Development And Analysis Of Octopod Using Klann's Mechanism

By

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ABSTRACT

The main aim of this project is presents a single degree-of-freedom crank driven walking leg mechanism which isused for walking machines.The mechanism is Joseph klan type having eight links. Using this type mechanism a walking robot with eight legs is designed and fabricated. Initially a walking leg mechanism is prepared. Its kinematics and synthesis analysis is conducted to achieve desires stride length using "mechanicallinkageanalysis software. Further the same mechanism are produced with eight numbers.Also a frame is fabricated. These mechanisms and frame are assembled to produce octopod bio-inspired robot by adding necessary electronic devices. Legs and frame are fabricated with Aluminium material due to it is light weight.

Furthermore kinematic analysis of the bio-inspired robot is carried out. Finally the robot is made to walk on surface.

Keywords: KLANN'S mechanism , octopod, linkage analysis simulator, DH parameters

1. INTRODUCTION

Robotics is an interdisciplinary sector of science and engineering dedicated to the design, construction and use of mechanical robots. The modern day's robots are the part of the human life so that the growth of the robots are rapidly improved. Apart of the human life also robots are playing important role in manufacturing industry and other areas i.e space, see, all other hazarders environments. Robotics evolved as part of the third industrial revolution. Robots – in the form of manipulators - were used in automotive assemblies to speed up the production process of automobiles. Since that time, robots are being used in all sectors – industrial, healthcare, manufacturing, and elsewhere. Since a robot executes one or more tasks automatically with speed, precision and repeatability, their use has increased manifold. Robots are used in space programs, for underwater exploration of oil and gas structures, for military surveillance purposes, in environmental monitoring, in archaeology, for plant maintenance, medical treatment, and varied other sectors.

1.1 Classifications of Robots

Defining robots is complex. There are many definitions that attempt to separate a robot from automation. Classifying them is not easy either. There are many ways to classify robots. They can be classified on the basis of how they perform tasks, on the basis of their application, on the basis of how they move and so on. For the purpose of this article, we will stick to the classification of robots based on the most popular ways to do so – by their application, or by their locomotion / kinematics. Before we proceed, let us make it clear that this classification is very broad, and we will not cover all robot types under it. Also, some types of classifications may overlap. For example, an industrial robot can be classified as a Cartesian robot as well. Or an airborne drone can also be classified as a defense robot.

1.2 Classifying Robots by their Application

One of the most popular way of classifying robots – and one of the simplest – is by what they actually do. Based on this classification, there are two broad ways of categorizing robots.

1.2.1 Industrial Robots

These were one of the first robots to be used commercially. In a factory assembly line, these are usually in the form of articulated arms specifically developed for such applications as welding, material handling, painting and others. They can be further subdivided as manufacturing robots and logistics robots. Manufacturing robots are designed to move materials, as well as perform a variety of programmed tasks in manufacturing and production settings. They are often used to perform duties that are dangerous or unsuitable for human workers. Logistics robots are mobile automated guided vehicles primarily used in warehouses and storage facilities to transport good Classifying Robots by their Kinematics or Locomotion

Robots can also be classified according to how they move – or not move.

1.3.1 Stationary Robots

This robot is not moving to anywhere .it can have performed the tasks with in their work volume and this type of robots also called as industrial robots. Example “Cartesian Robots, Cylindrical robots, Spherical Robots, Articulated Robots, Parallel Robots”.

1.3.2 Wheeled Robots and legged Robots

These are robots having wheels, and can be further be categorized as: single wheel robots, two-wheel robots, three and more wheel robots, bipedal robots (humanoid robots), tri-pedal robots, quadra-pedal robots and hexapod robots.

1.3.3 Aquatic Robots

These robots can work on or under water. They are mostly used for underwater exploration of oil, gas or minerals.

1.3 Hybrid Robots

The hybrid robots are migrated robots which will collaborated the mobile robots with industrial robots to performing a special task in industries and other applications.

1.4 Attributes of the legged Robots

Hybrid robots are model-driven or insect – driven robots. Hybrid mobile robots are automatic systems that use a combination of wheels (or tracks) and legs in different configurations to perform locomotion. To creating and controlling the locomotion is very important.

1.5.1 It can be used for both modelling and biological experiments

Robotics in biology give high valuable experiments related to a researchers and development of lifestyle. Those experiments which include biological samples of large numbers

- Highly control kinematic structure
- degrees of freedom
- localization
- Gait calculations
- HRI System

1.5.2 Modelling Difficulties

Three challenges focus on fundamental problems in robotics: developing robot swarms, improving navigation and exploration, and developing artificial intelligence that can "learn how to learn", and use common sense to make moral and social decisions. Another importance task and modelling Human-Oriented Interaction. One of the major hurdles that both personal and industrial robotics is facing is integrating a human-friendly interaction in all robots. Multi functionality. Modern industrial robots are generally good at performing one particular task. Biggest industry challenges. The field of robotics is facing numerous issues based on its hardware and software capabilities.

- Integration of mobile robot with IR
- Intelligence
- Trajectory planning
- multipurpose algorithm
- Obstacle identification and avoiding
- Kinematic structure adjustment
- Autonomy
- Robotics and AI

2. LITERATURE REIVEW

The present chapter deals with the design, kinematics, gait plan, and fabrication of single-degree-of-freedom robots.

Table 1 Literature Summary

S. No	Area of the literature	Reference number
1	Design of single degree of freedom walking robots	1-12
2	Gait analysis	12-22
3	Development of bio-inspired robots and its applications	23-30

2.1 Design of single-degree-of-freedom walking robots

Equipped with the unique ability to traverse tough terrain inaccessible to normal vehicles with wheels or tracks, legged robots represent a significant advancement in the field of robotics. This capability is especially crucial in tasks like search and rescue missions, where swift access to remote or hazardous locations can save lives. The key benefit of these robots stems from their advanced walking systems, designed to mimic the movement of living creatures, enabling them to navigate various landscapes smoothly and effectively [1–3]. YashPunde, YugandharDhande, et al. [6] Design and Linkage Analysis of the Theo Jansen Mechanism. The Theo-Jansen linkage is an eleven-bar mechanism designed by Theo Jansen in his collection "Strandbeest." The mechanism is crank-driven and mimics the motion of a leg. Its energy efficiency and predeterminable foot motion show promise of applicability in legged robotics. In order to determine an expression for the inverse Jacobian matrix in regressor form, we propose to separate the adjugate and determinant of this matrix and then form new regressors. The projection algorithm is employed in order to ensure singularity avoidance, avoid large variations in parameters, and provide a faster and better transient response. Simulation and experimental results verify the promising performance of the proposed method in practice.

Nick Gravish George V. Lauder. et al. For centuries, designers and engineers have looked to biology for inspiration. Biologically inspired robots are just one example of the application of knowledge of the natural world to engineering problems. However, recent work by biologists and interdisciplinary teams has flipped this approach, using robots and physical models to set the course for experiments on biological systems and to generate new hypotheses for biological research. We call this approach robotics-inspired biology; it involves performing experiments on robotic systems aimed at the discovery of new biological phenomena or the generation of new hypotheses about how organisms' functions can then be tested on living organisms.

GongfaLiFanXiao. [6] An inverse kinematics method for robots after geometric parameter compensation. One of the critical design decisions that arises during the design of an industrial robot is the function of the joints to be used and their location. Of course, for the designed robot to provide the expected performance, the selection of the motors and gear reducers that will create these joints will primarily affect the determination of these joints. However, both the examination of the existing industrial robots and the fact that the motor and gear reducer information that can be supplied can be easily obtained with today's technology mean that these joints can be determined quickly as a result of a short investigation. Along with the mechanical design, robot control unit design also has stages that progress in parallel and depend on or affect the mechanical design decisions. One of the most important of these is that inverse kinematics calculations can be performed analytically, enabling the robot control unit to make decisions and give commands in real-time. Experiments on the calibrated spherical-wrist and non-spherical-wrist robots show that the theoretical analysis is correct. It is concluded that the calibrated robot could be simplified into a structure with an analytic solution. Then, the IK of the original robot can be obtained by nesting the analytic solution into the proposed method.

