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Research Article

Electronic and mechanical design of a hexapod land searching robot

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ABSTRACT

In this study, it is aimed to design a robot that can be used in fields such as land exploration, mine search, ammunition transportation, search and rescue activities in natural disasters. For this purpose, a six-legged robot was designed. The robot can move evenly in uneven terrain conditions, stop, accelerate and overcome the obstacle when it sees an obstacle. The mechanical and electronic design of the robot was realized, and a prototype was manufactured. The flexibility of the legs used in the design ensures that the robot can move more easily in field conditions. The synchronous speed and direction of the motors are controlled, and the robot moves in a balanced way. With the IP camera mounted on a Raspberry Pi, snapshots were taken from the robot. Mechanical and electronic design of six-legged robot capable of moving on uneven ground was realized. The six-legged robot was placed with three legs on the right and three legs on the left. The motors were operated simultaneously to allow the robot to move evenly. Thanks to its leg structure, it was aimed to travel in land conditions. Image control was provided on the computer with the camera placed on the robot. In this study, the program written into the electronic cards run the motors simultaneously.

1. Introduction

In recent years, autonomous robots have been utilized in many areas such as search and rescue, mapping, reconnaissance, mine detection, packaging and geolocation [1-3]. Mobile robots have been designed with different modes of transportation such as wheel and leg structures. With the advancement of the sensors, robots can interact with the environment and autonomously carry a task using machine learning methods [4].

Positioning, mapping, road planning, road planning avoiding obstacles are among the most popular autonomous robot topics in literature [5-7]. In most of the studies, the robot is in a closed area and moves on a flat surface. The most important reason for this is that the signals received by the sensors are required to be noise-free and the control of the robot to be stable. These mobile robots generally use wheels. However, when it was desired to move the mobile robots in an uneven ground, there was a need to develop robots with different structures and number of legs [4], [8]. Although these robots can perform difficult tasks such as moving on rough terrain and climbing stairs, moving them in a stable and balanced way is one of the biggest problems.

Lauron II [9] of FZI (Forschungszentrum Informatik) group and Genghis robots improved by MIT (Massachusetts Institute of Technology) may exemplify six-legged robots. Each leg of Lauron II robot has 2 degrees of freedom (2-DoF) mechanism. Robot was monitored by 12 actuators in total. Each leg of Genghis robot has 1-DoF mechanism and the system was monitored by 6 motors in total.

In their study, mechanical, electronic and software design of a six-legged robot that can move in uneven surfaces was carried out. The robot designed in this study was inspired by the Rhex [8] robot, which was previously designed at the Code Laboratory at the University of Pennsylvania.

The RHex project first came out of the Darpa CBS / CBBS program in 1998. This project, which was carried out with the participation of many universities, provided 5m USD funding for 5 years. The first prototype was built in 1999 by Uluç Saranlı. Many revisions and improvements have been made on platform design and

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algorithms [10]. Throughout its development, it is an autonomous hexapod robot that has developed behavioral algorithms. It is due to a number of principles underlying its design and a significant amount of inspiration from biological systems [11]. It is the first documented autonomous leg machine that exhibits general mobility on a terrain. It can move over a wide range of uneven terrain with speeds exceeding 2.7 m/s, climbing slopes exceeding 45 degrees, swimming and climbing stairs [12].

The materials used in the design was chosen to satisfy the desired properties while being economical. In this way, the robot is intended to be more economical than similar robots. Samples of the robots developed in Aqua Rhex and Wheel Rhex types which are movable in water were also examined [2]. Different multipurpose mobile robots can be seen Figure 1.

The design of the robot was realized in three stages:

- Mechanical Design: design of the chassis and leg structure of the robot.
- Electronic Design: control of six motors simultaneously and stably and remote controller design that will enable wireless data exchange.
- Computer Image Acquisition: design of a camera system on the robot that sends the image to the control station.

