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DESIGN AND ANALYSIS OF MULTILEGGED ROBOT FOR ENVIRONMENT MONITORING

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ABSTRACT

A modern technological era marked by the onset of robotics and automation into every industrial field has increased the necessity to develop products for a wide range of applications, taking into consideration the cost, functionality, and authenticity of the product from a consumer's viewpoint. An attempt is made in this design work to design and analyse a hexapod mobile robot for environmental exploration. The mechanical part involves the mechanism that drives the hexapod in a forward, backward motion or to make a turn with the help of a walking-like motion created by the Theo Jansen mechanism. The mechanism involves a single input actuator to rotate the crank that subsequently moves each link with a relative motion to perform the walking. The basic linkage is modified in the dimensions by analysing for a path to get the appropriate step height. Sensors for measuring the particulate matter and to monitor the temperature with humidity of the atmosphere is incorporated in the product. The user gets the interface through an application where directional control and sensor system values are received through the Wi-Fi system.

1. INTRODUCTION

The need for large-scale persistent environmental monitoring has become particularly relevant in recent times after a set of serious natural disasters and environmentally harmful accidents. In India, development is having a growing impact on the environment. The environmental issues are increasing on the agenda of different organisations. These objectives are only achieved by proper technologies and it should provide measurable indications, based on existing data, observable, collected over a regular interval, widely accepted, easy to understand, comparable, and balanced between positive and negative impacts (UNDP 2020).

The application of hexapods in monitoring is getting more significant because of the need for accessing emissions remotely (Mouillot et al. 2014). It is important to monitor data which considers air pollution levels and obtain patterns. According to the recent global burden of disease (GBD) estimates, in 2016, estimated premature deaths are 1,030,000 due to outdoor and 780,000 due to household PM2.5 pollution (Bowe et al. 2019). The pollutant level assessments can be used for creating management plans for controlling emissions. A WHO global comparative analysis of air pollution concluded that ambient air pollution increased by 8% between 2008 and 2013 (WHO 2016). It also showed stringent policies or disruptive technological changes, increasing economic activity, and energy demand will lead to a significant increase in global emissions of air pollutants in the future. Thus, air pollution can indicate the underlying baseline assumptions of economic growth but at a slower pace (Rumpf 1990).

The OL-Sensor -MQ135 is used for gas concentrations and it responds from the change in resistance. When target pollution gas exists, sensitive material (SnO_2) of the MQ135 gas sensor's conductivity increases with gas concentration (Husain et al. 2016). Another sensor is Electrobot DHT11

Digital Temperature & Humidity Sensor Module which is highly reliable and excellent long-term stable digital temperature and humidity sensor (Srivastava, Kesarwani and Dubey 2018). NodeMCU V2 Esp8266 used for simple & smart, interactive, programmable & Wi-Fi enabled control (Saputra and Lukito 2017). NodeMCU has inbuilt Wi-Fi which is cheap compared to other devices and it helps in remote access (Patel and Devaki 2019). The system is accessible from any remote location around the globe provided an internet connection (Shelke et al. 2018). It can serve as an Access Point AP, Wi-Fi station or both station and AP together (Aziz 2018). Nova PM SDS011 is used for Particulate Matters and it can get the particle concentration between 0.3 to 10μm in the air and it has a digital output and a built-in fan for stability and reliability (Shinde 2020). Tower Pro MG995 Servo Motor is used for actuation. Since the application is based on mobile emission detection, these products can be efficiently used for measuring such trends (S. Fajardo et al. 2016).

The Theo Jansen mechanism is made up of seven to eight linkages with one crank, two oscillating rockers and two couplers all connected through pivot joints (Mohsenizadeh and Zhou 2015). The aim of a walking gait is smooth transitions with desired displacements. Some studies show trajectory techniques can be developed using polynomial functions (Ya-xin and Bo 2014). The driving forces are peculiar in legged motion and it also affects the body acceleration (Winkler 2018).

A hexapod that can traverse through varied terrain for air quality monitoring is the main functionality involved in this design. Electronic systems are integrated into a compact body with different sensors and power sources. The motion mechanism uses servo actuators and Theo Jansen motion mechanism, for the motion of leg with a single crank actuation. The application extends widely from local area monitoring to networked systems that lie under the future scope. Cost-effective and purpose-oriented product development are the important pillars of this design.

