DESIGN FRAMEWORK TO OPTIMIZE THE WALKING CURVE OF KLANN MECHANISM

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A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Mechatronics Engineering

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“I hereby declare that I have read through this report entitle “Design Framework to Optimize the Walking Curve of Klann Mechanism.” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronics Engineering.

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I declare that this report entitles "Design Framework to Optimize the Walking Curve of Klann Mechanism." is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

To my beloved mother and father

ACKNOWLEDGEMENT

First, I would like to thank my family and friends for their support leading up to and throughout this project. They helped me communicate my ideas more clearly and gave important feedback throughout my project. I am grateful for my supervisor Mr Nik Syahrim Nik Anwar for his guidance, ideas and time that made this project possible. I am also thankful for Faculty lab for giving me the incredible opportunity to use 3D printer in producing my Klann Prototype A as an undergraduate. I would also like to thank both my panel Pn. Irma Wani Binti Jamaludin and PM Dr Muhammad Fahmi for giving me many suggest to make the project a better success. Finally, I would like to give thanks to those who had help me in my project.

ABSTRACT

Wheels always have major disadvantage on uneven terrains especially those with short instant evaluation changes surface, such as stairs and steep or jagged rock. These surfaces are not a problem to normal human but for the disables who are using wheelchair, they avoid these surfaces. Therefore, legged mechanisms are recommended as an alternative for the purpose of accessing areas that wheels cannot. The most important aspect of the planar mechanism as legged mechanism is that it does not need large number of actuators for movement. All it need are a rotating motor or crank. There are many types of legged mechanism that fit the above description and the most effective mechanism are Theo Jansen Mechanism, resemble a human leg and Klann Mechanism, resemble a spider leg. In this project, Klann mechanism is chosen as it has more advantages. By creating this framework for Klann Mechanism, others are able simulate an operating or moving Klann mechanism easily. Furthermore, it can be used to determine the limitation of the walking curve, meaning the x step and y step for Klann. In addition, modification on the parameter of mechanism can easily be done by just using this Deign Framework of Klann Mechanism. Finally, if possible, by doing more simulation, a new understanding on Klann mechanism can be obtained.

ABSTRAK

Roda sentiasa mempunyai kelemahan yang besar terhadap rupa bumi yang tidak rata terutamanya mereka yang mempuyai permukaan perubahan yang mendadak, seperti tangga dan curam yang berbatu dan bergerigi. Permukaan ini tidak menjadi masalah kepada manusia biasa tetapi untuk manusia yang kakinya lumpuh dan perlu gunakan kerusi roda, mereka cuba mengelakkan permukaan ini. Oleh itu, mekanisme berkaki disyorkan sebagai alternatif untuk tujuan mengakses kawasan yang tidak mampu diakses oleh roda. Aspek yang paling penting dalam mekanisme satah sebagai mekanisme berkaki adalah ia tidak perlukan penggerak dalam jumlah yang besar untuk pergerakan. Apa yang perlu adalah motor berputar atau engkol. Terdapat banyak jenis mekanisme berkaki yang sesuai dengan huraian di atas dan mekanisme yang paling berkesan adalah Mekanisme Theo Jansen, menyerupai kaki manusia dan Mekanisme Klann, menyerupai kaki labah-labah. Kami memilih mekanisme Klann kerana ia mempunyai lebih banyak kelebihan. Dengan mewujudkan rangka kerja ini untuk Mekanisme Klann, orang lain dapat mensimulasikan mekanisme Klann yang beroperasi dengan mudah. Tambahan pula, ia boleh digunakan untuk menentukan had keluk berjalan kaki, bermakna langkah x dan langkah y. Di samping itu, pengubahsuaian pada parameter mekanisme mudah boleh dilakukan dengan hanya menggunakan Rangka Kerja ini untuk Mekanisme Klann. Akhir sekali, jika boleh, mereka yang menggunakan juga boleh mencipta jenis baru mekanisme.

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CHAPTER 1

INTRODUCTION

1.0 Introduction

The title for my Final Year Project (FYP) is Design Framework to Optimize the Walking Curve of Klann Mechanism. As most of us know, Klann mechanism purpose is to be used on uneven surface. According to general knowledge, one-third of the earth is made out of land. In those one-third of land, there are different terrain such as rocky terrain, muddy terrain, grass terrain, sand terrain and many more. The common similarities these terrains share is their surface, which are naturally uneven. In these modern days, there are many ways to travel on or across the uneven terrain. The land on earth are uneven to begin with and it is through human creativity and innovation that we are able to use technology to make the surface smooth, flat and paved for our tracks and to be blunts, it is the fastest method for traveling, as speed is the most effective way to travel. But, creating tracks for wheeled vehicle need to go through the process called reforming, which include destruction and creation. One of the best example of tracks that we use for travelling daily is the roads.

For a road, paved surface or pathway which all can be called tracks to be constructed, a few procedures are required which involve destruction and reforming in general. The clearing of the surface and land is done by remove and clear a path. In general, activities such as deforestation and blasting is done to change the natural surface to the desired surface, which is will form clear and clean surface without obstacle. Plants are cut down; tree roots are remove; blasting and many more are done with the help of big machinery and tools. All these works are just to achieve one goal, to make a long and free obstacle path for wheeled vehicle. Then, the flattening and paving is done and all these cost resources and our Malaysia Government Works Ministry spend RM1.037 billion for federal road maintenance in 2014 [5][6].

Road construction are normally done of soft soil but it is done on other type of surface too such as rocky surface, sandy surface, muddy surface and many more. But by doing that, it is cost more resources, man power and process. Therefore, I believe that legged robot, in my case legged robot with Klann mechanism is a good alternative for travelling and exploration without the need of creating paths.

1.1 Motivation

The main motivation for the development of legged mechanism, which is Klann mechanism are the following. Disable with wheelchair cannot get access to stair, surface with short instant evaluation changes and government of nations spending billion on road construction. Wheeled vehicles are able to travel on different type of surface, depending on their type of tires, but, there are still one limitation, which is wheeled robot cannot move through all type of uneven surface and the most obvious is stairs.

Figure 1. 1: Wheelchair.

Figure 1. 2: Prosthetic leg.

Wheelchairs, Figure 1.1 have severe limitations in building and urban roads, so there is a need for new concepts of chairs for disable. [1] This is true, wheels have limitation as the earth terrains are mostly uneven as they are made out of rocky terrain, muddy terrain, grassing terrain, sandy terrain and many more. March 2011, earthquake and tsunami struck Japan and one of the surviving victim was a disable and been confine since young age. When tsunami happened, he recalls the sound of the tsunami alert just minutes before the water rushed into his home. He remembers the feeling of helplessness, and how his family helped him up the stairs to safety. His electric wheelchair was destroyed by surging water. "The whole neighbourhood became like a dark, black lake and everything disappeared in it," he says. [2]. May 2008, earthquake hit China and a surviving girl need to use wheelchair for life as both of her legs were amputated above the knee. She gave a statement saying "My mother carries me and the wheelchair and I can help a little bit,"[3] when she need to attend her classes which are up three flights of stairs.

Some may suggest prosthetic leg, Figure 1.2 but do they know it cost from $5000 to $50 000. Even the most expensive limb can only withstand 3 to 5 year due to wear and tear, meaning it need to replace over the course of time, it is not a onetime thing but the wheelchair is. You just to need to buy one wheelchair can use it until it breaks down and it is way cheaper. In addition, wearing new prosthetics hurts and they need time to get used to it every single time. [4]

When talked about motion, we thought of cars as we use them daily. Governments spend billion in road construction and maintenance, creating tracks for vehicle with wheels, which is a very big sum. With billion, it can be used for other welfare such as building hospitals and schools or even, free education for the children. Malaysia is also included in spending billion in road construction and maintenance as in 2014, the Works Ministry allocates RM1.037 for federal road maintenance [5,6]. The main reason we still building road due to the world are still using technology from the caveman era, the wheels. Technology have improved since then and we should have make some changes as we are spending billion in road construction and maintenance. The concept of track and wheel had been widely use since 19^{th} century and 20^{th} century where the steam engine and the internal combustion engine were invented [7] mainly for train and car.

Figure 1. 3: The Tarim Desert Highway of China [8].

Figure 1. 4: Road construction of Dubai in Arab [9].

With wheeled vehicle, there must be tracks and that can only be done by destroying and reforming the naturally beautiful uneven terrains. The situation has become even worst as in the name of development, more cities and roads are build all over the world and process is still continue at an even faster pace. Tall building and roads are popping up fast everywhere all around the world and more terrains are reformed and developed into roads to connect all these cities. Many resources, man power and process are wasted on creating road and paved surface for wheeled vehicle.

Country which made out of dessert also spend many of their resources in making road to connect cities and the example are The Tarim Desert Highway of China and road construction of Dubai in Arab, [8][9] which is shown in Figure 1.3 and 1.4. Governments, Rulers of Nations, States, Cities and Town spend resources, man-power and process in building roads but not in the research to improve the vehicle moving on it. People have been constructing roads for centuries, since the 19th century and for decades many still doing research on enhancing roads quality or better road construction method. In state of improving the tracks, we should improve the vehicle or object traveling on it.

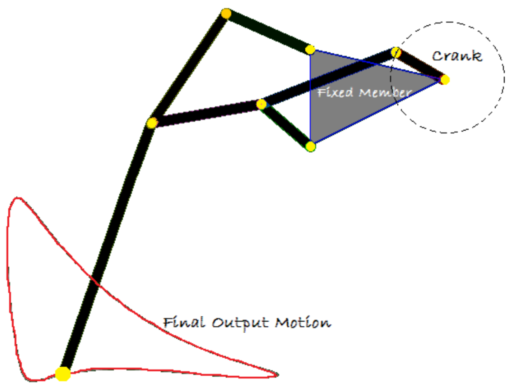


Figure 1. 5: Klann Mechanism [12].

Do not let the surface, limit the movement of the object. In state, the object build must have the ability to move on any surface. We should change our perspective and move forward by focusing on the object that travel on the surface, which is the vehicle. Do not change the natural uneven surface of the terrain but change the design of the vehicles which allow the vehicle travel on the uneven surface, the object design should adapt to the surface. In addition, it should have more function, such as moving on uneven surface, not paved path as the modern world now command products that can multitask. To reduce and prevent more tracks to be build, and the continuation of reforming the surface of our earth terrain, legged mechanisms are proposed for the use of mobile transportation. For this project, the focus will be on legged robot that uses planar mechanism and to be more precise, Klann Mechanism, Figure 1.5.

1.2 Problem Statement

The following are the problem statements for this project.

1.2.1 To identified the mechanism of crawler robot (legged robot) base on Planar Mechanism that can move on surface with short instant elevation.

For this project to start, the mechanism of the crawler robot that can move on surface with short instant elevation changes must first be identified and research. In addition, the mechanism need to consist the features of planar mechanism such as rotating cranks, linkages and connecting joints.

Short instant elevation changes surface, for example stairs are the most obvious surface that wheels cannot move on therefore, legged robot or crawler robot are suggested as alternative. For legged robot, they are normally made out of 2 type of mechanism which are planar mechanism and spatial/ complex mechanism. In a planar mechanism, all of the relative motions of the rigid bodies are in one plane or in parallel planes. If there is any relative motion that is not in the same plane or in parallel planes, the mechanism is called the spatial mechanism. [10]. In short, mechanism that are moving in 2-dimensional direction, which is x axis and y axis is planar mechanism, while more than 2-dimension direction is called spatial or complex mechanism.

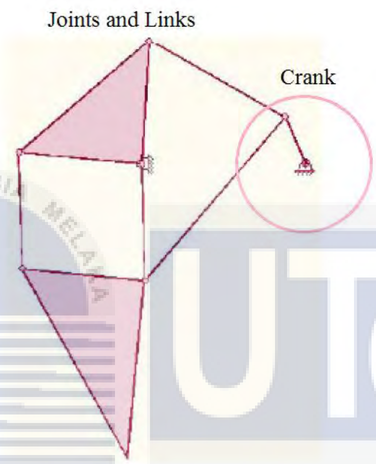


Figure 1. 6: Theo Jansen Mechanism (crank) [1].

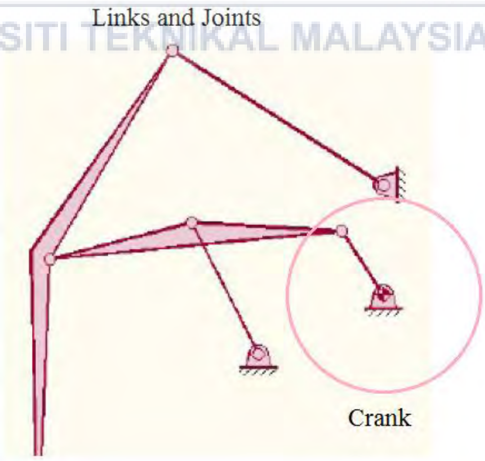


Figure 1. 7: Klann Mechanism (crank) [1].

For this project, planar mechanism is use for the crawler robot, where the links and joints are connected to a rotating crank. There are many types of mechanism that can be use and the following are a few examples that we going compare in the literature review. [14]

i. Klann Linkage

ii. Theo Jansen Linkage

The most effective and popular comparison of planar mechanism for crawler robot are Theo Jansen Mechanism, Figure 1.6, mimic human leg and Klann Mechanism, Figure 1.7, mimic spider Legged. Both these mechanisms follow the principle of having a rotating crank, linkages and connecting joints. But for this project, Klann mechanism is favour as it had more advantages and the detailed comparison can be seen in Literature Reviews.

1.2.2 To identified the limitation of the crawler robot mechanism in horizontal step distance (x step), and vertical step distance (y step) base on planar mechanism.

In this project, Klann linkage will be mainly use as example as it is the favoured and consist many advantages.

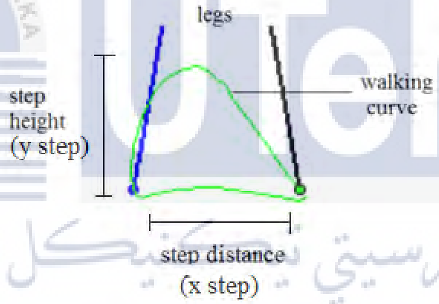


Figure 1. 8: Step Height and Step Distance [11].

The action of walking is first described as the lifting of leg. Next, move the leg forward or backward and finally move the leg downward. The action is repeated for each leg and the motion is mostly planar. The action of lifting your leg upward and downward is called step height (Height overcome with each step) and the action of moving your leg forward and backward is called step distance (distance move with each step), which is shown in Figure 1.8. For this project, the horizontal step is defined as step distance and the vertical step is defined as the step height.

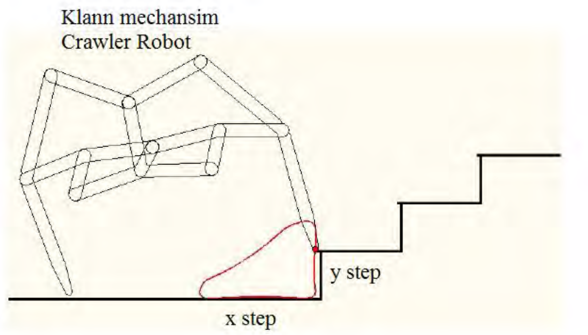


Figure 1. 9: Klann mechanism moving on a stair[1].

For each mechanism, there is a limitation for each taken step, in height and size. Since this project had decided on using Klann mechanism, Figure 1.9 will show Klann mechanism moving on a stair as we stated in our motivation, the mechanism need to move on surface with short evaluation changes that is stair, which step distance and step height. The step distance (x step) and step height (y step) are affected by many factor, mainly by the design of the mechanism which in this project consist of mainly linkages, joints and cranks and gears. Different length of linkages, position of joints, dimeter of cranks or no of teeth at gears should have effect on the on the walking curve, which will affect the x step and y step.

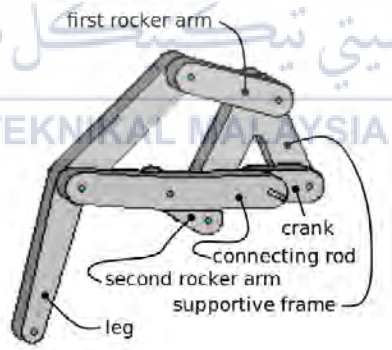


Figure 1. 10: Klann Legged mechanism for Crawler Robot [13].

For this modification, whether on the length of links, position of joints or radius of crank, Matlab will be use as simulation tool for creating the Framework for Klann mechanism. At this points, all the design will base on Klann mechanism. The modification of link will be done on the main linkages. The main linkages that may be modified are shown in Figure 1.10. The parts that will be modified will be determine after derivation of formula is done on the kinematic modelling of Klann mechanism.

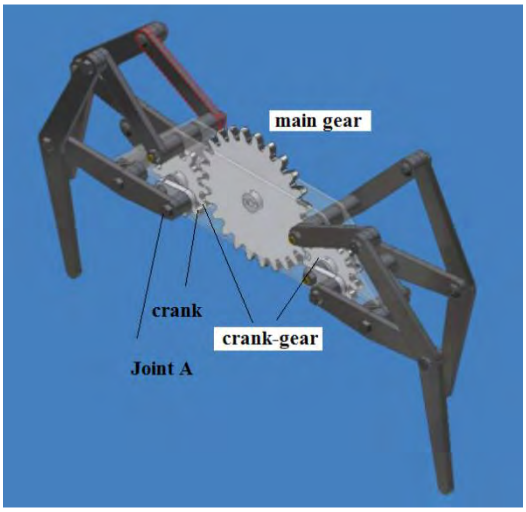


Figure 1. 11: The design of Klann mechanism crawler robot [18].

