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Speech controlled RoboQuad

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Abstract. In this paper, the development of speech controlled RoboQuad is presented. The objective of the study was to construct and implement a 4-legged speech controlled robot capable of proportional forward reverse speeds and steering. The robot has four legs and its movements are wirelessly controlled by speech. Each leg has three joints with 3 degree of freedom and all joints are driven by servo motors. Simple quadruped walking styles, Polygonal walking configuration and walking balance are applied in this study. All movements of the quadruped robot were controlled by speech recognition via Bluetooth. Voice commutation is used for communicating the computer and Arduino through Bluetooth. Kinematic analysis and experimental results are also described in this paper.

1. Introduction

A Robots is automation system that fundamentally works based on a program and control of an operator. Speech Controlled RobQuad robot is a 4-legged robot, that moves using a crawling motion and is controlled wirelessly by a Bluetooth enabled device governed by Arduino modules. Many of engineering applications could benefit from the advantages legged machines offer in traversing rough terrain. Industrial uses include forestry and hazardous waste inspection and disposal, while research applications include the exploration of inaccessible or dangerous locations such as volcanos and the surfaces of other planets where wheeled robots and humans can't go and perform tasks [1]. Surveillance, reconnaissance, and land mine detection and removal are just a few examples of the many military uses for legged machines. In these fields, 4 legged, quad robots bring about opportunities due to their tiny size and practicable mobility. Potential uses for walking or crawling robots is when being in situation they are preferred over wheeled vehicles.

Multi-legged robots can investigate forest and rough environments where wheeled mechanisms do not have that flexibility. Nonetheless, legged machines are likewise utilized for trial analysis on the behavior of living creatures and for testing Artificial Intelligence (AI) techniques [2]. Historically, researcher have been initiated of the ideas of developing a robot with the human image. Such a robot has two legs like human. In practice, Humanoid (2-legged) is hard to design [3]. Having two legs contribute to get a less sense of balance and it can fall over easily. The sense of balance that humans can get easily, is hard to develop into a machine. Fundamentally the robot needs a minimum of 3-legs on the ground to make balance. Thus, having four legs can make a perfect walking sequences. When looked from this aspect, 4-legged walking robot can be simply scroll by produced design in all types of topography is an advantage.

In a robot a leg is needed to consist of at least 2-Degree of Freedom for walking or crawling [10]. Having 2-Degree of Freedom is very ineffective for crawling or walking and it like human walking style. Humans are walking with the supporting of knees and ankles and it is difficult to install on the mechanism [4]. A quadruped robot will have the capacity to show smoother walking gait by having three degree of freedom legs as well as having functions of crouching and spider movements. There are numerous approaches to control a robot, among them one of the broadly utilized ways are wireless control for example, using android phone or wireless remote. Among them, controlling robot using speech become widely and prevalent develop in robotic field these days [5].

As the aim of this project the movement of the robots are controlled by speech and commands are spoken into the microphone. Robot will follow the commend actions. The robot can make simple performances such as, moving forward, backward, left, right and other movements. The paper is organized as follows: A methodology for implementation is given in this section. Testing and Experimental Results is presented in the section after. A conclusion is drawn at the end.

2. Methodology

2.1. System Overview

The main objective of this project is to make 4-legged mobile robot wirelessly controlled by using speech recognition through a Bluetooth module. The main process of the robot is leg's controlling process. The interface between a human and the robot is generated wirelessly through BitVoicer software and it is implemented using Bluetooth module HC 06. Once user give's a command to the computer's microphone, BitVoicer recognized the commands and transmit data to the Arduino mega wirelessly though HC-06 Bluetooth module. When the Arduino receive's the data, it reprograms the servo motions upon the commands. In this case, ultrasonic sensors make the robot to move backward if the sensor detect some obstacle in front of the robot. After making reprogrammed movement, the process is going to be ended and user is needed to give a new command to make next processes as shown in Figure 1.

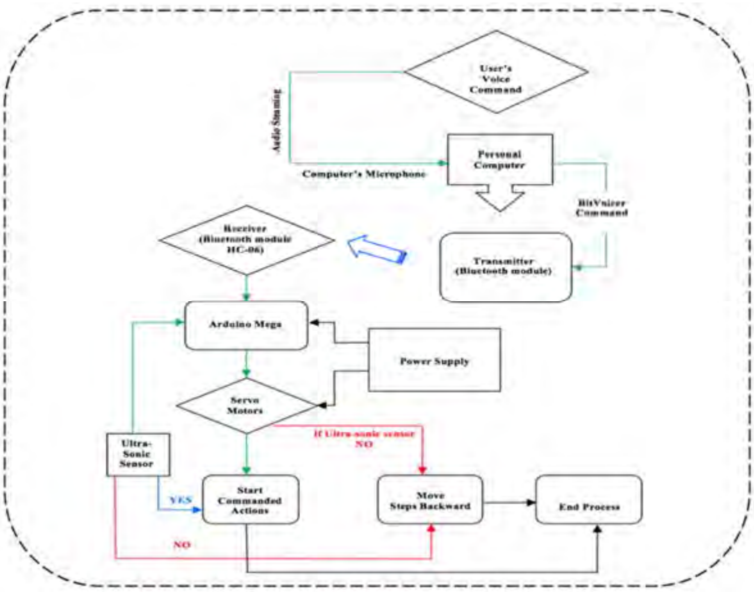
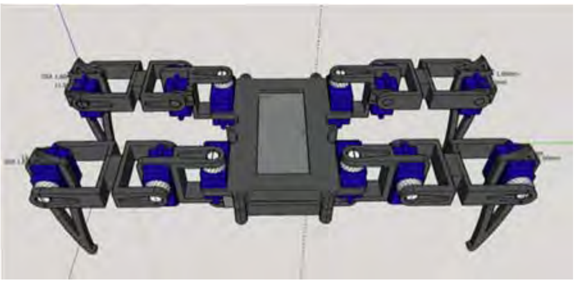