FanXiaoGongfaLi et al. [7] An effective and unified method to derive the inverse kinematics formulas of a general six-DOF manipulator with simple geometry. This article proposes an improved method of disconnection and reconnection to achieve this purpose. Firstly, we determined the position selection of the two cutting points and the attitude setting at the first cutting point. Next, we gave the new conditions for the re-connection of the two sub-chains and the corresponding equations. Then, we summarized five methods of cutting the manipulator into two three-DOF sub-chains and corresponding equation deformations, as well as the selection principles of equation deformations. Finally, we used three examples to demonstrate the effectiveness of the method. The results show that the expressions of six joint variables can be derived from only six equations. The solutions of the wrist joint variables are not affected by the singularity.

Vidoni, A. Gasparetto [8] Taking into account the anatomy and the adhesive and locomotion capabilities of the spider (i.e., an eight-legged system), we present on the one hand a study of the foot force and torque distribution in different operative and slope conditions and, on the other hand, a posture evaluation by comparing different leg configurations in order to minimize the torque effort requirements. Efficient force distribution and leg posture for a bio-inspired spider robot. In this paper, taking into account the anatomy and the adhesive and locomotion capabilities of the spider (i.e., an eight-legged system), we present, on the one hand, a study of the foot force and torque distribution in different operative and slope conditions and, on the other hand, a posture evaluation by comparing different leg configurations in order to minimize the torque effort requirements. This article addressed the force and torque distribution for an eight-legged spider robot. Then we considered the anatomy and the adhesive and locomotion capabilities of the spider.

Equipped with the unique ability to traverse tough terrain inaccessible to normal vehicles with wheels or tracks, legged robots represent a significant advancement in the field of robotics. This capability is especially crucial in tasks like search and rescue missions, where swift access to remote or hazardous locations can save lives. The key benefit of these robots stems from their advanced walking systems, designed to mimic the movement of living creatures, enabling them to navigate various landscapes smoothly and effectively [1–3]. Fascinating for their ability to replicate biological locomotion, walking robots can be categorized based on their degrees of freedom (DoF), which refers to the number of independent movements the robot can make. A single degree of freedom in walking mechanisms implies simple motion, often linear or rotary, without the complexity seen in multi-DoF systems. Beyond the single DoF, the complexity and capabilities of walking robots expand significantly [9]. In the category of single-degree-of-freedom (DoF) walking robots, the development of Theo Jansen's walking mechanism [10], powered by a single-degree-of-freedom crank, has played a crucial role in advancing the design of walking machines. Focusing on further investigation of the Theo Jansen mechanism, Shah, R. et al. [6] aim to enhance the capabilities of walking robots through innovative approaches to optimize performance. Their research focuses on proposing novel design modifications and cutting-edge control strategies, all aimed at maximizing stability and efficiency in robotic locomotion. In pursuit of these goals, researchers aspire to push the boundaries of robotic mobility, opening up new horizons for applications in various fields. The enhancement of the Theo Jansen mechanism has significantly advanced robotics, particularly in walking rehabilitation and terrain adaptability. By closely mimicking human ankle trajectories, the mechanism now offers improved rehabilitation tools and increased walking efficiency for robots navigating various terrains, highlighting its extensive applicability in healthcare and environmental exploration [10–11]. Continuing with the advancement of robotic mechanisms, Patnaik, L. et al. [12], through continuous improvement of the Jansen mechanism, have expanded its application into the domain of Araneae, thereby advancing the design of walking robots. This research leveraged the Jansen mechanism for the selection of optimal motors, enabling the construction of more robust and efficient spider-like robots, marking a significant contribution to the advancement of biomimetic robotics.

2.2 Walking Gait Planning

The gait planning and evaluation are very important for robot walking; hence, we are focusing on the existing work to follow to withdraw the biological walking patterns.

The J.C. Klann [13] mechanism introduces a novel approach to mimicking natural walking movements, enhancing robotic mobility and efficiency through its innovative linkage design. Building on this mechanism, the study presents a reconfigurable four-legged robot that can execute six bio-inspired gaits. It is designed for easy control in difficult terrains, featuring efficient servo control and maintaining stability across various walking patterns. Simulations validate its performance on uneven terrain, emphasizing its potential for advanced robotic applications. [14-15]. Kim, HyunGyu, et al. [15] successfully applied the Klann mechanism to bio-inspired amphibious applications, markedly improving the running speed of a robot on both water and land through advanced modeling and optimization techniques. Expanding on this success, Kashem, S. B., et al. [16–17] developed a compact amphibious robot equipped with bio-inspired webbed feet for the Klann linkage. This innovative design facilitates efficient navigation across a variety of terrains and aquatic environments, representing a significant advancement in the exploration of challenging areas and suggesting promising avenues for future robotic innovations. Furthermore, the Klann mechanism's applications were extended to araneae, leading to the development of a spider robot. This robot was successfully integrated into various environments, showcasing the versatility and potential of the enhanced Klann mechanism in bio-inspired robotics. [18-19] Under the category of single-degree-of-freedom robots, the pantograph mechanism presents an intriguing subject. Manuel A. Armada et al. [20] analyze the kinematics and dynamics of a 1-DOF Pantograph leg, emphasizing modularity, compactness, light weight, and minimal degrees of freedom to improve walking capabilities. To continue the research on pantograph mechanism walking robots, Ben Sheng Lin et al. [21] investigate how pantograph mechanisms have notably enhanced the performance and efficiency of walking robots, setting the stage for future technological advancements. Their innovative efforts, particularly in combining these mechanisms with the Chebyshev-Pantograph design, have resulted in the development of more streamlined and economical biped robots. To elevate the capabilities of pantograph mechanism-based walking robots, Ishihara, H. et al. [22] introduce a 4-legged locomotion mechanism incorporating a pantograph-jack leg design, tailored for heavy load-carrying tasks like disaster relief. This jack-like leg efficiently grasps and lifts heavy objects with minimal energy consumption or active control. The prototype achieves crawl walking resembling reptilian movement, boasting a walking speed of 0.001 m/s and a payload capacity of 45 kg. The paper details the locomotion concept, prototype design, and significant experimental findings. The Peaccular-Lipkin walking mechanism robot, due to its flexible design, is classified within the category of single-degree-of-freedom walking robots.

2.3 Development of bio-inspired robots and their applications

Bio-inspired robots draw inspiration from biological systems, organisms, and processes to design and develop robotic systems. This field has gained significant attention due to its potential to revolutionize various industries and address challenges in robotics and automation. Here's a breakdown of the literature, importance, and applications of bio-inspired robots:

