 are control panels for inverters, PV is solar panels, AK are accumulators, C is a controller, K is an agricultural mechanism for cultivation, SML and SMR are servomotors that performs the movement of the agricultural mechanism along the width and length of the EAR, nc1 and nc2 are the encoders that determine the angular velocity of the wheels, sγ, sv and sl are the sensors of the road, the course, and the linear speed of the EAR, respectively. The PLC is a logic controller that manages the work of EAR on in accordance with the developed program [4, 5, 6, 7, 8, 9, 10, 11, 12, 13].

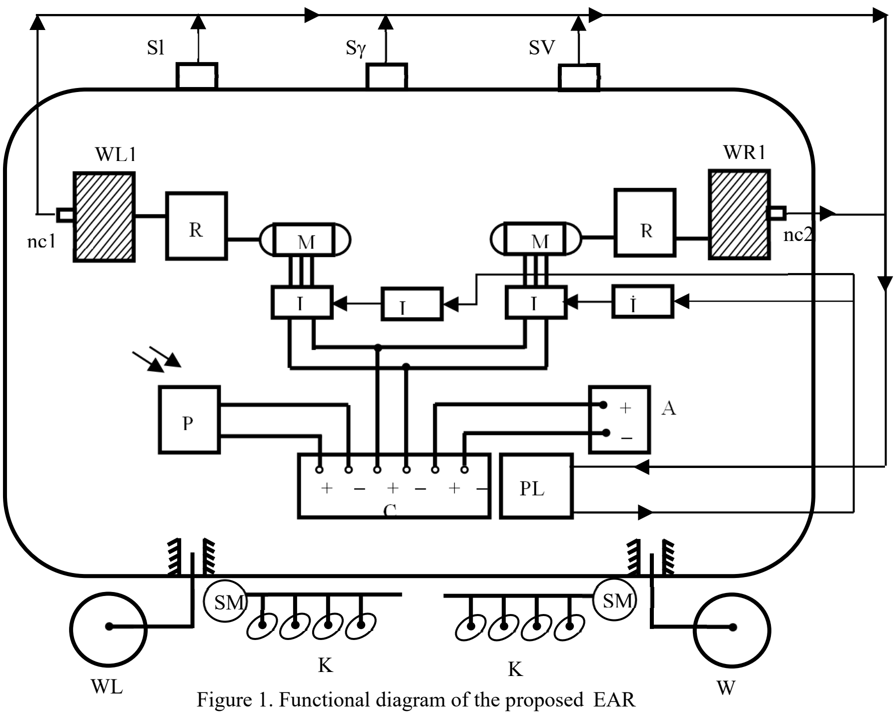

Figure 1. Functional diagram of the proposed EAR

2. THE WORKING PRINCIPLE OF EAR

In order to study the maneuverability of the Eco-Agrorobot, an experimental model of was developed in the laboratory. The size of the experimental model of the Eco-Agrorobot is 1.0×0.6 m (Figure 2). The model is powered by a front-wheel drives and the transmission consist of two numbers of 35W DC motors. Each motor is reversibly controlled independently and the speed is adjustable from zero to 1000rpm on both sides. The front wheels of the model are made of regular rubber tires, and the rear wheels are made of so-called caster wheels that can move freely. The front wheels fixed to the gears are driven by DC motors.

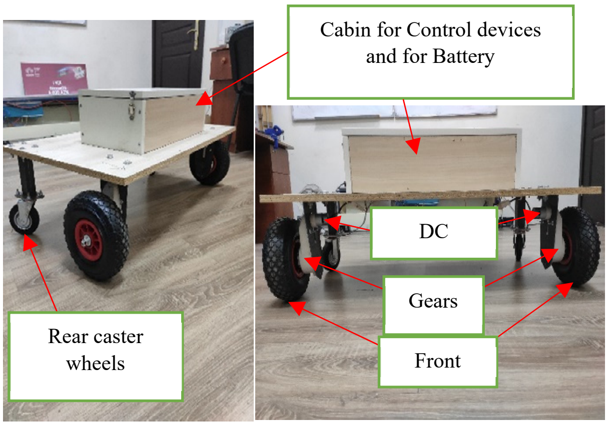

Figure 2. Experimental model of Eco-Agrorobot

The movements of the model are controlled by the Arduino microcontroller. The model is remotely controlled via a radio transmitter. The radio transmitter consists of an "Arduino Nano" microcontroller, an NRF24L01 wireless radio transmitter, 2 numbers of 10kOhm linear rheostats, a buzzer, 2 numbers of "Zero" position signal LEDs, a 9V DC battery and a switch. Two linear rheostats are installed on the radio transmitter for controlling the right and left wheels. The midpoint of the rheostat is the Zero level of the transmission signal. The speed of rotation of the wheels is adjusted by moving the sliders of the rheostat forward or backward, as well as are ensured that each wheel rotates independently forward or backward.