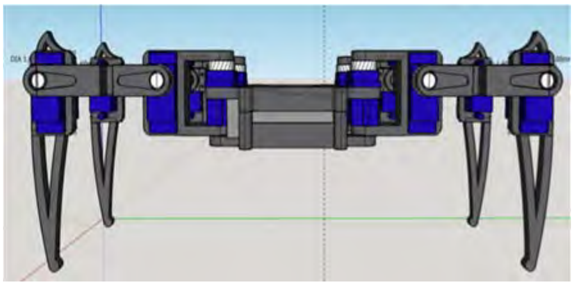
Figure 1.Overall flow diagram

2.2. Mechanical Design of RoboQuad

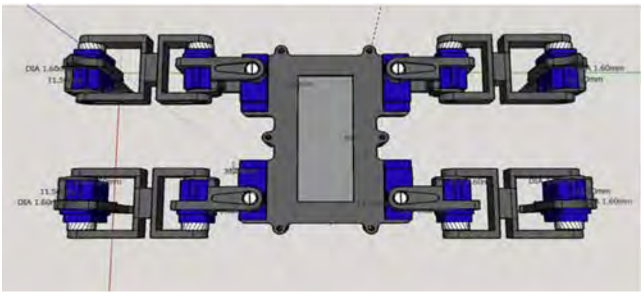
In order to get light weight and high strength, all parts of the robot are made from PLA filaments by 3D printing. The total weight of the robot is a 459 g. The robot will have the following dimensions of 2.5 cm thickness 10 cm width and 40 cm length. The legs are joined with the servo at the opposite sides of the body. The main importance is that the robot is needed to make balance itself during walking. Ultrasonic sensor is placed in front of the chassis and the battery is embedded in chassis. Arduino, control circuit and power buttons have been put on the chassis.



(a) Isometric View



(b) Side view



(c) Side view

Figure 2.Mechnical CAD design of RoboQuad

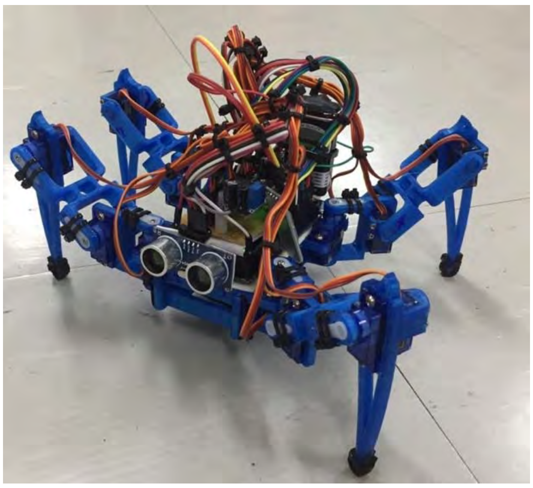


Figure 3.Assembled robot

The specifications of the robot is:

- Coxa length of 4 cm
- Femur length of 6.5 cm
- Tibia length of 9 cm
- Total length for each leg of 16.5cm
- Chassis width of 8cm
- Chassis length of 10 cm
- Robot total length of 40 cm
- Robot total width of 10 cm
- Robot height of 9.5 cm
- Robot total thickness of 2.5 cm
- Total weight of the robot 459 g

2.3. Legs Segments

Each leg has three joints, and all joints are connected with servo motors. An understanding of biological legged locomotion can also aid in the design and control of legged machines [6]. All legs have the same mechanisms for instance their mechanical systems and degree of freedoms but the difference is their motion algorithm. [7]. Therefore, functions such as unbalanced walking style and slow actions are prevented from this project. By considering those conditions the robot will get high efficient and stable performances were gained. The leg segments of the robot are the cox, femur and tibia as shown in Figure 4.

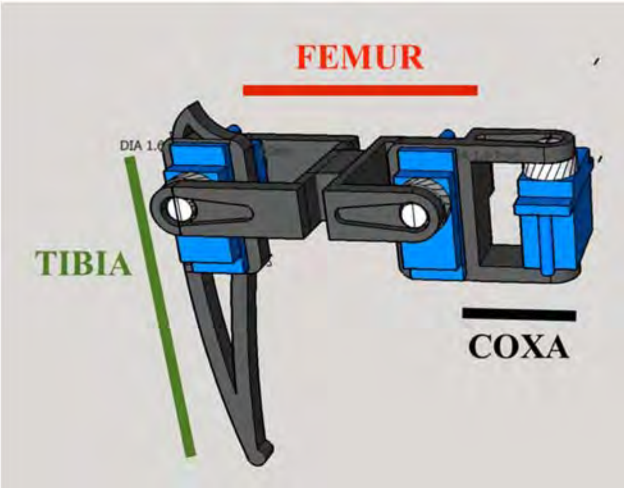


Figure 4. The Leg Segments

2.4. Walking Balance Analysis

At the initial state, the body of the robot is supported by 4 legs that contact with the ground surface and robot can stably stand at the standing condition with four leg. But in walking condition, each tip of the leg sequentially moves to one position to other position in planned motion gaits as shown in Figure 5. When the robot chooses a leg to move, remaining 3 legs are supposed to support the robot body to maintain stability of the robot body for walking. In walking situations, the balance of the walking system is necessary to be considered [8].