Diego A. et al. [23] introduce a new reconfigurable robotic leg based on the inverse Peaucellier-Lipkin mechanism, tailored for walking machines. This leg can traverse both straight and curved paths, determined by the ratio between two of its links and its kinematics. In parallel, Desai, S. G., et al. [24] present a novel single-degree-of-freedom crank-driven walking leg mechanism for walking machines and robots. This mechanism, refined from a planar Peaucellier-Lipkin type with eight links, undergoes kinematic analysis, with optimal design achieved using the Genetic Algorithm (GA) to determine link lengths. Practical accuracy is validated through an experimental model, and an eight-legged walking machine employing this mechanism undergoes successful testing. N.YashLokhande, et al. [25] The authors delve into bio-inspired walking mechanisms, particularly those that mimic spider locomotion. Using Klann's mechanism as a basis, a unique walking mechanism was developed, offering notable benefits. The primary advantage lies in its simplicity. Contrary to many modern designs, this mechanism avoids the need for microprocessor control or multiple actuator systems. It can be operated with simple techniques, like crank rotation, powered by a single actuator. Such straightforwardness might not only simplify control but potentially reduce costs and enhance reliability. KalyaniRadha et al. The motto underscores the significance of transcending conventional wheel-based designs. By drawing inspiration from natural entities such as spiders and human legs, innovative mechanisms can be crafted to traverse intricate terrains, notably in agricultural contexts. [26]. J. Estremera et al.: This work focused on developing crab and turning gaits for hexapod robots in uneven terrain, including forbidden zones. The proposed algorithm significantly improved the speed and stability of hexapod robots, making them robust solutions for various applications, particularly in complex environments. [27]. Li H. et al. Hexapod robots excel in stability and adaptability, making them ideal for challenging terrains. The proposed hexapod has two walking platforms and a unique waist joint, enhancing its walking stability and operational dexterity. A new method calculates the robot's workspace, factoring in leg-ground interference, aiding in efficient foothold selection. Simulations show its capability in obstacle navigation and stair climbing, which are confirmed by real-world prototype tests. [28]. D.C.Kar stated Inspired by the remarkable off-road mobility of legged animals, researchers have pursued the creation of artificial walking machines. Decades of global efforts have birthed numerous legged robots with varying sophistication. This review delves into the diverse design strategies employed in legged locomotion and covers both vehicle configurations and leg mechanisms. The aim is to provide a concise overview of past endeavors, guiding future designers towards more advanced walking robot creations. [29]. PriyaranjanBiswal et al. In the field of robotics, quadruped robots stand out due to their mobility, which is reminiscent of humans and animals. This study explores their design and perceptual methods, emphasizing their manoeuvrability, travers ability, and controllability. With robots such as "Spot" at the forefront, the study centres on their adaptability across diverse terrains and their smooth control systems. [30]

3.Redesign of leg mechanism

The Klann's mechanism is like a robot leg that walks. Imagine it as a set of bars and joints that move in a certain way to make the robot walk. When we talk about changing the fixed points, we mean adjusting where these bars are connected or anchored. By moving these connection points around, we can change how the robot walks. For instance, if we bring the points closer together or move them apart, it affects how long and wide each step is. Similarly, changing the height and angle of the points can make the robot walk higher or lower. So, when we say we're changing the fixed points of the Klann mechanism, we're basically tweaking how it moves. It's like adjusting the settings on a machine to make it walk differently. This flexibility lets us customize the robot's walking style to suit different needs, whether it's walking smoothly on flat ground or navigating rough terrain.

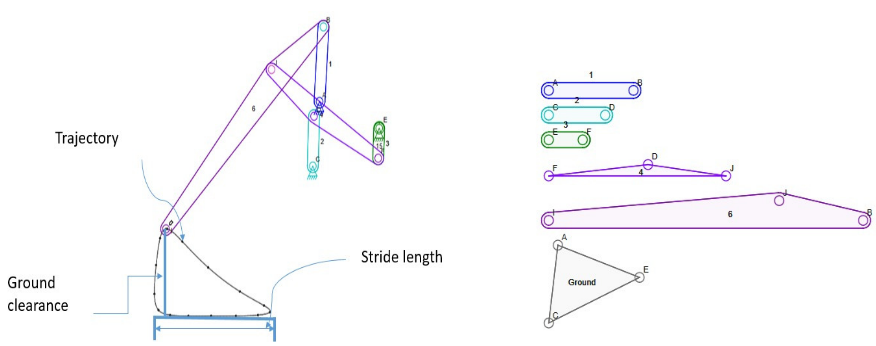


Figure 1. Geometric parameters of leg

In the figure 3(a),(b). The Klann mechanism consists of several links and joints that work together to produce walking motion.

3.1.1 Frame: The frame serves as the main structure of the mechanism, providing support and stability. It typically includes attachment points for other components.

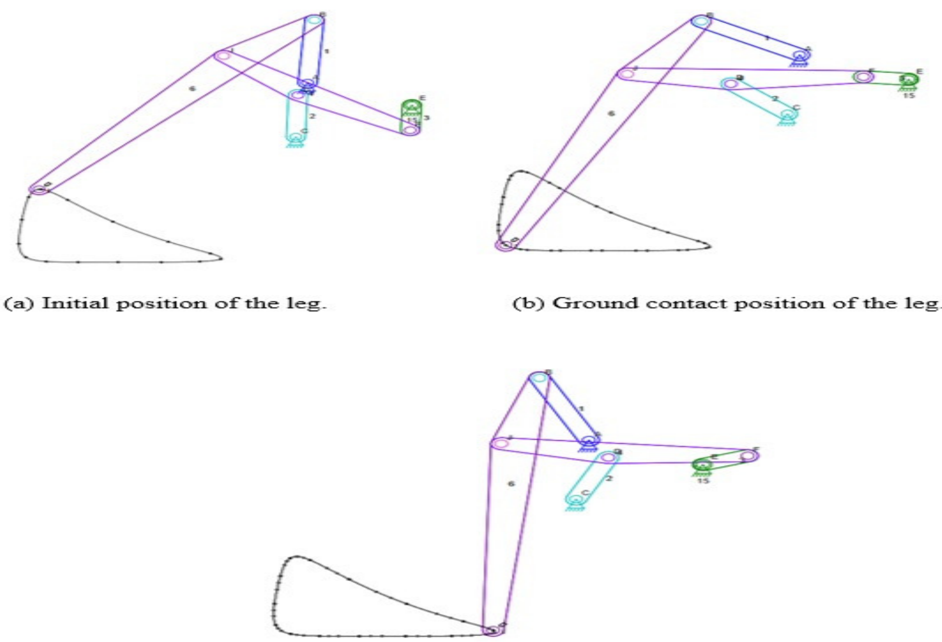
3.1.2 Crank: The crank is a rotating link connected to a motor or some power source. It usually serves as the driving force for the mechanism.

3.1.3 Rocker: The rocker is another rotating link that moves in response to the motion of the crank. It's connected to one end of the leg mechanism.

3.1.4 Coupler: The coupler is a connecting link that transfers motion between the crank and the rocker. It's typically attached to both the crank and the rocker and helps convert rotary motion into linear motion.

3.1.5 Leg Mechanism: The leg mechanism consists of multiple links connected in a specific arrangement to create a walking motion. It usually includes a set of pivoting joints that allow the leg to move in a controlled manner.

3.1.6 Fixed Points: These are the connection points where the various links of the mechanism are anchored to the frame or other fixed structures. The positions of these fixed points can be adjusted to modify the gait pattern and overall behavior of the mechanism.



(a) Initial position of the leg.

(b) Ground contact position of the leg.

(c) Ground release position on the leg.

Figure 2. Position of leg

3.2 Trajectory planning

In this study, we employ a method to analyze the trajectory of a walking mechanism, specifically focusing on the Klann mechanism. By measuring the position of the leg's end-effector relative to the crank angle, we systematically trace the leg's movement pattern. This involves defining a coordinate system and incrementally changing the crank angle, typically at intervals of 30 degrees. Through this process, we aim to evaluate various aspects of the mechanism's performance, including efficiency, stability, speed, terrain adaptability, and payload handling. This method provides valuable insights for optimizing the walking mechanism's behavior for different applications.

Table 2 Crank angle

ANGLE	X-AXIS	Y-AXIS
30	20.2	12.5
60	24.5	16
90	28.4	22
120	31.5	23
150	33.5	20.8
180	34.8	17.7
210	33	15.3
240	30.1	12.8
270	23.4	9.7
300	19.2	8.3
330	17.7	8.4
360	17	9.4

The above table shows that end effector position with respect to crank angle.