In this paper, mechanical and electronic design of the robot and image acquisition via computer are explained in detail. In the third unit, experimental results with robot are given. In the last section, the results and future works are discussed.

2. Method

There are six design components for the hexapod land searching robot, namely mechanical, leg, software, electronic and communication. These stages have been realized in parallel to each other. The designs of both shell and flexible leg structure of the robot were completed and first prototype has been manufactured. The essential control cards' design and the programming requirements were addressed to enable simultaneous movement of more than one motor.

2.1 Mechanical Design

Six stepper motors with a working voltage of 12V and a current of 1000 mA have been selected, which will allow

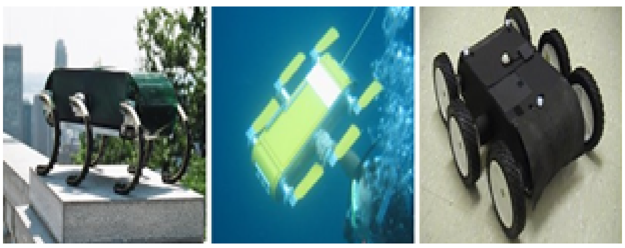

Figure 1. Multipurpose mobile robots [18]

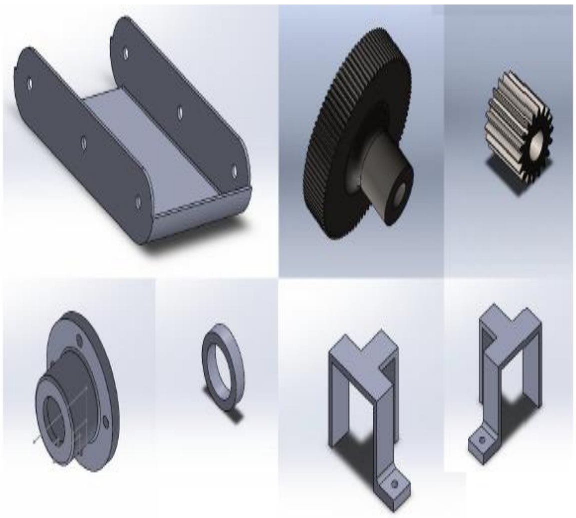

Figure 2. Designs of the components of the robot

the robot to move on uneven surfaces and carry the weight of the robot. A plate was designed for the lower body. Arduino Mega, Arduino Uno, Raspberry Pi, Servo motor, Step motors and gears are placed on this plate. The size of the plate is 25.6 x 19 cm and the wall thickness is 0.5 cm. The design of the components was created in Solid Works and Figure 2 show the images of the components.

The holes on the components were created with a laser cutter. The total weight to be placed on the body was calculated to be approximately 3 kg with motors, electronic cards, gears and shafts.

The completed mechanical design of the robot is shown in Figure 3. The legs are 7 cm in diameter and 1.2 cm in width, and the distance between each leg is 12.8 cm. The middle legs are 1 cm out of line from the front and rear legs. Thus, the legs can perform the movement without interfering each other. The feet are fixed to the 0.8 cm diameter shafts by drilling 0.4 cm holes. 4mm bolts, nuts and washers were used to fix the legs.

A gear system was designed to transfer the power from the motors to the legs as it did not directly produce the needed force for movement. For this reason, the force transferred from motor shaft to the legs was increased quintuple using a 1:5 gear design. Gears were illustrated at Solid Works and printed via 3D printer. Small gear used on motor shaft was tuned-up in accordance with the following criteria: gear tooth 18, module 0.6 and diameter 1 cm. Bigger gear was tuned-up in accordance with the following criteria: gear tooth 90, module 0.6 and diameter 5.2 cm. Shrink fit to the motor shaft was achieved with 5 mm bore diameter. Similarly, shrink fit to the shaft transferring force to the legs was achieved with 5 mm bore diameter.

A tab from main gear was attached to the shaft with a bolt for attaching bigger gear to the shaft firmly. The length of journal connecting bigger gear to the shaft is 15 mm while bore diameter was designed as 4 mm to be in the same size with the shaft hole.