2. METHODOLOGY

The basic idea of the product to be developed is made from the initial concept of a robot for environmental exploration purposes. The reviews from people at different domains mainly focused on tackling the pollution problems with an advanced technological approach. The motion mechanism adopted for the hexapod is "Theo Jansen Mechanism" which with its single crank motion to produce leg motion, can be facilitated for the product motion. The crank can be actuated by a servo motor and a controller for its defined timely rotation as per the need. The mechanism is analysed through a path analysing software and is optimized. The final structure is produced as a CAD model in Solid works software with the obtained link dimensions. The walking gait is developed by studying the required angular and directional motion of the leg with particular timing to obtain a controlled walking motion of the 6 legs for the movement of hexapods. The control codes to the servo motor are altered according to the specific needs of motion.

A humidity and temperature sensor, PM sensor, the gas sensor is included with the gas sensing system to check the presence of unwanted gas and particulate matter. A basic body structure is made in SolidWorks and the leg is assembled to it with the predefined dimensional criteria and clearances. It is optimized after analysing the structural functionality and degree of freedom and is tested for any misalignments. After continuous iterations, the assembly is finalized with legs, servo motors, electronic components and necessary support structures.

3. DESIGN AND ANALYSIS

The primary objective is to develop a design for sensor integrated hexapod in environment monitoring and suggest optimizations on current hexapod robot designs and their applicability in environmental monitoring with development of sophisticated & simpler walking gait with single rotor power for each leg.

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3.1 Graphs & Results (SAM Analysis)

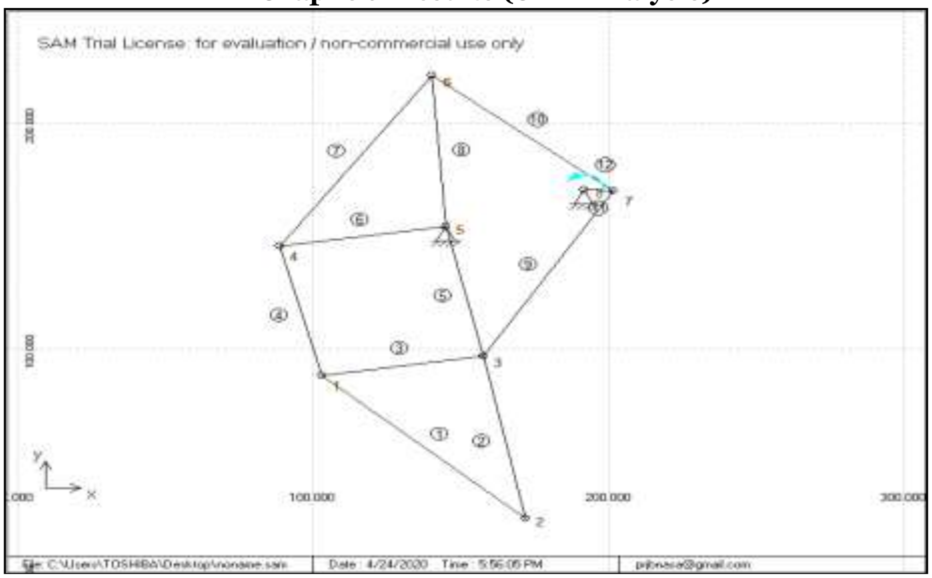

Figure 3.1 Theo Jansen linkage on SAM Interface

Figure 3.1 is the linkage produced on the SAM (Simulation and Analysis of Mechanisms) software interface with the help of hinges and link tools available in the software. A scaled model (1:1.5) is created for the Theo Jansen proportion to start with initially. The circled numbers represent the links while the plain numbers represent the nodes in the linkage. The rigid triangular portion of the linkage (h, g, i) and (d, e, b) are (1,2,3) and (6,7,8) respectively. The rocker linkages (f) and (c) are (4) and (5) respectively. (k) and (j) are (9) and (10). The crank (m) is (11). The rotation produced by the motor is depicted as (12).

Table 3.1 Link dimensions

	h	i	g	f	c	d	e	b	k	j	M
1	91.79	73.66	49.73	64.04	58.65	57.46	88.60	67.16	90.01	83.06	14.3
2	100.1	68.50	55.11	56.82	60.67	55.47	68.75	55.68	84.15	86.96	12.9
3	83.63	67.49	58.76	50.82	53.33	62.30	81.04	52.38	83.78	71.24	13.1
4	86.64	58.45	49.92	54.59	58.18	53.16	65.66	47.36	82.21	71.28	14.0
5	95.06	62.43	53.10	48.88	53.69	56.25	69.57	49.06	74.64	77.34	12.5
6	80.76	67.78	55.4	49.35	48.99	57	70.4	53.69	71.00	72.37	10.3
7	87.82	62.77	49.75	51.79	45.14	49.57	68.12	48.31	63.91	63.01	12.2
8	92.51	59.55	52.30	52.41	48.36	49.23	74.71	52.49	65.22	64.45	15.3

