TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 65, Issue II, June, 2022

ASPECTS REGARDING THE DYNAMICS OF A PROTOTYPE OF REMOTE CONTROLLED LOGISTICS TRANSPORT PLATFORM

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Abstract: *In the current context of the evolution of society and the need to strengthen its response to major risks related to the high degree of uncertainty of developments in the security environment, correlated with threats and vulnerabilities to defense and security, research on high-level activities with risk in the field of protection of personnel involved in military actions, has experienced a wide development. The work develops a remotely controlled mobile robot, capable of moving in unknown or dangerous environments for humans. The robot can be controlled by a web application and a Wi-Fi module, integrated in a Raspberry Pi board, and 4 DC motors will be used to move it. The aim of this paper is to conduct a parametric study on the one hand, and on the other hand some aspects of the dynamics of a prototype remote-controlled logistics platform.*

Key words: *miniature prototype of remote-controlled logistics platform, remote control platform, dynamic parameters, the raspberry pi platform, control system, numerical analysis.*

1. STATE OF ART

The term "mechatronics" were first used in 1975 by the Japanese concern Yaskawa Electric Corporation, being an abbreviation of the words Mechanics-Electronics-Informatics.

The purpose of this science is to improve the functionality of equipment and technical systems by uniting the component disciplines into a unitary whole [1].

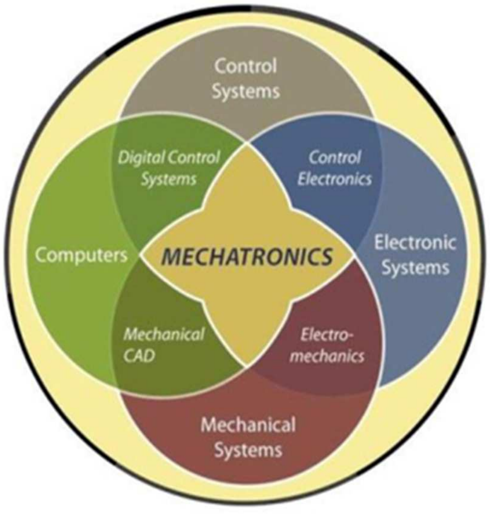


Fig. 1 Mechatronics [2]

Robotics is the science that deals with the technology, design and manufacture of robots. Robotics requires knowledge of electronics, mechanics and programming.

The name robot was first introduced by Karel Čapek in 1921 in his work "Universal Robots of Rossum", starting from the word ROBOT, work, routine activity, taken over by Isaac Asimov, in the science-fiction paper "Escape in a circle" (1941). Robots are "mechanisms that perform different tasks on their own". Robots are made mainly through a combination of disciplines: mechatronics, electrical engineering and computer science. To create autonomous systems (to find solutions on their own), it is necessary to connect as many robotics disciplines as possible. Here the emphasis is on the connection of the concepts of artificial intelligence or neuroinformatic (part of computer science) as well as biocybernetics (part of biology). From the connection between biology and technique, bionics developed [3]. The most important components of robots are sensors, which allow their mobility in the environment and the most precise guidance. A

Received: 30.04.22; **Similarities**: 18.05.22: **Reviewed**: 11.06./07.05622: **Accepted**:21.06.22.

robot does not necessarily have to be able to operate autonomously, which is why a distinction can be made between autonomous and remote-controlled robots. Although mobile robots have been used in industry since ancient times, they have become more and more present in everyday life.

The rapid development of communications, automation, navigation and robotics has rapidly changed the work environment, and now mobile robots are part of modern life (see autonomous vehicle, car with automatic control, drones, security service etc.). There are various constructive variants of mobile robots, but later, with the mass development of microcomputers and embedded systems, various robotic mobile products have been developed. Depending on the destination, mobile robots can have different configurations, multiple sensors (infrared, ultrasonic, webcams, GPS, magnetic, etc.) or different command and control algorithms, being monitored locally or remotely. Mobile wheeled robots can, for example, be controlled in real time via the Internet using a secure web page or Internet of Things (IoT) technology. All platforms are based on a single Raspberry Pi on-board computer and allow online viewing of the work environment via a webcam.

However, some works may also have a strong didactic emphasis, the mobile robots being modularly designed and reused as a support material in the study of robotics. There are, of course, platforms built for a more precise purpose.