For the crank, which can be refer in Figure 1.11, show a design of Klann mechanism that are connected to the cranks clearly. The position of the joint connection (joint A) will affect two aspects which are,

i. The shape of walking curve, x step and y step.
ii. The time taken to complete one cycle of walking curve of the mechanism.

The changes of position at joint A can only be done by changing the diameter of the crank-gear. The difference in lengths from point A to the center of crank-gear (r-crank, Radius of Crank) will affect the shape of walking curve, the x and y step as the rotating point A had changed. Next, since the r-crank of rotating joints has changed, the time taken to complete one rotation cycle for crank will also change which will affect the time taken to complete a cycle of walking curve. In simple word, the moving speed of the robot will be change either faster of slower depending on r-crank. The bigger the radius, the slower the robot as it takes longer to complete one cycle of walking curve. The affect is vice versa for smaller Radius of crank. The position of Joints at the crank-gear, r-crank will have effects on shape and speed of walking curve. Therefore, joints and crank must be taken in consideration while designing and building the crawler robot mechanism as it will determine x step, y step and speed of one complete cycle rotation of walking curve.

Since the rotation of the of the crank that allow translational motion of the crawler robot, therefore, a transferring medium or parts is needed. For, this project, gears will use the transfer medium for rotational force of motors. In Figure 1.11, both the side cranks are modified to gears. For these crank-gear, it has both the characteristic of crank and gear. It still acts as a crank for the mechanism but is modified to crank-gear as the gears objective is to receive rotational motion from the main gear, which is connected to the motor. In gears, the diameter and number of teeth will affect the angular velocity. This will affect the translational movement of the crawler robot. Therefore, changes in gears must be taken as consideration in the development of the mechanism.

In this project, the main focus will be given to x step and y step as the main objective is to move on uneven surface, speed in not the main focus. Therefore, in the design, the changes are going to be done at the links first. This is to determine the relationship between length of links toward x step and y step. The modification of the position of Joints, Rcrank and Gears will be secondary. With the data obtained for the Matlab simulation, limitation on the walking curve, x step and y step of crawler robot will be determined. This is the original plan; other parts may also be change after more research is done.

1.3 Objective

i. To design a walking mechanism that can overcome an obstacle of 2 cm height.
ii. To determine the design parameters that influent the x step and y step in walking mechanism.

1.4 Scope

The title of the project is Design Framework to Optimize the Walking Curve of Klann Mechanism. Since we are going to design the framework for the Klann mechanism, therefore, must focus on walking curve. This result in analysing of two parts, which are

i. The mechanism of crawler robot, the Klann mechanism.
ii. The uneven surface, related to walking curve.

The mechanism design, research and manufacture must consist of linkages, joints, cranks and gears. Then, the mechanism foundation is planar mechanism. Therefore, in this project, the focus is only on one type of mechanism which is the Klann Mechanism. The Klann mechanism which mimic the leg of spider will be the basic structure and foundation for the project, where many alterations will be done on the length of e and q, only to be more specific, on length of upper rocker arm and length from upper rocker arm to the center of crank which can be seen in Figure 1.10.

Next, for the design and drawing, there are many software that can be use but Solidwork the standard for drawing parts, assembly of parts and communicate with 3D printer for manufacturing parts, which is the Klann prototype A. This can be done by converting the file into STL file which is standard file type to interact with 3D printer for printing. Then, the simulation is Matlab to determine the height of obstacle that it can overcome. Therefore, Solidworks and Matlab will be the standard for this project in design and simulation.

Finally, minor correction will be done on the robot, which to be precise, hole will be added to design to reduce the material need for 3D printing. The modification is set on length of linkages for now but further changes will be added if necessary. The fill density of ABS plastic material that are used for 3D printing is set at 25 % fill density for now and any changes will be done is needed.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In the real world, reference and resources are needed to completing task. Therefore, literature review that discussed on related information in a particular subject area is need. The purpose is to summarize and synthesize the ideas of others. When we write a literature review, it usually consists of 3 main sections, Introduction, Body section and conclusions from the discussion of sources and recommendations. Related article, literature and research will be used in this particular section to explain our problem statement, objective and scope of the project.

2.1 Air and Land Robotics

There are many ways to travel through uneven terrain and the most common ways that are used in today society are wheeled and air vehicle. In robotic construction, the same concept applied, robot can move on uneven surface through air, flying or land, rotating wheels or walking or hopping.

Depending on the purpose such as traveling, transportation and exploration, air vehicle is the fastest as it can float, fly pass any surface and the only limitation is that it cannot travel in water. Yet, in real life, many people still use land vehicle, mainly the wheeled vehicle as air vehicle still have it limitations. Therefore, Mobile Robotics for uneven terrain can be categorized into two main type,

i. Air Robotics
ii. Land Robotics

The first and main limitation is that air vehicle technology is too costly to be used in daily basis. Current air vehicle still uses fuel as a power source and the price for the fuel is too expensive if compare to wheeled vehicle in a daily use basis. In mini sized mobile robot, which are mainly use for exploration or surveillance, air type mobile robots still consume way more power compare to land mobile robot. In addition, in term of the torque and the speed of the motors, air vehicles is more powerful and expensive. High performance motor for torque and speed are need in flight as the rotating fan blades need to sustain the whole-body weight of the vehicle in mid-air, fighting against gravity, air flow and air pressure. This parts need many complex calculations. These is why pilot need to added many years of studies to pilot plane but learning driving are car just need a few days. There is complex calculation and many factors are need to be accounted for when uses in exploration and surveillance.

Therefore, it is still more economical to use land mobile product compare to air mobile product. The following is brief and general comparison of Air Robotic and Land Robotics. In the end, land robotic is chosen for this project as the cost of production is cheaper. In addition, the process and manufacturing is less complex if compare to Air robotic.

2.2 Land Robotics

For land robot to travel on ground terrain, it must follow the law the of physic on the ground which are two main aspects, static and dynamic stability. In must able to stay stable in static and moving form.

2.2.1 Static and Dynamic Stability

Stability, which can be define or in simple words is called not falling or slip over, remain in balance in static position and moving position. This aspect is essential to all land living organism or object, where in this project, the object is a robot. First of all, the robot must have the ability to be achieve stability in static form of dynamic movement. For living organism, we achieve stability through learning process, development of muscle and then is become natural to so. In robotic, it is totally different, where tissues cannot be developing and the robot do not learn how to walk, but depend on engineers. The designer must design the robot so that it have the ability and structure strength to achieve stability, static or dynamic, in hardware and software. Many designed robotic can achieve stability in static easily but it is very difficult for dynamic stability. Since wheeled, legged and articulated robots only have a few small surfaces or parts of its body that are in contact with the ground, stability is going to be difficult. There are two ways of ensuring stability, which are Statically and Dynamically. [7]

2.2.1.1 Static Stability

Static stability is defined as “An ideal legged locomotion machine is statically stable at time, *t* if all legs in contact with the support plane at the given time remain in contact with that plane when all legs of the machine are fixed at their locations at time, *t* and the translational and rotational velocities of the resulting rigid body are simultaneously reduced to zero.” [7]. In simple word, a legged robot will have the ability to stay at a fixed location with the ability to support it whole body structure regarding the number of supports/legs that support the whole body. It will try to remain stable although some legs or supports are lifted up. A good example is human try to be stable while standing on one foot.

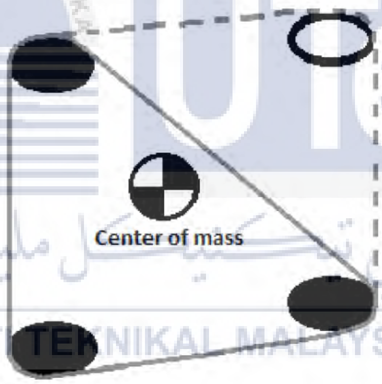


Figure 2. 1: Robot Trying to achieve center of mass concept [7].

The concept of center of mass which enable all thing to achieve static stability. For a robot, it is statically stable when the center of mass is within of the support area which is shown in Figure 2.1. The support area is the area created by drawing lines between outermost parts of the surfaces currently in contact with the ground. A 4-legged robot is use as example to describe about static stability.

When a foot of the 4-legged robot is lifted up from the ground, the support area for the legged robot becomes much smaller, which can be seen in Figure 2.1, resulting in the legged robot to become less stable. In this unique case, if the center of mass of the legged robot comes outside the support area, the robot will fall or slip over toward the ground if adjusting in balance is not done quickly, this is where the concept of dynamic stability can be use. For the legged robot, some part of margin must be kept between the center of mass and the edges of the supported area in order to handle external forces, such as the inertial forces applied to the robot when moving, sudden stops/breaks or turns.

2.2.1.2 Dynamic Stability

In dynamic, there are constant motion of bodies meaning the robot is constantly moving from one direction to another. When a legged robot is in motion, it need to allows its center of mass to come outside the support area, result in the lost it center of mass that will lead falling on the robot due to loss of stability. Therefore, to achieve stability in dynamic or motion, the moving robot in some other way, must compensate with a reaction, the shifting of another foot or the center of mass of the whole robot. Since the robot must continuously compensate its balance to achieve stability, preventing itself from falling or slipping over. The moving robot cannot simply just stop its motion suddenly or slow down for an instant amount of time. It can stop for a short amount of time but need to quickly compensate for that action. All of this actions and reactions requires high demand in the ability of control within the robot. The robot has to have the following [7].

i. Have sensors for the measurement of orientation and velocity of its body limbs with a sufficiently high update rate and precision.

ii. Calculate how it should move, need to be done fast enough.

iii. Move its limbs with sufficient speed and precision from the information receive from the sensor and the processor.

The biggest and core advantages of dynamic stability are that it allows for a less restricted pattern of motion, more degree of freedom in joints, which means higher speeds are achievable. Terrain that is uneven, soft, slippery or contains for example lose rocks, instant elevation and other type obstacles often gives difficulties of using static stability. The robot might even be forced to use dynamic stability if it for example slips on a patch of ice or steps on a loose rock that turns over unexpectedly. Note that a dynamically stable locomotive pattern might very well include intervals that are statically stable.

2.2.2 Type of land Robotic

Land robotic are the robots that are going to be use in land terrain and overall there are 3 main categories of land type robotic and they are as following.

i. Wheeled body
ii. Legged body
iii. Articulated body

Each type of this land robot has their own description, function, limitation and many more, more detail information can be seen in Table 2.1.

2.2.2.1 **Comparison between type of Land Robot**

Comparison on 3 type of land robot, wheeled robot, legged robot and articulate robot. This is done to show that the important of Klann mechanism especially it need to be use in legged robot. Sure articulated robot also able to walk on uneven surface, but the programming for the robot is to complex are each section is and individual robot and they need to communicated with each other. The comparisons are shown in Table 2.1.

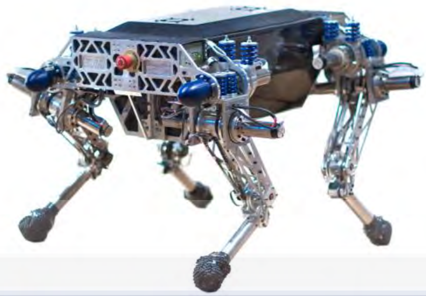
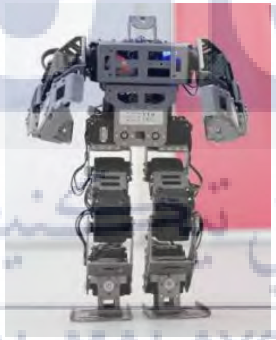
Table 2. 1: Comparison between type of Land Robots.

	Wheeled body	Legged body	Articulated body
Descriptions	Robot movement are powered by the rotation of DC motor which allow the rotation of wheel. The rotation direction of the wheel will determine the direction of the robot moving. Mostly move on tracks which are widely use in transportation in today society	Robot has excellent/superior mobility in natural terrain. It uses discrete footholds for each foot, allowing to move on irregular surface. Movement like legged living organism.	Robot consist or made out of several segment or parts. Connection imitate snake or centipede. Movement mimic organism such as snake or centipede.
Operating Surface	Move on continuous tracks, rough, soft, sandy, slippery surface. Depending type of tire. Unable to move on surface with instantaneous elevation or surface with steep jagged surface.	Move on rough, soft. sandy, slippery and surface with instantaneous elevation terrain.	Move on rough, soft. sandy, slippery and surface with instantaneous elevation terrain. Specially in moving at tight and small area.
Mechanism for motion/movement	Wheels	Legged Mechanism or leg with actuators at joints.	Legged Mechanism or leg with actuators at joints.
Motion Implementation	Wheel are normally attach at back of the robot, to move forward or	For planar type mechanism, the concept is same as wheels in moving	Same as the concept as legged body mechanism, both in planar and

	backward, both motor need to rotate at same speed in vice versa direction, one clockwise, another anti-clockwise. To move left and right different speed in motor must be achieve. Robot will normally move at the direction when the rpm of motor is lower. Allow to move to the desire direction.	forward, backward, left and right. For complex mechanism, the robot move at desired direction all depending on degree of freedom (dof) of the link which is affected by the rotation angles of the joints.	complex mechanism. Robot can either uses planar mechanism of complex mechanism in it movement.
Coding for motion/movement	Simple, rotate clockwise and anticlockwise only	Simple for planar mechanism, hard for complex mechanism.	Very hard as each section can act individually and sometime need to act as one unit.
Energy Consumption	High, motor rotate fast and continuous. Energy consumption is high.	Low, actuator only use energy at necessary joints. Less deformation on terrain due to less contact on earth compare to wheels. Therefore, less energy needed to get out of depressions which is lower compare to wheels. Wheels give out large imprint when moving of soft surface.	High, although energy consumption concept is like legged robot if uses centipede design but the whole body still made out of many section and each section must have its own power supply. Use too many actuator at one robot which made out of several

			sections, resulting in high consumption of power.
Pros/ Advantages	• Easy programing. • Easy to manoeuvre. • Easy Weight balancing. • Cheapest statically stable mobile robot, do not need much motors. • Fast mobility. • Give more grip to surface	• Move on surface with instant elevation. • Reduction in weight of the whole system. • The increase in the energetic autonomy. • Able to operate although loss some legs. • Legs can be manipulated into other purpose, such as holding.	• Able to operate although loss some legs of segments. • Move along and cross along irregular, weird, narrow terrains or passages, long body is adopted to the terrain • Are able to cross ditches, hardening the joint servomechanisms in order for them to form a bridge. • They are also able to cross, on a stable basis, swamp terrains, by weakening the joint servomechanisms in order to distribute its weight over its all segments • High reliability due to redundant unified structure.

			• Easy maintenance as malfunction parts or segment can be easily release, disconnected or separately for repairing purpose. • Easily transported when is divided segments.
Cons/ Disadvantages	• Need smooth and continuous track for maximum performance. • Placement of heavy component and equipment are fixed, not flexible in center of mass. • Large energy consumption • More internal friction. • Weight more.	• Move at lower speed • Complex and difficult to build • Complex algorithms • Jamming at links and joints.	• Move at lower speed • Complex and difficult to build • Complex algorithms • Jamming at links and joints. • Mechanism are heavy, due to large number of actuator and section. • Large energy consumption.

Examples of robotics	 Figure 2. 2: Two Wheeled Robot [26].  Figure 2. 3: Nomad HD Wheeled Robot [27].  Figure 2. 4: Zumo Tracked Robot Kit for Auiduino [28].	 Figure 2. 5: StarIETH – Dynamic Quadruped Locomotion [29].  Figure 2. 6: Walking robot Bioloid GP [30].	 Figure 2. 7: S5 Snake Robot Prototype (1998-99) [31].  Figure 2. 8: Surgical Snake Robots [32].

2.3 Legged type Robot Mechanism

There are two type of legged type robot mechanism planar and complex.

2.3.1 Planar mechanism and Complex mechanism

Legged robot is a good alternative for travelling and exploration without the need of paths. For legged robot, there are two type of mechanism which is planar mechanism and complex or spatial mechanism legged robot. In a planar mechanism, all of the relative motions of the rigid bodies are in one plane or in parallel planes. If there is any relative motion that is not in the same plane or in parallel planes, the mechanism is called the spatial mechanism. In short, mechanism that are moving in 2-dimensional direction, which is x axis and y axis is planar mechanism, while more than 2-dimension direction is called spatial or complex mechanism.

For planar mechanism, there are two mechanisms which are common used and compared on legged robot and they are the Theo Jansen Mechanism (Figure 2.9) and the Klann Mechanism (Figure 2.10). Each with their own pros and cons. In my Final Year Project (FYP), the mechanism that will be use is the Klann Mechanism as the main reason is it had a better center of gravity, meaning that it is more stable and will have less chance of flipping over. The main purpose is to move through uneven surface, therefore, center of gravity plays an important role.

Figure 2. 9: Klan Mechanism Robot [18].

