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Research article

Design and construction of a unicycle robot controlled by its center of gravity

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Abstract

In recent years, research centers and researchers have focused their efforts on producing vehicles with clean, compact, easy-to-transport, and low-emission vehicles. In this regard, many designs and ideas in the field of unicycle robots have been presented. Single-wheeled robots take up little space and are able to move in narrow spaces. The main purpose of this article is to significantly reduce the dimensions of the unicycle robot and to reduce its internal components, based on which the robot body is designed in the minimum possible dimensions. The mechanism design of this robot, unlike other robots, has its own difficulties and complexities. Using a wheel to move the entire assembly, including controllers, drivers, motors, and many other parts, requires a very precise design for the robot chassis. This design, in addition to including all the components of the robot, must organize the internal components in such a way that the center of gravity of the robot has as much inherent balance as possible. On the other hand, the design of the reversal mechanism in this structure is unique and is completely different from other reversal mechanisms in other unicycle robots. These changes caused a significant reduction in the dimensions and construction costs of this robot compared to similar robots. Using the CC3D controller and the LibrePiolet-GCS software, based on the maneuvers made for the robot, the necessary coefficients for the proportional-integrator-derivative controller were tested so that under them The robot is controlled and selected correctly and in balance. With the adjustment for the controller coefficients, the next maneuvers of the unicycle robot with a rate of over 85% were performed successfully.

Keywords: Unicycle robot; Center of gravity; Gyroscopic effect; Microcontroller; 3D printing

1- Introduction

One of the most important components of a robot is its wheels. Using wheels, robots will be able to achieve high speeds. In addition to wheels, legs and tracked slip/skid systems can be mentioned as the major components of a robot. Tracked slip/skid robots also have their own movement system and have their own importance and applications. Wheels and tracked slip/skid systems are easier to control than legs, and each has its own advantages and disadvantages. For example, the wheels should move in smooth or relatively flat environments, but the legs can also be used in uneven environments [1-5].

Often it is difficult to control unicycle robots. For this reason, they are less common but cost-effective. When a wheel is used to move a robot, the robot only makes contact with the ground using a point on a spherical wheel or a line of cylindrical wheels. Therefore, its stability is difficult to achieve. Spherical wheels are relatively easier to use for a single-wheeled robot than cylindrical wheels because the robot has easier access to all directions [6-10].

The design and construction of the first prototype unicycle robots dates back to 1980. The first prototype of this robot was presented by Osaka in Japan. In 1981, the first paper on single-wheeled robots was published at the University of Oxford, and in 2000, the first version of the Gyrobots robot was made at the University of Florida. The process of completing and presenting various designs around this group of robots continued. In recent years, several studies and innovations have been made in the field of completing these robots. The following is an overview of some of the activities carried out in this area.

Modeling of an amphibious single-wheeled robot was presented by Marzban [11]. This researcher investigated the idea of using blades in the outer environment of the robot wheel to allow the robot to move in fluids. Park and Jung [12] made a practical example of a one-wheeled robot during a study and performed various maneuvers with it. The proposed robot had the ability to move in a specific direction by the operator and the ability to cross gentle slopes. Fankhauser and Carius [13] studied the jump maneuver by a single-wheeled robot and demonstrated the results of his research by making a practical example. The proposed single-wheel robot could not maintain balance but could jump in place. In a study, Zhu et al. [14] proposed a method for stabilizing a single-wheeled robot using a non-linear controller based on the RBF neural network. They were able to model their proposed design with the help of simulation by MATLAB software. One of the main results of their study was that the RBF neural network algorithm could guarantee fast stability with the least possible error for the robot. Kimasi and Jalalnejad [15] investigated the control of a wheeled robot in the presence of wheel slip by a comparative stepwise return method. In their study, first the kinematic equations of the system were extracted. Then appropriate reference paths were generated for the robot and then a step-by-step adaptive control rule was designed to generate the values of the control inputs to minimize the robot error. In designing the control law, the effects of wheel slip were investigated and an adaptive slip mode estimator was used to compensate for them in the control loop. The efficiency of the proposed method for controlling the robot in following different reference time paths was confirmed by providing comparative results.

In the present research, the design and construction of a unicycle robot with new and innovative ideas is done in order to reduce the dimensions of the robot structure as well as its internal components and requirements. In this design, two principles of gyroscopic effect and using balance bar in reverse pendulum problem are used. The software is used to balance and control the built robot, and the efficiency of the built robot is demonstrated by performing practical tests. Reducing the dimensions of the robot structure as well as decreasing the internal components and requirements of the robot were the main objectives of this study. Another goal of the research is to design the robot control system in such a way that by controlling and moving the center of gravity of the robot, while maintaining the balance of the robot structure, the robot can be steered in the desired direction.