Four-legged mechanism means usually can stand with stability on four legs, but the stability of the robot cannot be certain in walking. Therefore it is the challenging part of the task. The robot was balancing of quadruped at walking and standing conditions were analyzed in this paper.

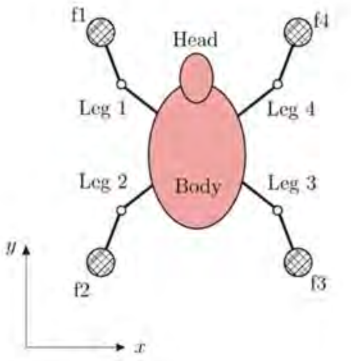


Figure 5. Motion steps of explorer gait

To get stability, the robot must have at least 3 feet in contact with the ground surface to support the body during walking in quadruped locomotion. Thus, when quadruped lifts one leg while walking the other three will remain stable. And then, when a leg is lifted for walking, remaining 3 legs will support the body on the surface like a shape of well-defined triangle as shown in figure 6. In the figure, the solid circle show feet that contact with the ground; the open circle show the leg which is chosen to lift for walking.

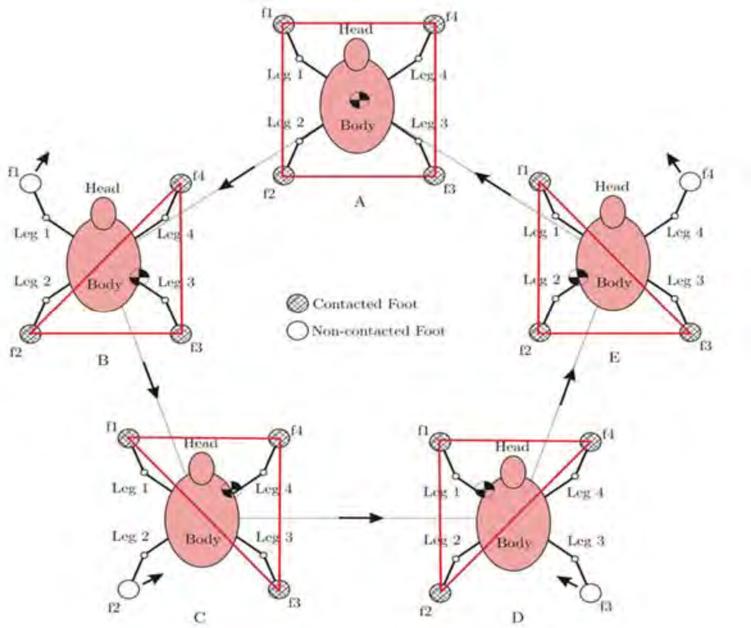


Figure 6. Step process of four foots

Generally, if a mechanism has n legs, the number of possible moving style(K) can be calculated by:

$$K = (n-1)! \tag{1}$$

The robot will specially consider the walking gait starting from leg 1. As the first swing the robot is always going to choose leg number 1 so, this robot can make (4-1)! =6 walking gaits [10]. Therefore, this quadruped robot can make 6 walking patterns of foot configuration as shown in Figure 7. As we will see later, Case III (1342) keep the highest balance for walking. Consequently, the robot was used

Case III (1342) walking patterns for forward and backward walking movements in this paper. For example, Case III's specifically sequential walking patterns was described as shown in Figure 8.

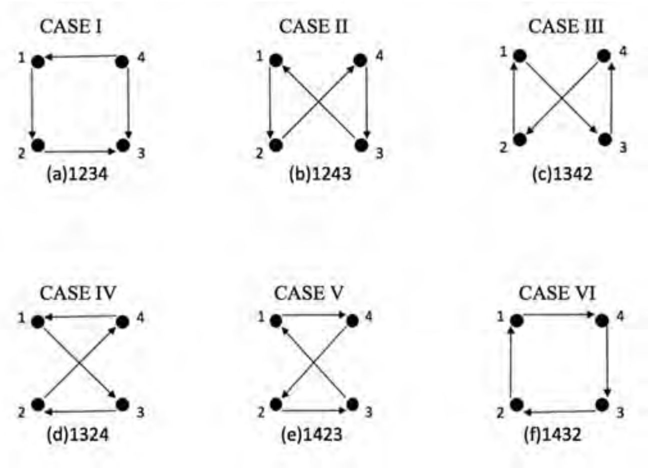


Figure 7. Quadruped walking gait

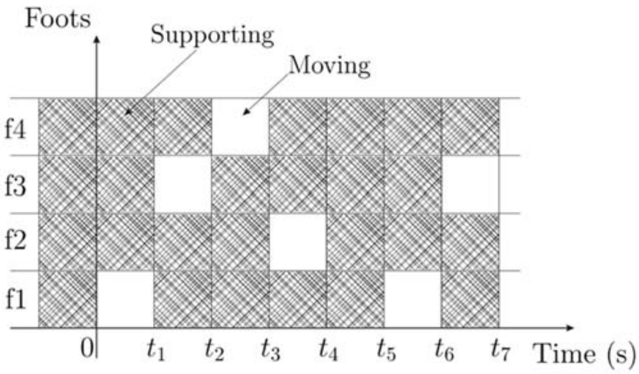


Figure 8. Walking pattern of a quadruped robot

A foot polygon is primarily considered in the 4-legged robot to make analysis for centroid-based analysis. Absolutely, the different types of polygon shape which formed in each of quadruped walking are triangular foot polygon shapes and rectangular foot polygon shapes as illustrated in Figure 9. If one leg is swung in the quadruped walking, the triangular shape of foot configuration is formed for example, Figure 9(a) shows such a triangular shape of foot polygon and its centroid coordinate position $C_g(x_g(t),y_g(t))$ can be obtained by