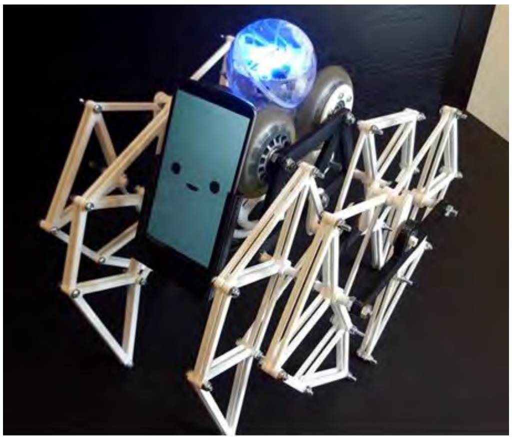
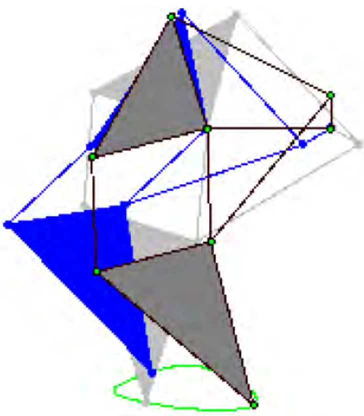
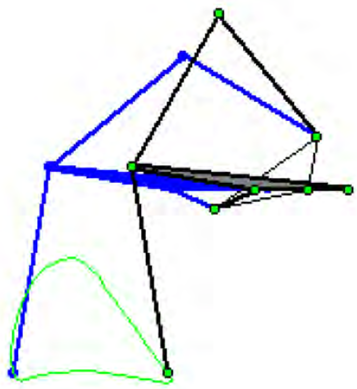


Figure 2. 10: Theo Jansen Mechanism Robot [33].

2.3.1.1 Example of Planar Mechanism

There are many robots that uses planar mechanism due to its advantages to complex mechanism. Complex mechanism may be more advance and superior in control of their joints but the programming is way complex and time consuming for this project. In addition, the parts are way too expensive for this peculiar project which have a budget of about RM300. Therefore, Planar mechanism is chosen due to the simplicity in programing and cost way cheaper. Among many robot mechanisms, Theo Jansen and Klann mechanism is the most compare mechanism and the following table shows the comparison.

Table 2. 2: Comparison between Theo Jansen and Klann Mechanism [18].

Comparing Aspects	Jansen Linkage (existing method)	Klann Linkage (Proposed method)
Figures	 Figure 2. 11: Jansen Linkage.	 Figure 2. 12: Klann Linkage.

Number of links per leg	8 link per leg	6 links per leg
No of leg to replace wheels	3 legs will replace a wheel (Robot with 4 wheels)	2 legs to replace a wheel (Robot with 4 wheels)
Degree of crank rotation per stride	120 degrees of crank rotation per stride.	180 degrees of crank rotation per stride.
Step height	Step height is achieved by the parallel linkage in the leg which is folded during the cycle angling of lower portion part of the leg.	Step height is achieved due to rotating of the connecting arm which is connected to the crank on one end and the middle of the leg on the other. The leg pivots itself on a grounded rocker.
Surface and terrain	Can walk only on even surfaces and terrain.	Can walk on uneven surfaces and terrains.
Cost	The number of links in the Jansen mechanism is more when compared to that in the Klann mechanism. It is costly.	The number of links in the Klann mechanism is less when compared to that in the Jansen mechanism. It is less costly.

2.3.1.2 Example of Complex Mechanism

First, Manopod Robot, a one leg robot that Perform locomotion through hopping, also known as hopping robot. Natural example of hopping movement is the kangaroo. Achieving dynamic balance is hard as the first prototype could only move forward and backward. The second prototype, called ‘Pogostick’ able to move at any direction but with limited speed.

Next, Biped robot or two-legged robot advanced slower compare to multilegged robot due to the difficulty in achieving dynamic stability. Difficulty to archive stable control. Need both aspects in development, ‘intelligence’ and ‘mobility’ in robot. First, prototype just the legs are developed, below human body waist but full humanoid design has been built throughout the years.

Finally, Robot with three legs and above. Normally are preferable as able to achieve better dynamic stability compare to monopod and biped robot. But the programming algorithms is much more complex due the large amount of actuator that needed to be control. More legs, more actuators need to be control.

2.3.2 Comparison Between Planar and Complex Mechanism

In this project, we have chosen planar mechanism and more specific Klann mechanism because of the following aspect.

i. Cheaper in cost of construction, operation and maintenance
ii. Less complex in mechanism construction, program construction and control.

The following are the detailed information and reasons in both type of mechanism.

Table 2. 3: Comparison between Planar and Complex Mechanism.

	Planar Mechanism	Complex mechanism
Complexity in coding	Simple and direct	Complex and interconnected
Cost of product/ maintenance	Lower as less actuator and sensor are needed. Less actuator and sensor meaning less problem, less maintenance.	Expensive depending on number of actuators, required better and more sensitivity sensor and controller. Maintenance vice versa with planar mechanism.
Degree of freedom (dof) for joints	2 dof only, x axis and y axis	More than 2 dof. Depending on the design of joints.

Stability / Balance	Easier in achieving static and dynamic stability. All of them depend on the design of the mechanism.	Difficult in achieving stability static and dynamic. All actuator are important and must interconnection to achieve stability. In addition, the reaction on links and joints must be fast and accurate.

2.4 Cranks

In this project, cranks are important part of the Klann mechanism where it transfers the rotation motion of the crank into translational motion of the robot. For explanation purpose, Klein's Construction [17] method is use. Figure 2.13 show the construction.

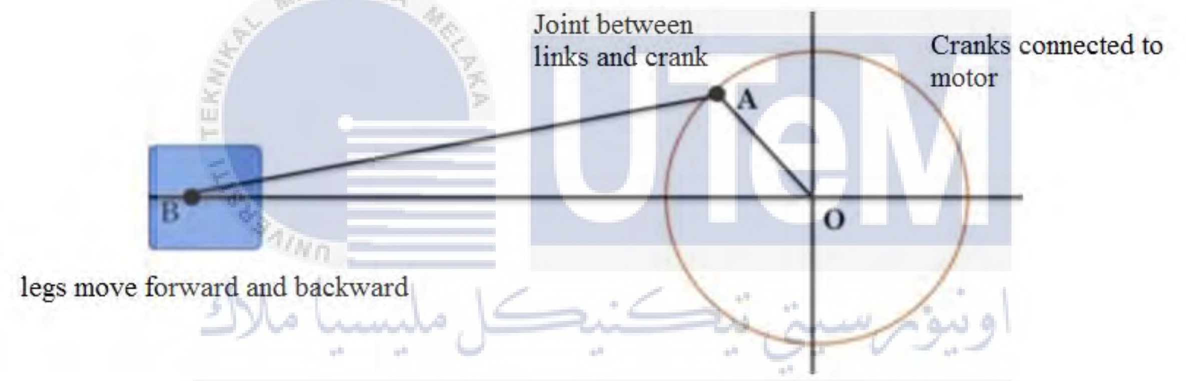


Figure 2. 13: Klein's Construction method [17].

Just imagine that point B is the leg of the robot, when the motor rotates, the crank rotates causing point A to move in a circular motion. The circular motion at Point A will result in the forward and backward movement pf point B, which mimic a walking robot moving forward and backward. Which can also be define as x step. In Figure 2.14, a sample of Klann mechanism robot, when the crank rotates, the leg mechanism will move which will form a walking curve, that has x step and y step. Therefore, crank is important in forming of walking curve for the robot.

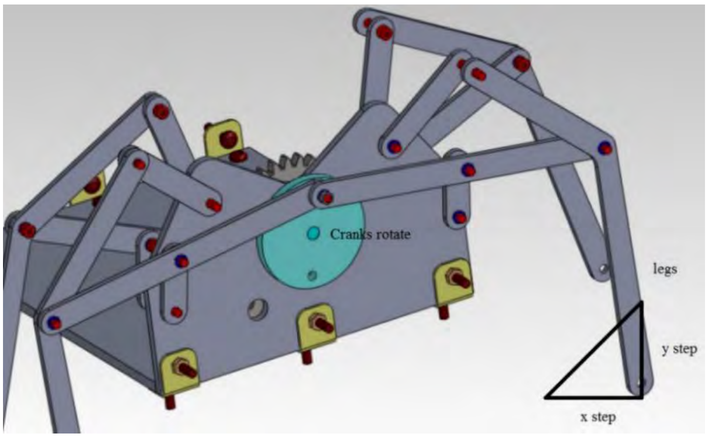


Figure 2. 14: A sample of Klann mechanism robot forming walking curve [33].

2.5 Gears

In Figure 2.14, the design does not have gears but for out design of klann mechanism, gears will be use. A sample design can be seen Figure 1.11. Gears are normally used to control the rotating speed. By changing the radius and number of teeth at gears, the rotating speed of each individual gear can be controlled. But for this project, where the robot design with Klann mechanism, all gears have the same radius and number of teeth as the project do not focus speed, but rather, on the analysis of the walking curve of the robot. The gears are use as optional, if there is a need in adjusting the speed of the robot.

2.6 Servomotor

To operate the Klann mechanism, a motor need to be use and in this project servomotor is selected for our Klann mechanism crawler robot.

Figure 2. 15: Tower Pro MG995 Servo Motors 360° Continuous Rotation.

Tower Pro MG995 Servo Motors 360° Continuous Rotation is used for the Klann crawler robot which is shown in Figure 2.15. Most servo motor can only rotate at until certain degree and most is 180 degrees, but can be overcome by some mortification. In addition, the component is easy to get as it is sold on online store. Lighter in weight, can rotate 360 degrees in angle, move in clockwise and anticlockwise direction. Finally, the torque value is able to operate the Klann linkage for crawler robot.

2.7 Microcontroller Genuino Zero

For the crawler robot with Klann linkage or Klann Prototype A, microcontroller Genuino Zero was use.

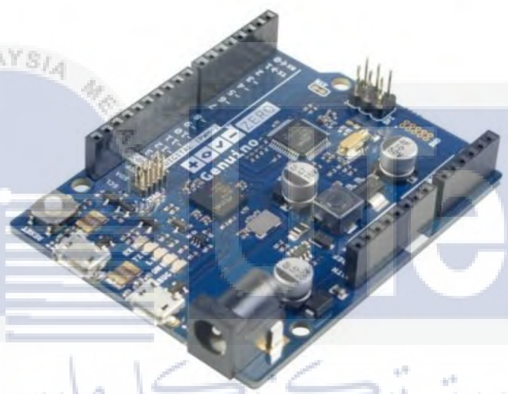


Figure 2. 16: Arduino Genuino Zero.

The main reason Arduino Genuino Zero is chosen, not Arduino Uno as the processing speed is 32-bit ARM processor while Uno is only 8-bit, which is 3 time faster. This is important for the communication of the sensors and Servo motor. The microcontroller must have the ability to process multiple sensor. In addition, it also made room for improvement without worry about processing speed.

2.8 Klann Prototype A

In this project, a crawler robot with Klann linkage is produce and is named Klann prototype A.

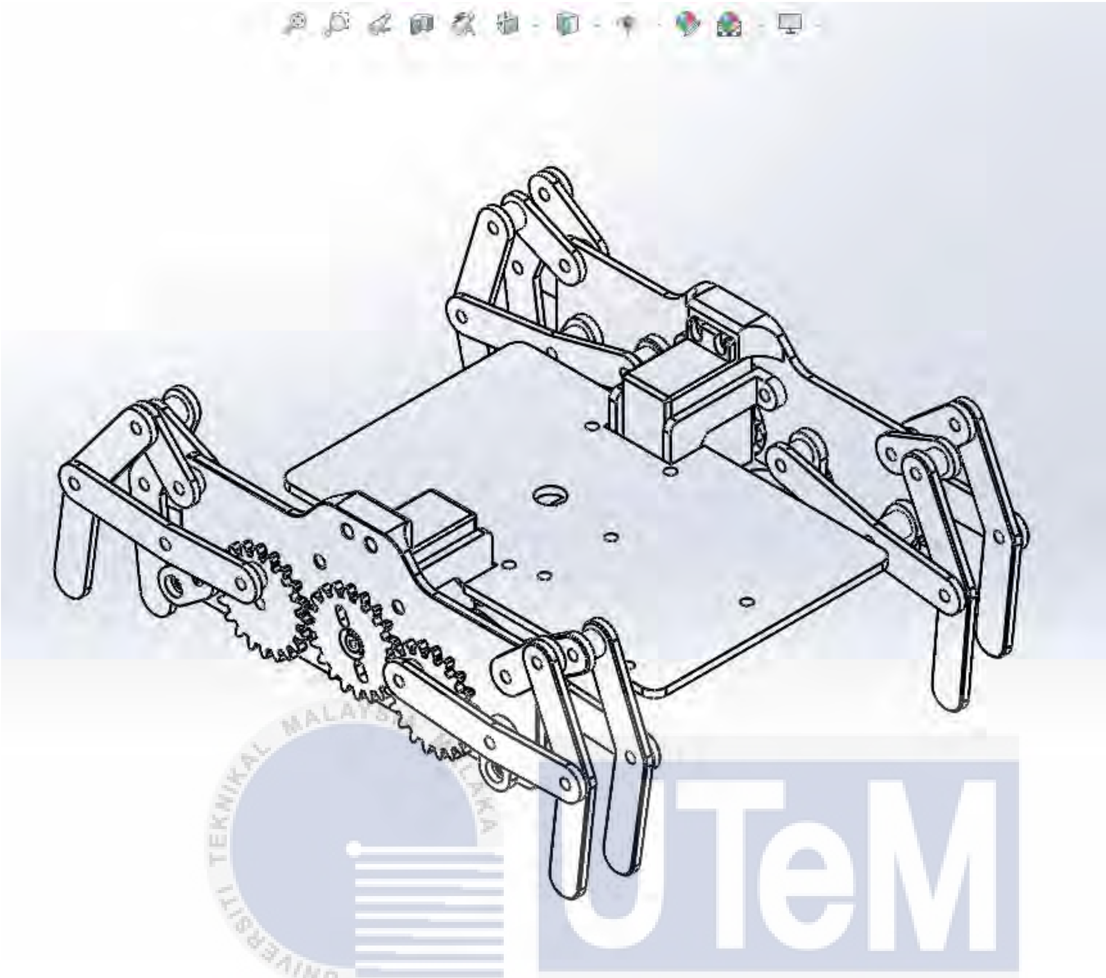


Figure 2. 17: Klann Prototype A.

The final product is shown in Figure 2.17. The parameters and measurements for Klann linkage is obtain from the internet and then integrated with the crawler robot. For the designs of the robot, they are drawn using the design software, Solidwork and then, produced using 3D printer. By adding servomotor and microcontroller Genuino Zero, the crawler robot is able to operate. The video of an operating robot is attached to the disc and the drawings for the Klann Prototype A are at the appendix A and B.

2.9 Theory of Klann Mechanism in Obtaining x step and y step.

In this project we must first determine the factors that affect x step and y step of the walking curve for Klann mechanism. To do that, we must use kinematics modelling. [1]

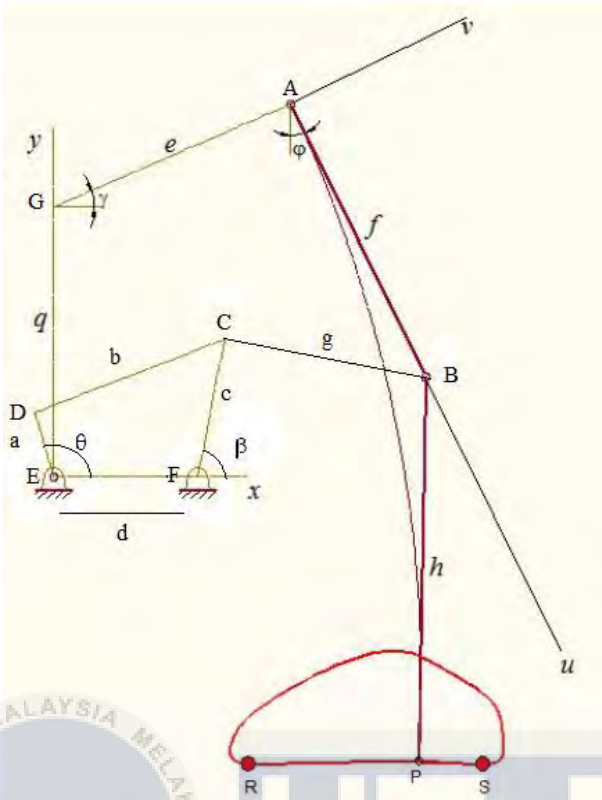


Figure 2. 18: Local system for calculating the displacement of point p [1].

From the ABCM Symposium Paper, 'Mechatronic Design of a chair for Disabled with Locomotion by Legs' [1], a formula is derived which is stated below

$$\begin{Bmatrix} x_p \\ x_p \end{Bmatrix} = \begin{Bmatrix} e \cdot cos\gamma \\ q + e \cdot sin\gamma \end{Bmatrix} + \begin{bmatrix} cos\varphi & -sin\varphi \\ sin\varphi & cos\varphi \end{bmatrix} \cdot \begin{Bmatrix} u \\ v \end{Bmatrix} \tag{2.1}$$

Since u and v is constants therefore, only *e* and *q* are treated as variable. Form equation 2.1, we can conclude that x_p is effected by *e* and y_p is effected by *q* and *e*. x_p is defined as x step while y_p is y step. Therefore, referring figure 2.8 length of *e* will affect the x step and distance of *p* and length of *e* will affect the y step. After a framework is create, the following are the parameter that should be change in the framework.

i. Length of e, length of upper rocker arm (link_1)
ii. Distance of q, length from upper rocker arm to the center of crank (pin_2_y)

For the Length of e or can be called as the length of the upper rocker arm and the length of q, the length from the upper rocker arm to the center of cranks, Figure 2.18 shows a clear description on the parts that going to be change. All this is going to be done using Matlab simulation where data will be retrieve form each change. Then a graph of y step against x step will be plotted for each data to do analysis.