3.2.1 Determining DH Parameters for Configuring the Leg Mechanism

Link Identification**:** Identify the links and joints in your leg mechanism. Assign a unique index to each link, starting from the base link and moving towards the end-effector.

Coordinate Systems**:** Define coordinate systems for each link and joint according to the DH convention. Typically, the coordinate system origin is located at the joint axis, with the Z-axis pointing along the joint's axis of rotation and the X-axis oriented perpendicular to the previous joint's Z-axis.

DH Parameter Assignment**:** Assign DH parameters to each link and joint. These parameters include:

θi**:** The angle between the Z-axis of the i-th and (i-1)-th coordinate systems about the common normal (joint variable).

di**:** The distance along the Z-axis of the (i-1)-th coordinate system to the point where the X-axis of the i-th coordinate system intersects the Z-axis of the (i-1)-th coordinate system (link offset).

ai**:** The distance along the X-axis of the i-th coordinate system to the point where the Z-axis of the i-th and (i-1)-th coordinate systems intersect (link length).

αi**:** The angle between the X-axes of the i-th and (i-1)-th coordinate systems about the common normal (link twist).

DH Parameter Table**:** Organize the DH parameters into a table format. Each row corresponds to a link or joint, and each column represents one of the DH parameters (θ, d, a, α).

Forward Kinematics**:** Use the DH parameters and the DH transformation matrix to derive the forward kinematic equations of the leg mechanism. These equations relate the joint variables (angles) to the position and orientation of the end-effector.

Inverse Kinematics**:** If needed, use the forward kinematic equations to derive the inverse kinematic equations, allowing you to determine the joint variables required to achieve a desired end-effector position and orientation.

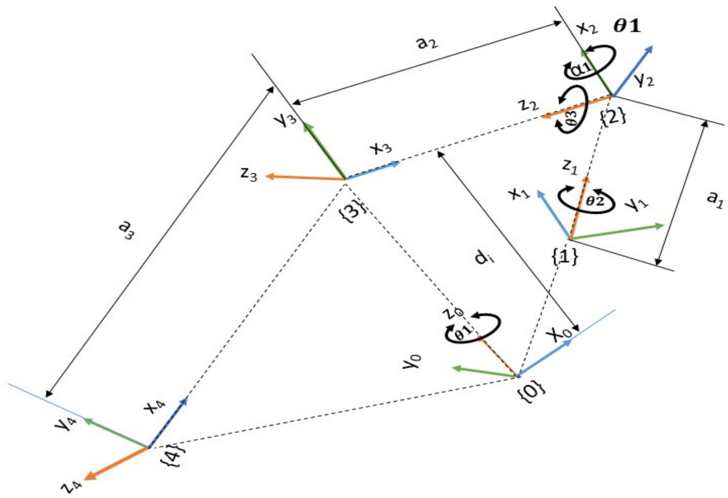


Figure 3. Coordinate frame mapping by using DH approach

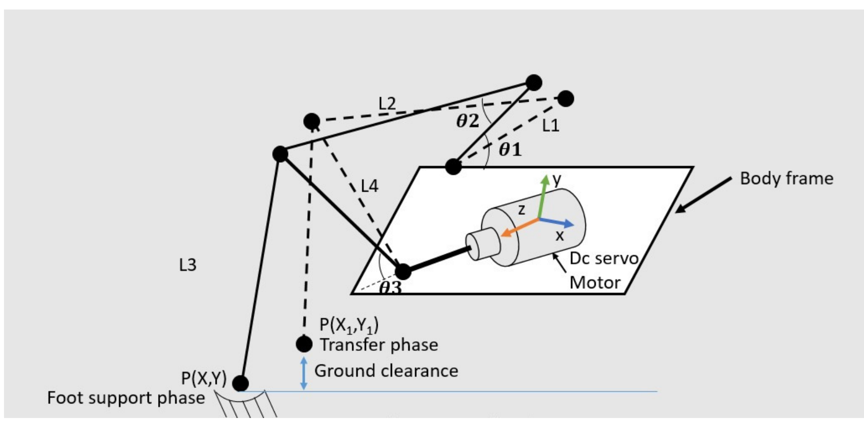


Figure 4. Leg position at end effector position

Link AB (with offset d_AB = 100 mm):

$$T_{AB} = \begin{bmatrix} 0.0872 & -0.9962 & 0.0000 & 0.0000 \\ 0.9962 & 0.0872 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & 1.0000 & 100.0000 \\ 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{bmatrix}$$

Link BF (length l_BF = 300.42 mm):

$$T_{BF} = \begin{bmatrix} -0.6820 & 0.7314 & 0.000 & -204.8859 \\ -0.7314 & -0.682 & 0.000 & -219.713 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

Link FC (length l_FC = 256.11 mm):

$$T_{FC} = \begin{bmatrix} 0.9659 & 0.2588 & 0.000 & 247.3833 \\ -0.2588 & 0.9659 & 0.000 & -66.2861 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

Link FG (length l_FG = 300.42 mm):

$$T_{FG} = \begin{bmatrix} 0.2419 & 0.9703 & 0.000 & 72.678 \\ -0.9703 & 0.2419 & 0.000 & -291.149 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

Link GH (rigid link, length l_GH = 112.42 mm):

$$T_{GH} = \begin{bmatrix} 1.000 & 0.000 & 0.000 & 112.42 \\ 0.0000 & 1.000 & 0.000 & 0.0000 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

Link GH (rigid link, length l_GH = 112.42 mm):

$$T_{GH} = \begin{bmatrix} 1.000 & 0.000 & 0.000 & 112.42 \\ 0.0000 & 1.000 & 0.000 & 0.0000 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

Link GE (length l_GE = 300.42 mm):

$$T_{GE} = \begin{bmatrix} 0.7071 & -0.7071 & 0.000 & 212.4290 \\ 0.7071 & 0.7071 & 0.000 & 212.4290 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

Link ED (length l_ED = 241.12 mm):

$$T_{ED} = \begin{bmatrix} 0.6626 & -0.7490 & 0.000 & 159.7709 \\ 0.7490 & 0.6626 & 0.000 & 180.5882 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

Link EB (length l_EB = 300.42 mm):

$$\begin{bmatrix} -0.2419 & -0.9703 & 0.000 & -72.6782 \\ 0.9703 & -0.2419 & 0.000 & 291.4962 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

$$T_{Final} = \begin{bmatrix} -0.754 & 0.6561 & 0 & 5.72 \\ -0.6561 & -0.754 & 0.000 & -722.30 \\ 0.0000 & 0.0000 & 1.000 & 0.0000 \\ 0.0000 & 0.0000 & 0.000 & 1.0000 \end{bmatrix}$$

3.3 Kinematic Analysis of Walking Mechanisms: Understanding Motion for Design and Control

By performing kinematic analysis, we can gain valuable insights into the motion of a walking mechanism and understand how its various parts move in relation to each other. This information is essential for designing, optimizing, and controlling the mechanism for specific tasks and applications.

Here the table(3) represented that relation between the joint angles with respect to the crank displacements.

Table 3 Crank angle position

Description	L1(mm)	L2(mm)	L3(mm)	L4(mm)	L5(mm)
LEG INITIAL POSITION	268.34	86.26	88.26	51.35	51.35
LEG COMING CONTACT TO GROUND	162.86	150.71	135.35	68.31	68.31
LEG MOVING AWAY FROM GROUND	20.36	114.7	66.52	88.56	88.56

3.3.1 Kinematic performance of leg mechanisms

We currently employing simulation tools to analyze the motion of a linkage mechanism tailored for walking or locomotion. By concentrating on the crank position as the primary input, I can derive crucial metrics such as angular displacements and accelerations of the mechanism's individual links. This thorough analysis offers valuable insights into the dynamic behavior and overall performance of the mechanism. These findings are instrumental in optimizing the design and making informed engineering decisions.