To prevent the engines from starting with the maximum current the LED signal lamps and buzzer are installed on the wireless transmitter. If the sliders of the rheostat are located outside the boundary of the "Zero" point in start time of the model, the signal will not be transmitted, and this situation will alert the operator through a buzzer and signal LEDs. After the slider of the rheostat is brought to the "Zero" position, the sound and light signals stop, and the transmitter is ready to perform its function. The wiring diagram of the transmitter is given in Figure 3. Here the AMS1117 voltage regulator is used as the power source of the NRF24L01 wireless transmitter. The assembled wireless transmitter is shown in Figure 4.

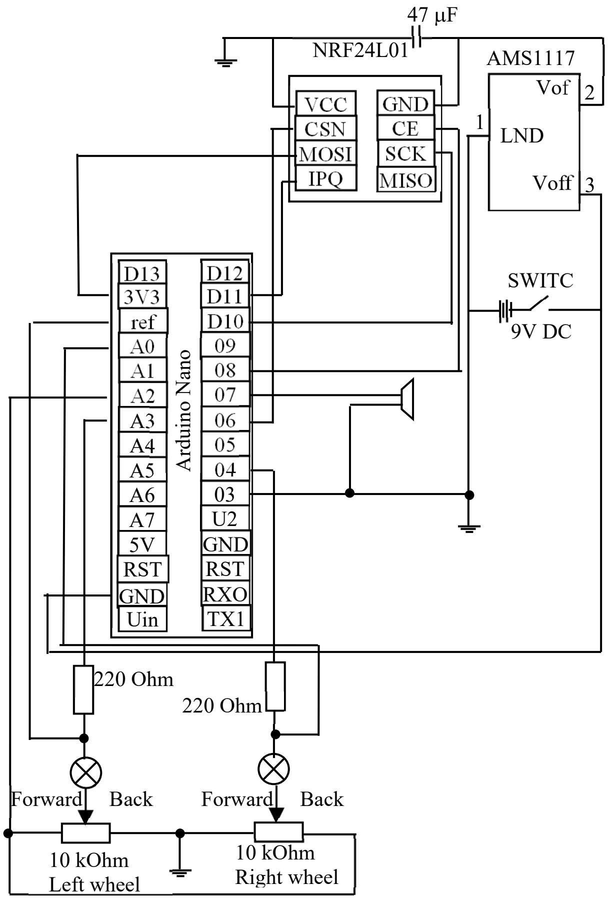

Figure 3. Wiring diagram of wireless transmitter

The main drive DC motors of the model are controlled by the "Arduino Nano" microcontroller. Control of the model is carried out remotely through a wireless radio transmitter. The NRF24L01 wireless radio receiver installed on the model receives the signals given by the wireless transmitter and ensures the rotation of the wheels (forward or backward) according to the given command.

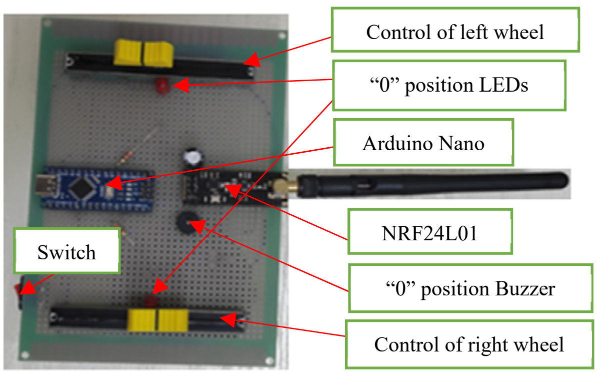

Figure 4. Assembled wireless transmitter

The PWM signals for motor control are transmitted from the Arduino Nano microcontroller to the BTS7960 Dual H-bridge High-power Motor Driver is connected to the motor power circuit and it drives the motors at the required speed and in the required direction based on the given command.