$$x_g(t) = \{x_1(t) + x_2(t) + x_3(t)\}/3 \tag{2}$$

$$y_g(t) = \{y_1(t) + y_2(t) + y_3(t)\}/3 \tag{3}$$

Foot configuration that form a rectangular shape polygon as shown in Figure 9(b) is built at the standing state by four legs. The rectangular polygon's centroid can be obtained by

$$x_g(t) = \frac{1}{s_1(t) - s_2(t)}\{s_1(t)x_{g1}(t) - s_2(t)x_{g3}(t) + y_{g3}(t) - y_{g1}(t)\} \tag{4}$$

$$y_g(t) = \begin{cases} s_1(t)\{x_g(t) - x_{g1}(t)\} + y_{g1}(t), & or \\ s_2(t)\{x_g(t) - x_{g3}(t)\} + y_{g3}(t) \end{cases} \tag{5}$$

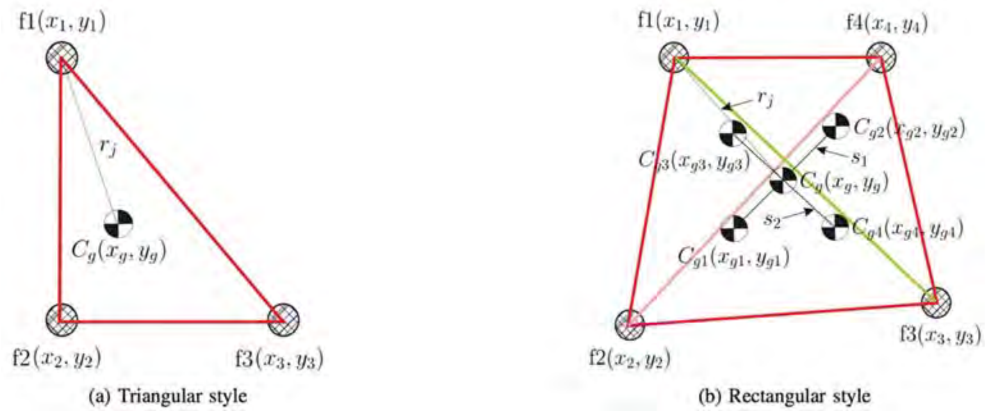


Figure 9. Foot polygons

Although the robot's centre of mass has been conformed to the centroid of foot polygon. The walking configuration and walking level cannot be the same due to the different shape of the polygon [8]. As the shape of the polygon has more sides, the higher the walking balance of the robot. By this view, we simply describe performance index (IB) of the quadruped for walking balance depend on a distance as the following equation.

$$I_B = \min(r_j(t)),\ j = 1, \cdot\cdot\cdot, n \tag{6}$$

where the minimum value of $r_j(t)$ have been referred as $\min(r_j(t))$ and (n) represent 4 for a rectangular polygon shape and 3 for a triangular shape polygon [8]. For example, the distance between the j^{th} vertex of a polygon and centroid of polygon in Figure 9, $r_j(t)$, is derived by

$$r_j(t) = \{x_g(t) - x_j(t)\}^2 + \{y_g(t) - y_j(t)\}^2 \tag{7}$$

Approximately, the minimum distance between the support centroid of the polygon and each foot positions in a walking configuration is represented by the value of IB in equation(6) [8]. It is the last evaluated that the walking style with larger I_B has batter walking balance possibility by a comparative study through many walking styles.

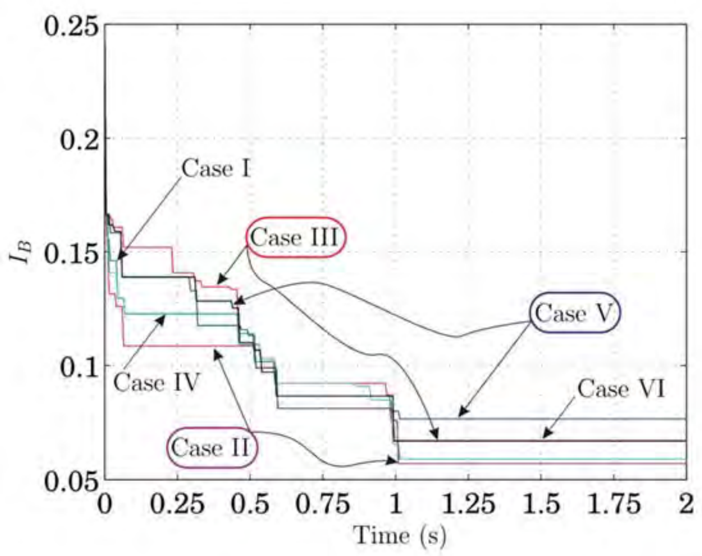


Figure 10. The result of IB (balance index) in six case

The balance index in defined equation(6) was check to survey which style have better walking balance during walking. Figure 10 shows the values of IB that indices for the six walks assigned in Figure 7. From Figure 10, we can approve that the Case III walking style, keep the best balance at early of time. But the Case V is higher walking balance than the others in later part of time and the long-range walking balance of the Case II (124311) is the lowest. On the other hand, Case I and Case VI get the intermediate balance and stability. Thus, both case is suitable for turning. Thus, the robot was focused on Case III for walking forward and backward and Case I and Case VI for turning left and right in this project