“One of the main visions in the field of robotics is to produce fully flexible devices, but the problem has always been to replace rigid components such as batteries and electronic control systems with flexible ones, which can then be put together. This research demonstrates that we can easily manufacture the key components of a simple and completely flexible robot”, said octoberbot project coordinator Professor Robert Wood in a press release from Harvard University [4].

Most researchers in autonomous inventions present as the first example in which Nicola Tesla exhibited an autonomous machine at Madison Square backyard, 1989.

Using a small control box with a radio transmission, he managed to maneuver a tiny ship around a pool of water and even ignite and he turned off his driving lights, all without any visible connection between the boat and the controller [5].

Between 1966-1972 the Standford Research Institute introduced the Shakey Robot, which was equipped with a video camera, sound rangefinders and sensors that made it possible to avoid a collision, all controlled by a wireless connection. It has been declared as the first mobile robot capable of interpreting environmental signals so that it can navigate obstacles. The French laboratory for systems analysis and architecture designed the Hilare 1 mobile robot, equipped with ultrasonic sensors and a video camera with a robotic arm, in 1977 [6].

Another important invention for developing autonomous systems, which occur in 1986, is the machine developed by the team of Ernst Director Dickmanns, who was able drive alone on streets without traffic, with speeds of up to 90 km/h [8]. Based on the literature, during 2009 he began to test his autonomous driving technology on the Toyota Prius, on the streets of California.

First Look Company released the iRobot in 2010, a small, lightweight robot that can help soldiers get an overview of a mission without being discovered. It is equipped with a video camera that offers a 360-degree image that is transmitted to a touchscreen located on the soldier’s arm, also acting as a controller.

In addition to the video equipment, audio equipment helps the military to listen to what is happening around the robot, but also to be able to send messages on the battlefield. It catches a speed of up to 5.5 km/h, can withstand underwater with a depth of 1 m and has a range of 6 h [7]. In 2012, NASA successfully launched the Curiosity autonomous rover, which landed on Mars. In 2014, Google unveiled the new prototype autonomous vehicle, which has no steering wheel and pedals.

By the beginning of 2016, Google’s fleet of autonomous vehicles had driven 2,777,585 km. Also in 2018, an EOD robot was developed capable of defusing bombs and fighting terrorism without creating human damage [8].

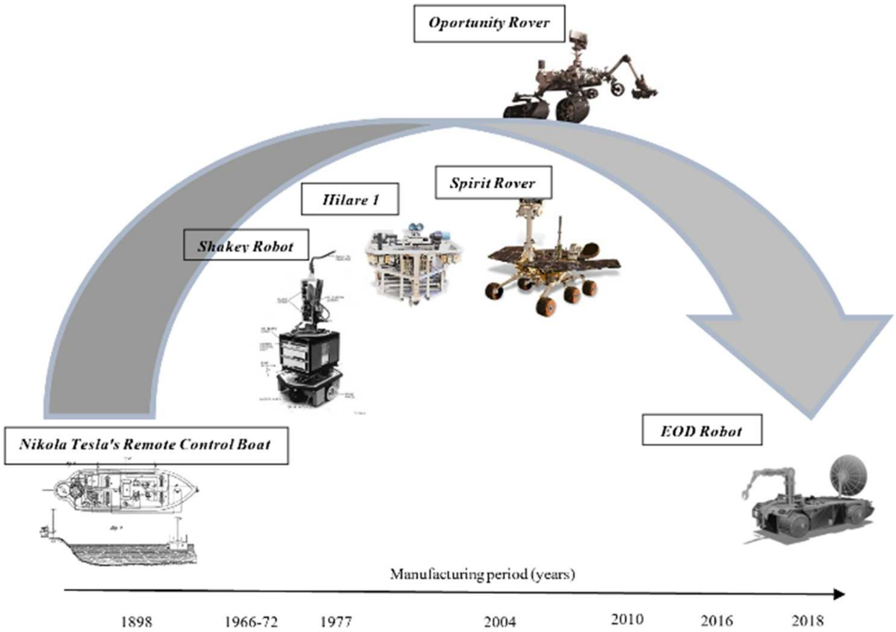


Fig. 2 The evolution of autonomous systems over time

2. DEVELOPMENT OF THE MINIATURE PROTOTYPE OF THE REMOTE-CONTROLLED LOGISTICS PLATFORM

2.1 Preparing the work environment / Design variants

One of the design variants is the logistics platform using as command-and-control element the Arduino module that is controlled via Bluetooth.