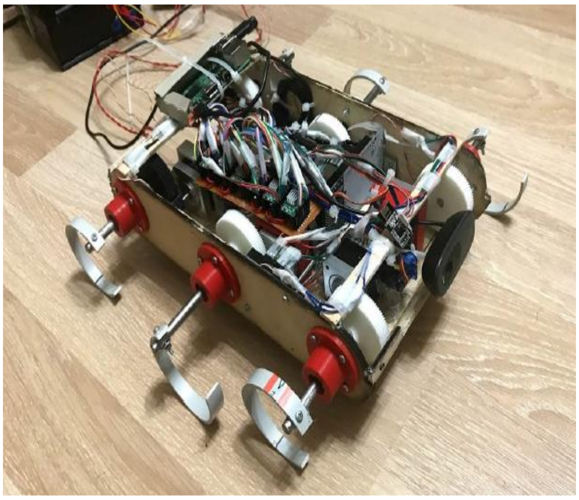

Figure 3. Mechanical design of the robot

The shaft should move properly and periodically in order for a proper transfer of force to the legs. As the shaft is within the bearing, shaft should be fixed from outside firmly. That is why, it was designed a bearing retainer. Two bearings in 1.5 cm from each other are placed in a retainer and a distance piece is used within the retainer to prevent the contact of bearings. Bearing retainer's outside diameter is 4.9 cm and bearing hole diameter is 22 mm. Shrink fit is ensured by setting internal hole to the same degree of outside diameter of bearing. Distance between two bearings is set by extending 15 mm retainer piece from internal bore diameter of main body. Through this way, the shaft becomes more solid as it is supported from two points. In order to keep the shaft inside, bore diameter at the outmost part of retainer is measured 16 mm. Lastly, 4 mm diameter bolt holes are made to bolt down outside part of retainer to the robot's side walls.

Finally, a clamp was designed to attach the motors to the main body to enable the steadiness of motors on the main body. Motor is screwed to the main body with three-leg clamp while other two legs prevent the motor's skidding. The design of clamp was made via Solid Works and printed with 3D printer.

2.2 Leg Design

A different foot design has been considered for mobility in terrain and unfavorable environmental conditions. This design is inspired by six-legged insects that provide flexible movement across various terrains. The foot design can be highly useful to provide the robot's ability to move [13]. This foot design ensures reliable and robust operation. Stable and highly maneuverable feet work in a coordinated manner on the move as seen in Figure 4. It can be recognized that the C-shaped leg has more effective lifting and pulling forces than the other two. The circular shape of the leg is the one that performs the mobility most efficiently.

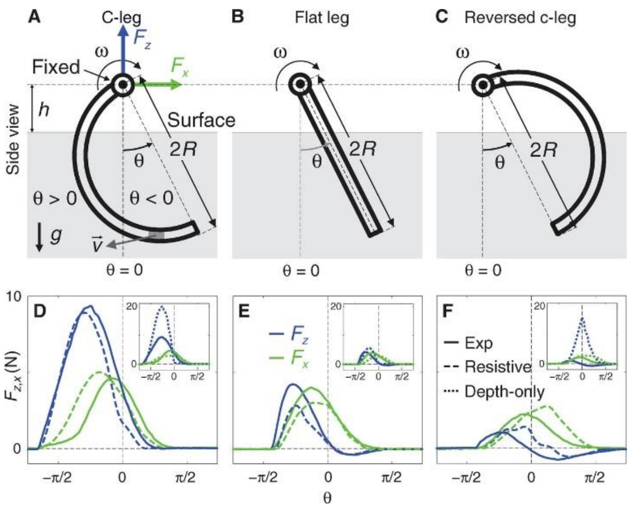

Figure 4. Lifting and pulling forces of the leg Geometry

The straight leg has the optimal lift only at the start of contact and the optimal drag in the vertical position. In this paper, the vehicle consists of six C-shaped legs. The vehicle is always in contact with the ground for three feet during the movement [14].