Table 3.1 shown above is the different dimensions of the linkages when simulated for different paths with varied link dimensions and crank angles with it. Changing each link dimension changes the overall path trajectory, the step height and the ground contact patch during the motion. All the values are in "mm" and the unit provides precision than simulating in "cm". The rise height is shown in table 4.2 and can be compared to choose the suitable one. The values are in "mm" and can be seen that the step height can be varied from approx. 7 cm to less than 1 cm. The selection will depend on the path width, link interference during motion and other manufacturability factors. Figure 3.2 shows the different paths traced by each linkage from 1 to 8 in the table represented above. The instantaneous points are plotted together in the

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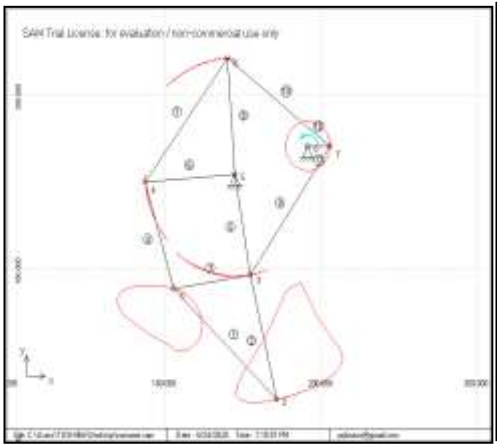
software at each node to visually represent the path traced by the linkage at each node. The path trajectory and the step height can be seen in the figures below. The graphs are also available for each linkage set but it is not included in this report as the main focus is on the linkage that is chosen for the motion purpose, which is described in detail below

Table 3.2 Step /rise Height

	1	2	3	4	5	6	7	8
Step height	69.08	40.537	24.37	46.463	47.693	8.207	50.92	47.80



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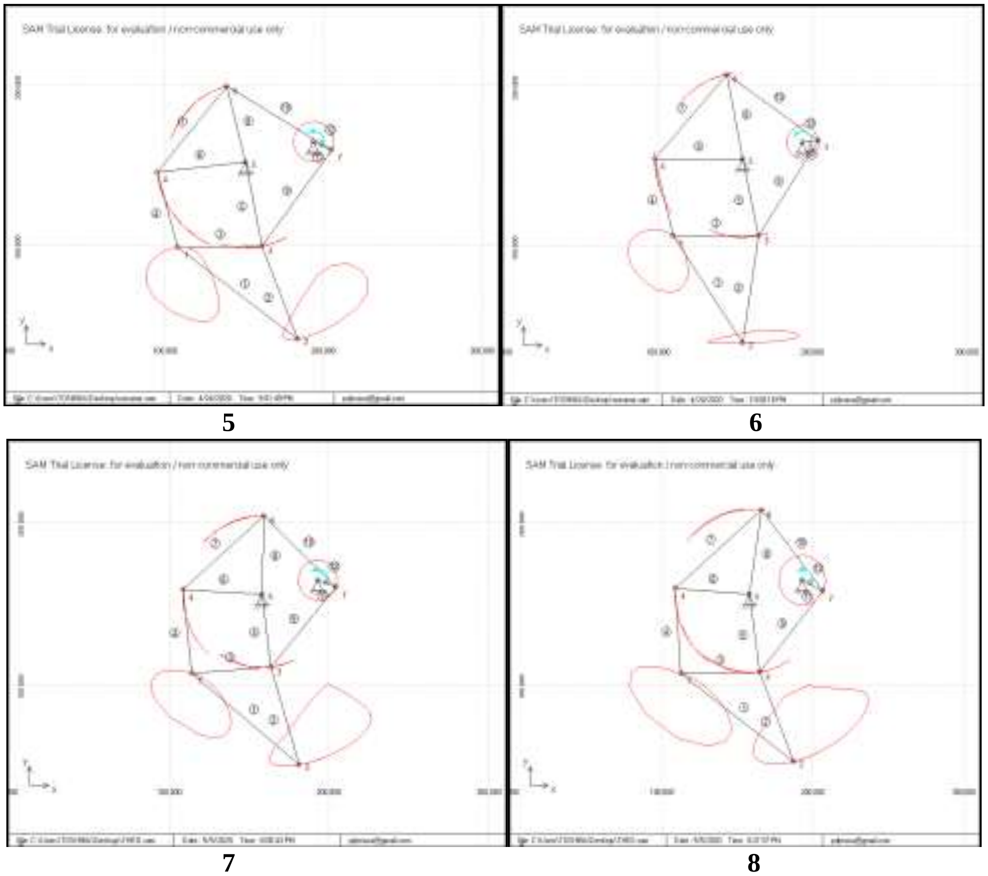