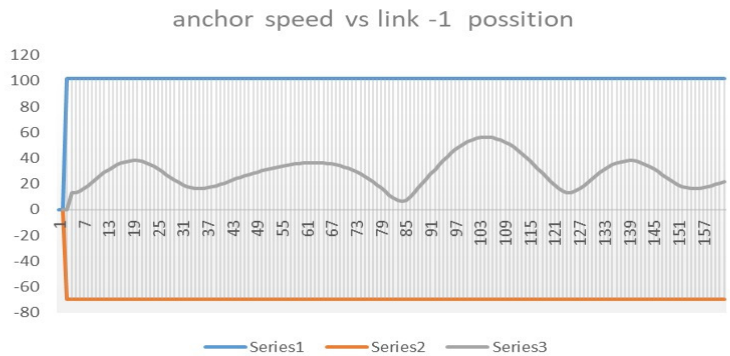


Figure 5. Anchor speed vs Link 1

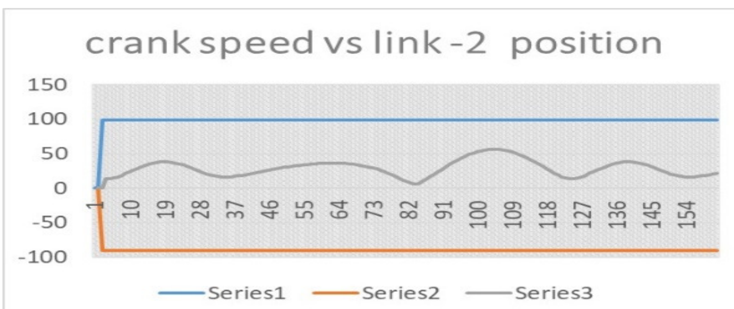


Figure 6. Crank speed vs Link 2

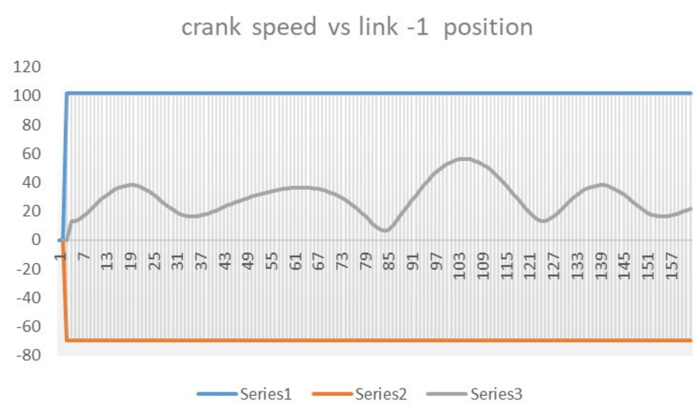


Figure 7. Crank speed vs Link 1

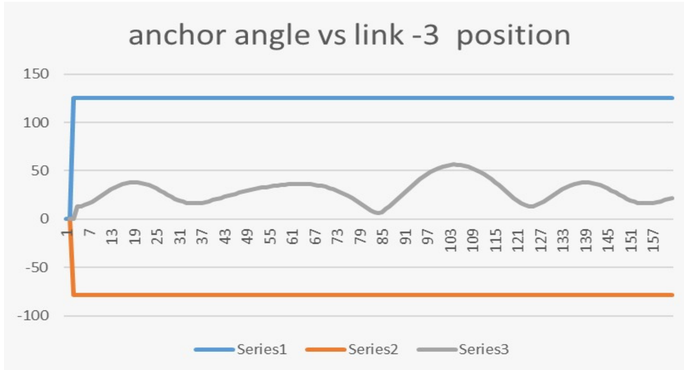


Figure 8. Anchor angle vs Link 3

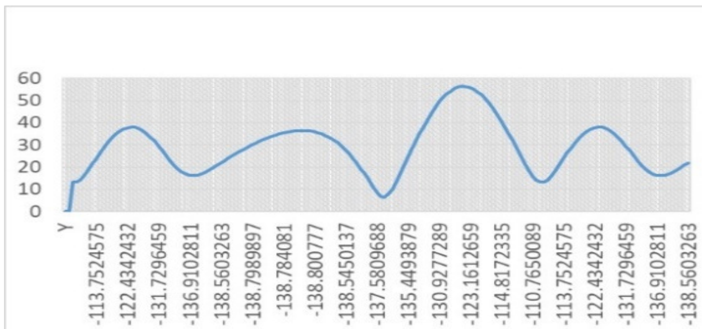


Figure 9. Crank speed vs Displacement at Y-axis

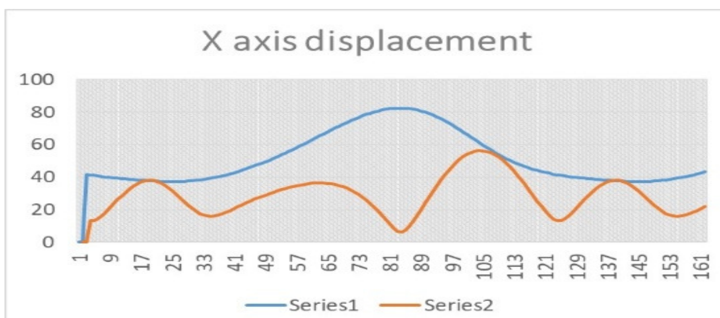


Figure 10. Crank speed vs Displacement at X-axis

3.3.2 Velocity and accelerations of links

Hence we are taking a cubic polynomial trajectory is often used because it allows for smooth and continuous motion planning, which is important for controlling robotic systems effectively. This type of trajectory generation is commonly employed in path planning, motion control, and trajectory optimization tasks in robotics and automation. For this we are using a mechanical analyser software to find the mathematical relationship of the joint positions or angles change over the time. The below figures representing the end effector position.

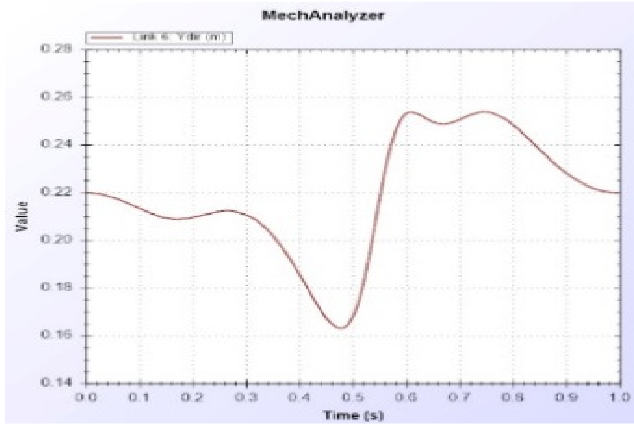


Figure 11. Linear velocity of L6

The fig. 14 represent the linear velocity of the crank (L2) with respective to X&Y axis.

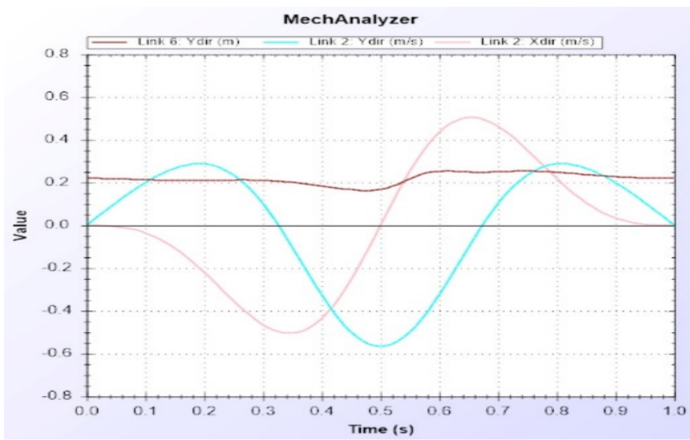


Figure 12. Linear velocity of L2

The fig. 15 represent the crank velocity vs end effector linear velocity with respect to X&Y axis.