The wiring diagram of the motor control circuit is shown in Figure 5. Here, the AMS1117 voltage regulator is used as the power source of the NRF24L01 Radio receiver. The schematic diagram of the BTS7960 H-bridge Motor Driver is shown in Figure 5. The 43A BTS7960 H-bridge type devices ensure the reversible operation of the motors. The waveforms of voltage applied to electric motors at different speeds fixed by Oscilloscope are shown in Figures 6 and 7 [14].

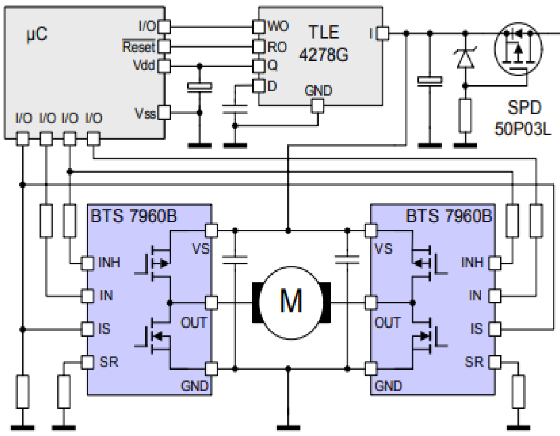

Figure 5. Wiring diagram of BTS7960 Dual H-bridge High-power Motor Driver

The electricity generated by the *PV* panels not only drives the EAR but also recharges the batteries. The charging of the *AK*, power supply from *PV* to *AK*, or to the consumers (*I*1, *I*2) is controlled by the controller (*C*). Operating of EAR starts when the solar radiation intensity is high (12:00-17:00). Until 12:00 and after 17:00 the power from *PV* charges only the *AK*. Before starting operation of EAR, the following parameters, which determine the operating mode of the EAR, are set to PLC:

- γ_T is assigned value of movement course of EAR;
- V_T is assigned value of linear speed of EAR's platform according to the technological process;
- L_T is maximum length of the cultivated road when moving in one direction;
- ω_{LT}, ω_{LT} ate assigned values of angular velocities of *WL*1 and *WR*1 wheels.

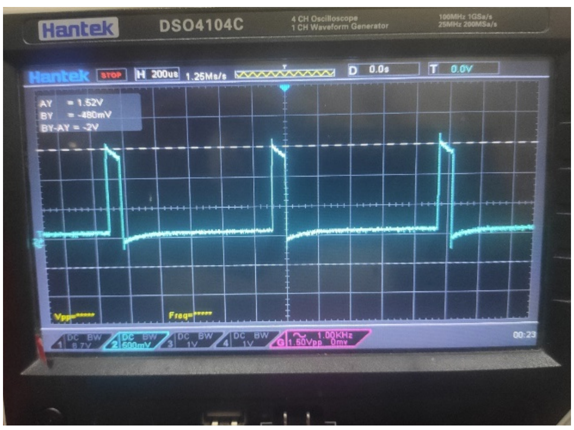

Figure 6. The waveforms of the voltage applied to the DC motors at the min. speed

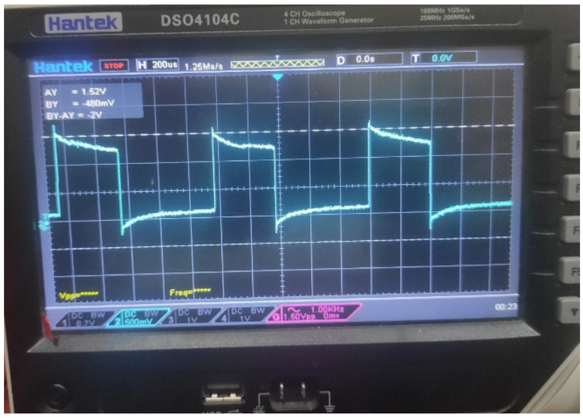

Figure 7. The waveforms of the voltage applied to the DC motors at the middle speed

The current values of these parameters are measured by sensors sγ, sv, sl, nc1 and nc2 and entered into the PLC. The algorithm shown in Figure 2 is implemented during movement of the EAR on the course. The 1st block is input of task values γ_T, V_T, L_T, ω_{LT}, ω_{RT} to the PLC, and the 2nd block is input of the current values of the γ, V, L, ω_L and ω_R parameters from the sensors to *PLC*. The 3rd block checks the course of EAR $(\gamma_T - \gamma)$. If the course rate of EAR is equal to the set value, i.e. $\gamma_T - \gamma = 0$, then checking process continues. Otherwise, the direction of the course is determined. The 4th block increases or decreases the angular velocities of the left *(WL1)* or right *(WR1)* wheels, depending on whether the EAR turns to the left or to the right. The blocks 5 and 6 continue these operations until they the set value of the course is reached. After the EAR moves along the assigned course, its linear speed is checked (block 7). If the current value of the linear speed (V) is less than the set value (block 8), then the angular velocities of the left and right wheels are increased (block 9). Otherwise, the angular velocities of the left and right wheels are reduced (block 10). This check is continued until the condition $V_T = V$ is satisfied (block 7).