2- Design idea and constructing robot

One of the major challenges in designing unicycle robots is maintaining their balance. However, balancing a unicycle robot is only part of the complexity of such robots. Another challenge is controlling the path of the robot. Changing the course of a unicycle robot so that the robot's balance is not disturbed requires a very precise mechanism of action with a suitable controller in order to change the course of the robot. If we imagine a person riding on a wheel, this person can maintain the balance of the device by changing the center of gravity of his body while pushing the wheel forward. Now, if a long bar is placed in this person's hands, it will be much easier for him to maintain his balance with great care while moving and even become skilled enough to do it on a tight rope. A simplified model of this structure is given in Fig. 1.

The movement of the rod can create a force in the opposite direction of the deviation of the center of gravity, and thus the robot structure will be balanced and stable as long as enough force can be applied to the system to keep the center of gravity constant. Therefore, this simple and and efficient issue can be used in the design of unicycle robots by presenting a similar mechanism, the proposed idea can be optimized for use in the new robot. Therefore, a bar can maintain the balance of a unicycle robot while moving, but the use of a bar can increase the space required for the robot to move. By shortening the length of the rod while increasing its density, the same effect can be applied to the center of gravity of the robot. Therefore, in the proposed design, we will use a small plate instead of a bar.

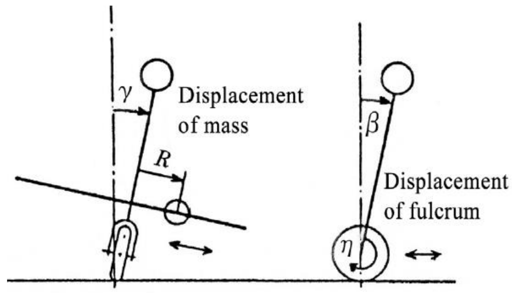

Fig. 1 Schematic of a person riding a wheel.

By placing a number of heavy weights on it, we can create the force needed to deal with the movements of the center of gravity in the desired range. In order to increase the robot's efficiency, instead of using heavy weights that will lead to the use of additional components, the robot's own batteries are used, which will be a part of the control system.

The special feature of non-holonomic robot makes it possible to move freely on the surface in any direction, despite the limited control parameters. However, this equation cannot show how the robot changes direction or rotates when moving forward. To better understand how the robot rotates, a dynamic model for the robot is presented. The robot's dynamic model can be seen at an angular velocity in Fig. 2 as it moves forward.

When the robot is perfectly vertical, it will not have a complex subject to analyze and its analysis will be simply straight-line motion analysis. With this assumption, the effect of changing the center of gravity of the robot structure can be investigated. When the angle θ reaches a certain value, the displacement of the center of gravity can return it to its original state. The force due to the gravity also causes the robot to move in circles along the path with radius R.

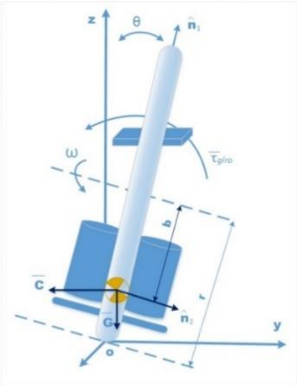

Fig. 2 Robot dynamic model at angular velocity.

On the other hand, the force of friction is created perpendicular to the wheel and parallel to the ground. The centrifugal force will also reduce the wheel deflection. In addition, in the constant motion of the robot and with a certain angle, there will be the effect of gyroscopic force, which will greatly prevent changes in the angles of the wheel axis and reduce the rotation speed of the robot. However, this effect will greatly stabilize the robot. With a summary of the dynamic model of the robot, the motion model of the unicycle robot can be described according to following equation:

$$\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{\varphi}\end{bmatrix} = \begin{bmatrix}\cos\varphi\, r\\ \sin\varphi\, r\\ 0\end{bmatrix}\omega + \begin{bmatrix}0\\ 0\\ g \Big/ \left[r\left(1+\frac{m}{Mc}\right)\right]\end{bmatrix}\tan\theta \qquad (1)$$

Accordingly, the speed of the wheel and its angle are two controlling factors. It can also be concluded that when the robot is not moving (or its motion is very slow) there is no centrifugal force and no gyroscopic torque is applied to it, which can prevent the robot from falling. According to the results of the robot dynamic model and equations, a mechanism to control the robot wheel speed as well as a tool to change the robot angle should be designed. Since a change in the center of gravity can lead to a change in the angle of motion of the robot, these two must be considered when designing the structure of the robot.