Another variant would be logistics platform with Arduino board controlled with IR remote control, as in the previously proposed version, the remote-controlled logistics platform is equipped with an Arduino board, but differs the way of transmitting information (infrared environment). Infrared (IR) radiation is electromagnetic radiation whose wavelength is longer than that of visible light (400-700 nm), but shorter than that of terahertz radiation (100 µm - 1 mm) and microwaves (~ 30000 µm). Most of the thermal radiation emitted by objects at room temperature is infrared.

The third design option is the logistics platform equipped with Raspberry Pi board controlled via Wi-Fi.

The most important difference between the design variants defined above is the way the data is transmitted. In the first case, the Bluetooth connection offers a stable connection, with low power consumption, but also large limitations in terms of distance. The infrared module has, in turn, numerous advantages: low cost, simplicity, low energy consumption, but also has several disadvantages, which, in this case, are indispensable, more precisely, the short range. The Wi-Fi module does consume more power than the other variants, but when it comes to the driving distance, it is the most efficient. Additionally, it can be accessed by any device with a modern browser and an internet connection.

2.2 System architecture

The Raspberry Pi model 3 B board is the command-and-control element of the platform (system) and is connected to two 3.7 V 2200 Ah Li-Ion batteries. To connect the Raspberry Pi module and the DC motors that operate each of the four wheels of the platform, the 4WD HAT module is used, connected to the 40 pins (input and output) of the Raspberry Pi module. An ultrasonic sensor HC-SR04 is connected to a 4WD HAT module, which is driven by a servomotor. Another sensor connected to the Raspberry Pi board is the photo-interrupter, which helps to measure the speed of the miniature prototype. The programming language used is Python, and a source code was created to execute the commands. To enter in the terminal of the Raspberry Pi module the command to execute the source code from Python, a monitor (display), a keyboard and a mouse are used. After inserting the source code access command, an IP address is displayed, which is used to access the created application (interface) via a cell phone.

2.3 Wiring diagram of the system and power balance

Next, in „Fig. 3" is presented the wiring diagram of the connections between the brain of the system - Raspberry Pi 3 B board, batteries, sensors and DC motors, which is integrated in the miniature prototype of the remote-controlled logistics platform.

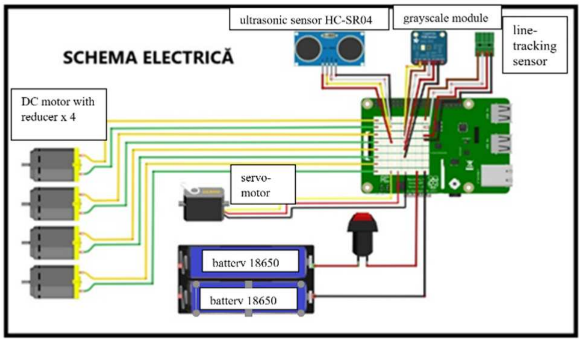


Fig.3. Wiring diagram of the system

Next, the power balance was performed and an available power of 12.75 W, also an installed power of 6.55 W was obtained. Available power, calculated as the product of the output voltage of the Raspberry Pi - 5.1 V and the current through the circuit supplied by the 2.5 A board:

$$P_d = 5{,}1V \cdot 2{,}1A = 12{,}75W \quad (1)$$

P

$$\text{P}_{\text{ultrasonic}}:\ P_u = 3{,}3V \cdot 0{,}015\,A = 0.0495W \quad (2)$$

$$\text{P}_{\text{servomotor}}:\ P_s = 5V \cdot 0{,}1\,A = 0{,}5W \quad (3)$$

$$\text{P}_{\text{motor}}:\ P_M = 5V \cdot 0{,}3\,A \cdot 4buc = 6W \quad (4)$$

Installed power, calculated as the sum of the power supplied to the sensors and motors of continuous cleaning:

$$P_i = P_u + P_s + P_M = 0{,}0495W + 0{,}5W + 6W \cong 6{,}55W \quad (5)$$

A power reserve will result, by the difference between the available power and the installed power:

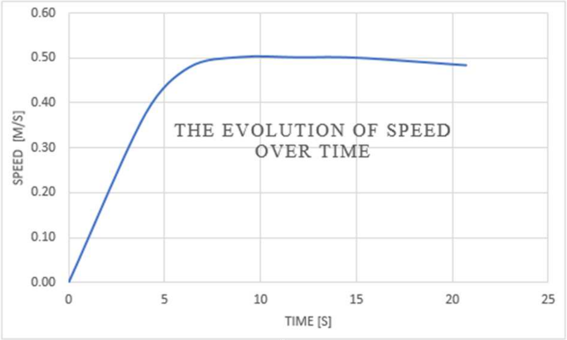
$$P_{rez} = P_d - P_i = 12{,}75W - 6{,}55W = 6{,}2W \quad (6)$$

In conclusion, just over 50% of the power provided by Raspberry Pi is used. Due to the power reserve, more powerful motors can be used or other sensors can be added, such as the introduction of a sensor for tracking a traced path - grayscale.

3. ASPECTS OF PROTOTYPE DYNAMICS IN THE MINIATURE OF REMOTE - CONTROLLED LOGISTICS PLATFORM

Vehicle dynamics studies the movement of vehicles. The basic parameters of the vehicles define the qualities that must be assigned to it, from the design phase, so that the performances obtained place it at the level of the best models in the same category. The main dynamic parameters of a vehicle are the dynamic factor of the vehicle, the maximum pulling force on the hook, the maximum speed, the average technical speed, the operating speed, the economic speed, the starting time, the effective braking distance, the stopping distance, the running space free, maximum slope, the stability of the vehicle.

3.1. Results. Average speed and maximum affordable ramp

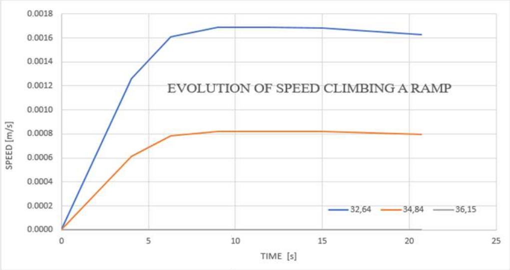


(a)

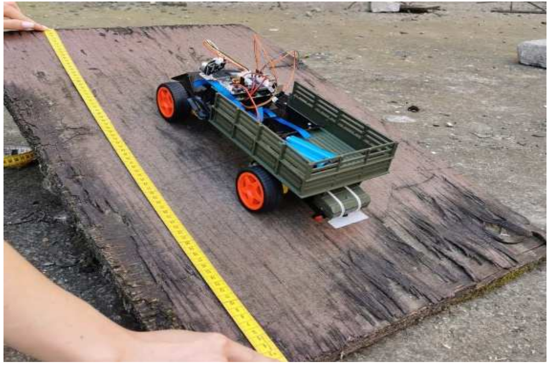
(b)

Fig. 4. (a) Graph of the evolution of speed over time of the prototype and (b) experimental determination

The Fig.4 shows the graph of the evolution of the speed of the prototype of the remote-controlled transport platform over time.



(a)



(b)

Fig. 5. **(a) Graph of the evolution of the speed for different inclination angles of the ramp, and (b) experimental determination**

The determination was performed experimentally, measuring the time in which the prototype traveled a certain distance. It can be seen that after about 7.6 s, the car starts to reach a constant speed of 0.50 m/s, which indicates that until the moment t = 7.6 s the prototype was in a state of acceleration, reaching a maximum speed of movement, which he kept constant until it stopped.

Note: The measurements were performed on a section of paved road in a straight line and without unevenness.

Figure 5 shows the graph of the evolution of the speed of the prototype over time, as it climbs ramp. Experimental determination was performed (for a slope inclined at an angle of 32.68 degrees, 34.84 degrees and 36.15 degrees), measuring the maximum speed that the car can reach when climbing the slope and the maximum slope that it can climb. It can be seen that at a slope of 36.15 degrees the prototype no longer develops enough power to climb it.

Simultaneously, note that for the ascent of the slopes of 32.68 and 34.84 degrees, respectively, the speed of the platform is low, respectively, with a percentage of 66% in the case of the slope with an inclination of 34.84 degrees and a percentage of 84% in the case of a slope of 34.84 degrees.