After crossing the L_T path EAR stops. Then *SM*1 and *SM2* servo motors start moving the cultivating devices forward and outward from the center. The purpose of these operation is that the cultivation works can be carried out on far side of the strip when EAR moves back. In this case, the previously cultivated soil layer is not damaged by EAR wheels. Moving on to opposite direction the EAR approaches to the next lane with maneuvering mode after reaching the initial position. EAR resumes its work by switching to the program "movement course in new lane".

It should be noted that the steering control of the EAR, both during move on with determined course and in maneuver mode, in contrast to the steering control mode of the wheels [1], is performed only by changing the angular velocities of the wheels *WL*1 and *WR*1. The wheels *WL*1 and *WR*1 are rotated by *M*1 and *M*2 engines independently from each other around their axes referring to EAR platform.

Let's determine varying of the steering angle of EAR platform referring to the difference of angular velocity of the wheels WL1 and WR1. Figure 3 illustrates the angular velocities $(\omega_{L1},\ \omega_{R1})$ of the WL1 and WR1 wheels in the fixed *OXY* coordinate system referring to the EAR platform, the linear velocities of the wheel axes referring to the ground $(V_{L1},\ V_{R1})$ and the angular velocity of platform (ω) referring to the instantaneous center of speed *(O1)*. The coordinates of *L1, R1* and O_1 as follows: $L1(-X2;0)$, $\mathrm{R1}(X2;0)$, $\mathrm{R1}(X2;0)$, $\mathrm{O}_1(X1;0)$. The distance between rotational axes of wheels is $\Delta W = L1\times R1 = X2-(-X2) = 2\times X2$.

The distance between coordinate start and instantaneous center of velocity [1, 4, 14]: $\Delta X = OO_1 = X1$. The following expressions can be written for the specified parameters:

$$\left.\begin{aligned} V_{L1} &= \omega(\Delta X + 0.5\times\Delta W) \\ V_{R1} &= \omega(\Delta X - 0.5\times\Delta W) \end{aligned}\right\} \quad (1)$$

If the radius of the wheels WL1 and WR1 are denoted by *r*, then we can write for velocities V_{L1} and V_{R1},

$$\left.\begin{aligned} V_{L1} &= \omega_{L1}\times r \\ V_{R1} &= \omega_{R1}\times r \end{aligned}\right\} \quad (2)$$

Since the left side of (1) and (2) are equal:

$$\left.\begin{aligned} \omega_{L1}\times r &= \Delta X + 0.5\times\Delta W \\ \omega_{R1}\times r &= \Delta X - 0.5\times\Delta W \end{aligned}\right\} \quad (3)$$

We divide these expressions side to side:

$$\frac{\omega_{L1}}{\omega_{R1}} = \frac{\Delta X + 0.5\times\Delta W}{\Delta X - 0.5\times\Delta W} \quad (4)$$

The $K_\omega = \frac{\omega_{L1}}{\omega_{R1}}$, if we accept this substitution:

$$K_\omega = \frac{\Delta X + 0.5\times\Delta W}{\Delta X - 0.5\times\Delta W} \quad (5)$$

or

$$\Delta X = 0.5\times\Delta W\frac{K_\omega + 1}{K_\omega - 1} \quad (6)$$

The $\Delta X - K_\omega$ characteristic is demonstrated in Figure 10.

The analysis of this characteristic shows that when $K_\omega = 1\times\Delta X$ approaches to infinity [2, 3]. This means that the wheels WL1 and WR1 rotate in the same direction at the same angular velocities, the EAR moves towards straight line and the instantaneous speeds center is at infinity.

When $K_\omega = -1,\ \Delta X = 0$, that is, if ω_{L1} rotates in the forward direction, ω_{R1} rotates in the reverse direction, and the absolute values of the angular velocities of the wheels are equal to each other, then the EAR will rotate around the midpoint "O" of an axle connecting the centers of rotation of the wheels. This is used in maneuver mode when EAR moves to a new lane.