2-1- Robot mechanism design

Different methods are used to transmit power to the wheel in unicycle robots. In order to achieve the goal of shrinking the components of this robot, a structure is needed to transfer power to the main wheel that, in addition to its small components, can provide enough force to move the main wheel. Also, this structure must be designed in such a way that the components of the power transmission part cause the robot to support the robot, otherwise more force will be needed to control the center of gravity of the robot. The amount of force transmitted to the wheel will also determine the speed of the wheel, and this is one of the effective factors in controlling the stability of the robot.

Advances in some technologies, such as MEMS and NEMs [16-20], have led to structural changes in some of the basic equipment of robots, such as gyroscopes and accelerometers. On the other hand, these advances significantly reduced the weight and dimensions of the equipment needed to build the robots, making it easier to access. In addition, the introduction of new electric motors with very small dimensions and significant torque caused fundamental changes in the structure of unicycle robots. So that the placement of all accessories and equipment, including motors, controllers, sensors, etc. in the interior of the wheel was possible, and thus this robot was able to open a place for itself in industry, especially among transportation equipment. This method is considered in the design of the present robot. However, a new challenge we faced is how to put the motor inside the robot wheel, which was fraught with problems.

2-2 Robot modeling

To place the motor inside the robot's moving wheel, it is necessary to create a special chassis. This will mean that this part must remain in place relative to the wheel. Different solutions can be offered to transfer the motor power to the wheel, but in most of these cases, the use of special motors is required, which limits the construction of the robot prototype. The chassis must be placed inside the wheel in such a way that allows the required equipment to be mounted on it. The first part to be designed in the chassis is the location of the robot's balance arm. The unicycle robot that we are looking to design and build in this research should be able to change its center of gravity around the robot support by changing the angle of this arm. The robot batteries which are responsible for powering are placed on this arm. A servomotor will also be used which could perform the appropriate reaction; which is the result of information processing in the controller, and generate the torque needed to maintain balance or change the direction of the robot. Besides, the shorter the distance of the arm to be designed from the fulcrum, the less change it will make to the center of gravity. On the other hand, by moving the arm and the batteries on it away from the robot's support, the slightest change in its angle will lead to a larger displacement from the robot's center of gravity. Therefore, in order to increase the efficiency, this part should be located at the farthest possible distance from the robot support point. However, there will be some limitations in this case, for example, adding this distance will increase the final dimensions of the robot structure. Also, the

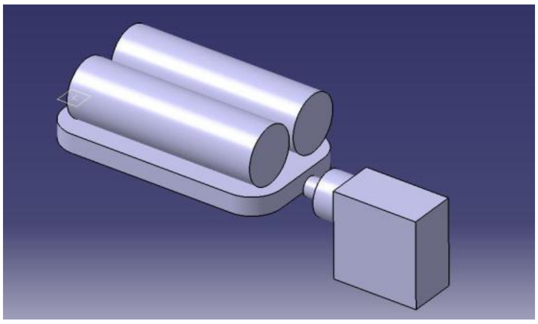

Fig. 3 The desired design for the arm mechanism

angle control motor must be able to be installed next to it. Fig. 3 shows the desired design for the mechanism of this arm.

The maximum estimated weight for this arm is about 200 grams, which will include the weight of the batteries and balancing weights. Thus, it can be said that the weight of the arm will be within the tolerable weight range of the servomotor. So, to simplify the arm movement mechanism, one side of the arm can be connected directly to the servomotor shaft and the other side of the shaft can be connected to a loom. This set must be located at the top of the robot chassis so that it can efficiently affect the robot's center of gravity.

The next step in designing the robot will be to locate the transmission mechanism on the robot chassis. According to what was stated, in order to implement this idea, the prototype of the robot was created in Catia software. After 3D modeling of the robot, the initial idea became somewhat more tangible and it became possible to make some necessary changes to the original design. But before completing the robot design, the type of mechanical actuators required for the robot's main wheel and balance arm must be determined.