In order to prevent the vehicle from tipping during movement, it is necessary to have 3 legs on the ground during the movement. This is because a plane passes through three points. Six legs of the vehicle were divided into two groups. The numbering of legs has been presented with Figure 5.

The movement of the legs from the first point to the second point moves the vehicle forward. In order to continue the movement of the vehicle on rough terrain, the operation mode of the engine is determined as Step 16 during the movement of the legs from the first point to the second point. Since the time from the first point to the second point must be equal to the time from the second point to the first point, the mode of operation of the motors must be selected for the second point to the first point.

Figure 5. Numbering of legs

Table 1. Features of Step Motor Operation Modes

Micro Resolution	Pulse Required for a Tour	Speed
Full Step	200	16V
Half Step	400	8V
Quarter Step	800	4V
Eight Step	1600	2V
Sixteen Step	3200	V

As seen in Figure 6 and Figure 7, the movement of leg from one point to another moves the vehicle forward. For a continued movement of vehicle on a rough terrain, the operating mode of motor was determined to be 16th step during the legs' movement from one point to another point. Operating mode features of step motor are presented at Table 1.

Since the arrival duration from point 1 to point 2 must be equal to the arrival duration from point 2 to point 1, operating mode of motors has been set as quarter step for the move from point 2 to point 1. This means the duration of the legs' A and B movement in Figure 6 is same. The angle of these movements can be calculated as in Equation (1), (2), (3) and (4).

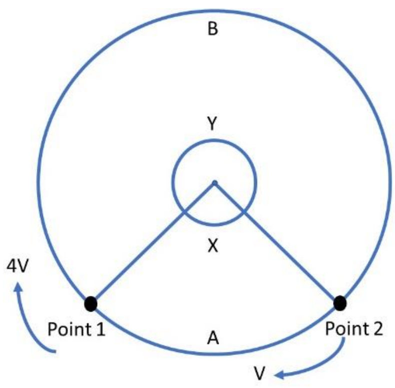

Figure 6. Angle of step

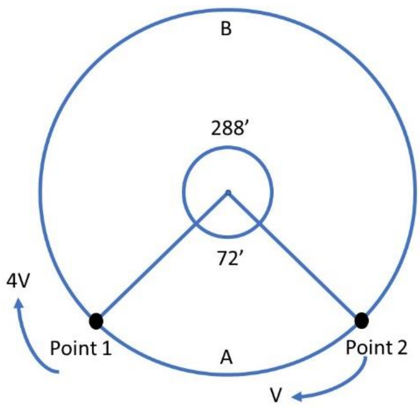

Figure 7. Angle of step motion

$$A = V * t \rightarrow X = K \tag{1}$$

$$A = 4V * t \rightarrow Y = 4K \tag{2}$$

$$X + Y = 360° \rightarrow 5K = 360° \rightarrow K = 72° \tag{3}$$

$$X = 72°, Y = 228° \tag{4}$$

The duration *'t'* can be calculated by the pulse required for a tour in Table 1. Equation (5), (6) and (7) shows the calculation of the movement duration.

$$1\, pulse = 1ms \tag{5}$$

$$A = \frac{3200}{5} pulse = 640\, pulse \tag{6}$$

$$640\, pulse = 0.64\, s \rightarrow t = 0.64s \tag{7}$$

Displacement of the leg of the can be calculated with radius of the leg as in Equation (8) and (9).

$$r = 7\ cm, \qquad A + B = 2 * \pi * r \tag{8}$$

$$A + B = 0.2512\, m \tag{9}$$

The velocity of the movement can be calculated with duration and the displacement as in Equation (10), (11) and (12).

$$A = V * t, B = 4V * t \tag{10}$$

$$A + B = 5V * t = 0.2512\, m \tag{11}$$

$$V = 0.0785\, m/s \tag{12}$$

The robot operates two groups of legs synchronized with each other so that the height of the trunk can remain constant while moving.