3.2. Results and discussions. Determining the stability of the miniature prototype and determining the type of control

Among the performance requirements used in the design, the most important is that the system is stable. An unstable system is considered useless. A good suspension can ensure good handling on the road - maneuverability and stability, while providing comfort for passengers when the transport platform is facing any road disturbance (eg potholes, cracks and uneven pavements). The body of the transport platform should not have large oscillations and the oscillations should disappear quickly. To analyze the stability of the system, the simplified model 1/4 of the suspension model (on one of the four wheels) was considered.

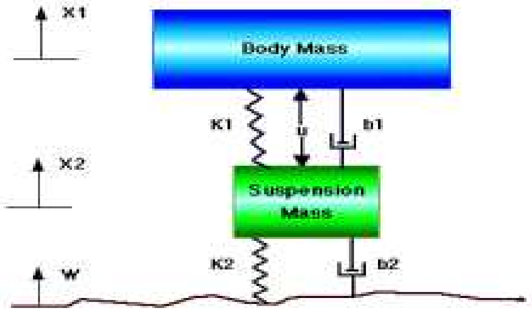


Fig.6. Simplified model - 1/4 of the suspension

To identify the mass and coordinates of its center of gravity of the remote-controlled logistics platform prototype, the 3D model is designed in the Autodesk Inventor.

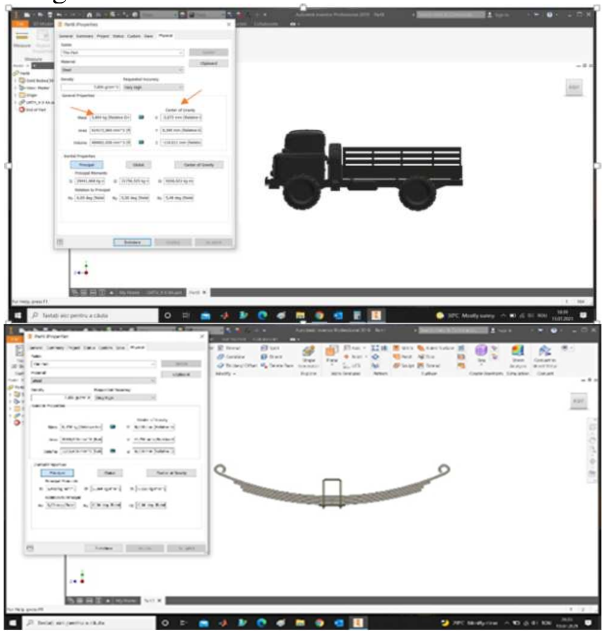


Fig. 7. Mass and coordinates of the center of gravity for 3D Model

The following values are obtained: suspended mass - remote control platform body (m1) = 950 g, suspension mass (m2) = 10 g, elastic constant of the suspension spring (k1) = 30.4 N / m, elastic constant of the wheel with tire (k2) = 15.63 N / m, suspension damping constant (c1) = 0.13 Ns / m. tire damping constant with tire (c2) = 0.47 Ns / m. control force (u) = output of the controller to be determined.

The road disturbance is a step input. All of this simulates the situation in which the remote-controlled platform crosses a bump in the road.

Using the equations of motion: (Newton-d'Alembert method) - (in the time domain) and applying the Laplace transform the equations of motion in the Laplace domain are obtained, s-domain.

Assuming zero initial conditions, the transfer functions of the system are obtained:

$$m_1\ddot{y}_1 + \ddot{b}\dot{y}_1+k_1y_1=u(t) \quad (7)$$

$$m_2\ddot{y}_2 + \ddot{b}_2\dot{y}_2+k_2y_2=u(t) \quad (8)$$

$$y_1(t)=0, y_2(t)=0, \dot{y}_1(t)=0, \dot{y}_2(t)=0 \quad (9)$$

$$L\big(F(t)\big)=F(s)= \int_0^\infty F(t)e^{-st}dt \quad (10)$$

$$L\big[f(\dot{t})\big]=sF(s)-f(0) \quad (11)$$

$$L\big[f(\ddot{t})\big]=s^2F(s)-sf(t)-f(\dot{0}) \quad (12)$$

Applying the Laplace transform it is obtain:

$$m[s^2Y(s) - sy_0 \dot{-}\ y_0] + c[sY(s) - \ y_0] + kY(s) = F(s) \quad (13)$$

The initial conditions are considered:

$$y_0=0, y_0=0 \rightarrow (ms^2+\dot{b}s+k)Y(s)=F(s) \quad (14)$$

The transfer function is defined: the ratio between the Laplace transform of the output quantity and the Laplace transform of the input quantity:

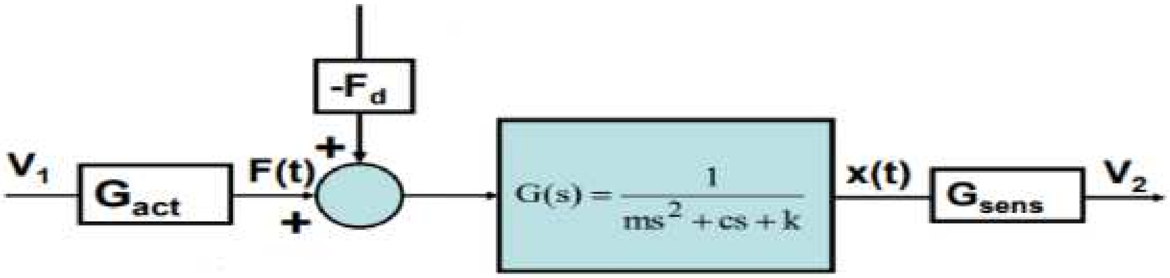
$$G(s)=\frac{Y(s)}{F(s)}=\frac{1}{ms^2+cs+k} \rightarrow Y(s)=G(s)F(s) \quad (15)$$

In order to obtain the system response in the time domain, the inverse of the Laplace transform must be determined, from the Laplace domain, s-domain, to the time domain (time response):

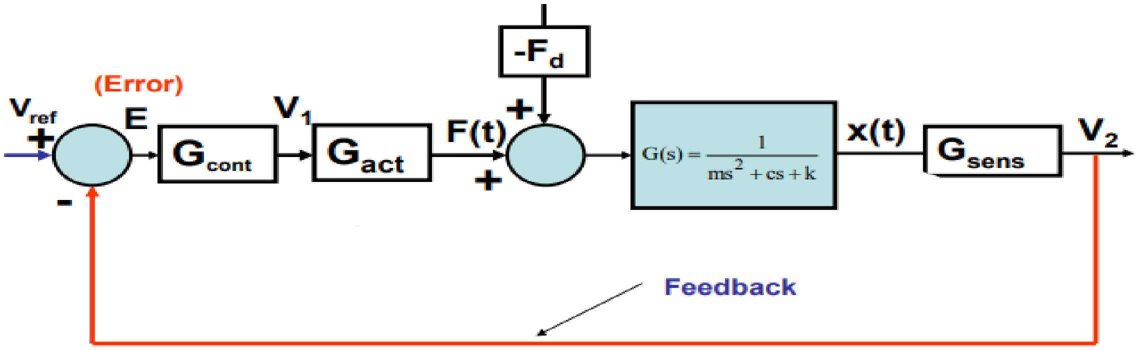
$$y(t)=L^{-1}Y(s)=L^{-1}[G(s)F(s)] \quad (16)$$

The study also includes the analysis of open circuit control when the system is and when it is not disturbed from the outside, to easily analyze the effectiveness of such control.

The open circuit and closed-circuit control have the block diagram as in the "Fig.8":