Figure 4.2 Trajectories of the motion path with different link dimension

The selected trajectory and link dimensions are (8) with crank angle 154.103°. The width of the path and the height of the step seems to be suitable compared to the other trajectories while taking into consideration the minimum length needed for the crank for ease of manufacturing (1.5 cm) and keeping the overall size of the linkage small. Figure 3.3 shows the instantaneous position when the leg touches the ground and hence at its lowest height possible in its trajectory based on the vertical axis. The graph is Position vs. Time graph which traces the position of the leg at each second in a 60-step process. The lowest point is at 51.734 mm according to the x-y graph Figure 3.4 shows the path trajectory when the leg points to its peak. According to the x-y graph, the height is marked at 99.535 mm.

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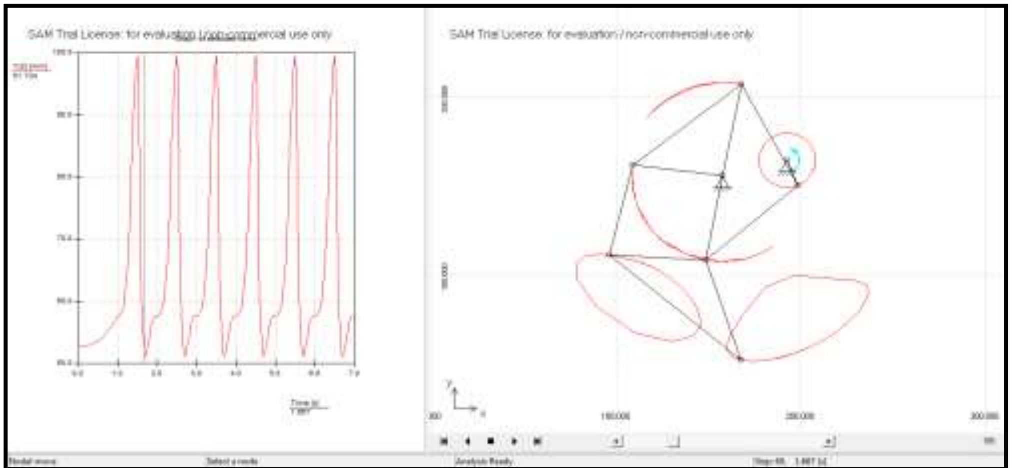

Figure 3.3 Leg at its lowest point on the path

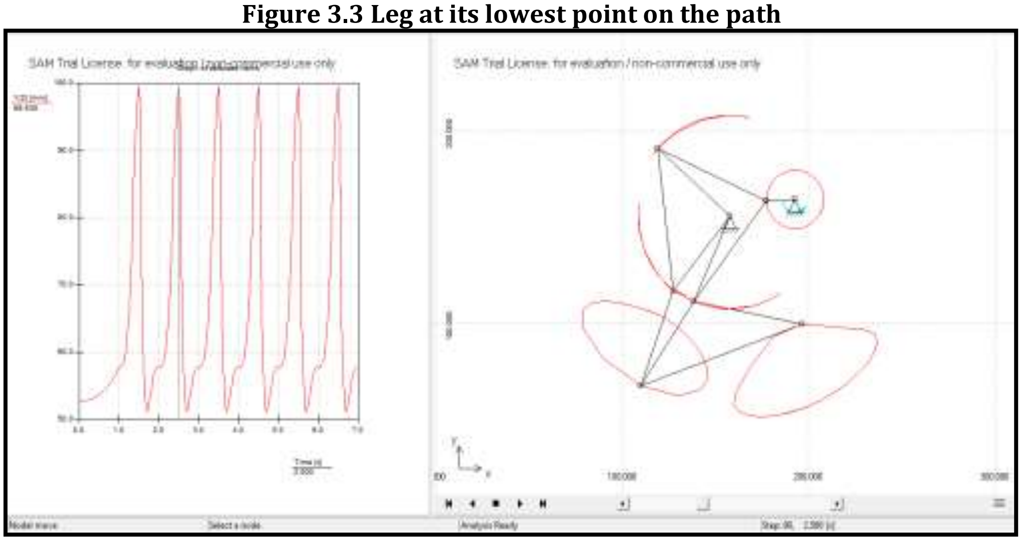

Figure 3.4 Leg at its highest point on the path

Taking the difference between the highest and lowest point with the reference coordinate will give the step height or rise height of the trajectory.