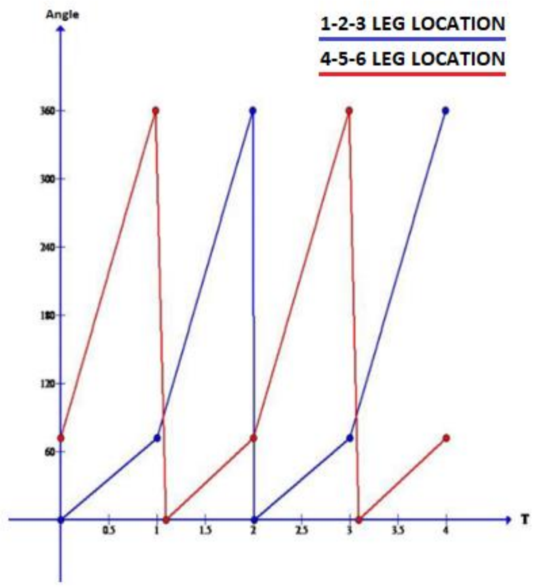

Figure 8. Leg angle position vs Time

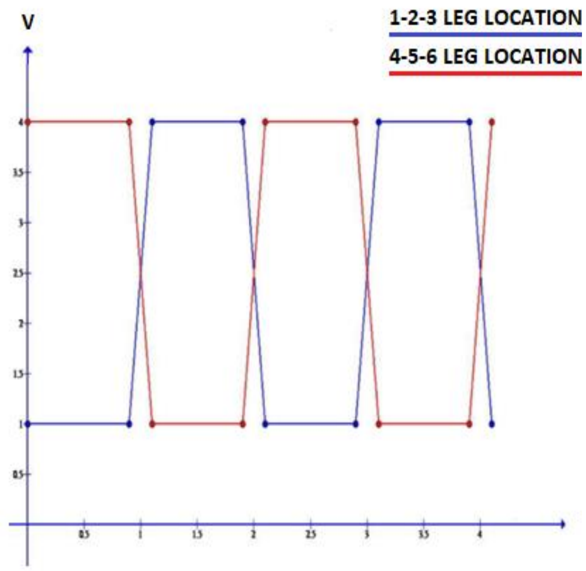

Figure 9. Speed vs Time

The first group consists of legs 1, 2 and 3, the second group consists of legs 4, 5 and 6. Initially, the position of the legs in the first group is 0 degrees and the position of the legs in the second group is 72 degrees.

As shown in Figure 8, while first group of legs move from 0 degrees to 72 degrees, second group of legs move from 72 degrees to 360 degrees at the same time.

Figure 9 shows the speed of the leg groups. While first group of legs moves with 0.0785 m/s, the second group of legs moves with 0.314 m/s. In the second part of the motion, while first group of legs moves with 0.314 m/s, the second group of legs moves with 0.0785 m/s. During the 0 - 2t (1.28s) duration, all the legs of the vehicle take a full turn.

2.3 Software Design

By pressing any button on the control, information is entered to the previously selected pin of Arduino-Nano. With this incoming information, Arduino-Nano generates 8-bit data due to previously installed program. This generated data is sent to the robot unit via the transmitter NRF24101 connected to Arduino-Nano. This data is received by the receiver NRF24101, which is connected to Arduino Uno in the robot unit. The received data is converted to three-bit data by previously installed program in Arduino Uno. Arduino Uno transmits these three bits of data to Arduino Mega via serial communication. If one of the step motor movement buttons on the controller is pressed, program in the Arduino Mega processes the incoming data and sends the direction and speed information to the drivers. If one of the camera position buttons on the controller is pressed, program sends the angle information to the servo motor. This provides control of the camera motion.

2.4 Electronic Design

In this paper, Arduino Mega, Arduino Uno, Arduino Nano, NRF24101, Raspberry Pi 3, A4988 driver card were used electronically. The layout of the electronical components and wiring diagram are shown in Figure 10.