2-2-1 Motor selection

Any robot needs some kind of mechanical actuator to perform any mechanical movement. Motors are one of the most widely used types of actuators in the robotics industry. Among direct current motors, DC motors with gearboxes are a very good choice to create the necessary torque on the robot's main wheel. Small size and light weight against high torque are the most prominent features of these motors. On the other hand, having a gearbox on the motor will save significant costs in building a robot. These motors are also available in different torques with different torques. In addition to the useful features provided, it is possible to control these motors easily and the required speed and torque can be received at any time. This feature will allow you to see very good torque from these motors at very low speeds, which is very important during the initial movement of the robot. The balance arm of the robot is another moving part of the robot that must be precisely controlled so that it can maintain the center of gravity of the robot in a controllable range. Servomotors are commonly used to precisely control the moving parts of robots, such as robot arms. These motors have a controller and an internal mechanism for feedback from the motor shaft position. Thus, by receiving commands, the motor shaft is placed at the desired angle. Here, the digital micro servomotor MG90S is used. This servo has a convenient gearbox that can be connected directly to the arm and control its angle due to the small torque required to change the arm angle. Fig. 4 shows this servo with its actual dimensions. Dimensions are in millimeters.

The balanced structure of the robot can have a significant impact on the final performance of the robot. Therefore, the motor is placed on the chassis in such a way that it can transfer the power to the main

Fig. 4 Servomotor MG90S

wheel of the robot, not causing the robot to move away from the center of gravity. It turned out that the best way to use two engines from both sides of the robot chassis. Because due to the high weight of the motors, using one motor will move the center of gravity of the robot to one side. In positioning the motors, due to their high weight compared to other components, they should be placed at the closest distance to earth to reduce the possibility of unwanted deviation of the robot when changing the angle of the robot. Thus, two engines with exactly the same specifications are placed on both sides of the robot chassis. With this option, in addition to maintaining the balance of the robot chassis, the amount of torque required is divided equally between the two motors, and smaller motors can be used. In addition, the space required for the motors is divided into two equal parts on both sides of the robot, and as a result, the final dimensions of the robot are reduced. Fig. 5 shows how to install the motors on the robot chassis.

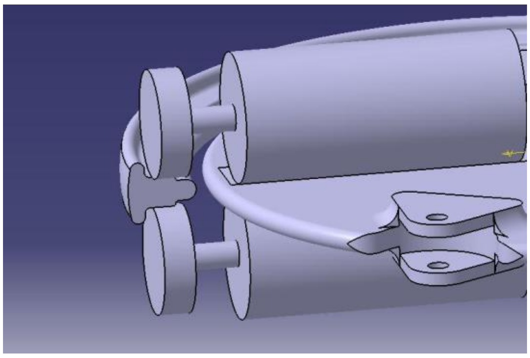

Fig. 5 a schematic of how to install motor on robot chassis

To transfer the torque of the motors to the main wheel, a place must be devised on the main wheel of the robot, which is transferred to the main wheel of the robot by rotating two aluminum wheels with rubber cover and due to the friction between them. Gears can also be used to transfer engine power to the wheel, but the cost of building and prototyping the robot is greatly increased. To mount each of the motors, a base was made by which the motors were connected to the main body of the robot. Below each of the bases are two springs that can be used to control the amount of pressure applied by the aluminum wheel to the main wheel of the robot with the help of the mounting screws of the base and these springs. When the output torque is transmitted to the main wheel by the motors, its reaction force can cause the internal body of the robot to rotate, in which case the internal components will rotate around their axis along with the main wheel. To solve this problem during design, it should always be noted that the amount of force required to overcome the friction between the main wheel and the robot support should be less than the amount of force that causes the robot chassis to move inside the complete wheel. This point will be very important when designing this robot. Because otherwise, instead of moving, the robot will rotate around its axis. In order to increase the force required to rotate the inner body of the robot around its axis, a few spools were used between the inner body and the main wheel of the robot. These loose pulleys will also be needed to ensure that the robot body does not protrude from the main wheel. These wastes will move on the main wheel at the desired location and in addition to reducing the friction between the moving wheel and the robot chassis, will keep the chassis in place within the robot main wheel. In positioning, we placed these wheels at an angle of 120 degrees to each other. In addition, a replaceable shaft is provided for each of them, so that when assembling the robot chassis inside the main wheel, the idler pulley can be removed and the pulley shaft can be put in place after assembly. A 120-degree angle between the three idler pulleys will reliably prevent the chassis from protruding from the main wheel. Fig. 6 shows the location of this tramp.