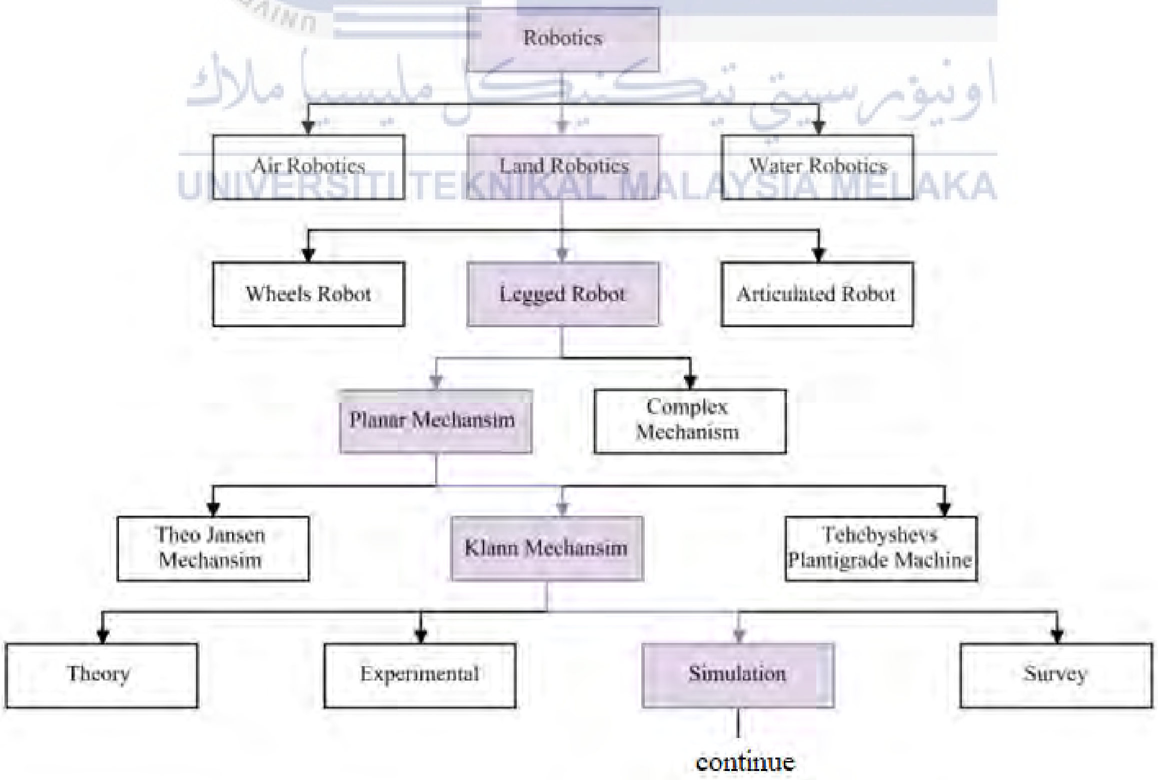
CHAPTER 3

METHODOLOGY

3.0 Methodology

The steps, procedures, methods and techniques that are used to conduct the study/project are outlined here. The purpose is to enable such study/project to be repeated by other. Flow charts and clear explanation are required here to present as methodology. In addition, since the experiment has been done, past tense and passive voice will be use in this part. Finally, when it is appropriate, reference method to other researchers should be made.

3.1 K Charts



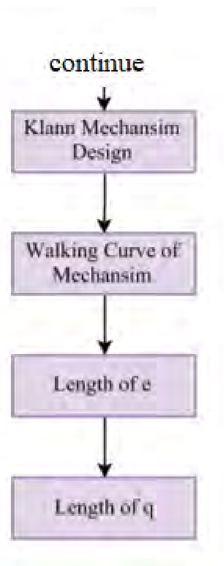
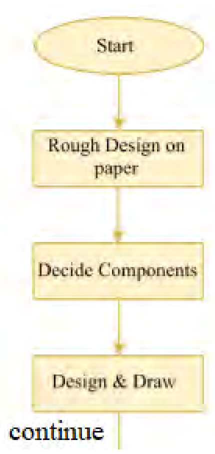


Figure 3. 1: K Charts.

Figure 3.1 show the K charts of the project. To conduct the project, we must first understand the use of Klann mechanism which is to overcome land surface with sudden elevation. In order to do that, the Klann mechanism is hooked on land mobile robot which is categorized under legged robot. In addition, in type of mechanism, Klann mechanism is a planar mechanism. To conduct this project in simulation, the framework for Klann must first be build using Matlab. After there is a framework, the walking curve can be obtained, and changes can be done on both e (link_1) and q (pin_2_y).

3.2 Flow Charts



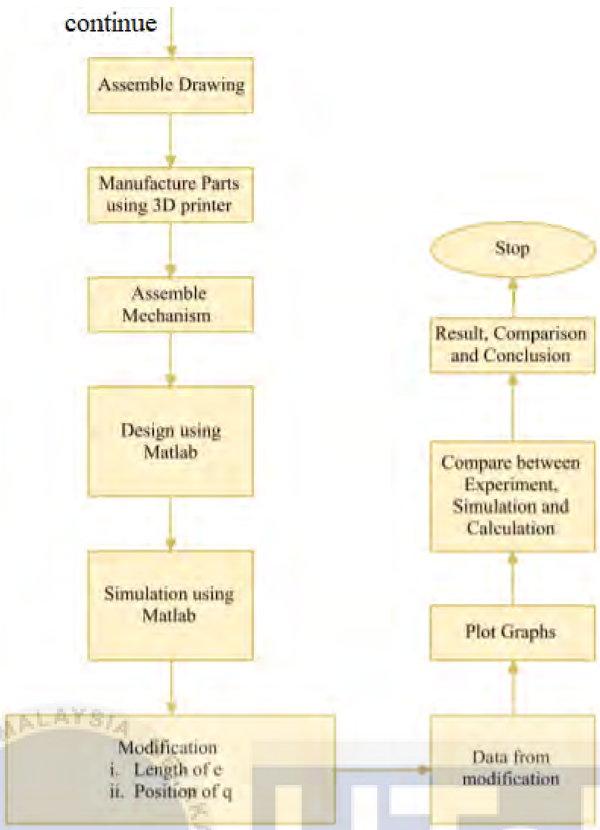


Figure 3. 2: Flow Charts.

In this project, before the framework, there must be a design as a reference. The drawing for the crawler robot base on Klann Prototype A which can be seen in appendix or chapter two. The crawler robot has been manufacture using 3D printer in parts and then assemble. It is working fine and since it is operational, the crawler robot will be the base design for the framework in Matlab.

The design will base on the measurement and parameter of the working model. After the design and simulation of the Klann mechanism is done, alternation and modification must be able to done easily by just changing the value. The changes that are focus are the lengh of e, which is link_1 and position of q, which is pin_2_y. The x step and y step is obatain through the walking curve and result is recorded, analysed and discussed.

3.3 Framework for Klann Mechanism using Matlab

In this project, Matlab is used in designing, simulating and analysing in order to obtain the walking curve of the designed Klann Mechanism. By using Matlab software, we were able to design, simulate or analyse the movement of a multibody mechanical system using methods such as Formulation, Programing and Applications. This means that the framework for Klann can be design, simulate and analyse using the concept of multibody mechanical systems [36].

The multibody mechanical systems can range from the very simple to the very complex system. Example of simple system are a moving pendulum and slider crank mechanism. Examples of Complex systems are suspension and steering systems of an automobile, a bicycle or various type exercise machines as long there are mechanical parts. In this project, the multibody mechanical system that need to plot was a Klann Mechanism, which a working model has be produced, the Klann Prototype A.

3.3.1 Design and Simulation

Since a working crawler robot based on Klann mechanism had been produced and it was able to function properly, the design for the framework of Klann mechanism will based on the working model, Klann Prototype A which is show in Chapter 2. The following are methods to design and simulate the Klann Mechanism.

i. Identified the parameters and measurement of the Designed Klann mechanism.
ii. Formulation, Programming and Application of Klann Mechanism using Matlab.

3.3.1.1 Identified the parameters and measurement for Klann Prototype A.

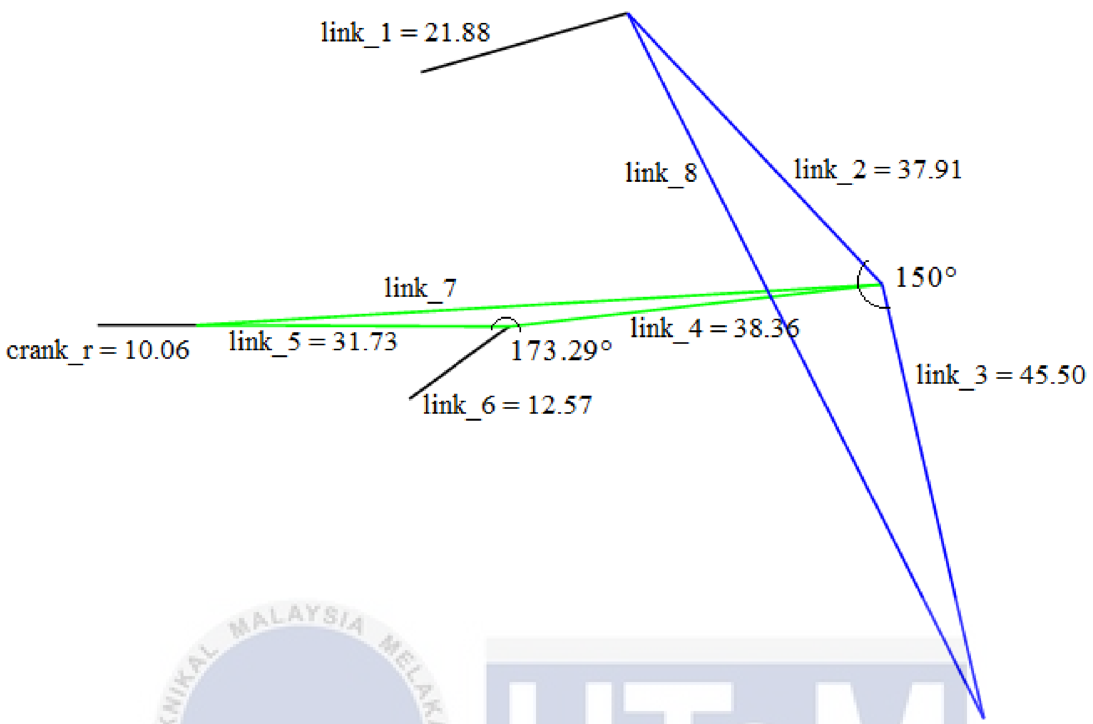


Figure 3. 3: Length of Links and Angles for Klann Prototype A.

The measurements and parameters of the mechanism were obtained through the drawings of Solidwork which are at the appendix. The radius of cranks and length of the links were obtained too. All these data are shown in Figure 3.3 and Table 3.1.

Table 3. 1: Measurements of links for Klann Prototype A.

Type of Mechanisms	Symbols	Measurement (mm)
Radius of Crank	crank_r	10.06
Link 1	link_1	21.88
Link 2	link_2	37.91
Link 3	link_3	45.50
Link 4	link_4	38.36
Link 5	link_5	31.75
Link 6	link_6	12.57

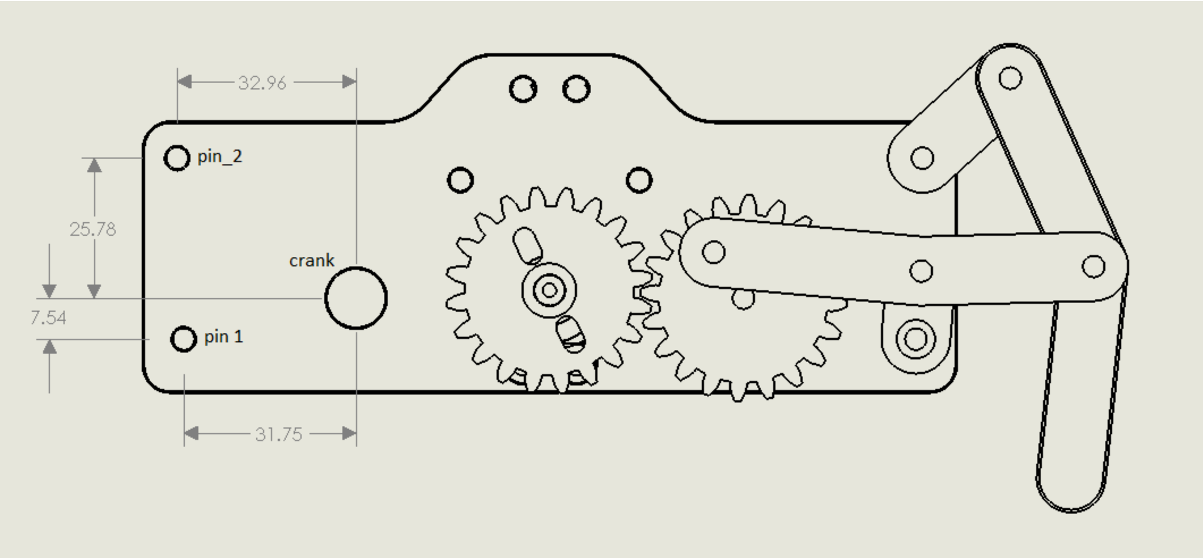


Figure 3. 4: Measurement for crank and pinned joints for Klann Prototype A.

The position of crank, the position of joints being pinned and dynamics joints were labelled. For the position of cranks and pinned joints, they were identified through the drawing, "Linkage Fame" which is in appendix and can be seen in Figure 3.4.

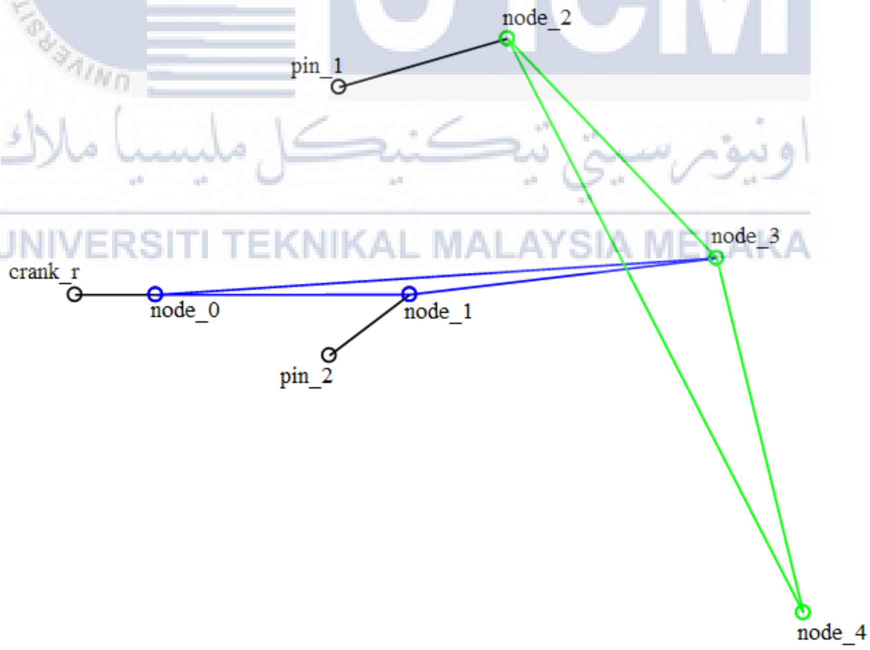


Figure 3. 5: Coordinates for Crank, Pinned Joints, Joints Klann Prototype A.

Since Matlab were use, the position of the crank, pinned joints and joints (being declare as node in Matlab) must be declare as coordinates. Figure 3.5 and Table 3.2 show all the coordinates. Since the coordinates of joints are not yet known, they will first be declared as node_(number)_x and node_(number)_y. The coordinates are shown in Table 3.2.

Table 3. 2: Position for Crank and Pinned Joints for Klann Prototype A.

Type of Mechanisms	Symbols	Coordinates (x,y)
Cranks	crank	(0, 0)
Pinned Joint 1	pin_1	(31.75, -7.54)
Pinned Joint 2	pin_2	(32.96, 25.78)
Joint 0	node_0	(node_0_x, node_0_y)
Joint 1	node_1	(node_1_x, node_1_y)
Joint 2	node_2	(node_2_x, node_2_y)
Joint 3	node_3	(node_3_x, node_3_y)
Joint 4	node_4	(node_4_x, node_4_y)

3.3.1.2 Formulation for Klann Mechanism

Step 1: Understanding the concept.

i. Vector

Vectors possess a line of action with a direction, and a magnitude. [36]

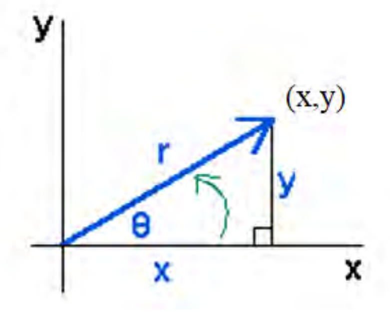


Figure 3. 6: Vector **r**.

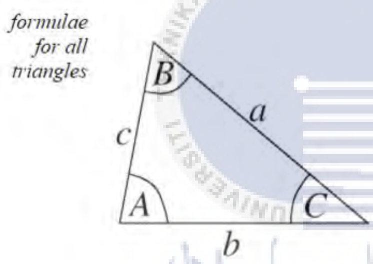
Figure 3.6 it shows an example of vector, that is **r**. By using vector **r**, the coordinate of (x,y) can be determine by resolving r into Cartesian components r_x and r_y along the x and y axes. If angle of **r** with respect to the x-axis is θ, the components of vector are computed as

$$\begin{Bmatrix} x \\ y \end{Bmatrix} = \begin{Bmatrix} r_x \\ r_y \end{Bmatrix} = \begin{Bmatrix} r\cos\theta \\ r\sin\theta \end{Bmatrix} \tag{3.1}$$

Since we already had a design for Klann Prototype A and all the parameters had been identified, by using the concept of Cartesian component, the position of nodes for Klann mechanism can be declare in simulation software, Matlab. The position of nodes can be referred at Figure 3.5.

ii. Formulae for Triangle

Since Klann mechanism design made out of two triangles, therefore formulae for triangle is used.