2.5 Communication Design

The communication between Arduino Nano and Arduino Uno is provided by NRF24101 module. In the transmitter section, first a channel is selected to send data and communicate. Once the channel is defined, NRF24101 module is set to transmit. After making the adjustments, data is sent to the receiver on the other side with NRF24101 module when the button is pressed.

In the receiver section, the channel is selected same as the transmitter part. After defining the channel, the NRF module on the receiver is set to read. The module constantly checks to see if any data has been received. When a data arrives, it checks whether the incoming data is received beforehand. After the mechanical, electronic and software design of the robot was completed, experiments were carried out to move the robot steadily. In these experiments, it was aimed to move the robot legs at different speeds simultaneously and move the robot without falling and damaging itself.

The calculated speed values are sent from the microcontroller via analog input to ensure that the motor goes at the desired speed. The microcontroller can be supplied as predictive and sliding [15-17]. Before the robot started to move, an initial position was determined to ensure the simultaneous movement of the motors and the measurement of the positions of the motors.

These start positions were reported to the microcontroller via limit switches. Figure 11 shows the position of the robot before moving on the ground. As the robot started to move, it stands up on six legs as in Figure 12 and waits for the speed information to be applied to the motors in a position ready to walk.

Experiments were carried out at different speeds in order to ensure a stable movement of the robot. While three motors were programmed to complete its revolution, the other three motors completed their revolution slowly. In this way, the robot's feet were never cut off from the ground, remained stable and smooth movement was ensured.

The simultaneous operation of the motors was the most challenging problem during the experiments. Other encountered problems were very slow movement of the system in low speed and motor’s inability to provide enough torque at high speeds. Despite these situations, the robot can move in a balanced way.

After the installation of the system, the test drive was carried out. Forward-backward, right-left movements were carried out. The robot fulfilled its functions without any problems. Image acquisition and control of the camera were tested instantaneously. System process is presented at Figure 13 in detail.