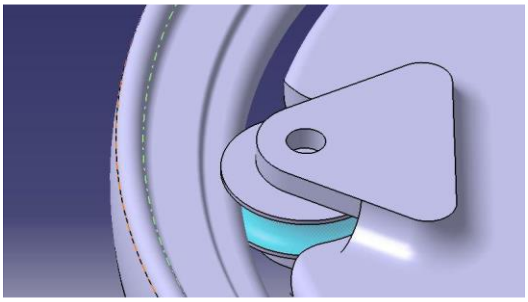
Fig. 6 Location of the tramp

Fig. 7 shows the prototype of the robot's internal chassis. On this chassis, the installation location of the motors, idler wheels and arm mechanism have been carefully selected and located. The installation location of screws and other components is also considered.

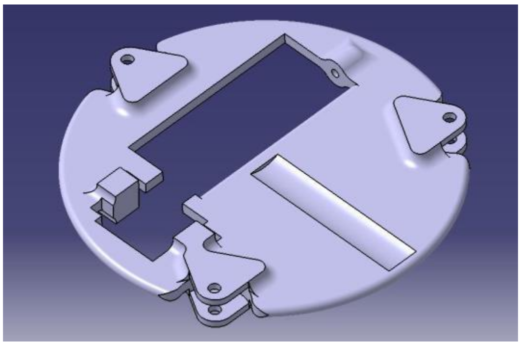

Fig. 7 A schematic of the chassis

2-2-2 Robot main wheel design

In a unicycle robot, there will be only one wheel to move, change direction and carry equipment. Therefore, the design of this wheel must be done with high precision and meticulousness to be able to meet the needs of the design. The robot can be divided into two parts; One part that is moving and the other part that is fixed. The fixed part is located inside the moving part. Therefore, the amount of space inside the wheel should be selected in such a way that while it is possible to place all the components of the robot inside it, its dimensions should be as small as possible. In designing the main wheel of the robot, both the design of the inner part of the wheel and the design of the outer part must be optimized according to the requirements of the design. The robot is in contact with the ground or the support only at one point, and the shape of the wheel will greatly affect the parameters related to this point. The amount of friction and the amount of slip angle around the point are the most important factors that are directly related to the shape and structure of the wheel contact with the bearing surface. As the wheel-to-ground contact point decreases, the amount of friction between the wheel and the surface decreases. On the other hand, the amount of freedom of the robot to move at an angle around this point will increase. In addition, by increasing the freedom of angular movement around this point, it will be easier for the robot to change the angle of the robot. However, reducing the contact of this point with the support intensifies the response of the whole structure to changes in the center of gravity and in practice can lead to instability and imbalance of the robot structure, so that the smallest reaction of the control system to compensate for the lack of balance can lead to instability and increase the angle to a critical point and the wheel falling. On the other hand, this reduction in dimensions leads to a reduction in the robot's friction with the surface, which ultimately affects the possibility of the robot moving and will cause the robot to slip while moving. Of course, the calculated effect of reducing the point of contact with the support can be reduced by carefully calculating the wheel material. For this purpose, in designing the outer part of the main wheel of the robot, in addition to using a special shape, two different materials were used to achieve maximum efficiency at this level. The best shape that can be used for the outer surface of the wheel will be a curved surface according to the design needs. Because when the contact surface with the support is small, it will be possible to change the angle. Therefore, by choosing the right amount of curvature, the best state for smooth movement and freedom of movement for the robot can be achieved. The inside part of the robot wheel must be designed so that the main chassis of the robot can be mounted on it and the motor power can be transmitted to it. On the inside of the wheel, there are two aluminum wheels transferring the power of the motors to the main wheel. These two wheels rotate on one edge inside the main wheel, and this rotation causes the main wheel to rotate. A rail is also installed to move the spools freely, allowing the robot chassis to be mounted inside the main wheel. Due to the diameter of the aluminum transmission wheels, the thickness between the inner edge and the outer edge should be slightly more than the radius of the power transfer wheels so that they do not touch the ground while the robot is moving and changing the angle. Otherwise, the first contact of the transmission cycles with the ground will cause the robot to lose its balance. In order to complete the design and improve the performance of the external surface of the robot, a polyurethane strip is used on the outer part of the wheel. This strip can create a small friction between the robot and the ground due to the small contact area. Considering the above, the general design of the robot chassis was completed and finalized as shown in Fig. 8.