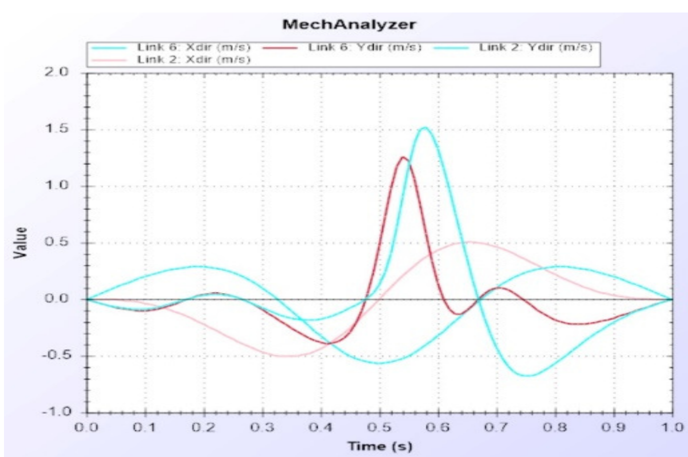


Figure 13. Crank vs End effector linear velocity

The fig. 16 represent the crank acceleration vs end effector linear acceleration with respect to X&Y axis.

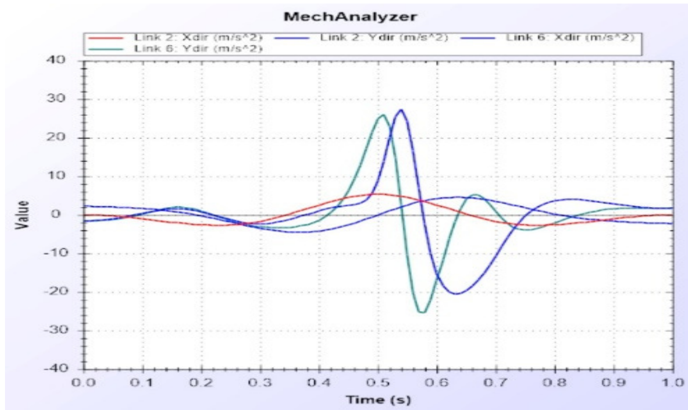


Figure 14. Crank vs End effector linear acceleration

The fig. 17 represent the crank angular velocity vs end effector angular velocity with respect to X&Y axis.

Figure 15. Crank vs End effector angular velocity

The fig. 18 represents the crank angular velocity vs Link 3 angular velocity.

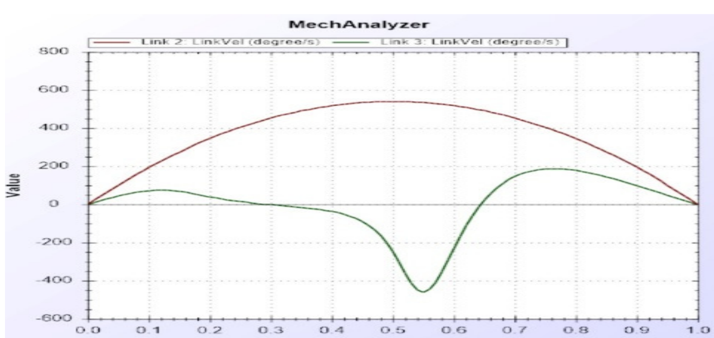


Figure 16. Crank vs L3 angular velocity

The fig. 19 represents the crank angular acceleration vs Link 3 angular acceleration.

Figure 17. Crank vs L3 angular acceleration

The fig. 20represents the crank angular velocity vs Link 4 angular velocity.

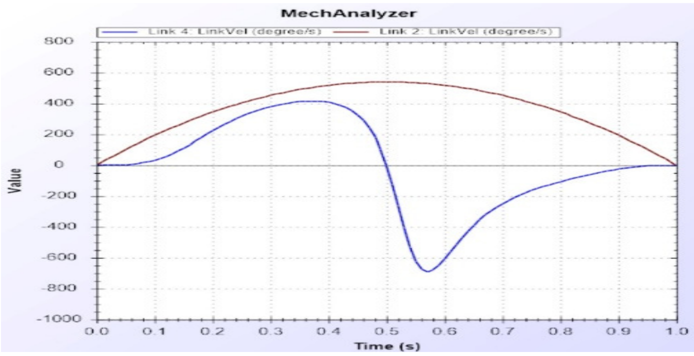


Figure 18. Crank vs L4 angular velocity

The fig. 21 represents the crank angular acceleration vs Link 4 angular acceleration.

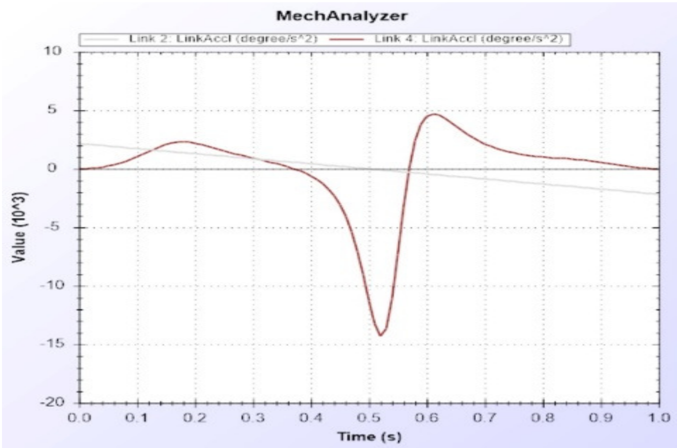


Figure 19. Crank vs L4 angular acceleration

The fig. 22 represents the crank angular velocity vs Link 5 angular velocity.

Figure 20. Crank vs L4 angular velocity

The fig 23 represents the crank angular acceleration vs Link 5 angular acceleration.

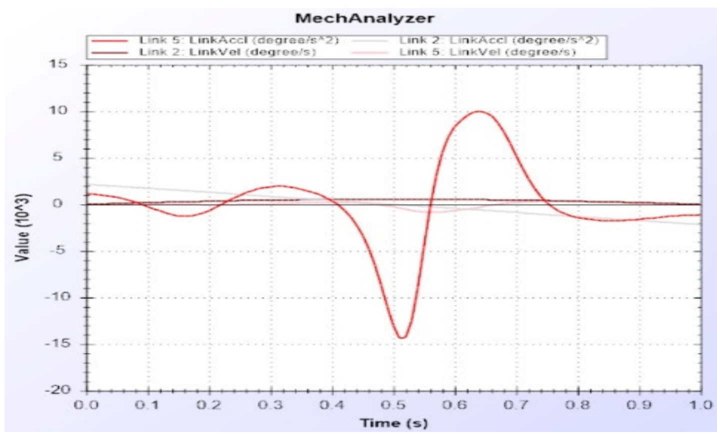


Figure 21. Crank vs L5 angular acceleration

The fig. 24 represents the crank angular velocity vs Link 6 angular velocity.