Sine Rule

$$\frac{a}{sin(A)} = \frac{b}{sin(B)} = \frac{c}{sin(C)} \quad \text{or} \quad \frac{sin(A)}{a} = \frac{sin(B)}{b} = \frac{sin(C)}{c}$$

Cosine Rule

$$a^2 = b^2 + c^2 - 2\,bc\,cos(A) \quad \text{or} \quad cos(A) = \frac{b^2+c^2-a^2}{2bc}$$

(for finding sides) (for finding angle)

Figure 3. 7: Formulae for Triangle.

From figure 3.3 and 3.5, Kalnn mechanism are made out of two triangles the green and the blue. Therefore, the formulae for triangle are need specially to find length and angle for the triangular part of the Klann mechanism. The formulae are shown in figure 3.7.

Step 2: Declare all the length of links, radius of crank, coordinate of crank and pinned joints.

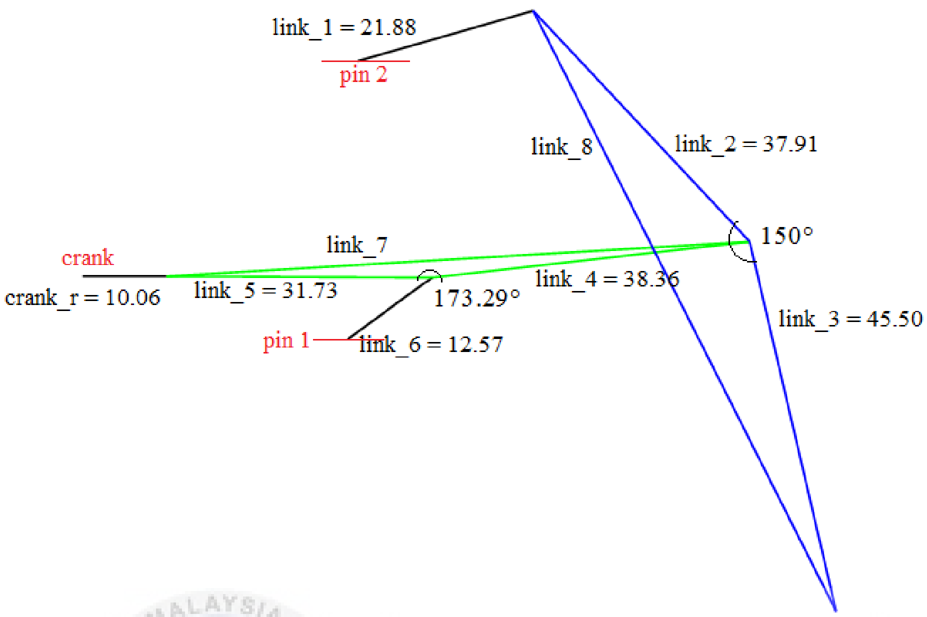


Figure 3. 8: Klann mechanism with the measurement of links and position of fixed joints.

In previous, all the parameters and measurement for the designed Klann Mechanism is obtained and the information can be seen in Figure 3.8. In addition, from Figure 3.8, we were able to see the location for the crank, pin 1 and pin 2. The following parameter are declared in Matlab.

Step 3: Calculate the position for 4 bar linkage mechanism include crank, link 5 and link 6.

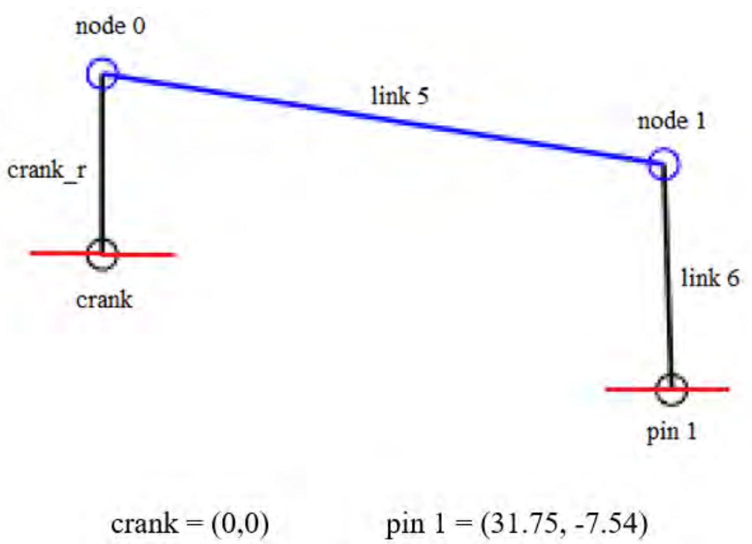


Figure 3. 9: The 4 bar linkage mechanism include crank, link 5 and link 6.

In order to know the position of nodes, figure 3.5 can be use as reference. First, the coordinate for node 0 and node 1 are declared using the formulae below.

$$\begin{bmatrix} \text{node}_{0_x} \\ \text{node}_{0_y} \end{bmatrix} = \begin{bmatrix} \text{crank\_x} \\ \text{crank\_y} \end{bmatrix} + \begin{bmatrix} \text{crank\_r}\cos(angle\ at\ crank) \\ \text{crank\_r}\sin(angle\ at\ crank) \end{bmatrix} \tag{3.1}$$

$$\begin{bmatrix} \text{node}_{1_x} \\ \text{node}_{1_y} \end{bmatrix} = \begin{bmatrix} \text{pin}_{1_x} \\ \text{pin}_{1_y} \end{bmatrix} + \begin{bmatrix} \text{link}_6 \cos(angle\ at\ \text{pin}_1) \\ \text{link}_6\ \sin(angle\ at\ \text{pin}_1) \end{bmatrix} \tag{3.2}$$

Next node 0 is simulated to move in a circular motion while node 1 movement will depend on the position of node 0. Line connecting all points are plotted and simulation is done.

Step 4: Calculate the coordinate for node 3.

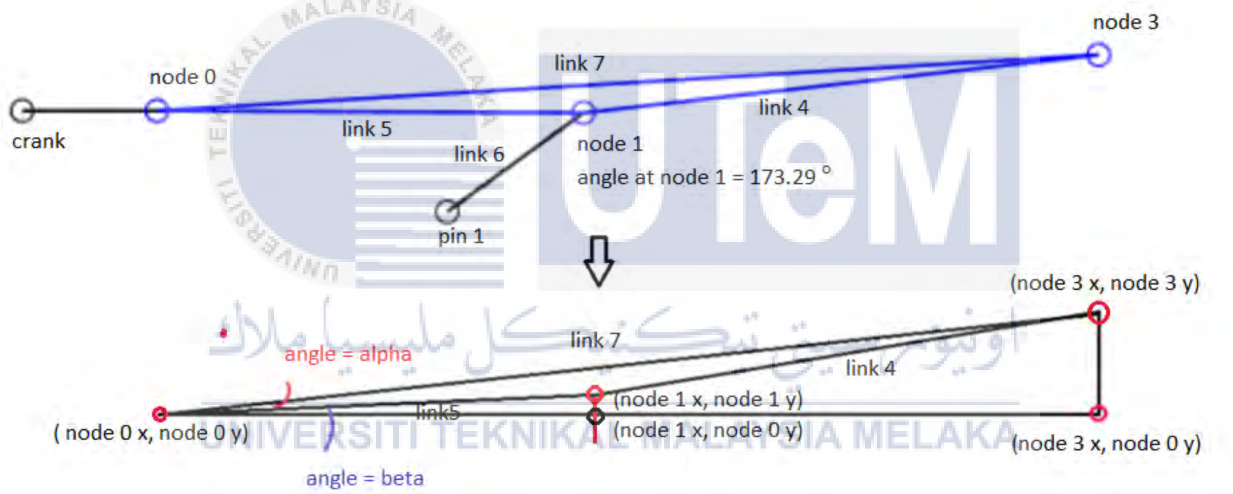


Figure 3. 10: Sketch to determine coordinate of node 3.

First, a sketch of part 3 design with node 3 is drawn where the crank is position at 0° which is shown in Figure 3.10. Next, the angle for alpha and beta are found using the Triangle sine rule which is shown in Equation 3.3 and 3.4.

$$\frac{\text{link}_4}{\sin alpha} = \frac{\text{link}_7}{\sin 173.29°} \tag{3.3}$$

$$\frac{\text{node}_{1_y} - \text{node}_{0_y}}{\sin beta} = \frac{\text{link}_5}{\sin 90°} \tag{3.4}$$

The length of link 7 is found using the triangle cosine rule which is show in equation

$$link_7{}^2 = (link_5{}^2 + link_4{}^2 - (2)(link_5)(link_4)\cos(173.29°)) \quad (3.5)$$

Then, based on the concept of vectors, the coordinate of node 3 is found. The equation is shown in Equation 3.6.

$$\begin{bmatrix} node_{3_x} \\ node_{3_y} \end{bmatrix} = \begin{bmatrix} node_{0_x} \\ node_{0_y} \end{bmatrix} + \begin{bmatrix} link_7 \cos(alpha + beta) \\ link_7 \ \sin(alpha + beta) \end{bmatrix} \quad (3.6)$$

Step 5: Declare the connecting triangle, node 0, node 1 and node 3 into a rigid body.

The triangle on the 4 bar, triangle node 0, node 1 and node 3 is declared as rigid body. First, using the concept of secondary point base on Point Coordinate: Kinematics [36] the values of alpha3 and beta3 are found, the equations are stated below.

$$alpha3 = \frac{1}{link\ 5}\left[\begin{pmatrix} node_{1_x} \\ node_{1_y} \end{pmatrix} - \begin{pmatrix} node_{0_x} \\ node_{0_y} \end{pmatrix}\right]^T \left[\begin{pmatrix} node_{3_x} \\ node_{3_y} \end{pmatrix} - \begin{pmatrix} node_{0_x} \\ node_{0_y} \end{pmatrix}\right] \quad (3.7)$$

$$beta3 = \frac{1}{link\ 5}\left[\begin{pmatrix} -node_{1_y} \\ node_{1_x} \end{pmatrix} - \begin{pmatrix} -node_{0_y} \\ node_{0_x} \end{pmatrix}\right]^T \left[\begin{pmatrix} node_{3_x} \\ node_{3_y} \end{pmatrix} - \begin{pmatrix} node_{0_x} \\ node_{0_y} \end{pmatrix}\right] \quad (3.8)$$

Next, node 3 as rigid body is declared and the equation is shown below.

$$node_{3_x} = 1 - \frac{alpha3}{link_5}\left(node_{0_x}\right) + \frac{alpha3}{link_5}\left(node_{1_x}\right) + \frac{beta3}{link_5}\left(-node_{1_y} + node_{0_y}\right) \quad (3.9)$$

$$node_{3_y} = 1 - \frac{alpha3}{link_5}\left(node_{0_y}\right) + \frac{alpha3}{link_5}\left(node_{1_y}\right) + \frac{beta3}{link_5}\left(node_{1_x} - node_{0_x}\right) \quad (3.10)$$

Step 6: Calculate the position for 4 bar linkage mechanism include link 1, link 2 and link 4

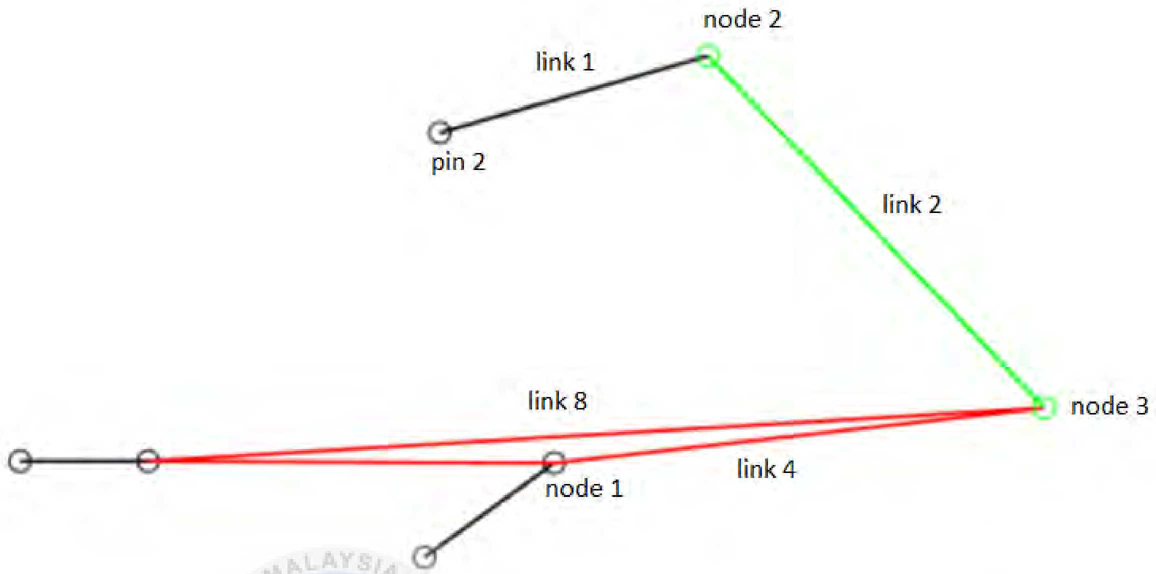


Figure 3. 11: The 4 bar linkage mechanism include link 1, link 2 and link 4.

First, the coordinate for node 2 is declared using the formula below.

$$\begin{bmatrix} node_{2_x} \\ node_{2_y} \end{bmatrix} = \begin{bmatrix} pin_{1_x} \\ pin_{1_y} \end{bmatrix} + \begin{bmatrix} link_1 \cos(angle\ at\ pin_2) \\ link_1\ \sin(angle\ at\ pin_2) \end{bmatrix} \quad (3.11)$$

Next the movement of node 2 is simulate to depend on the position of node 3. Line connecting all points are plotted and simulation is done.

Step 7: Calculate the coordinate for node 4.

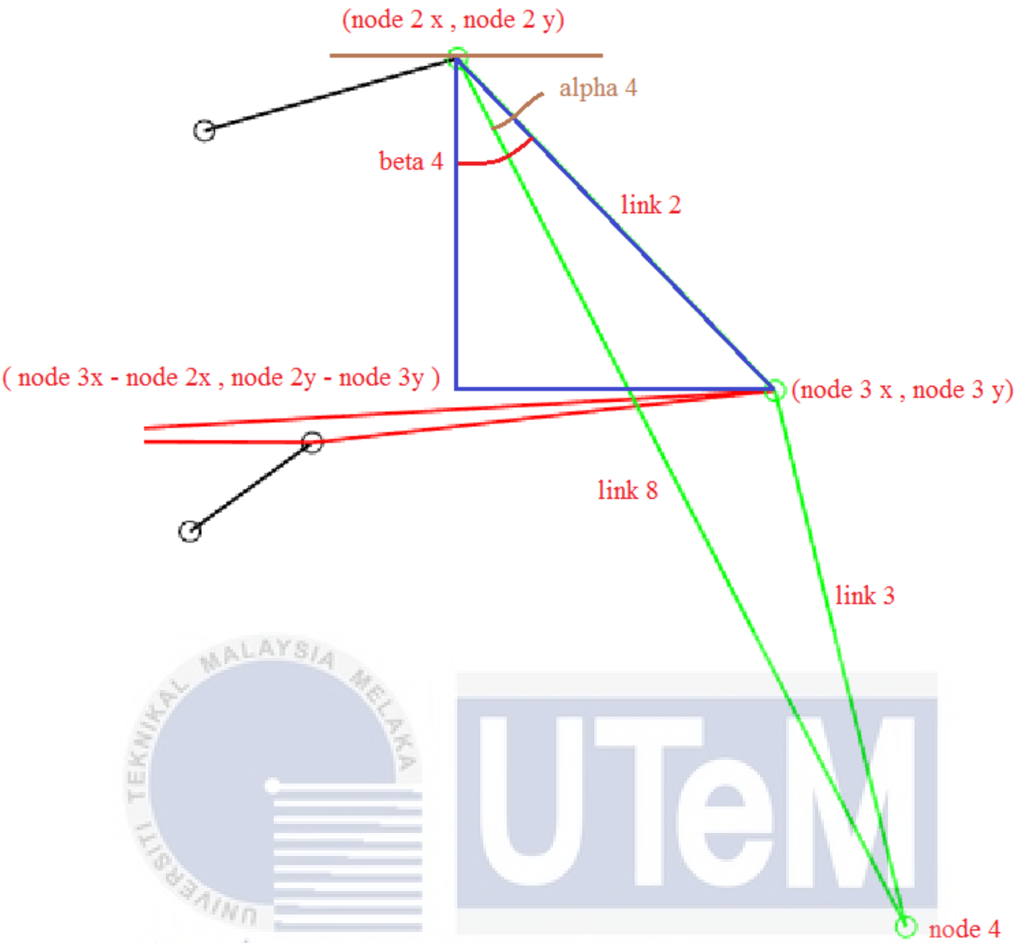


Figure 3. 12: Sketch to determine coordinate of node 4.