Diagram of EAR's transition to a new lane illustrated in Figure 11. The figure shows the positions "a", "b", "c" and "d" of the EAR during the transition from the first lane to second lane

At position "a", EAR moves back to a distance of $0.5\Delta W$ from the boundary line of the cultivated lane (*S*1 - *S*1), then the wheels *WL*1 and *WR*1 rotate in opposite directions to each other at equal speed $K_\omega = -1$ turns 90° clockwise around the point "O".

At position "d", already turned 90° EAR moves at a certain speed *V* in a straight line along the boundary line (*S*2 – *S*2). When the EAR reaches the border line (*S*1 – *S*1) activates the agricultural mechanism (K) which carrying out the cultivation works and starts cultivating in the second lane. EAR continues moving, avoiding the obstacles encountered while moving on the defined course.

Figure 12 is a graphical description for determining the parameters of the EAR performing this process. In the figure, there is an element of *M* as obstacle that has entered the lane as far as Δl distance. The parameters of the obstacle element are determined by a camera installed in the EAR. Let determine the coordinates of EAR's instantaneous turn center (O_1) and the turning radius (*R*) of EAR around that point to bypass the obstacle element.

For this purpose, the point WL1 is connected to the point M1 by a straight line. From point M1 straight line is drawn at an angle equal to the angle *M1WL1O*(α_1). The point O_1 where this straight line intersects the OX axis will be the instantaneous turning center, and the straight line $M1O_1$ will be the turning radius (*R*). Based on the distances $M1WL1 = l_2$ and Δl, $\sin\alpha_2 = \frac{\Delta l}{l_2}$ and $\alpha_2 = \arcsin\frac{\Delta l}{l_2}$.

Since the radius *R* is:

$$R = \frac{\Delta W}{2} + \Delta X \quad (8)$$

Then according to (7) and (8):

$$R = \frac{l_2}{2\times\cos\alpha_1} = \frac{l_2}{2\times\sin\alpha_2} \quad (7)$$

Parameters are calculated [14].

$$\left.\begin{aligned} \frac{\Delta W}{2} + \Delta X &= \frac{l_2}{2\times\sin\alpha 2} \\ \Delta X &= \frac{l_2}{2\times\sin\alpha_2} - \frac{\Delta W}{2} \end{aligned}\right\} \quad (9)$$

After determining the coordinates of the instantaneous turning center, according to Equation (5), Equation (10) is calculated.

$$K_\omega = \frac{\Delta X + 0.5\times\Delta W}{\Delta X - 0.5\times\Delta W} \quad (10)$$

Taking the values V_{L1} or $\omega_{L1} = \frac{V_{L1}}{r}$ from Equation (11).

$$K_\omega = \frac{\omega_{L1}}{\omega_{R1}} = \frac{V_{L1}}{V_{R1}} \quad (11)$$

where, $V_{R1} = \frac{V_{L1}}{K_\omega}$ or $\omega_{R1} = \frac{\omega_{L1}}{K_\omega}$ is defined.