Step height= {Highest Point height - Lowest point height}

= {99.535 - 51.734}

= 47.801 mm = 4.7 cm

3.2 CAD Model - Theo Jansen Linkage

The CAD model of the linkage with the dimensions selected from the analysis is made with the help of SOLIDWORKS software. In addition to the basic linkage system, a grip structure for the leg is implemented for the ease of motion with an aided support of the leg. The model is shown in Figure 3.5 with its dimensions of each link represented. The hole inserted for the hinge is 0.5 mm. This is the basic model of the leg used for the hexapod in this project. Further simulations of the leg for strength are possible in other advanced software like ADAMS or ANSYS but the scope of this project doesn't allow for deep simulations as the force distribution is approximately even for the hexapod and the actuators (servo motors) doesn't impose a heavy load on the crank. The individual parts in the linkage can be seen in figure 3.6 displayed below. The triangular sets, rocker links and other links with the crank can be seen from the figure.

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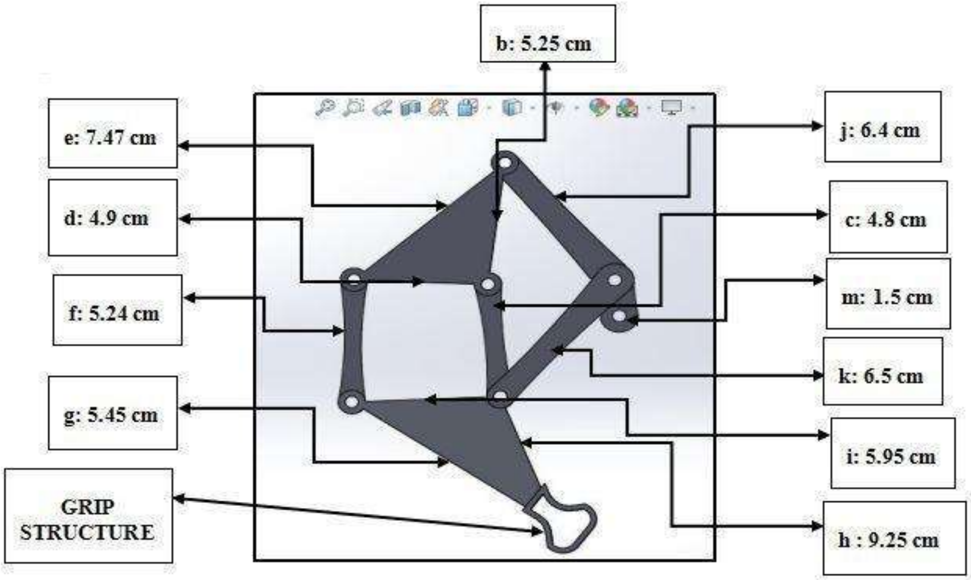