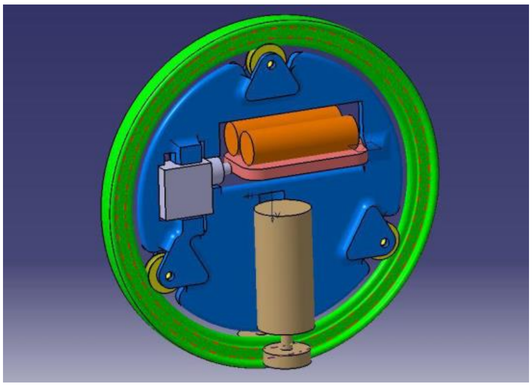

Fig. 8 Robot Chassis Outline

2-2-3 Robot body

The 3D printing method of components is used to build the body. The three main body parts, including the main wheel, the inner body and the arm, were printed separately. ABS filament was used to ensure the strength of the components. Existing ready-made fittings were also used for three idler wheels.

2-2-4 Electronics and robot control

The unicycle robot is an inherently unstable robot, and its movement and stability will be achieved by the robot's control and electronics. The first block that this robot will urgently need is a suitable controller that can take control of all the components, check the incoming forces and estimate the amount of system error and apply the appropriate response at the output. Thus, maintaining the stability of the single-wheeled robot while moving. This controller must be able to control all the robot operators. It therefore needs an intermediary to transmit the required commands to the motors. This will be done by the DC motor driver. The robot, on the other hand, will need a radio communication to be able to receive and respond to user commands. The control system must be aware of the amount of force and its angle at any time in order to be able to create the appropriate amount of force in the opposite direction, thus preventing the robot from upsetting the balance by neutralizing the applied force. Each vector that applies force to the robot structure will have direction, value and angle. Therefore, the robot must have a mechanism to measure these force vectors so that by specifying the direction, amount and angle of each force vector, the controller can calculate the appropriate response and create a neutralizing force to balance the robot structure. So, sensors are required to measure the amount and direction of force and force angle. A gyroscope is used to calculate the deflection angle. A compass can also be useful in effectively navigating the robot.

2-2-5 Motor driver

In order to control the torque and speed of DC motors, it is necessary to use a suitable driver. This driver should be able to provide the required speed and torque to the controller, depending on the required amount. It also has the ability to reverse engine speed. The most common method and most practical circuit for DC motors is to use the H bridge, which consists of four power transistors, which is known as the English letter H because of the closed connections. Figure 2 14 shows an H-bridge circuit with ancillary components.

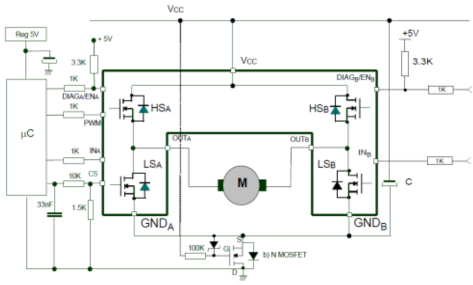

Fig. 9 An H bridge circuit with ancillary components

With the activation of each pair of bridge transistors, the direction of the electric current passing through the motor is reversed and thus the direction of rotation of the motor is reversed. However, in this project, in addition to the direction of movement of the engine, there will be an urgent need to change the engine speed. Because the amount of power and speed of the robot depends on the speed of these motors. To control the DC motor speed, the amount of energy given to the motor can be easily controlled at any time, thus achieving the desired speed and torque. Usually, a type of pulse modulation called PWM is used for this purpose, in which the greater the pulse width, the more energy is received by the motor, and the reduction of the pulse width leads to a reduction of the motor energy. Applying this pulse with a suitable periodicity to the pair of H bridge transistors can create the desired torque and speed in the desired direction by the motor. Therefore, the main controller of the robot can control the speed and torque of the motor with this pulse and can change the direction of the motor with another pulse.

A DC bridge motor driver has a relatively large number of parts that will require a lot of space to build the circuit and assemble the parts. Due to the priority of shrinking the circuits, an integrated DC motor driver is used to reduce the final dimensions of the robot. Thus, all the components required for the H bridge are available on the VNH2SP30 chip. The base circuit of this chip is easily available in the market and can be used in robots. Figure 2 shows the 15 base circuits for starting the VNH2SP30 chip.