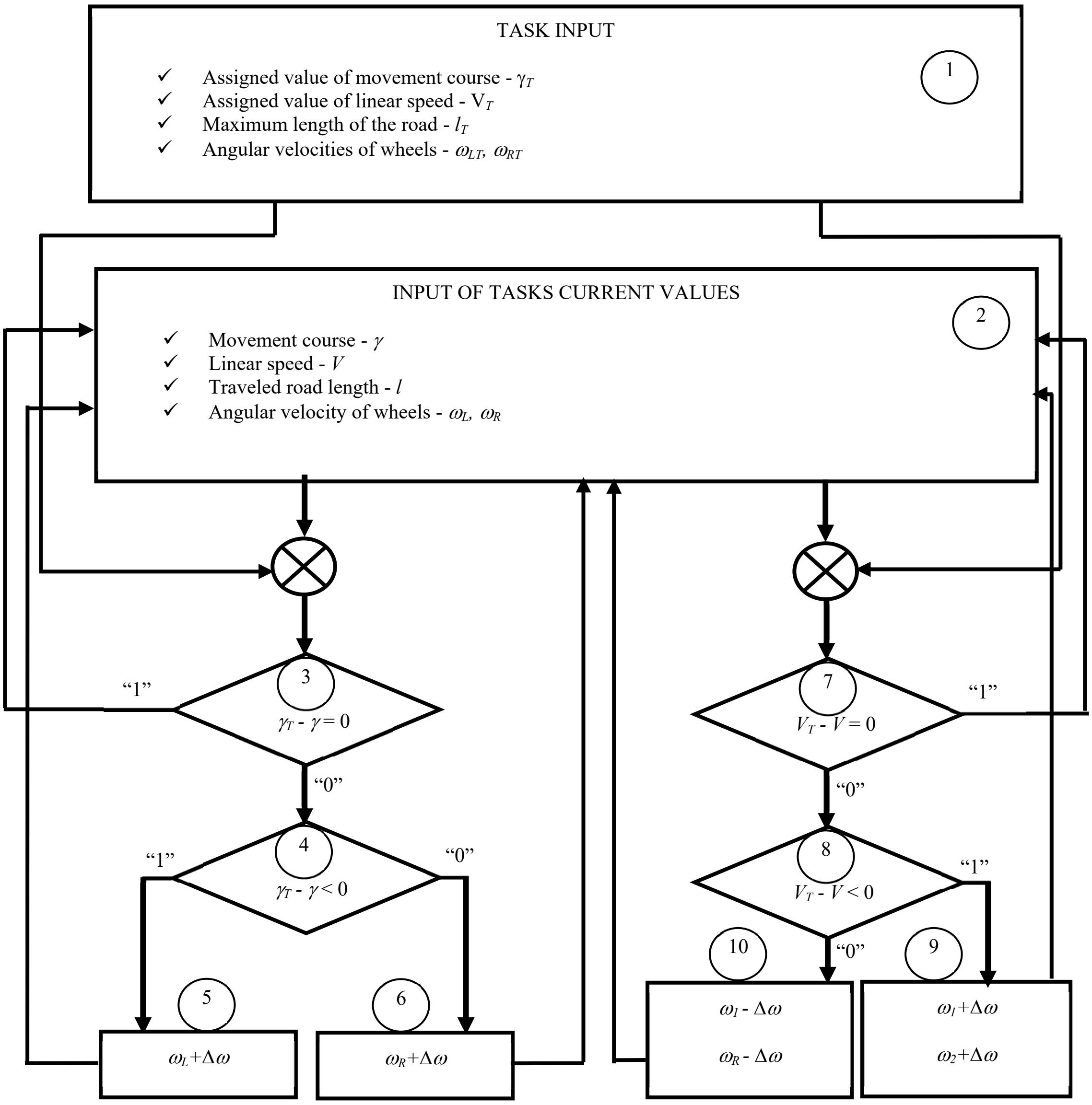

Figure 8. Block diagram of movement program of EAR according to course

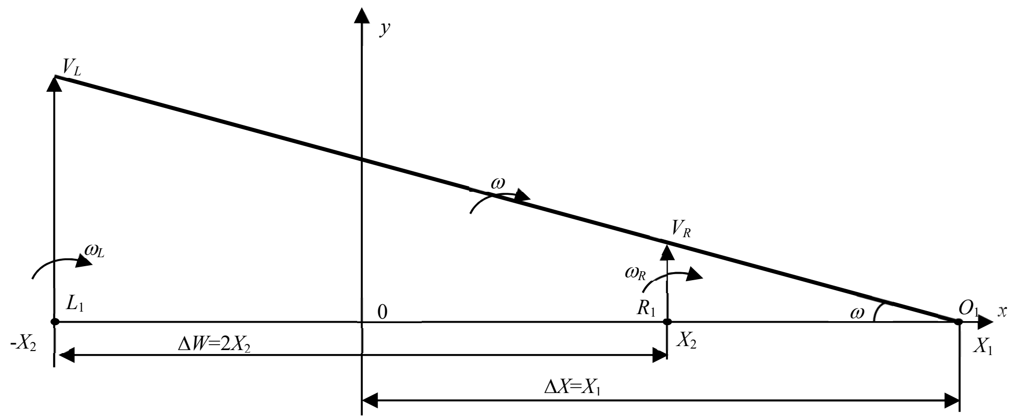

Figure 9. Angular $(\omega_{L1}, \omega_{R1}, \omega)$ and linear velocities (V_{L1}, V_{R1}) in the fixed OXY coordinate system referring to the EAR platform