2.5. Calculations

2.5.1. Inverse Kinematics Calculations of Legs

After choosing one of the walking patterns, we must calculate the values for the servos. The quadruped has total 12 degrees of freedom, where there is 3 degrees of freedom on each leg. This section show the simple calculation to get the degrees for the servos of each joint to turn this into programming language, we need to work it out using equations and trigonometry.

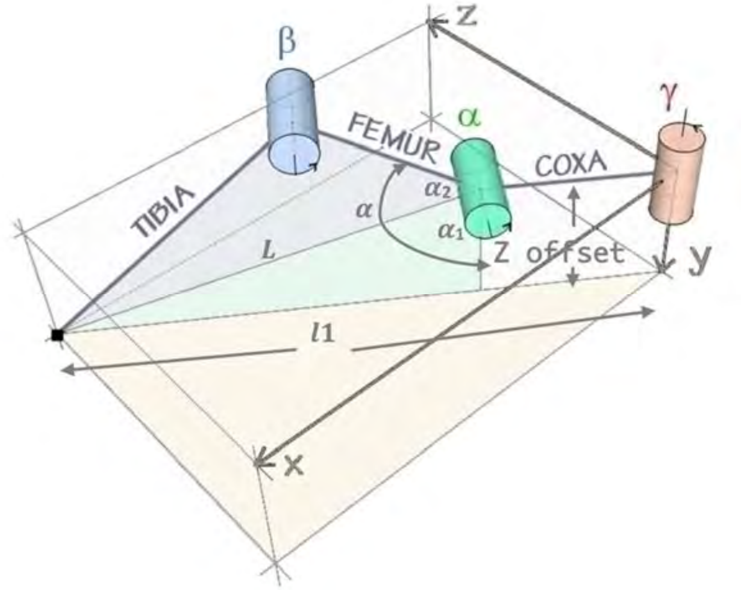


Figure 11. Trigonometry diagram of the robot's leg

$$\gamma = \tan^{-1}\left(\frac{x}{y}\right) \tag{8}$$

$$\alpha_1 = \cos^{-1}\left(\frac{Z\,offset}{L}\right) \tag{9}$$

where,

$$L = \sqrt{Z_{offset}^2 + (L1 - COXA)^2}$$

$$\alpha_2 = \cos^{-1}\frac{TIBIA^2 - FEMUR^2 - L^2}{-2(FEMUR)(L)} \tag{10}$$

And α is,

$$\alpha = \alpha_1 + \alpha_2$$

By (9) and (10)

$$\alpha = \cos^{-1}\left(\frac{Z\,offset}{L}\right) + \cos^{-1}\frac{TIBIA^2 - FEMUR^2 - L^2}{-2(FEMUR)(L)} \tag{11}$$

And finally,

$$\beta = \cos^{-1}\frac{L^2 - TIBIA^2 - FEMUR^2}{-2(TIBIA)(FEMUR)} \tag{12}$$

At that point, we have our values for our servos then transferred the mathematics into a program. Inverse kinematics is what's actually driving the robot. In simple words **inverse kinematics**, for short **ik**, is a bunch of trigonometric equations that determine the position of the tip of the leg, the angle of each motor, and other values when given a couple of pre-sets that we need to determine. For example, the length of each step which we want our robot to reach and the height where we want our robots body to be at. Using this pre-determined (data) it will derive how much it should move each servo to be able to manage to perform the given task.

The rotation matrices example for the quadruped robot are obtained:

$$R_x(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\alpha & -\sin\alpha \\ 0 & \sin\alpha & \cos\alpha \end{bmatrix},$$
$$R_y(\beta) = \begin{bmatrix} \cos\beta & 0 & 0 \\ 0 & 1 & 0 \\ -\sin\beta & 0 & \cos\beta \end{bmatrix}, \quad (13)$$
$$R_z(\gamma) = \begin{bmatrix} \cos\gamma & -\sin\gamma & 0 \\ \sin\gamma & \cos\gamma & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

Therefore, the homogeneous rotation matrix is represented by

$$R = R_x(\alpha)\, R_y(\beta)\, R_z(\gamma)$$

and R' = R (x, y, z) is the foot position vector, thus

$$R' = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = R \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (14)$$

From the above example equations, we got the values for the foot positions. It is important to notice that, when programming walking algorithm, balance walking giant can control by adjusting these values.

3. Testing and Experimental Results

3.1 Speed and Time Testing

The purpose of this experiment is to test how long the robot takes to move to the destination point by varying speeds. In this case, the destination point is set to 150 cm from the starting point 0 cm and the body move speed is fixed at 3. First experiment is investigated at the plane and smooth surface.