First, a sketch of Klann mechanism is drawn where the crank is positioned at 0°. Next, the angle for alpha 4 and beta 4 were found using the Triangle sine rule which is shown in Equation 3.12 and 3.13.

$$\frac{\text{link}_3}{\sin alpha4} = \frac{\text{link}_8}{\sin 150°} \tag{3.12}$$

$$\frac{\text{node}_{3_x} - \text{node}_{2_x}}{\sin beta\ 4} = \frac{\text{link}_2}{\sin 90°} \tag{3.13}$$

Then using both alpha 4 and beta 4, the value of angle 8 is found which is shown in equation 3.14.

Angle 8 = (270 + beta 4 – alpha 4) (3.14)

The length of link 8 is found using the triangle cosine rule which is show in equation

$$link_8^2 = link_2^2 + link_3^2 - (2)(link_2)(link_3)\cos(150°) \tag{3.15}$$

After that, with the concept of vectors, the coordinate of node 3 is found. The equation is shown in Equation 3.6.

$$\begin{bmatrix} node_{4_x} \\ node_{4_y} \end{bmatrix} = \begin{bmatrix} node_{2_x} \\ node_{2_y} \end{bmatrix} + \begin{bmatrix} link_8 \cos(angle\ 8) \\ link_8 \sin(angle\ 8) \end{bmatrix} \tag{3.16}$$

Step 8: Declare the connecting triangle, node 2, node 3 and node 4 into a rigid body.

The triangle on the 4 bar, triangle node 2, node 3 and node 4 is declared as rigid body. First, using the concept of secondary point base on Point Coordinate: Kinematics [36] the values of alpha5 and beta5 are found, the equations are stated below

$$alpha5 = \frac{1}{link\ 2}\left[\begin{pmatrix} node_{3_x} \\ node_{3_y} \end{pmatrix} - \begin{pmatrix} node_2 \\ node_{2_y} \end{pmatrix}\right]^T \left[\begin{pmatrix} node_{4_x} \\ node_{4_y} \end{pmatrix} - \begin{pmatrix} node_{2_x} \\ node_{2_y} \end{pmatrix}\right] \tag{3.17}$$

$$beta5 = \frac{1}{link\ 2}\left[\begin{pmatrix} -node_{3_y} \\ node_{3_x} \end{pmatrix} - \begin{pmatrix} -node_{2_y} \\ node_{2_x} \end{pmatrix}\right]^T \left[\begin{pmatrix} node_{4_x} \\ node_{4_y} \end{pmatrix} - \begin{pmatrix} node_2 \\ node_2 \end{pmatrix}\right] \tag{3.18}$$

Next, node 4 as rigid body is declared and the equation is shown below.

$$node_{4_x} = 1 - \frac{alpha5}{link_2}\left(node_{2_x}\right) + \frac{alpha5}{link_2}\left(node_{3_x}\right) + \frac{beta5}{link_2}\left(-node_{3_y} + node_{2_y}\right) \tag{3.19}$$

$$node_{4_y} = 1 - \frac{alpha5}{link_2}\left(node_{2_y}\right) + \frac{alpha5}{link_2}\left(node_{3_y}\right) + \frac{beta5}{link_2}\left(node_{3_x} - node_{2_x}\right) \tag{3.20}$$

The walking curve at node 4 is simulate and plotted. The data is use to analyse x step and y step.

3.3.2 Analysis

The walking curve is obtained by simulation in Matlab software. The walking curve is obtained and find x step and y step. The alteration is done both on link_1 and pin_2_y by adding or reducing the value by 1. Alteration is done until it reached it limitation and the limitation is reached when the case below happens.

i. Drastic changes in the shape of the Klann mechanism
ii. The value for the angle for leg = $150^\circ \pm 1^\circ$.
iii. The value for the angle of powerlink = $173.29^\circ \pm 1^\circ$

3.3.2.1 Changes in Length of link_1 and Position of pin_2_y

The following is the procedure to get analysis for alternation in link_1 and pin_2_y.

1. The simulation on the Klann mechanism is ran.
2. The x maximum of walking curve is determined.
3. The x minimum of walking curve is determined.
4. The x step of walking curve is determined.
5. Step 2 to 4 are repeated to obtained y step.
6. The value of link_1 is added by 1.
7. The simulation on alternation is ran.
8. The x step and y step of walking curve is obtained by repeating step 2 to 5.
9. Step 6 to 8 are repeated until limitation is reach.
10. From the reference value of link_1 the value of link_1 is reduced.
11. Step 7 to 8 is repeated until limitation is reached.
12. The data is recorded.
13. Step 1 to 12 is repeated for Position of pin_2_y.

By following the procedure above, the data that are recorded are then tabulated. Then the data is plotted into graphs and analysis is done.

CHAPTER 4

RESULT AND DISCUSSION

4.1. Simulation Result and Discussion using Matlab

The simulation of framework is also the result for the project. Below are the simulations of the Klann mechanism framework.

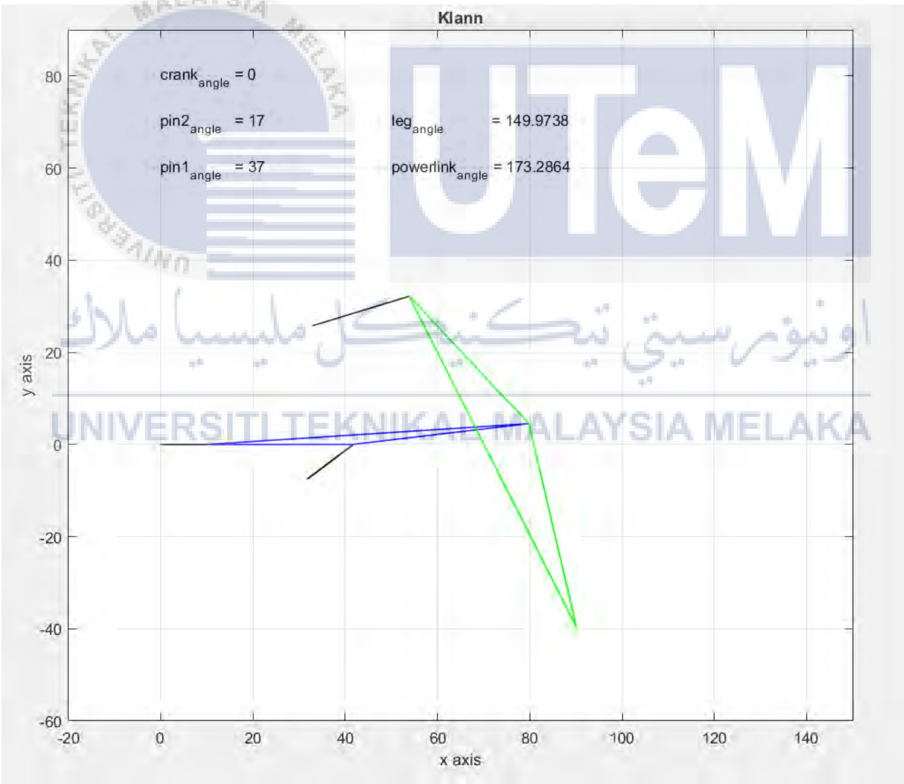


Figure 4. 1: Klann mechanism when crank at 0°.

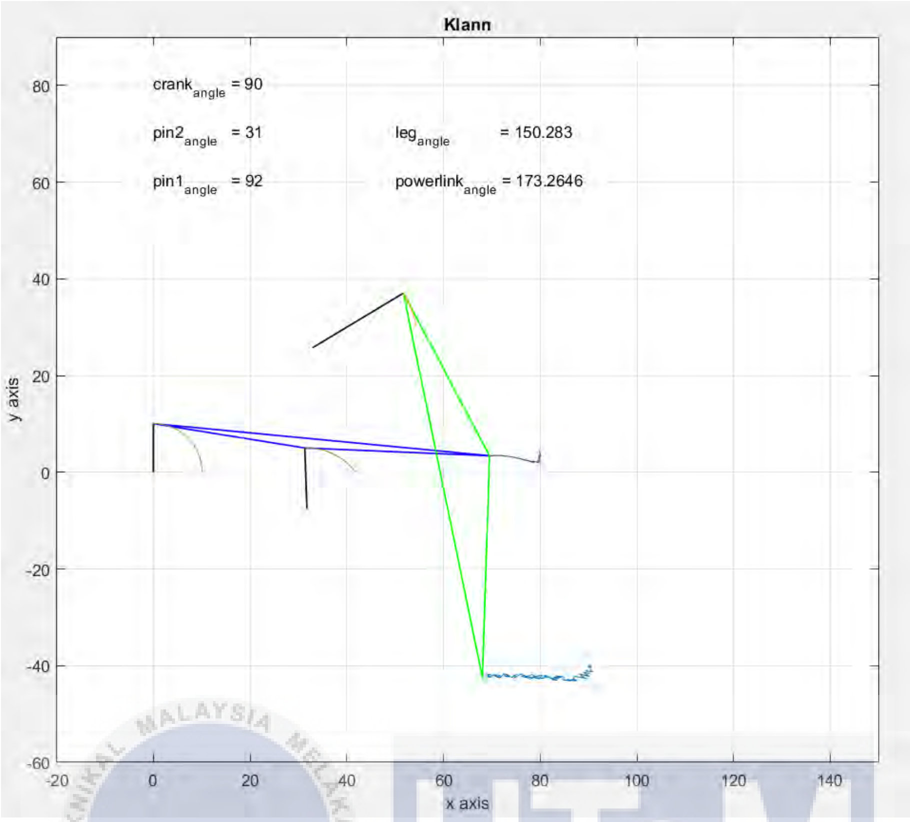


Figure 4. 2: Klann mechanism when crank at 90°.

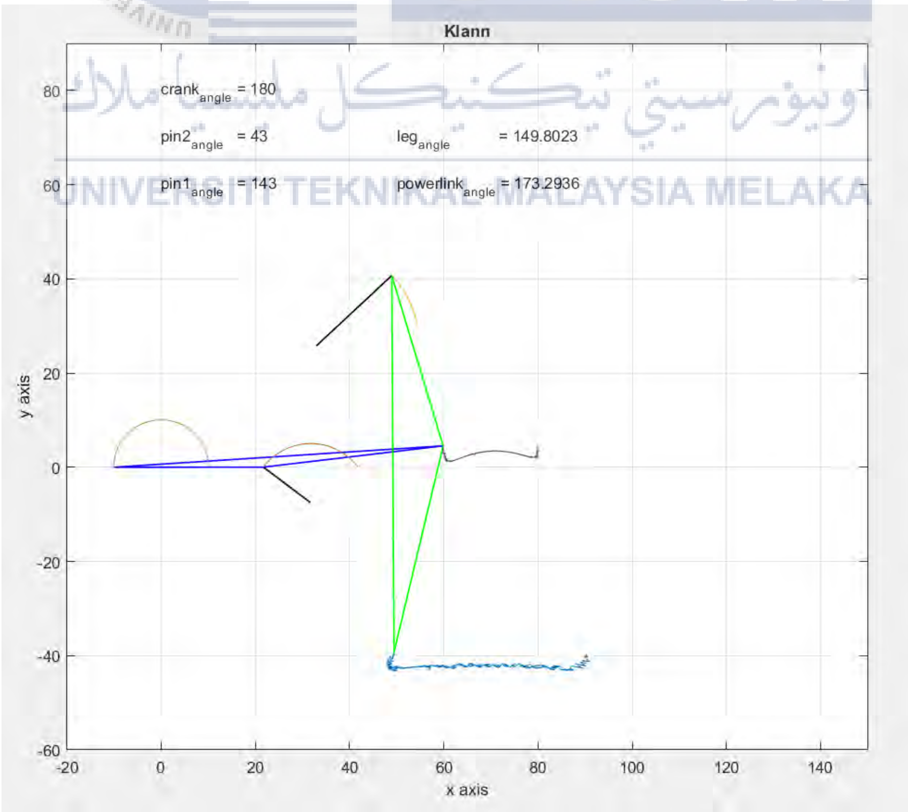


Figure 4. 3: Klann mechanism when crank at 180°.

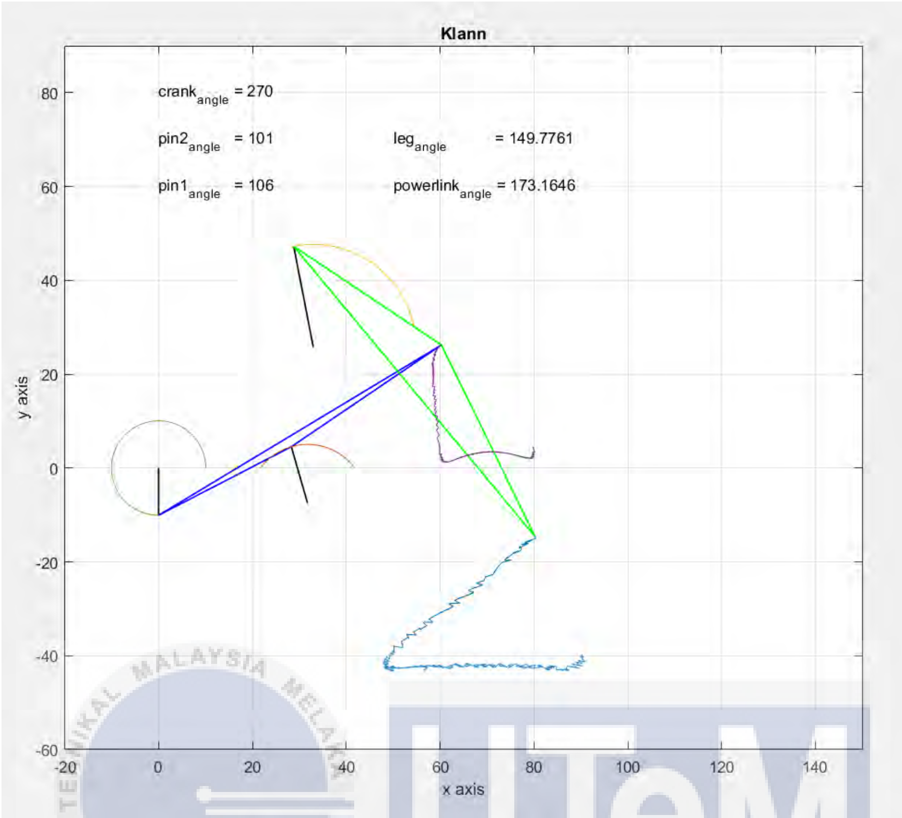


Figure 4. 4: Klann mechanism when crank at 270°.

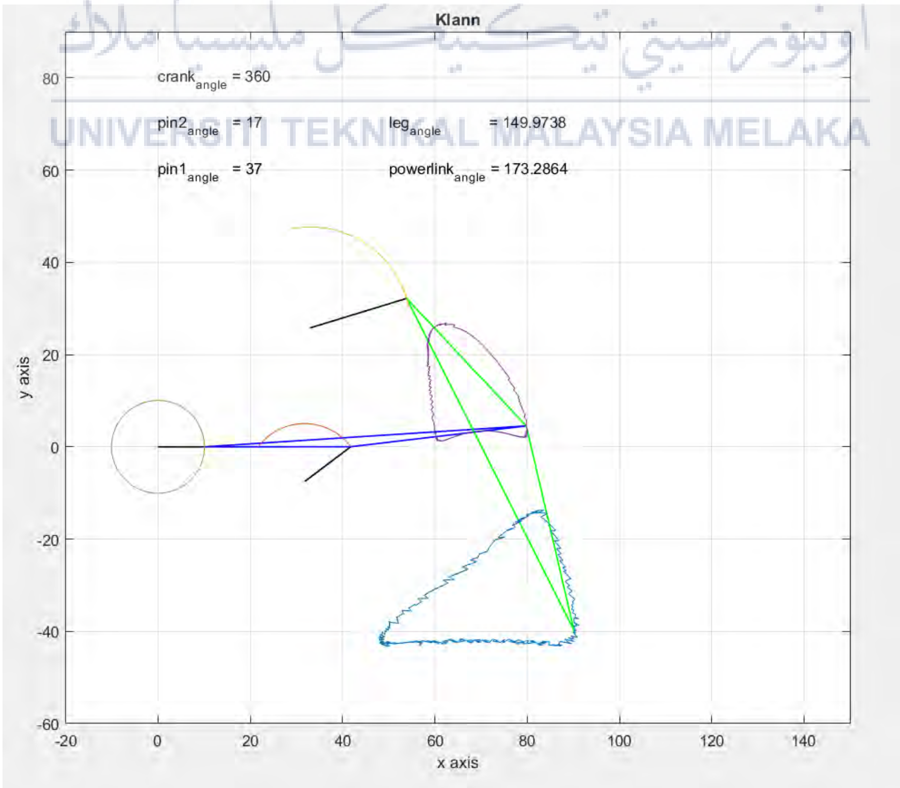


Figure 4. 5: Klann mechanism when crank at 360°.

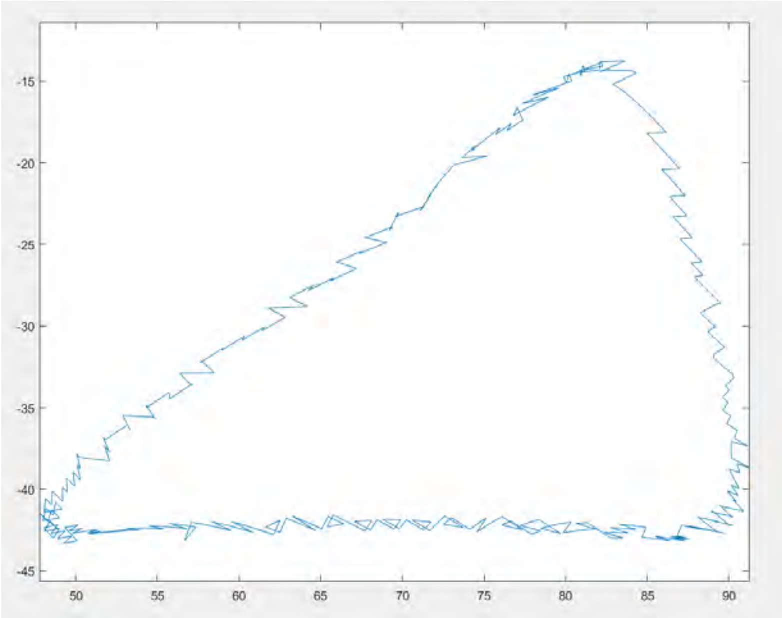


Figure 4. 6: Walking curve for Klann mechansim.