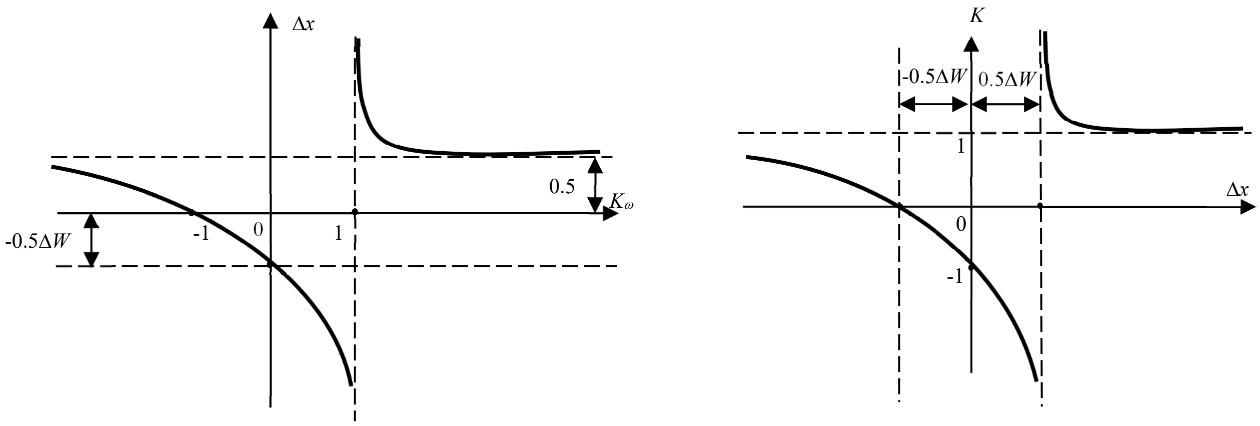

Figure 10. ΔX–K_ω and K_ω–ΔX characteristics

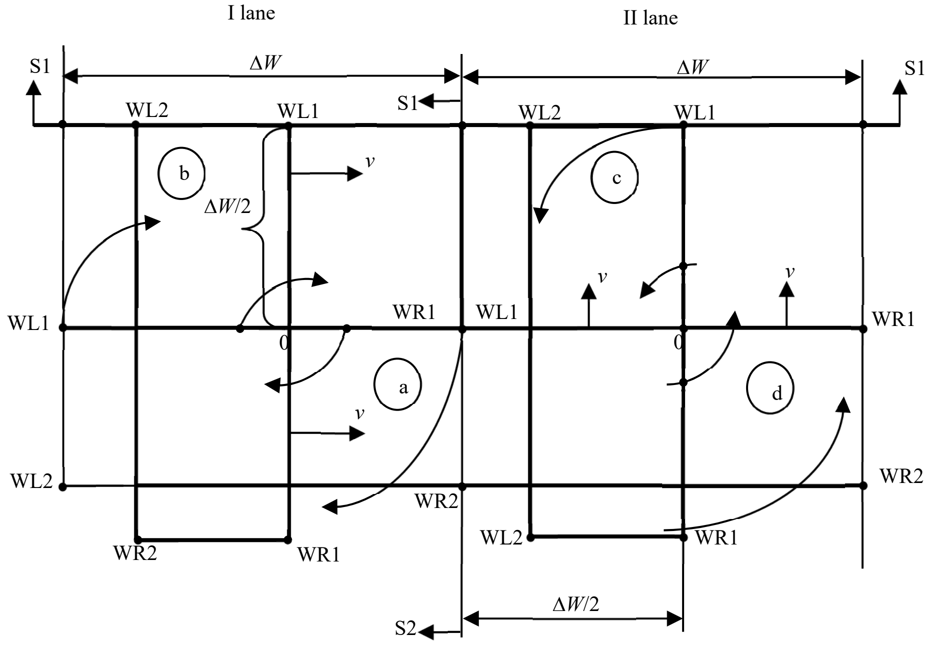

Figure 11. Diagram of EAR moving to new lane

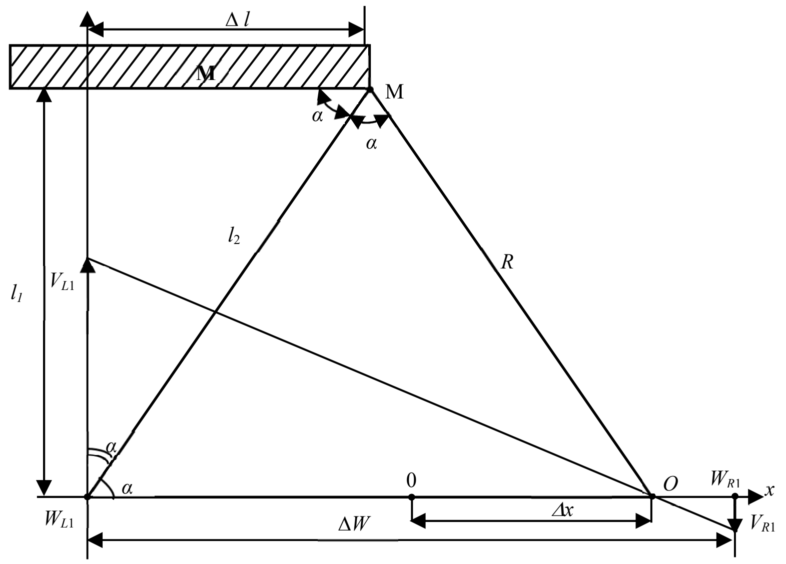

Figure 12. Graphical illustration of the parameters of EAR to continue its defined course, bypassing the obstacle

REFERENCES

[1] A.M. Shelemetyev, Y.V. Shelemetyeva, A.V. Smirnov, "Development of a Wheeled Vehicle Control System Based on the Difference in the Speeds of Rotation of the Control Wheels", Bulletin of the Chuvash University, pp. 259-312, Chuvashia, Russia, 2016.
[2] National Atlas of the Republic of Azerbaijan, "State Land and Mapping Committee", pp. 132, Baku, Azerbaijan, 2014.
[3] E. Kayacana, E. Kayacanb, H. Ramona, W. Saeysa, "Towards Agrobots: Identification of the Yaw Dynamics and Trajectory Tracking of an Autonomous Tractor", arXiv, 2104.06833v1, pp. 1-17, April 2021.
[4] H. Fang, L. Dou, J. Chen, R. Lenain, B. Thuilot, P. Martinet, "Robust Anti-Sliding Control of Autonomous Vehicles in Presence of Lateral Disturbances", Control Engineering Practice, Vol. 19, pp. 468-478, May 2011.
[5] J. Backman, T. Oksanen, A. Visala, "Navigation System for Agricultural Machines: Nonlinear Model Predictive Path Tracking", Computers and Electronics in Agriculture, Vol. 82, pp. 32-43, March 2012.
[6] D. Piyabongkarn, R. Rajamani, J.A. Grogg, J.Y. Lew, "Development and Experimental Evaluation of a Slip Angle Estimator for Vehicle Stability Control", IEEE Transactions on Control Systems Technology, Vol. 17, pp. 78-88, 2009.