Table 1. Average time taken of the robot at plane surface

No	Distance (cm)	Body speed (rpm)	Leg speed (rpm)	Time taken to the destination point (s)					
				1st	2nd	3rd	4th	5th	Average
1	150	3	3	54.35	54.31	54.10	54.05	54.40	54.24
2	150	3	6	30.33	30.10	30.56	30.22	30.34	30.31
3	150	3	9	21.57	21.46	21.30	21.49	21.56	21.48
4	150	3	12	22.51	22.44	22.30	22.20	22.40	22.37
5	150	3	15	23.16	23.02	23.13	23.23	23.22	23.15
6	150	3	18	Walking error					

Next, the same speeds and distances with the above experiment are tested at the rough surface.

Table 2. Average time taken of the at rough surface

No	Distance (cm)	Body speed (rpm)	Leg speed (rpm)	Time taken to the destination point (s)					
				1st	2nd	3rd	4th	5th	Average
1	150	3	3	56.45	56.60	54.51	56.75	56.67	56.19
2	150	3	6	32.37	32.14	32.45	32.22	32.42	32.32
3	150	3	9	22.21	22.65	22.86	22.79	22.38	22.58
4	150	3	12	23.68	23.78	23.89	23.45	23.67	23.69
5	150	3	15	25.22	25.34	25.45	25.65	25.32	25.39
6	150	3	18	Walking error					

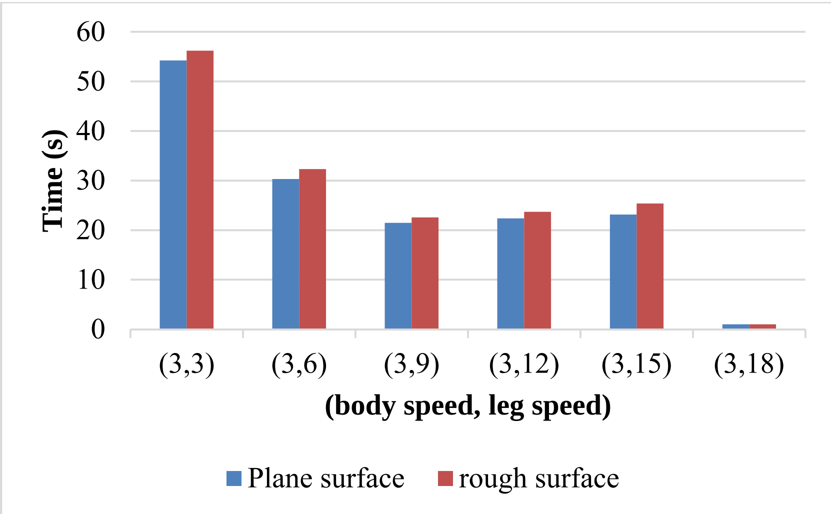


Figure 12. Comparison of speed and time taken

According to the results, the time that take to reach the destination point at plane surface is not much more less than the time taken at the rough surface. The legs of the robot are hard to move and it may slip in each step so, the time taken in rough surface is longer than the other.

In both case, speed (3,9) is the best speed for quadruped. If the speed is more than that, the possibility of slipping rate is more and more due to the discontinuity of the feet forces. If the leg move speed more than the maximum speed (3,15), friction force from high speed have less time to make centroid foot polygons for balance because the swing let cannot continuously transit. In high speed, robot's legs are supposed to continuously move one position to another in short time so, the legs couldn't perfectly support the body to make stable. Thus, the possibility of slipping rate become highest and robot cannot move properly. Secondly, when the body moves the body speed is changed with the change in legs speed, the time taken to the destination point is a slightly less than above experiment in which body speed are fixed at 3. These experiments were also performed at the plane surface and the results of the experiments are show in the below table.

Table 3. Average time taken of the robot by varying speed

No	Distance (cm)	Body speed (rpm)	Leg Speed (rpm)	Time taken to the destination point (s)					
				1st	2nd	3rd	4th	5th	Average
1	150	3	3	54.40	54.45	54.01	54.50	54.43	54.36
2	150	6	6	25.52	25.59	25.50	25.46	25.49	25.51
3	150	9	9	19.75	19.76	19.80	19.81	19.71	19.77
4	150	12	12	20.11	20.45	20.35	20.20	20.18	20.26
5	150	15	15	28.56	28.61	28.73	28.34	28.54	28.56
6	150	18	18	Walking error					

3.2 Movement of The Robot Experiment and Result

The purpose of the test is to describe resulting movement characteristics of the robot by the normal sight. The robot was place as in Figure 13 for the movement test and the speed is set up at leg move speed 15, body move speed 3.

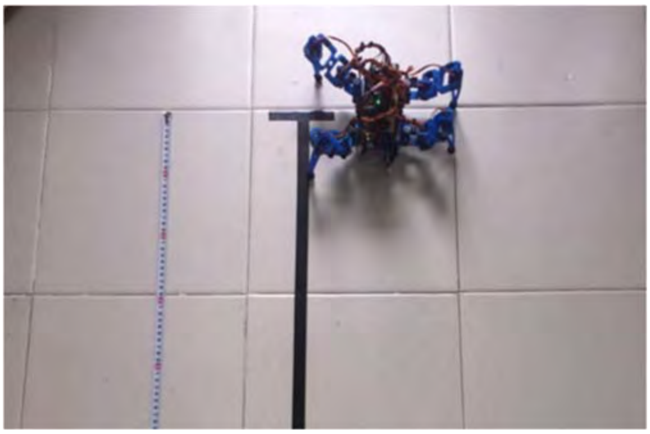


Figure 13. The robot movement test arrangement

The result of the test with preprogramed robot is shown in Figure 14. As mentioned above experiment, robot could not move in a straight-line position during the movement of forward and backward. The misalignment can be seen since the robot's reach is just 70 cm. When the robot reach is 300 cm, it already shifts 90 cm from the straight line of the robot. According to the results, robot make slip event during each of it's movements.