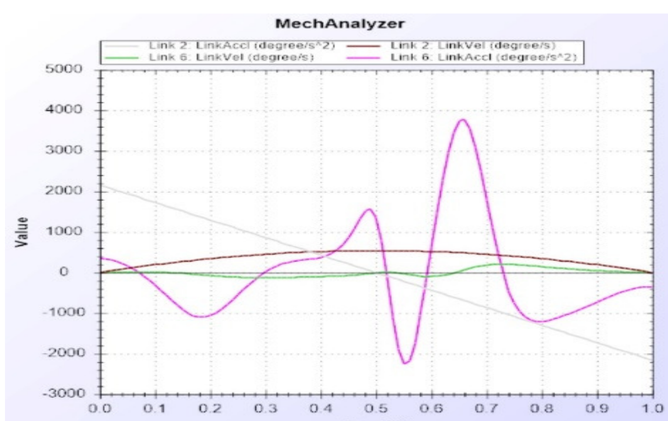


Figure 22. Crank vs L6 angular velocity

4.Methodology

4.1 Electronics

4.1.1 Microcontroller (ESP32-CAM)

ESP32-CAM is a low-cost ESP32-based development board with onboard camera, small in size. It is an ideal solution for IoT application, prototypes constructions and DIY projects. The board integrates Wi-Fi, traditional Bluetooth and low power BLE, with 2 high-performance 32-bit LX6 CPUs. It adopts 7-stage pipeline architecture, on-chip sensor, Hall sensor, temperature sensor and so on, and its main frequency adjustment ranges from 80MHz to 240MHz. Fully compliant with Wi-Fi 802.11b/g/n/e/i and Bluetooth 4.2 standards, it can be used as a master mode to build an independent network controller, or as a slave to other host MCUs to add networking capabilities to existing devices ESP32-CAM can be widely used in various IoT applications. It is suitable for home smart devices, industrial wireless control, wireless monitoring, QR wireless identification, wireless positioning system signals and other IoT applications.

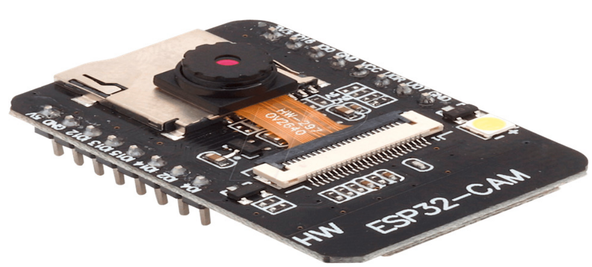


Figure 23. Micro controller

Summary

Microcontroller	ESP32-CAM
SPI Flash	Default 32Mbit
RAM	Built-in 520 KB, external 4MPSR
Bluetooth	Bluetooth 4.2 BR/EDR and BLE standards
Wi-Fi	802.11b/g/n/e/i
Support Interface	UART, SPI, I2C, PWM
Support TF card	maximum support 4G
IO port	9
Serial Port Baud-rate	Default 115200 bps
Image Output Format	JPEG(OV2640supportonly),BMP
GRAYSCALE	
Spectrum Range	2412 ~2484MHz
Security	WPA/WPA2/WPA2-Enterprise/WPS
Power supply range	5V
clock speed	160MHz

4.1.2 Motors (SG 90 Micro Servo Motor)

The SG 90 servo motor is converted into DC geared motor.60 RPM Side Shaft 30mm Diameter High Performance DC Gear Motor is suitable for small robots / automation systems. It has sturdy construction with gear box built to handle stall torque produced by the motor. Drive shaft is supported from both sides with metal bushes. Motor runs smoothly from 4V to 6V and gives 60 RPM at 6V. Motor has 6mm diameter, 18mm length drive shaft with D shape for excellent coupling.

Figure 24. Servo Motor

Specifications

Speed:4.8V: 0.11 sec/60°

Torque: 4.8V: 2.20 kg-cm, 6.0V: 2.50 kg-cm

Voltage: 4V to 6V

Shaft diameter:	30mm
Height:	29mm
Gear assembly:	Spur
Gear type:	Metal
Motor weight:	14gms

4.1.3 Motordrivers

A motor driver is a device or group of devices that serves to govern in some predetermined manner the performance of an electric motor. A motor driver might include a manual or automatic means for starting and stopping the motor, selecting forward or reverse rotation, selecting and regulating the speed, regulating or limiting the torque, and protecting against overloads and faults.

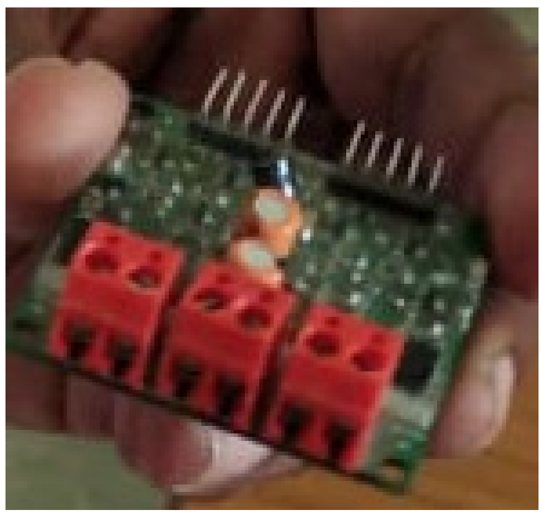


Figure 25. Motor drives

4.1.4 Battery 6v

Battery is a part of a circuit that provides the electricity. Battery can be said as the source to provide electricity to the circuit. So, its main function is to supply electric power in order for electric items to work.

A battery is a device consisting of one or more electrochemical cells with external connection provided to power electric device. A battery has a positive terminal or cathode and a negative terminal or anode. The terminal marked positive is at a higher electrical potential energy then is the terminal marks negative terminal have electron that is flow external circuit and deliver energy here for battery are connected in series and it is use to power supply to BLDC motor, than motor is make forward and backward to wheel.

Features

- Light weight, high capacity and density
- No explosion or burning risk
- International standard safety performance, Low self-discharging rate, Highly endurable
- Batteries with less than 3% self-discharge rate per month, High and consistency
- Able to freely assemble and flexible usage.
- Custom-made battery size, shape and capacity, environment friendly.

Figure 26. Battery

4.1.5 Battery charger

A battery charger or recharge is a device used to put energy into a secondary or rechargeable battery by forcing an electric current through it. The charging protocol depends on the size and tyre of the battery being charged. Some batteries have high tolerance for overcharging and can be charge by connection to constant voltage source or constant voltage source or constant voltage source. Microprocessor controller to adjust the charging current, determine the sate of charge and cut off at the end of charge.

Figure 27. Battery charger

4.1.6 Connecting/jumper wires

Connecting wire is a piece of wire used to attach two circuits or components together. The gauge or the size of the wire must be large enough to support the amount of current flow. Wires are used to join parts of a circuit. Electricity flows through wires.

Its main function is to provide electrical items the power they need to work, Provided by battery.

Jumper wires are of 3 types. They are:

Male to Male(M2M)

Male to Female(M2F)

Female to Female(F2F)

Figure 28. Jumper wires

4.3 Specifications

Body	Dimensions	Length (Lb)	0.3 m
		Width (Wb)	0.2 m
		Body height (Hb)	0.3 m
	Mass		1.8 Kilo grams
Leg	Leg configuration	Number of links (1:05)	8
		Height of the leg	0.3 m
		Ground contact angle	85^0
		Ground clearance angle	355^0
	Stroke Rx	Stride length	0.19 m
	Mass	single leg	0.3 Kg
	Foot speed	swing phase	50%
		stance phase	50%
	Body height (Hb)		30cm
Robot	Total mass		4.2 kg
	Speed		0.05m/s
	Position accuracy		0.01mm
	GC		8 cm

Figure 29. Material specifications

4.4 Leg Geometry

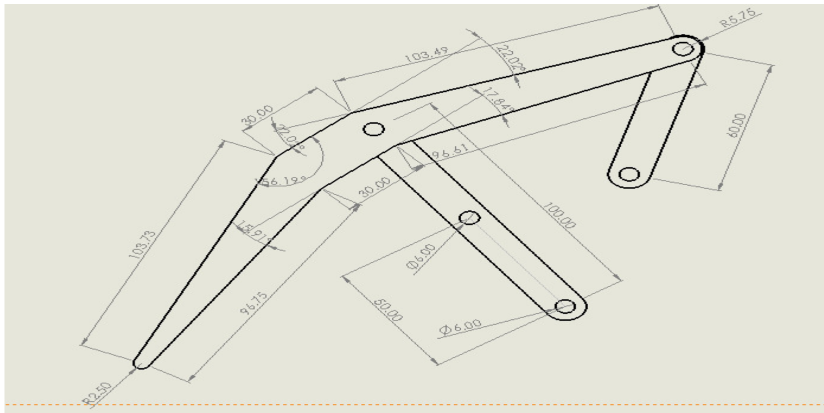


Figure 30. Geometry of leg

The fig. 32 shows the geometrical measurements of the joseph klann'smechanisam. And also these measurements will give you the better overview like a exact parameter of leg.