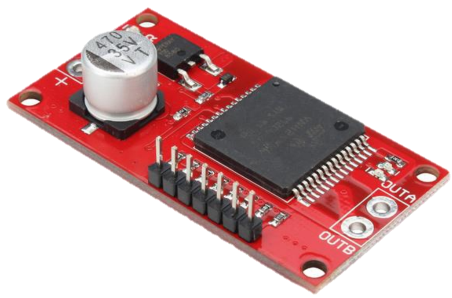

Fig. 10 Base circuit for launching VNH2SP30 chip

3- Robot controller

The robot controller must process the information of the forces entering the robot at any time and maintain the balance of the robot according to them and the specified programs. On the other hand, it must also execute commands sent by the user at the same time. The processing of this information will require a very fast and powerful controller, so that it can provide a suitable response to the dynamic state of the robot at a very high speed. In addition to very powerful hardware, this controller requires a very powerful software to receive and apply control parameters in the control loops to be able to apply the exact values of the PID loops in it. For this purpose, a very advanced controller is used, which is commonly used to control drones. This controller has a sufficient processing speed and besides possessing an IMU module for analyzing vector forces, so that all the forces applied to the robot can be measured and processed at any time. On the other hand, providing a powerful software for initial hardware programming has been able to have a lot of flexibility to coordinate with different mechanisms. Working with these controllers eliminates the need for tasks such as heavy programming and designing complex hardware for such robots, so the robot designer can spend more energy. Optimize the movements and mechanisms of the robot. CC3D is an aircraft control project supported and supported by the LibrePiolet Group as a piece of hardware and open source software. CC3D is commonly used to control multi-rotors and as a fly control. However, it is also possible to configure it for some other mechanisms. In this project, it was possible to use this controller as the main controller of the robot with innovation and creativity. A powerful ARM processor is responsible for processing information and controlling the output at all times. The MPU-6000 integrated circuit, which is an IMU, is responsible for measuring acceleration and angle on three axes for each and sends the relevant information to the processor. This controller has six programmable output channels and six channels for receiving commands from the radio control. All inputs and outputs of this controller are configured by LibrePiolet-GCS software. In addition, all the necessary parameters to keep the robot balanced are determined and adjusted by this software. One of the features of LibrePiolet-GCS is the ability to control a wide range of robotic devices. These include a variety of drones and ground-based vehicles, helicopters, cars with wheels or even tracked slip/skid robots. In addition to all the options for the device type, the advanced mode can also be used for the desired configuration of the controller. The feature of using defined modes, along with the possibility of defining some details by the user, has been placed in all parts of the software in such a way that the designer has a very high flexibility in all parts. In the first step, the device must be introduced to the controller. The device we are looking for is not among the default devices defined in this section. Therefore, either the device must be fully defined using the advanced mode, or by changing some of the parameters of the existing defined devices, the desired device, which is a single-wheeled robot, can be determined for the software. To do this, you can find the most similar device to the robot and select it as the default device, and then make some changes to determine the type of device for the software. The most similar device to start the configuration among the available devices will be a motorcycle, because it is very similar to a unicycle robot. Details of this process can be seen in Fig. 11.

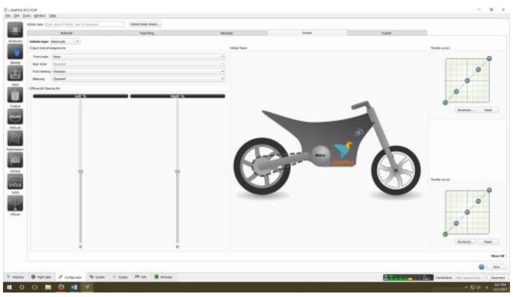

Fig. 11 Device choosing in LibrePiolet-GCS software

PID controllers are one of the most common examples of feedback control algorithms used in many control processes such as speed control of motors, pressure control, temperature control, etc. A PID controller relation is:

$$u(t)=k_p e(t)+k_i\int e(t)dt+k_d\dot{e}(t) \qquad (2)$$

where k_p, k_d and k_i are proportional, derivative and integral coefficients, respectively. Error and error derivation are obtained by position output and derivation feedback. The unicycle robot is a non-linear and inherently unstable robot, and maintaining its stability is a function of the robot's physical principles of movement, and the movements of the balance arm. Therefore, the control system must be created in such a way that by receiving the input information and processing it, it can create a suitable error correction signal at the output. Apart from the manual control method, there are two basic methods for implementing the feedback loop in libre pilot-GCS software, which are the Rate Control method and the Attitude Control method. Fig. 12 shows the block diagrams of each of these two control methods.