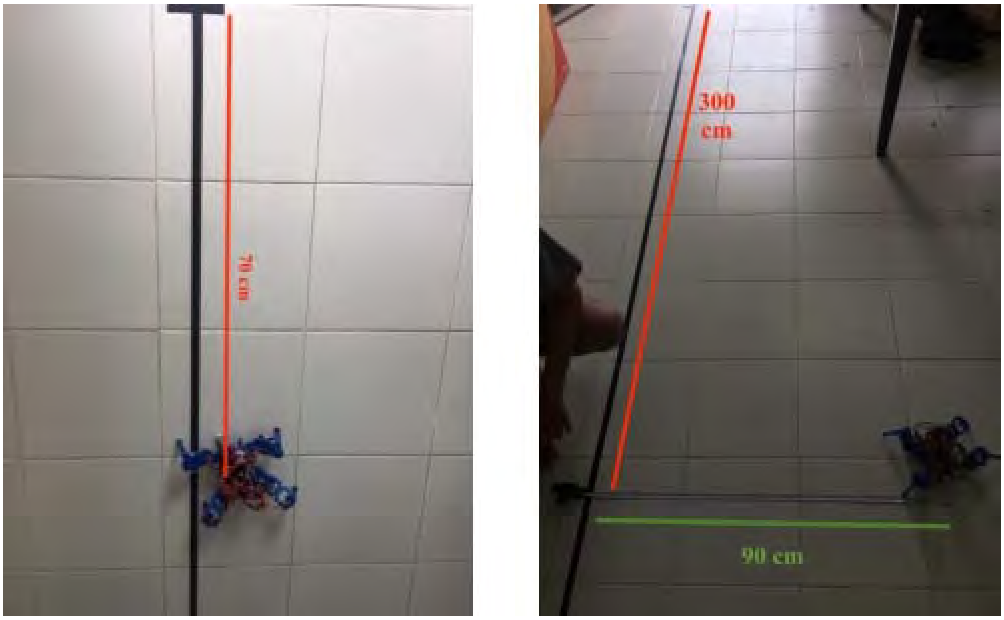


Figure 14. The movement test result

The slip is because the robot has only 4 feet with only 3 degree of freedom in each leg, thus various areas of exposure of the feet make to occur slips during different movements. After that, the movement experiment was investigated by varying speed of leg at the plane surface like the first experiment. In this case, body move speed is fixed at 3. As the result shown in above experiment varying body speeds is majorly different with the condition when it was fixed.

Table 4. Relationship of speed and movement

Speed	Slip distance at final position (cm)
3	8
6	10
9	0.5
12	40
15	90

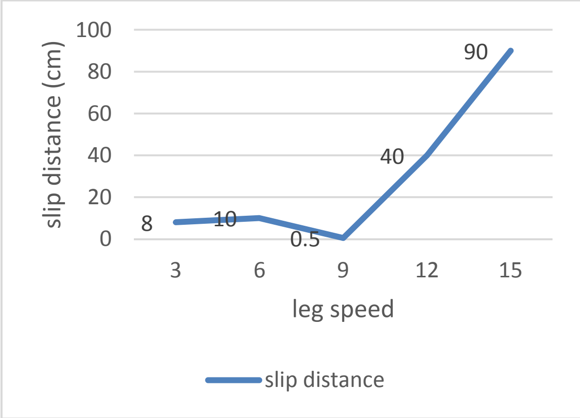


Figure 15. The result of movment test by varying speed

According to the result, the higher the leg speed is set up, the higher the slip event is occurred. But at the leg speed (9), the robot moves just 0.5 cm from the line. Thus, the speed, (3,9), is the most suitable speed for this quadruped robot. Next the robot is placed as in Figure 16 for movement trace test. A white board marker was added at the back of the robot. Robot was installed and preprogramed to move forward for 20 steps, turn left 90• and move forward 20 steps with speed (3,9).

Figure 16. Movement trace test arrangement using whiteboard marker

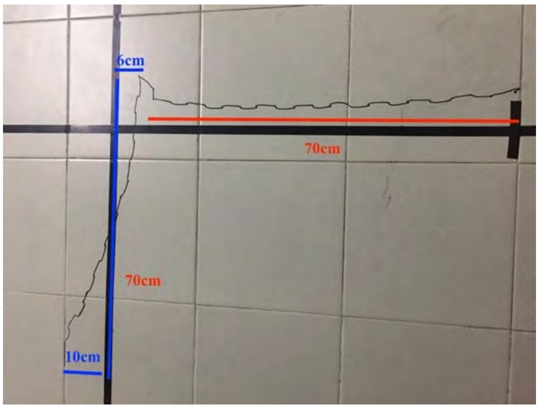


Figure 17. Result of movement trace test

The result of the test that plot by preprogramed robot with the movement gaits is shown in Figure 17. The curve that was plotted by the trace of robot and every step of the robot.