4.5 Hardware connections

The hardware connections are made through the similar connections for the servo motor drive that uses aurdino programming to simulate the moment of the legs of the octopod.

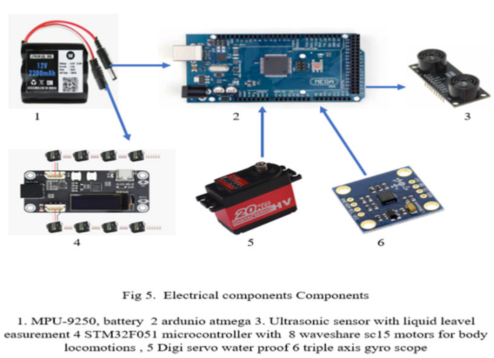


Figure 31. Hardware connections

These connections are done through the material mentioned above in fig. 33. And these are connected to a board called bread board with consists upto 10V capacity of voltage passage.

5. RESULTS & DISCUSSIONS

Final result is the assemblyof product, and it isshown in figure. This mechanism can walk forward and back word. Also this robot can be operated by using computer program. The strength of each link is just enough to carry self weight as well as machine control unit. The nuts and bolts and axils used in this mechanism are made of aluminium steel. It can be mentioned as four legs front and four legs back. All legs will move with sequential manner so that there is a continuous motion, with minimum or almost zero acceleration and deceleration accept during starting and stopping situations.

The matlab programming resulting graph is attached below fig. 33 which records the gyroscopic reading of the walking robot using Joseph klann's mechanism.

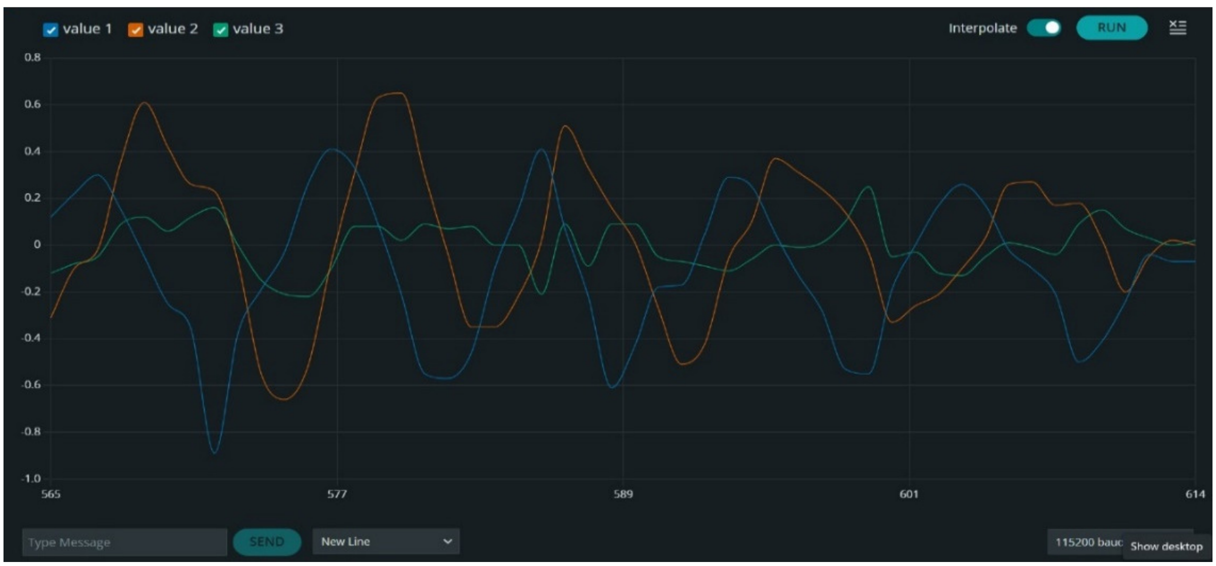


Figure 32. Output graph

Working model

The assembly of the octopod robot is attached below fig. 34 and the project has simulated successfully. And the working model is given below.

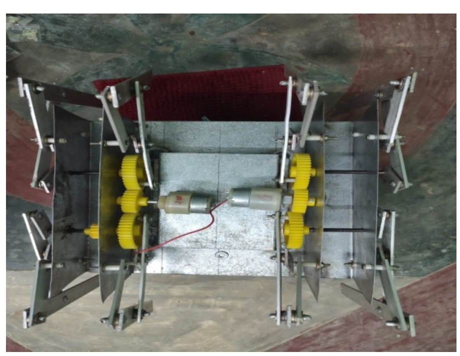


Figure 33. Top view

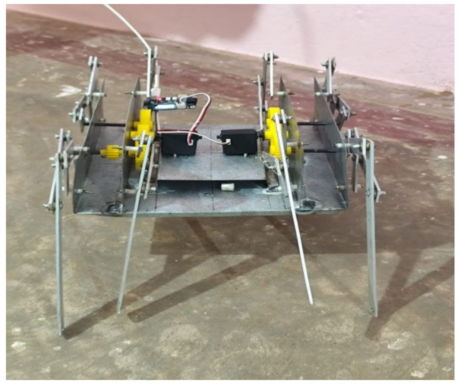


Figure 34. Front view

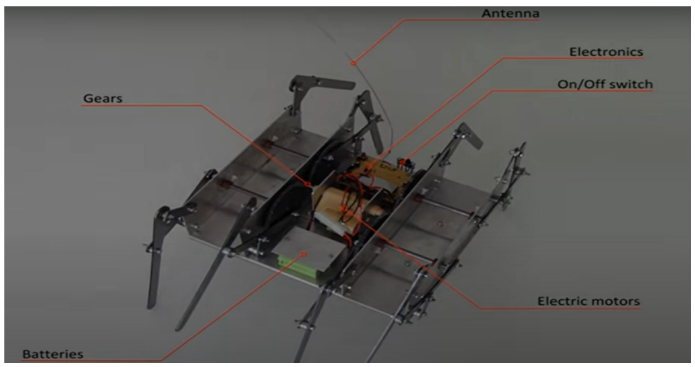


Figure 35. Orthogonal view

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6. CONCLUSIONS

- The designed legged robot, aimed at achieving a single degree of freedom in walking, has undergone meticulous development and validation processes.
- Initially, its intricate leg mechanism was meticulously crafted and assessed using advanced simulation tools.
- The parameters derived from this simulation were rigorously tested and found to be within acceptable bounds, ensuring optimal functionality.
- Subsequently, the integration of advanced sensor technologies has yielded promising results, showcasing the robot's exceptional stability during locomotion.
- This stability is a critical aspect, particularly in the context of single-degree-of-freedom walking robots, where maintaining balance and precision is paramount.
- Moreover, the analysis of gait patterns has confirmed adherence to established norms, indicating the robot's efficiency in mimicking natural walking motions.
- Additionally, thorough examination of stability margins has provided reassurance that the robot operates within safe operational limits.
- With these achievements, the legged robot is poised to excel in environments characterized by both 4A and 4D complexities.
- Its robust design and reliable performance make it well-suited for a wide array of applications, ranging from exploration and surveillance to industrial tasks and beyond.

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