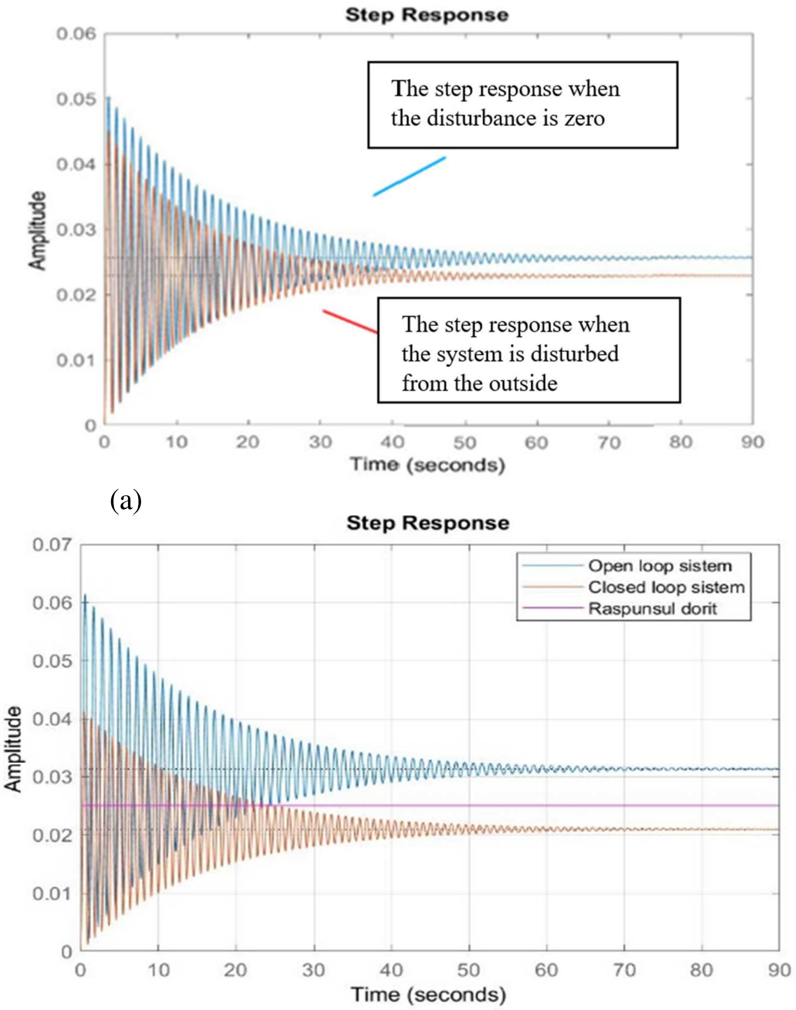
(a)



(b)

Fig. 8. (a) Block diagram of open loop control, (b) Block diagram of closed loop control.

By introducing relationships in the MATLAB software obtains the graphs corresponding to the two types of control.



The step response when the disturbance is zero

The step response when the system is disturbed from the outside

(a)

(b)

Fig. 9. (a) Block diagram of open loop control, (b) Block diagram of closed loop control

From this graph of the response, in the open circuit (loop) ("Fig. 9 (a)"), for a unit stage input we notice that the system is under-amortized.

The error (deviation from equilibrium) is about 0.01 m. From the graph of the open circuit response for the 0.1 m step disturbance, ("Fig. 9 (a)" drawn in red) we notice that. When the platform crosses a 10 cm high road bump, the platform body will oscillate for an unacceptably long time (50 seconds), with a higher amplitude, 13 cm, than the initial impact. People (or merchandise) on the platform will not feel comfortable with such an oscillation. It is a great time (from the actual impact) of decline and this will cause damage to the suspension system.

The solution to this problem is to add controller feedback in the system to improve performance "Fig. 9 (b)".

Next, is analyzed the behavior for the simplified model 1/4 of the suspension model (on one of the four wheels) using the PID algorithm, with the values of the proportional, integral and derivative amplification factor;

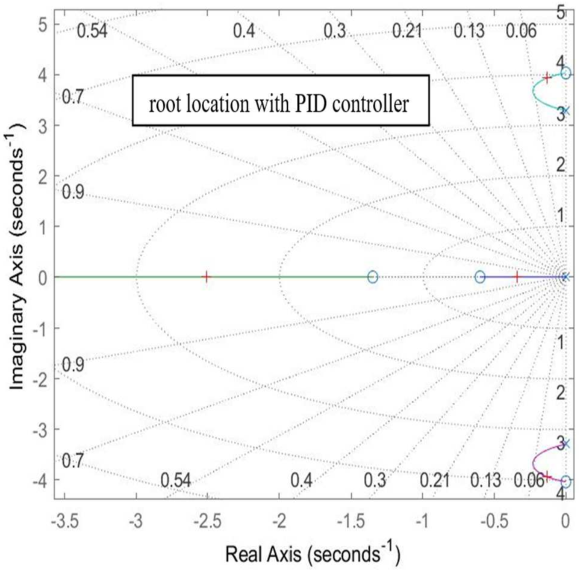


Fig. 10. Place the roots of the transfer function with PID controller

The graph, "Fig. 10", shows the root location of the G (s) transfer function of the system for the case under study. The stability of a control system is directly related to the location of the roots of the characteristic equation G (s). The roots obtained by numerical analysis in MATLAB, for the reference point -9.0047 + 26.7492i, are drawn with a red x:

Table 1

The roots of the G (s) transfer function

No.	Roots
1.	-94.1617 + 0.0000i
2.	-51.8578 + 0.0000i
3.	-0.0710 + 3.3424i
4.	-0.0710 -3.3424i
5.	-0.0353 + 0.0000

There are no roots in the right half of the plane and it is observed the system is marginally stable because the number of positive roots is equal to the number of signal changes. Also, the calculations in MATLAB determine the critical value of critical coefficient = 0.7234> 0. The system is stable for any K> 0.

We can conclude that the use of PID control algorithm provides excellent control performance for the dynamic characteristics of the vehicle suspension because the output signal is sent to the controlled system and a new output is obtained, which will be retransmitted to the sensor to identify a new error signal.

The controller picks up this new error signal and calculates the derivative amplification factor and the integral amplification factor. This process is conducted until the design requirements are met. It can be seen that the suspension system now meets the design requirements. Overgrowth is below 5% of the input amplitude and the decrease time is 2 seconds, so less than the requirement of to be under 5 seconds.

Among the performance requirements used in the design, the most important is that the system is stable. An unstable system is considered useless, hence the importance of studying the stability of the system.

4. CONCLUSIONS

Based on a partially validated numerical model, a parametric study was conducted to analyze on the one hand the dynamics of the remote-controlled logistics platform, and on the other hand its control system.

Close loop system control is proving to be a competitive solution in terms of system stability, especially if it is disrupted from the outside.

The analysis of the theoretical and experimental results performed in the paper leads to the outlining of some directions for developing a remote-controlled transport platform.

The analysis of the theoretical and experiential results, in terms of dynamic aspects for the prototype of the remote-controlled transport platform was performed using simulation and design software.

Thus, to determine the value of the mass and the position of the center of gravity for the prototype, the Autodesk Inventor software was used, the values provided were the basis of the study dynamic aspects; for the choice of a competitive control system in terms of system stability and the effectiveness of remote control to travel on a certain route set by the operator avoiding unforeseen obstacles as well as for modeling, analysis and numerical simulation of the dynamic system the MATLAB software package was used; Autodesk Inventor software was used to analyze the behavior to draw directions for developing a remote-controlled logistics platform.

The software used in the analysis helps you for the stages of system design, as well as the elimination of possible malfunctions that were not identified in the initial phase of system implementation, but which could be identified with their help.

The creation of remote documentation on remotely controlled mobile robots, which is also the objective of the paper, shows the need to develop vehicles to revolutionize the way the armed forces and the police act and last but not least an innovative way to fight terrorism without causing fatal damage, the latter stressing the importance of remote control as a design requirement.

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ASPECTE PRIVIND DINAMICA UNUI PROTOTIP DE PLATFORMĂ TELECOMANDATĂ

Rezumat: În contextul actual al evoluției societății și al necesității de a consolida răspunsul acesteia la expuneri majore legate de gradul ridicat de incertitudine al evoluțiilor din mediul de securitate, corelat cu amenințările, riscurile și vulnerabilitățile la adresa apărării și securității, cercetările la nivel înalt privind activităţile cu risc în domeniul protecţiei personalului implicat în acţiuni militare, a cunoscut o dezvoltare largă. Lucrarea are la bază conceptul unui robot mobil controlat de la distanță, capabil să se deplaseze în medii necunoscute sau periculoase pentru oameni. Robotul poate fi controlat printr-o aplicație web și un modul Wi-Fi, integrat într-o placă Raspberry Pi, iar pentru deplasarea acestuia vor fi folosite 4 motoare DC. Scopul acestei lucrări este de a realiza un studiu parametric pe de o parte, iar pe de altă parte prezentarea unor aspecte ale dinamicii unui prototip de platformă logistică telecomandată.

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