Figure 3.5 CAD model with link dimensions

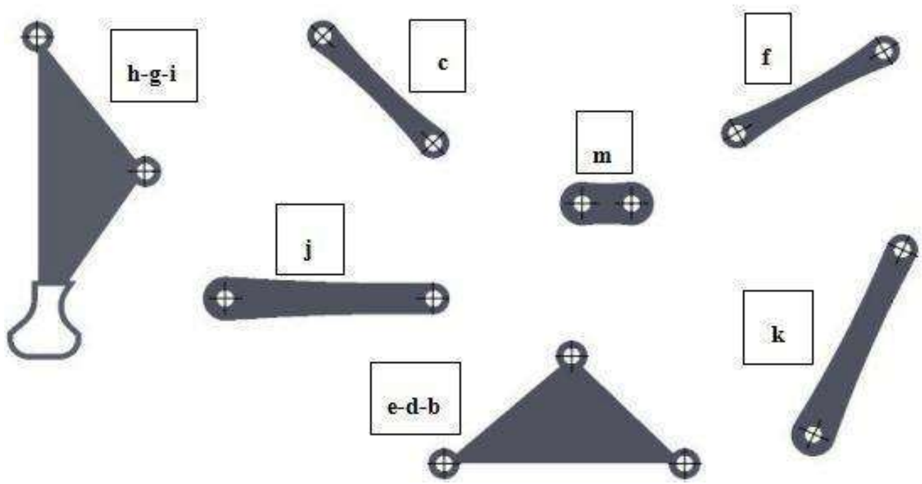

Figure 3.6 Parts of the linkage

3.3 ELECTRONIC CIRCUIT AND CONTROL SYSTEM

The primary objective of the circuit design was to integrate the sensor system and control to the user. The electronics circuit consists of NODEMCU, gas sensor, temperature and humidity sensor, PM sensors and motors. A voltage regulator circuit is given to regulate the power distribution. The voltage and current consumptions are given in Table 3.3. Figure 3.7 shows the designations for the motors and the legs. L represents the left leg and R represents the right leg. M represents motors and they are numbered from one to six. The motion primarily depends on the directions of rotation of motors. These are given in Table 3.4. The motors are actuated according to the direction of motion.

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Table 3.3 Electronic components

COMPONENTS	VOLTAGE	CURRENT
NODEMCU ESP8266	3V-5V	10uA~170mA.
MQ135	5V	150mA
DHT-11	5V	0.5mA
PM SENSOR	5V	70mA±10mA
SERVO MOTOR	4.5V	Stall current:1200mA

Table 3.4 Commands and motor actuation

	M1	M2	M3	M4	M5	M6
Left	no motion	c.c.w.	no motion	c.w.	no motion	c.w.
Backward	c.w.	c.w.	c.w.	c.c.w.	c.c.w.	c.c.w.
Forward	c.c.w.	c.c.w.	c.c.w.	c.w.	c.w.	c.w.
Right	c.c.w.	no motion	c.c.w.	no motion	c.w.	no motion
Stop	no motion	no motion	no motion	no motion	no motion	no motion

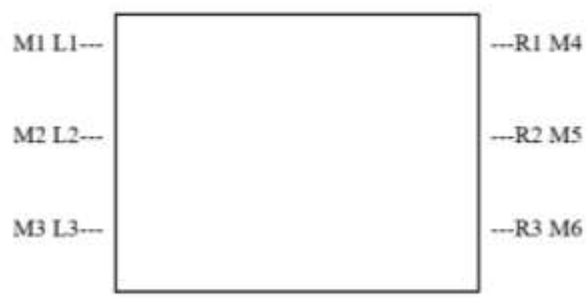

Figure 3.7 Motors and Leg designations

3.5 CAD ASSEMBLY

An assembly model of the hexapod is made in SolidWorks 2018 with the components integrated, i.e. Gas sensor (MQ135), Temperature and Humidity sensor(DHT-11), PM sensor(at an elevated surface in the assembly to facilitate efficient functionality by detection of airflow), Battery pack(at the rear end), the Circuit board(situated within the platform provided on the structural body) and the Servo motors attached to the six legs which are secured by a bracket for the front & rear motors and a seat like structure for middle motors, built within the structural base body to mount the servo securely. An elevated pavement is designed to mount the PM sensor. The battery pack is securely placed and fixed on to a structure designed behind the elevated platform in a slanting position to facilitate easy removal and also to incorporate within the structure with balanced weight distribution. On to the base structure, all the components are placed in such a way that the components don't hinder the functionality of each other and there is enough room for the electronic component to give up the heat produced during the working. The servo motors are kept following the clearance required for the smooth operation of the Theo Jansen leg motion. Figure 3.8 below shows the different views of the assembly model of the product.

The structural member that acts as the base and support to accommodate all the components of the hexapod is shown in Figure 3.9. It is designed to accommodate the circuit board and other components. The size of the leg was another consideration taken to design the appropriate size of the body member. The clearances were measured by virtual means in the software to ensure the proper motion of all the legs

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without interfering with the body structure. The incorporation of the servo motor and its attachment members were also checked for dimension and measured before designing the supportive members and mounting brackets. An elevated pavement can be seen on the structure which is meant for mounting the PM sensor to facilitate its proper functioning. The battery is mounted to the rear of the hexapod due to design constraints within the available dimensional space and to distribute the weight of the total components equally within the body. The dynamic weight distribution during motion is not taken into consideration as it is out of the project scope.