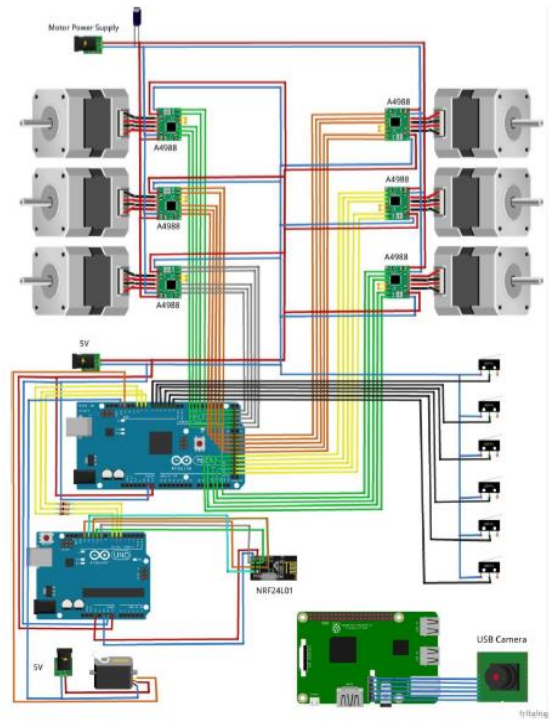

Figure 10. The layout and the wiring diagram of the electronic components

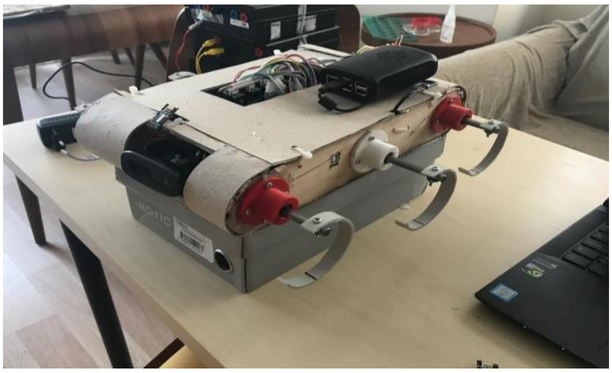

Figure 11. Position of the robot

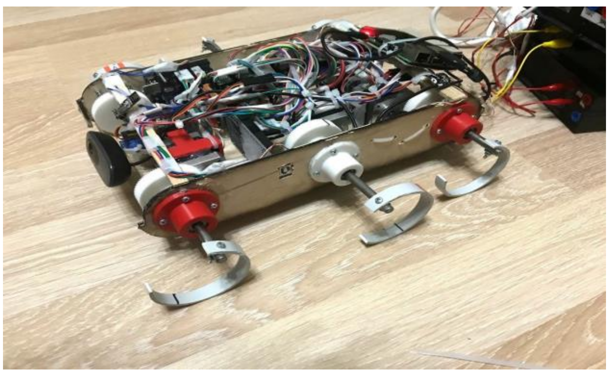

Figure 12. The motors in a position ready to walk

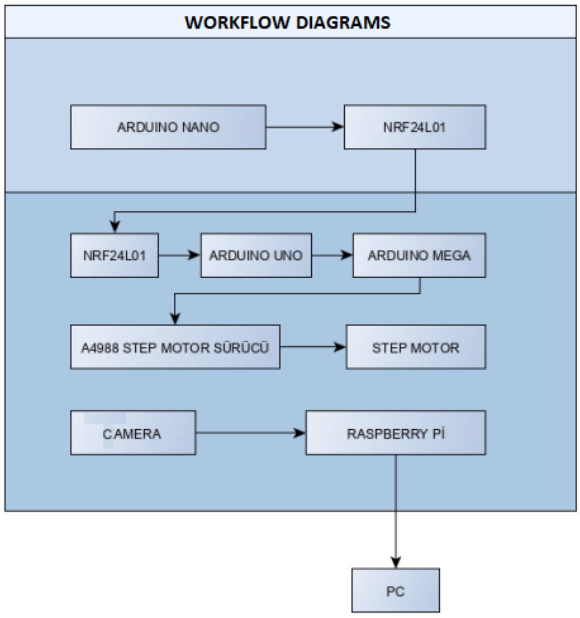

Figure 13. System Process

3. Conclusions

Robots have been a strategic element of today's technology. Multiple-leg robots and mechanisms that could perceive, ratiocinate, decide and move in line with that decision are fundamental tools of contemporary automation technology that are used for different purposes such as spatial studies, detecting the information of living creatures as a result of natural catastrophes (i.e. earthquake), explosive ordnance disposal, fight against terrorism as well as in various fields such as mining, defense industry and medicine. The most important of all is the successful implementation of the commanded functions by robots. This success depends on designing a mechanism to facilitate the control of the robot as well as a model to minimize energy consumption and with a self-evaluation capacity.

In this study, mechanical and electronic design of six-legged robot capable of moving on uneven ground was realized. The six-legged robot was placed with three legs on the right and three legs on the left. The motors were operated simultaneously to allow the robot to move evenly. Thanks to its leg structure, it was aimed to travel in land conditions. Image control was provided on the computer with the camera placed on the robot. In this study, the program written into the electronic cards run the motors simultaneously.

The control circuit designed for the project is controlled by the vehicle. Arduino Uno collects and sends the commands sent from the control circuit to the Arduino Mega for the vehicle to perform the required commands.

The program written in Arduino IDE sends direction and step information to the stepper motor driver in response to the corresponding commands. Via a defined IP address, the image obtained by the camera on the vehicle is transferred to the computer instantly by computer or telephone.

In future work, it is aimed for the robot to perform tasks such as climbing stairs and overcoming obstacles with the development of power unit and motor capacity. In addition, the vehicle is intended to be coated with carbon fiber in order to increase the strength.

Declaration

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The author(s) also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

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