3.3 Speech Recognition Accuracy Tests and Results

In the test of voice recognition, a simple test is performed with comparison of using single words and double to confirm that the Arduino gets the right information from the Bitvoicer for controlling the movement of the robot. Several accuracy tests are investigated with two conditions, recognized (Yes) and rejected (No) of words. Firstly, the recognition accuracy is tested by single words. Secondly, with the double word which was used in this project. These two tests are test's conducted under silent environment.

Figure 18. Bitvoicer program

Figure 18 describes how the voice was noted. The recognition accuracy test consists of 10 tests for each command. Tests' results are shown in the following tables.

Table 5. Results of the speech recognition accuracy test using single words

	1	2	3	4	5	6	7	8	9	10
Forward	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Backward	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
Left	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Right	No	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes
Stand	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Sit	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Faster	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Slower	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No

As per above results of the total accuracy percentage of using single words from Table 5 is;

- Total test = 8×10 = 80
- Rejected number(No) = 20
- Recognized number (Yes) = 60

So, the total accuracy percentage is: $\frac{60}{80} \times 100\% = 75\%$

Table 6. Results of the speech recognition accuracy test using double words

	1	2	3	4	5	6	7	8	9	10
Move Forward	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Movebackward	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Turn Left	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Turn Right	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stand up	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Sit Down	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Go Faster	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Go Slower	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No

As per above result of the total accuracy of using double words from Table 6 is;

- Total test = 8×10 = 80
- Rejected number (No) = 7
- Recognized number (Yes) = 73

Therefore, accuracy percentage is: $\frac{73}{80} \times 100\% = 91.25\%$

According to the results, it is clear that the accuracy of using double words is higher than using single word accuracy. The more the number of word increase the better the accuracy is gained [9]. Thus, double words are used to control the robot in this project. The same tests were also investigated in a noisy area to check the accuracy of the recognition but the system cannot be able to recognize as well as silent environments.

4. Conclusion

A quadruped robot with 3 Degrees of Freedom in each leg have been developed using speech control. This project is a simple demonstration of technology which we can control the robotic movements by serial communications. The speech controlled quadruped has been made by using software like Arduino programming. The mechanical design of quadruped works pretty well and the robot can move to the determined position without serious resistance. Through many investigations, we have confirmed that 4-legged locomotion need consequence legs movement in each step-in order to get stability. And then, the walking balance of 4-legged mechanism is also depending on the walking style that the robot applied. Particularly, it is familiar that the walking gaits of Case III can be applied as a useful walking style for the 4-legged robot in forward direction and Case I and Case VI can be utilized for turning. The robot has only four legs with 3 degree of freedom has slip occurrence during each of movement and the robot cannot move the direction of straight line with high speed, such that the forward movement with speed at 15 has changed 90 cm from its straight position after it reached 300 cm forward distance from its starting point. All the results show robot occurs slip events in every movements. Speech controlled RoboQuad is practiced and carry out with sufficient results. The Quadruped robot can be control 41.54 m range with the perfect signal. The robot only can control with speech. In this project, Bitvoicer software was used instead of Python and Eclipe because Bitvoicer is open source due to which we were easily able to make the necessary programs and no money was wasted to acquire the software.

5. Further developments

As a further development of this project a student at AIT is currently developing the concept of attaching wheels to the bottom surface of the legs of this RoboQuad. The advantages of having wheels at the bottom surface of the legs will be enabling the quad greater mobility and flexibility. It will have the functions of covering greater distances as well as cover range of surfaces.

References

[1] K. Arikawa and S. Hirose, Development of quadruped walking robot TITAN-VIII, *in Proc. of IEEE/RSJ Int. Conf. on Intelligent Robots and Systems*, 1996.

[2] Woering, R. (2011). Simulating the first steps of a walking hexapod robot. *University of Technology Eindhoven*.

[3] M. Fujita and H. Kitano, Development of an autonomous quadruped robot for robot entertainment, *Autonomous Robots*, vol. 5, 1998, pp. 7-18.

[4] G.S.Hornby,S.Takamura,T.Yamamoto,andM.Fujita,Autonomous evolution of dynamic gaits with two quadruped robots, *IEEE Trans- actions on Robotics*, vol. 21, no. 3, 2005.

[5] Soonggalon, E. F., & Tejawibawa, K. (2011, November). Developing a quadrupedal robot with speech recognition movement control. In *Instrumentation Control and Automation (ICA), 2011 2nd International Conference on* . IEEE.

[6] Kajita, S., & Espiau, B. (2008). Legged robots. In *Springer handbook of robotics* . Springer Berlin Heidelberg.

[7] Karakurt, T., Durdu, A., & Yilmaz, N. (2015). Design of Six Legged Spider Robot and Evolving Walking Algorithms. *International Journal of Machine Learning and Computing*, *5*(2), 96.

[8] Kim, B. H. (2009, June). Centroid-based analysis of quadruped-robot walking balance. In *Advanced Robotics, 2009. ICAR 2009. International Conference on* (pp. 1-6). IEEE.

[9] Adith Jagadish, Speech controlled Quardropod. (2015) (In- formation available at http://www.instructables.com/id/Speech-Controlled-Quadropod/?ALLSTEPS)

[10] Adith Jagadish, Speech controlled Quardropod. (2015) (In- formation available at http://www.instructables.com/id/Speech-Controlled-Quadropod/?ALLSTEPS)