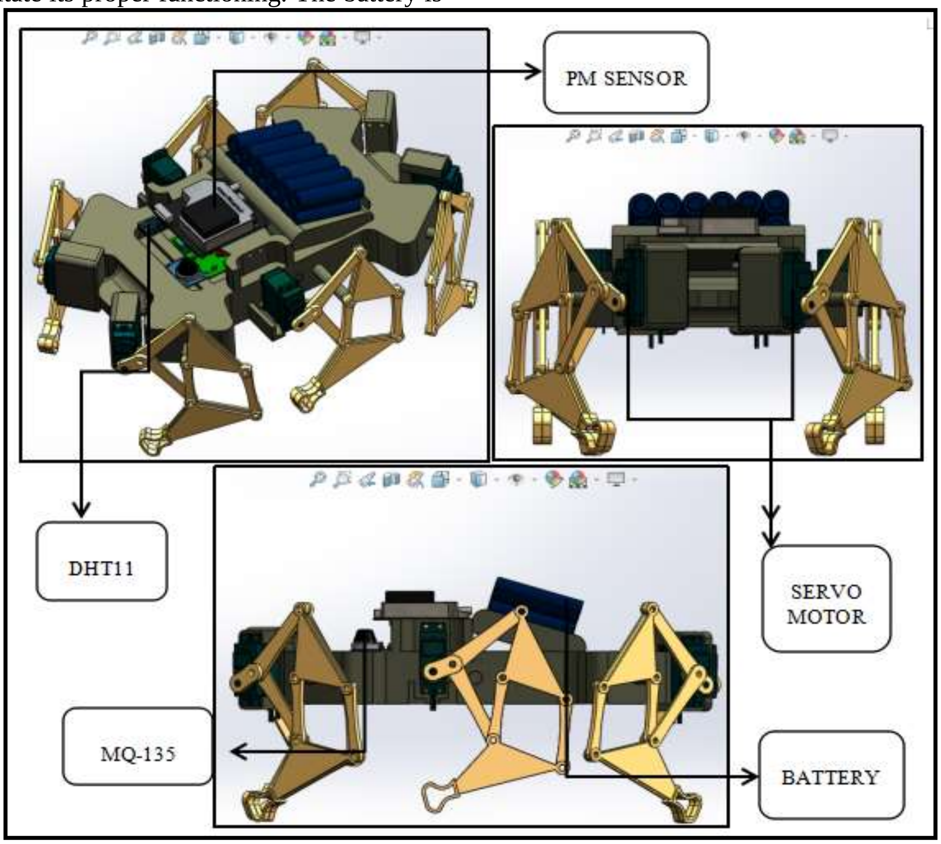

Figure 3.8 Assembly model with components

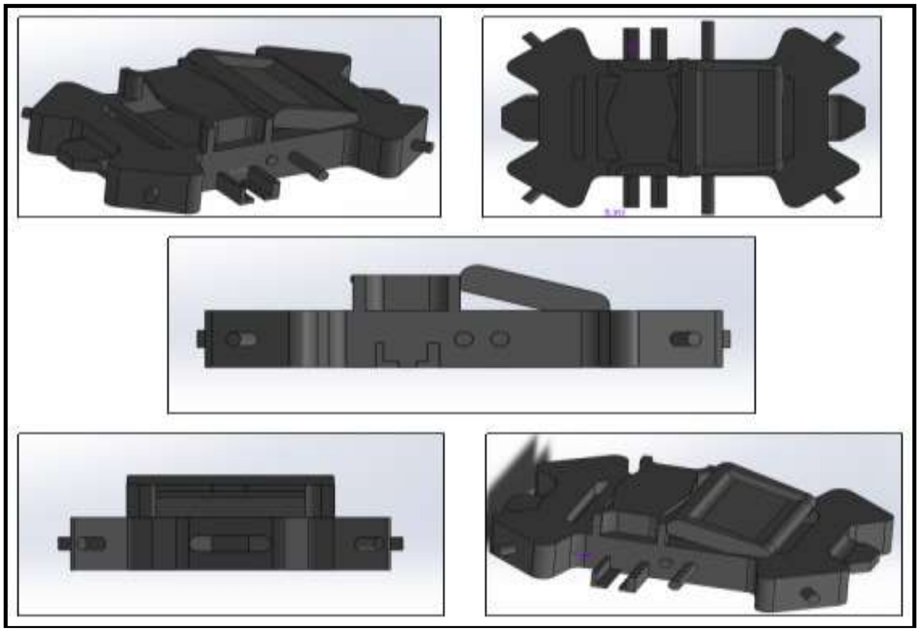

Figure 3.9 Base structure with mounting platform

3.6 WORKING

The timely control of the motor is obtained through a microprocessor “NodeMCU”, that can be incorporated with specific computer application to provide the desired motion which is explained in detail in the further chapters. The walking gait is developed by studying the required angular and directional motion of the leg with particular timing to obtain a controlled walking motion of the 6 legs for the movement of hexapods. The control codes to the servo motor are altered according to the specific needs of motion.