The simulation of the Klann mechanism is shown from figure 4.1 to 4.6 where figure 4.1 to 4.5 show the simulation of the mechanism when the crank rotates from 0° to 360°. While for figure 4.6 showed the walking curve of the mechanism. Form figure 4.6, x step and y step are obtained by determine the value of maximum and minimum for both x and y axis.

4.2 Effect of mechanism towards walking curve

By constructing the Klann mechanism using the software Matlab, the walking curve can be obtained. Next, through the walking curve that being plotted, the x-step and y-step can be obtained using Matlab. These are done by determining the maximum value and minimum value for both x and y axis using Matlab. After receiving these information, the following are the equations to determine the value of x-step and y-step.

x-step = x maximum – x minimum (4.1)

y-step = y maximum – y minimum (4.2)

To determine the limitation of the mechanism, angles at the leg and powerlink are display. When angles display do not show the required value, meaning the mechanism is facing failure and that last alternation is the limitation for the mechanism. In addition, the value of t = 1° meaning that the crank rotates by adding 1° each time.

4.2.1 Effect of Length of link_1 towards walking curve

After changes is done on link_1, the data are record and are shown in the table below.

Table 4. 1: Result of x step and y step for alteration of length of link 1.

Length of Link 1 (mm)	x max (mm)	x min (mm)	x-step (mm)	y max (mm)	y min (mm)	y-step (mm)
16.8800	98.6451	54.0587	44.5864	-9.4208	-44.4344	35.0136
17.8800	96.6122	52.8755	43.7367	-10.3086	44.1699	33.8613
18.8800	95.0936	51.6735	43.4210	-11.2788	-44.0759	32.7971
19.8800	93.7053	50.4559	43.2494	-12.2361	-43.7394	31.5033
20.8800	92.0643	49.2259	42.8384	-12.9972	-43.4393	30.4421
21.8800	**91.2480**	**47.7886**	**43.4594**	**-13.7376**	**-43.3157**	**29.5781**
22.8800	89.9501	46.5757	43.3744	-14.4492	-43.2931	28.8439
23.8800	88.7405	45.3685	43.3720	-15.0563	-43.5285	28.4722
24.8800	87.0710	44.1848	44.2882	-15.5786	-43.7283	28.1497
25.8800	86.2977	42.9652	43.3325	-16.1437	-43.5918	27.4481
26.8800	84.6502	41.7450	42.9052	-16.4905	-43.8896	27.3991
27.8800	83.5917	40.5153	43.0764	-17.0201	-44.0571	27.0370
28.8800	82.5968	39.2878	43.3090	-17.3253	-43.9615	26.6362
29.8800	81.4146	38.0711	43.3435	-17.5578	-44.2309	26.6731
30.8800	80.0223	36.8667	43.1556	-17.9628	-43.9567	25.9939
31.8800	78.7430	35.6762	43.0668	-17.9423	-44.0027	26.0604
32.8800	77.4799	34.5007	42.9793	-18.3728	-43.8740	25.5013
33.8800	76.2156	33.3411	42.8745	-18.2922	-43.7501	25.4580
34.8800	75.0366	32.1778	42.8588	-18.5767	-43.4505	24.8739
35.8800	73.9062	31.0243	42.8819	-18.2103	-43.2172	25.0069
36.8800	72.7883	29.8821	42.9062	-18.0935	-43.0044	24.9108
37.8800	71.6741	28.7512	42.9229	-17.9754	-42.8628	24.8874
38.8800	70.4377	27.6311	42.8066	-17.7134	-42.7780	25.0645
39.8800	69.0147	26.5213	42.4934	-17.5304	-42.5114	24.9810

40.8800	67.9227	25.4210	42.5017	-17.1609	-41.8587	24.6979
41.8800	66.8030	24.3290	42.4740	-16.5285	-41.6791	25.1506
42.8800	65.5840	23.2441	42.3400	-15.8856	-41.5008	25.6152
43.8800	64.3857	22.6012	41.7845	-15.1060	-40.8526	25.7466
44.8800	63.2251	21.4863	41.7388	-14.0803	-39.9831	25.9028
45.8800	62.0858	20.6927	41.3931	-12.9499	-39.5688	26.6189
46.8800	61.0201	19.6348	41.3853	-11.3475	-39.7203	28.3727
47.8800	59.9138	18.7389	41.1748	-9.6763	-38.9943	29.3180
48.8800	58.6194	18.1304	40.4890	-8.0100	-38.3496	30.3396
49.8800	57.5994	17.3124	40.2870	-6.1905	-37.9714	31.7810
50.8800	56.5472	16.5050	40.0423	-4.2934	-37.3305	33.0372

4.2.1.1 Graph of Length of link_1 against x step

From data in table 4.1, more specific the x step, a graph is plotted and analysed.

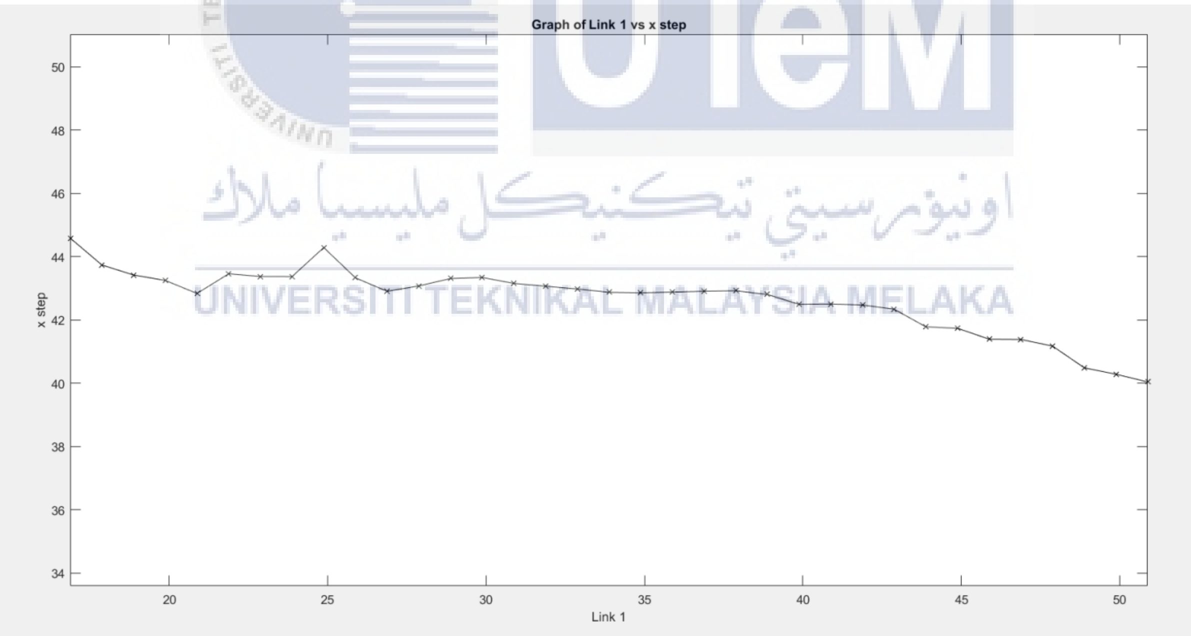


Figure 4. 7: Graph of Length of link_1 against x step.

From table 4.1 data, a graph is plotted to determine the effect on link_1 against the x step. From the graph the length of link 1 do not show a clear effect toward x-step. The maximum x step obtain is 44.5864mm, at length of link 1 =16.88mm and minimum x step is 40.0423 mm, at length of link 1 = 50.88mm The different from both these value is just 4.5441 mm. In addition, the graph does not how any clear sign of increment or decrement, it just shows an average value of 4mm for x step. The values received are more on the average x step for the Klann mechanism which is about 4mm.

4.2.1.2 Graph of Length of link_1 against y step

From data in table 4.1, more specific the y step, a graph is plotted and analysed.

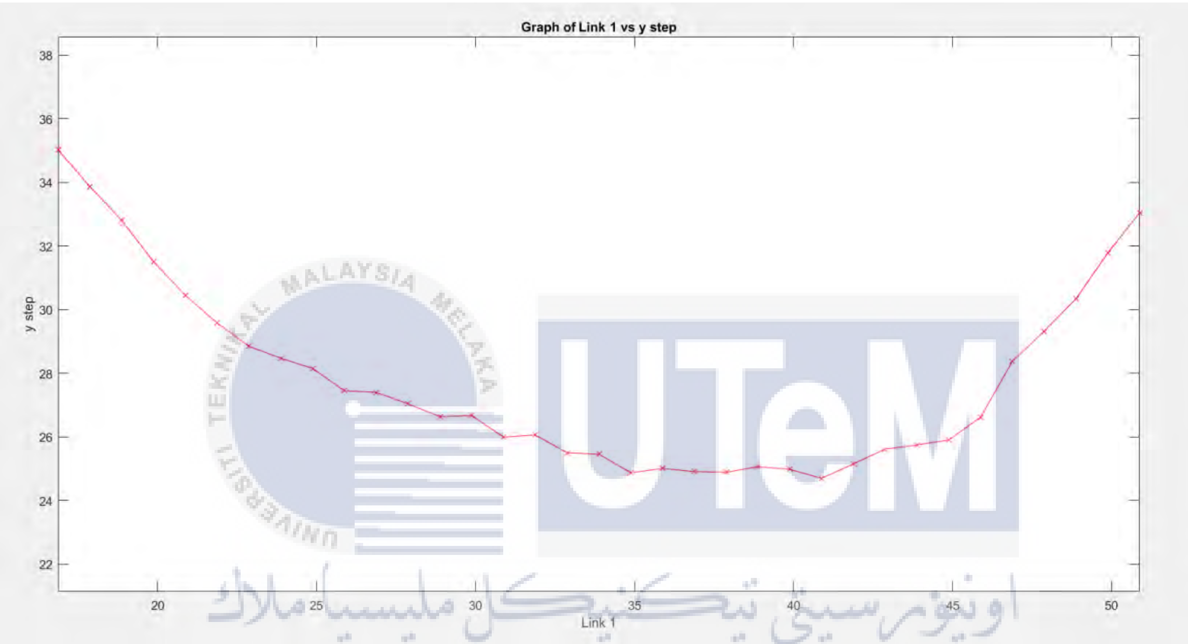


Figure 4. 8: Graph of Length of link_1 against y step.

From table 4.1 data, a graph is plotted to determine the effect on link_1 against the y step. The graph show that when link 1 increase, y step decreases. This happen from length of link 1 of 16.88mm to 34.88mm. Then, when link_1 increase, y step increases which is when length of link 1 from 40.88mm to 50.88mm. The maximum y step is 35.0136mm, at length of link 1 =16.88mm and minimum step is 24.6979 mm, at length of link_1 = 40.88mm. The different is 10.3157 mm which consider quite big to increase by 1 cm. The reason for this pattern will discuss more in transformation on working curve part.

4.2.1.3 Comparing both x step and y step for the changes in length of link_1

Both graph in figure 4.7 and 4.8 is combine to for graph below for analysis purpose where to determine whether link_1 will effect either the x step or y step.

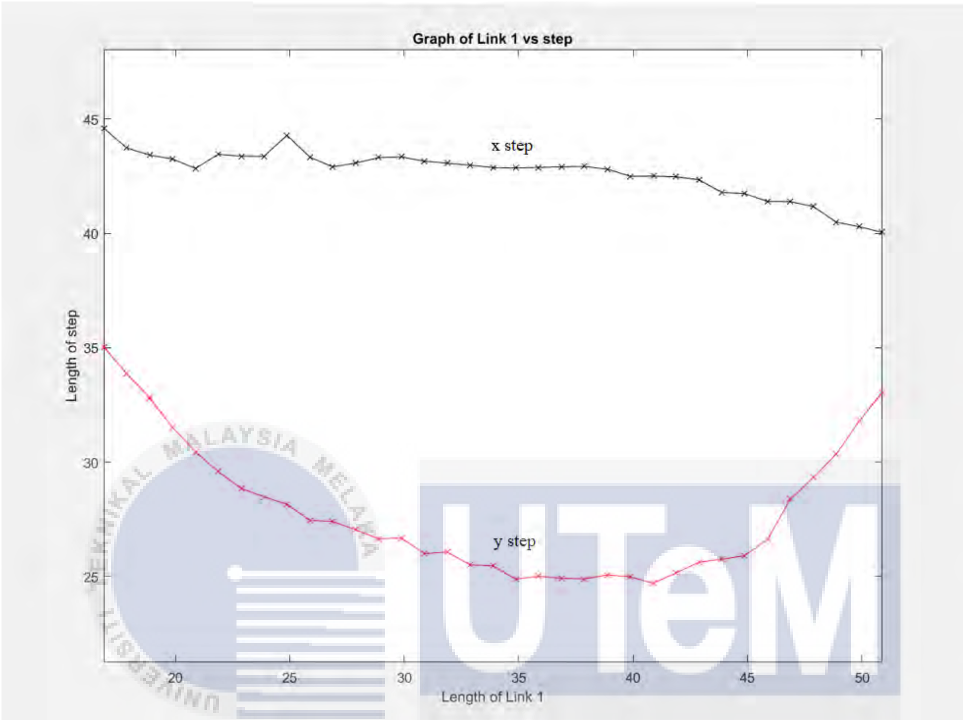


Figure 4. 9: Graph of Length of link_1 against step.

The Changes in Link 1 do not have much effect on x step by for y step, the size decreases from length of 16.88 mm to 35.88mm and increases from length of 40.88 mm to 50.88mm. from 35.88mm to 40.88mm, the y step do not show any increase or decrease.

4.2.2 Effect of Position of pin_2_y towards walking curve

After changes is done on pin_2_y, the data are record and are shown in the table below.

Table 4. 2: Result of x step and y step for alteration of position of pin_2_y.

Position of pin_2_y (mm)	x max (mm)	x min (mm)	x-step (mm)	y max (mm)	y min (mm)	y-step (mm)

16.7800	97.5520	56.6176	40.9344	-5.3163	-44.6633	39.3470
17.7800	96.5624	55.3283	41.2340	-6.4624	-44.5214	38.0589
18.7800	95.6382	54.1106	41.5276	-7.4310	-44.3499	36.9189
19.7800	95.0726	53.1713	41.9013	-8.7554	-44.2361	35.4807
20.7800	93.9777	52.0926	41.8851	-9.5331	-44.2023	34.6693
21.7800	93.3768	51.2688	42.1080	-10.4622	-43.9208	33.4586
22.7800	92.9145	50.2949	42.6195	-11.3866	-43.7427	32.3561
23.7800	92.2451	49.4563	42.7888	-12.2861	-43.7477	31.4616
24.7800	91.6678	48.5819	43.0859	-13.0354	-43.3564	30.321
25.7800	**91.2480**	**47.7886**	**43.4594**	**-13.7376**	**-43.3157**	**29.5781**
26.7800	90.6921	47.2087	43.4834	-14.4257	-43.2959	28.8702
27.7800	90.3182	46.4920	43.8262	-15.0641	-43.0242	27.9601
28.7800	90.0307	45.9441	44.0866	-15.5786	-43.2394	27.6608
29.7800	89.5376	45.3176	44.2200	-16.1463	-43.0097	26.8234
30.7800	89.7401	44.7757	44.9644	-16.4290	-43.2279	26.7989

4.2.1.1 Graph of Position of pin_2_y against x step

From data in table 4.2, more specific the x step, a graph is plotted and analysed.

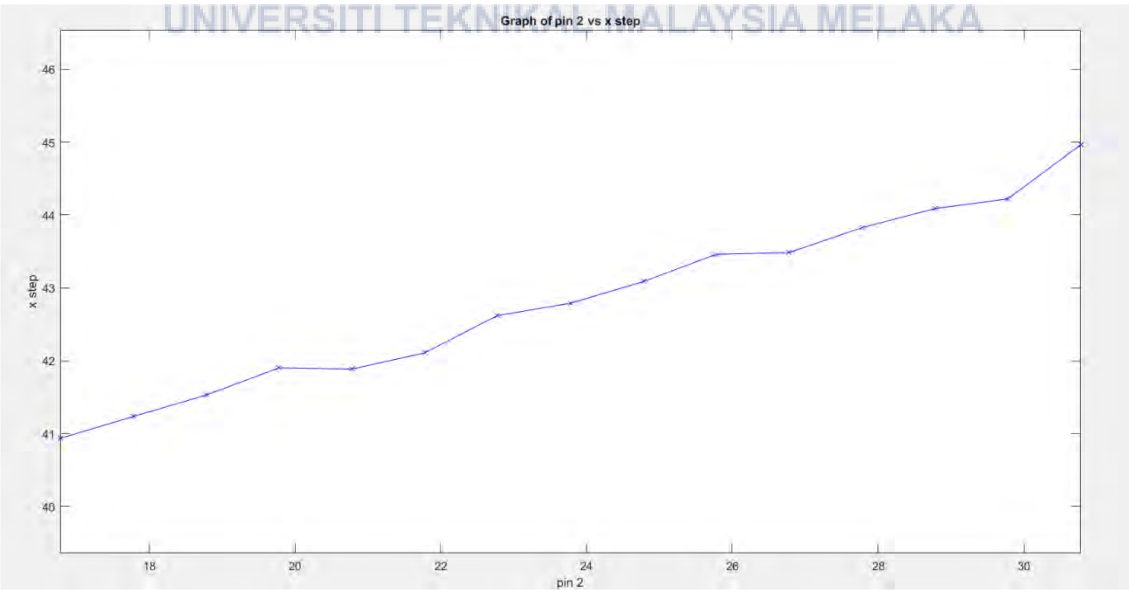


Figure 4. 10: Graph of position of pin_2_y against x step.