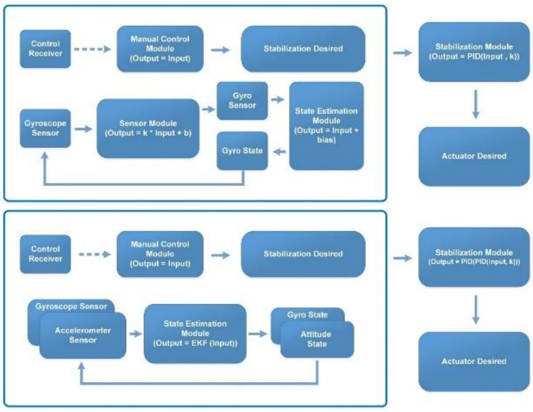

Fig. 12 Control block diagram

Using acceleration sensor feedback is critical to keeping the robot stable. For this reason, the attitude control loop is used to assess the effect of acceleration on the PID controller. In this way, the structure of the robot control system can be shown in Fig. 13.

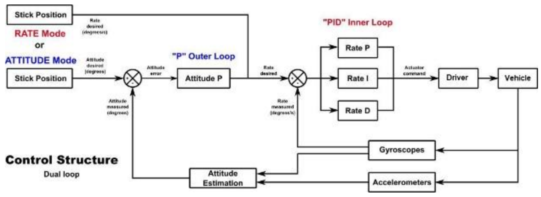

Fig. 13 Robot control system

To create a control loop with proper feedback, one must first have a proper analysis of the behavior of the device under control. The present unicycle robot has a point of reliance on the surface that may be accidentally tilted to one side and fall under the influence of various forces. Therefore, in the first step, the control system must calculate the direction and size of each force vector applied to the robot. Then, according to the PID values set in the control loop, it generates an error signal. According to the designed structure, the robot can neutralize the forces entered from both sides by moving its center of gravity by the arm and its weights. Slowly But this will not be enough to keep the robot balanced. Moving the robot backwards or forwards can also upset its balance. For this purpose, the control system must create a combination of moving the main motors back and forth while neutralizing the lateral forces by the arm in order to maintain the balance of the robot by creating positive or negative acceleration. This state must have a much lower effect factor when the robot moves due to the stability of the robot under the influence of the gyroscopic effect, because otherwise the balance of the robot will be disturbed. Using acceleration sensor feedback is critical to keeping the robot stable. For this reason, the attitude control loop is used to have the effect of acceleration feedback and gyroscope on the PID control loop at the same time.

The correct configuration of the controller is displayed in the System Health window of the Flight Data Tab page, with each section green (Fig. 14). If any part of this window is displayed in red, you should troubleshoot that part because otherwise the controller will not be activated.

In some cases, it may be necessary to review or modify the settings of the control parameters together. For this purpose, these changes can be made from the System Tab section of the software. Also in the Scope Tab section, you can check and view the entered forces and its value in each axis.

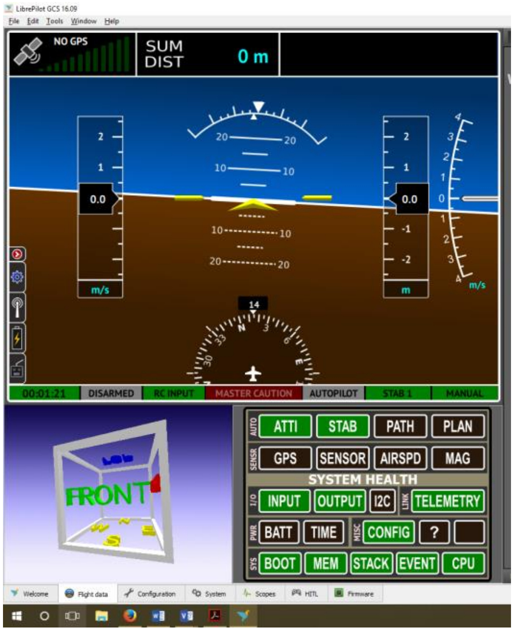

Fig. 14 Robot controller screen

4- Conclusion

The design and construction of a unicycle robot with a new and innovative approach in order to reduce its dimensions as well as decrease internal components were investigated. The necessary components and parts of the presented design were created using 3D printing. After constructing the desired unicycle robot, using CC3D controller and LibrePiolet-GCS software, based on the maneuvers performed for the robot, the necessary coefficients for the proportional-integral-derivative controller were attempted. A control system was designed for the robot so that by changing the position of the robot battery, which is one of the necessary components of the robot, it became possible to move the robot to the desired direction while maintaining its balance. With the adjustment for the control coefficients, the next maneuvers of the unicycle robot with a rate of over 85% were performed successfully.

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