The user has a control interface in the Blynk app. For this user connects the mobile with the product. When the product is turned on, the reading from sensors is shown on mobile. The user interface is provided with control. When control is used the motors move as per the instructions given in mobile. This gives an indication of air quality over an area. The working is shown in figure 3.10.

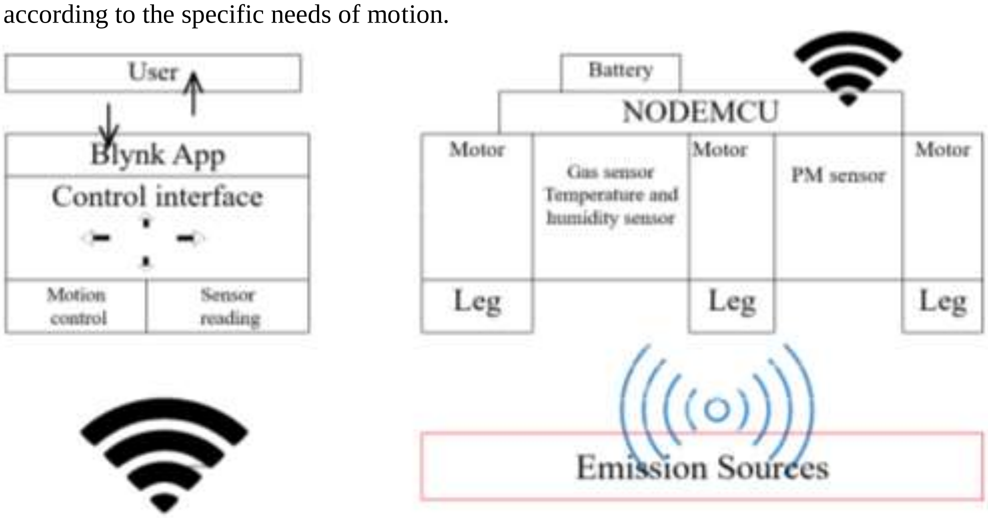

Figure 3.10 Working of hexapod

4. CONCLUSIONS

The application of an efficient yet simple multi-legged robot for environment exploration mainly for the quantification and subsequent analysis of air quality across a region, summed up, forms the work done in this project. Starting with the need for such a technological concept for society, the deteriorating level of air quality and its effect on the human population is briefly studied from authenticated sources. The appropriate mechanism to drive the robot and its efficiency in a less complicated manner were incorporated using the Theo Jansen mechanism which perfectly did the role of legs of the product. The selection of six legs and hence a hexapod was deliberately chosen because of its added advantage of stability and degree of motion compared to four-legged robots or wheeled robots. The basic CAD design of the leg is done in Solid works after analysing the link dimensions in SAM software where the required path is analysed and step height is chosen. The selection of gas sensors, particulate matter sensor, and temperature-humidity sensor is done based on the market availability, cost and sufficient functionality as per the scope of this project and hence MQ135, NovaPM-SDS011 and DHT11 are chosen. The control system to integrate the electronic circuit is done with NodeMCU which also has Wi-Fi connectivity. The user interface is developed using BLYNK application through which directional control of the hexapod and real-time sensor values can be availed through the Wi-Fi system. The circuit system is designed in Proteus software to a compact PCB. The role of the actuation system is done by six servo motors, one for each leg. The entire mechanical structure with the electronic system is assembled in Solid works to form the virtual model of the final product. The walking gait chosen is a tripod gait that ensures at least three legs at the ground every time during the motion. The controlled motion is analysed by depicting the gait with timely inputs of motor actuation and checking the contact, the non-contact sequence of the legs in a graphical form.

FUTURE SCOPE

The product is explained in this project can be taken to another advanced level with the integration of more sophisticated electronic components for different purposes, improve the design and aesthetics of the product, manufacturing with the help of 3D printing and laying down alliances with different organizations to expand the scope of the product with collaborations from different like-minded companies. The electronic system can improvise in sensors to measure a wide range of harmful gases specifically showing its respective amount in the atmosphere, cameras to aid the manoeuvrability, a signal system to receive and send pieces of information to a distant point and a fleet system where multiple robots can be deployed to different areas around a locality to monitor the air quality of a larger part. The design could be modified into a covered system with proper heat dissipation vents, improve dynamic stability by controlled damping techniques and could be altered in such a way to incorporate rotational features.

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