[7] E. Kayacan, E. Kayacan, H. Ramon, W. Saeys, "Modeling and Identification of the Yaw Dynamics of an Autonomous Tractor", The 9th Asian Control Conference (ASCC), pp. 1-6, 2013.
[8] E. Kayacan, E. Kayacan, H. Ramon, and W. Saeys, "Towards Agrobots: Identification of the Yaw Dynamics and Trajectory Tracking of an Autonomous Tractor", Computers and Electronics in Agriculture, Vol. 115, pp. 78-87, April 2015.
[9] A. Khalaji, S. Moosavian, "Robust Adaptive Controller for a Tractor-Trailer Mobile Robot", Mechatronics, IEEE/ASME Transactions on, Vol. 19, No. 3, pp. 943-953, June 2014.
[10] M. Michalek, M. Kielczewski, "The Concept of Passive Control Assistance for Docking Maneuvers with n-Trailer Vehicles", Mechatronics, IEEE/ASME Transactions on, Vol. 20, No. 5, pp. 2075-2084, Moscow, Russia, October 2015.
[11] J.B. Derrick, D.M. Bevly, "Adaptive Steering Control of a Farm Tractor with Varying Yaw Rate Properties", Jour. of Field Robotics, Vol. 26, No. 6-7, pp. 519-536, 2009.
[12] M. Karkee, B.L. Steward, "Study of the Open and Closed Loop Characteristics of a Tractor and a Single Axle Towed Implement System", Journal of Terramechanics, Vol. 47, No. 6, pp. 379-393, 2010.
[13] H. Li, W. Yan, "Model Predictive Stabilization of Constrained Underactuated Autonomous Underwater Vehicles with Guaranteed Feasibility and Stability", IEEE/ASME Transactions on Mechatronics, Vol. 22, No. 3, pp. 1185-1194, June 2017.
[14] Z.A. Hasanov, T.D. Jafarov, S.A. Khanahmedova, S.K. Gasimov, "Development of Ecoagrorobot Powered by Solar Panels", The 18th International Conference on Technical and Physical Problems of Engineering (ICTPE), pp. 91-98, 30 October 2022.

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