From table 4.2 data, a graph is plotted to determine the effect on pin_2_y against the x step. The maximum x step obtained is 40.9344mm where the position is at 16.88mm vertically. The minimum x step is 44.9644 mm where the position is at 30.88mm vertically. The different between the maximum x step and minimum x step is 4.030 mm. When position of pin 2 increase vertically, x step of walking curve increases.

4.2.1.2 Graph of Position of pin_2_y against y step

From data in table 4.2, more specific the y step, a graph is plotted and analysed.

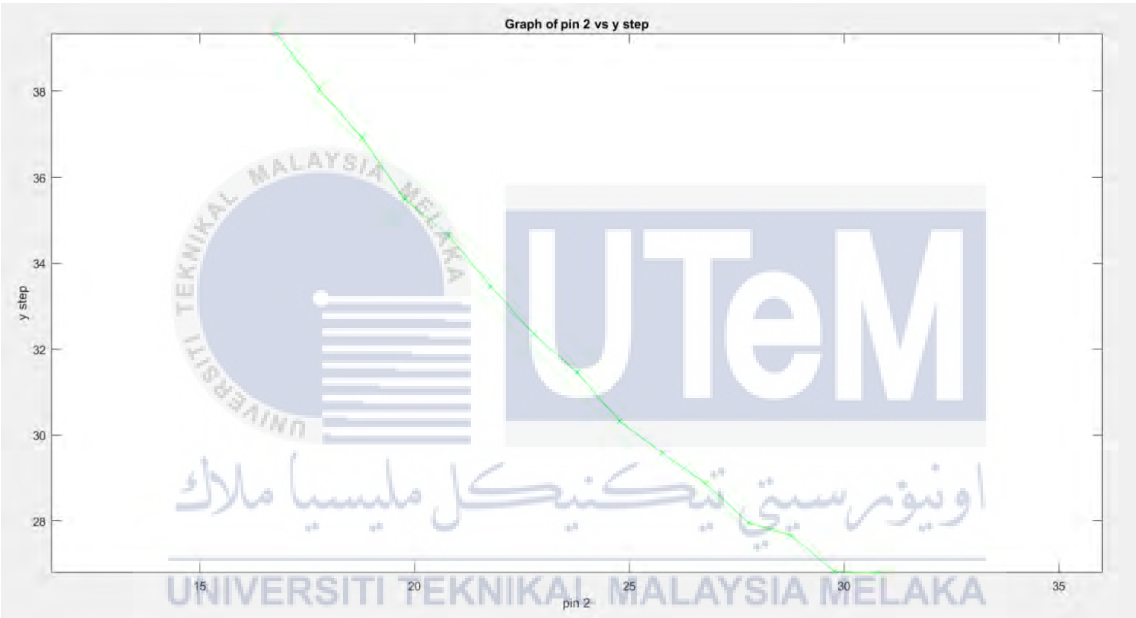


Figure 4. 11: Graph of position of pin_2_y against y step.

From table 4.2 data, a graph is plotted to determine the effect on pin_2_y against the y step. From the graph we can observe that when the position of pin 2 increases vertically, y step decreases. The maximum x step is 39.3470mm, which at the position of 16.88mm vertically. While the min x step is 26.7989 mm, at position of 30.88mm vertically. The different between maximum value and minimum value is 12.5580 mm.

4.2.1.3 Comparing both x step and y step for the changes in position of pin_2_y

Both graph in figure 4.10 and 4.11 is combine to for graph below for analysis purpose where to determine whether position of pin_2_y will effect either the x step or y step.

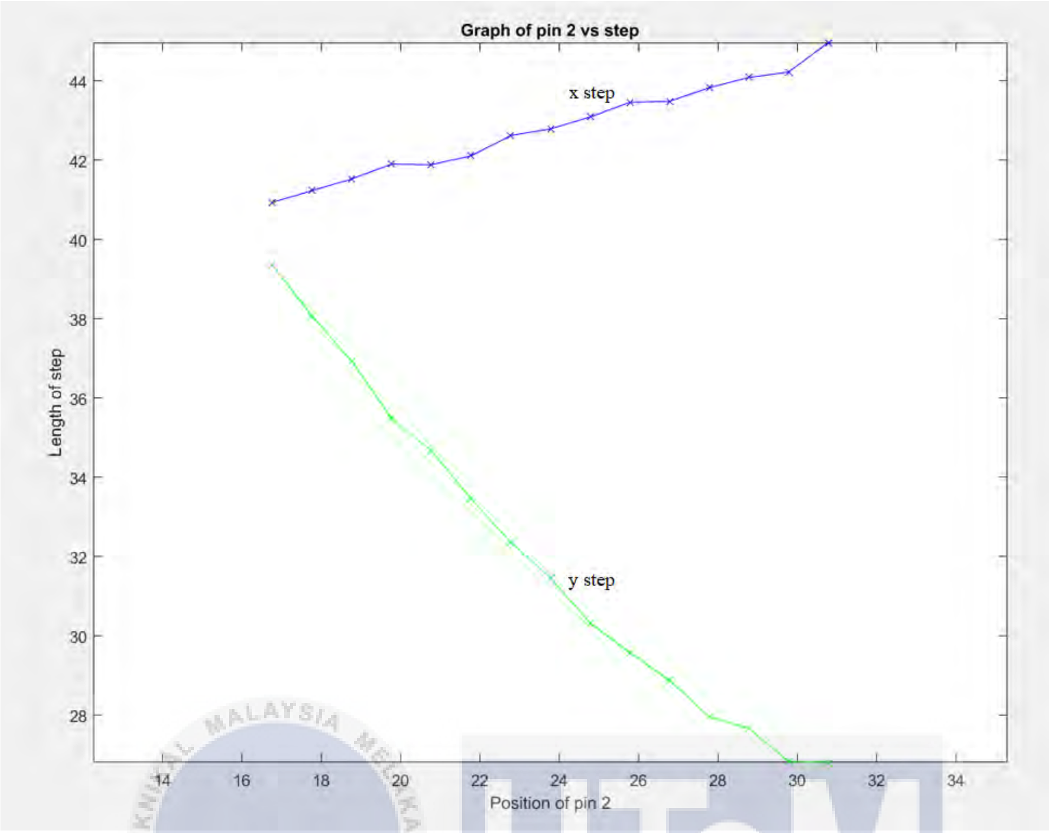


Figure 4. 12: Graph of position of pin_2_y against step.

When the position of pin_2_y increase vertically x step increase but y step will decrease. This show that by altering the position of pin_2_y vertically, the effect on x step and y step is opposite. Meaning that when x step increase, y step will decrease and if x step decrease, y step will increase.

4.3 Graph of walking curve transformation

The walking curve of Klann mechanism from it minimum limitation to maximum limitation is plot here as the graph. In here, the transformation of walking curve from the minimum limitation to the maximum limitation can be seen. In addition, the walking curve show has been filter using Matlab 'smooth' application and the span for the walking cure is 15. The coding can be seen in Appendix C.

4.3.1 Graph of walking curve transformation for link_1

A few walking curve graph is filter and then plot to see the effect of alteration at link_1.

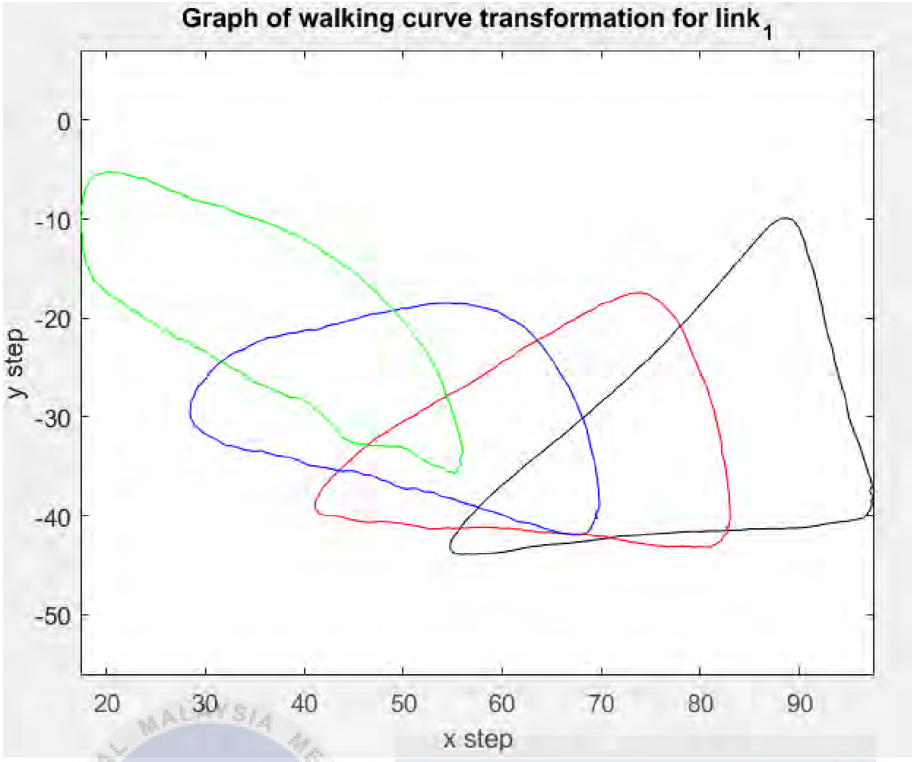


Figure 4. 13: Filtered Graph of walking curve transformation for link_1.

From figure 4.13 the following are the colors that represent the length of link_1 which is shown in table 4.3.

Table 4.3: Colours representing Length of link_1.

length of link_1 (mm)	colours
16.88	Black
27.88	Red
38.88	Blue
50.88	Green

When the length of link_1 increases the position of walking curve moves nearer to the main body and the y step decreases. In Figure 4.8, the reason y step increase at first because of the black colour walking curve which look like proper right angle triangle which give the best y step and the x step is nearer to the surface. But when the length of link_1 increases, the maximum y step decrease and the walking curve look less like a triangle as the y maximum decrease. Then, for x step, it seems elevated as the leg is more further from the walking surface and moving nearer to the main body. Looking at the green walking cure, the y step is so big is due to the minimum y step is low but maximum is so high since the leg is reaching nearer to the main body of the mechanism. That is why the y step decrease from the beginning and the increases at the end as the leg is moving nearer to the main body.

4.3.2 Graph of walking curve transformation for pin_2_y

A few walking curve graph is filter and then plot to see the effect of alteration at pin_2_y.

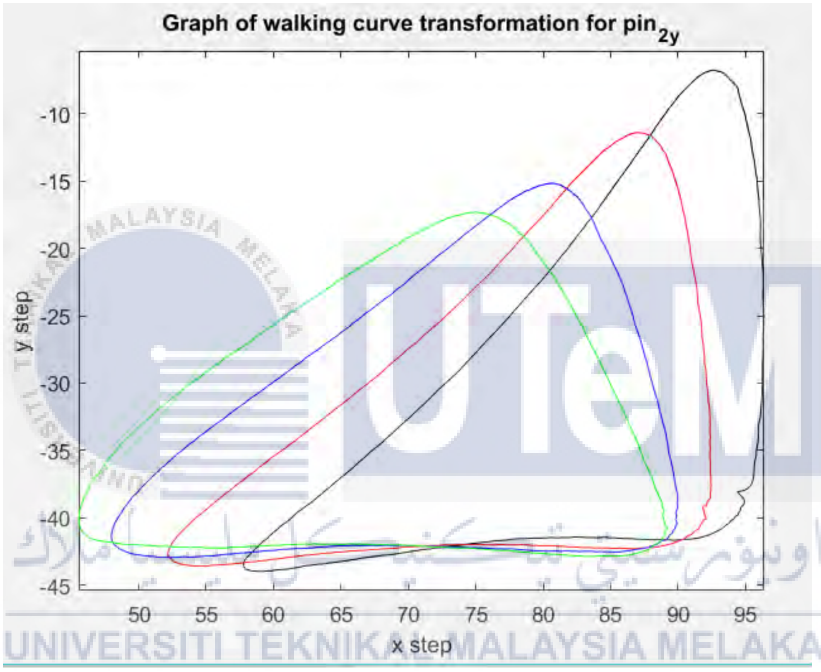


Figure 4. 14: Filtered Graph of walking curve transformation for pin_2_y.

From figure 4.14 the following are the colors that represent the Position of pin_2_y.

Table 4. 3: Colours representing Position of pin_2_y.

Position of pin_2_y (mm)	colours
16.78	Black
21.78	Red
26.78	Blue
30.78	Green

When the position of pin_2_y increases vertical, the y step become smaller as the y maximum is becoming smaller. In addition, the walking curve of x step should increase but is not clearly shown in the graph above. Furthermore, the shapes of the walking curves do no change drastically and show some pattern in decreasing in y maximum.

4.4 Walking Curve Jerking Movement

From the figure 4.6, the walking curve are not smooth due to jerking of the whole mechanism at it can be clearly form the movement of the leg. This happened may due to using cosine and sin triangular rule. In addition, in vector cos in sin is used. When using cos and sin, something the software itself need to figure out whether it is in position value or negative value which causing jerking for the whole system. Therefore, I suggested, instead of using cosine and sine equation, try using formula that related tangent.

4.5 Filtering for Walking Curve

In these section, the reason the walking curve is filter is discussed here.

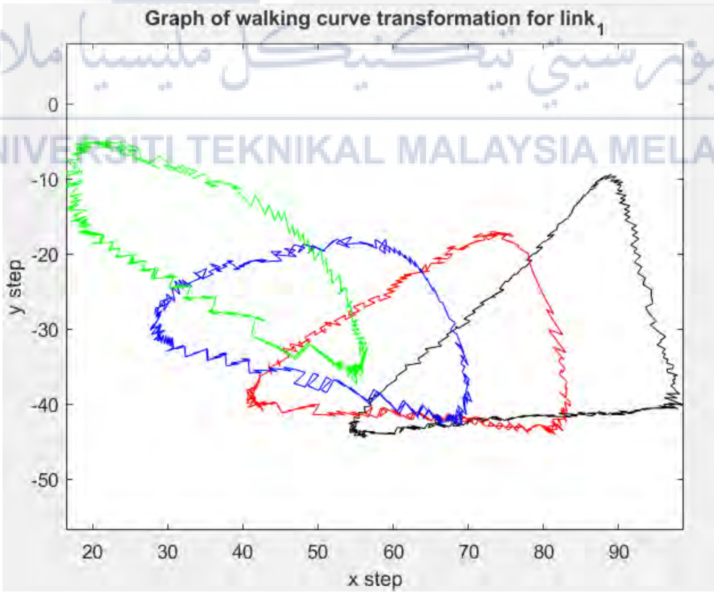


Figure 4. 15: Unfiltered Graph of walking curve transformation for link_1.

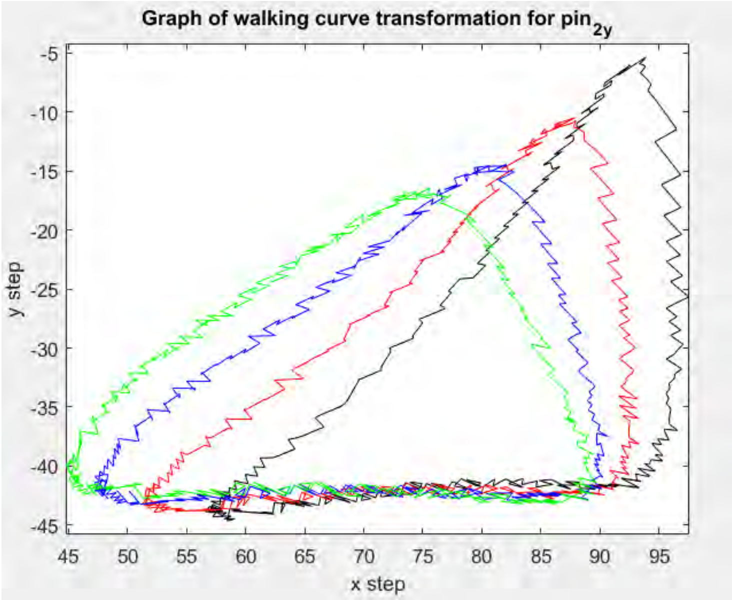


Figure 4. 16: Unfiltered Graph of walking curve transformation for pin_2_y.

The walking curve at Graph of walking curve transformation must be filter but a span of 15 is only use. Minimum span value is use to ensure there is a minimum change in data. The data must be filter as due to the jerking movement which the effect can be seen the walking curve. For presenting it look confusing and therefore the data is filter as minimum as possible. Figure 4.15 and Figure 4.15.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the objectives for this project were able to achieve where the design for walking mechanism that can overcome an obstacle of 2 cm height had be designed using Matlab software. Next the design parameters that influent the x step and y step in walking mechanism are determine, which is link_1 and pin_2_y. In addition, a framework base on Klann mechanism is able to be constructed using Matlab software where user can just add the value wanted and simulate the walking curve of the Klann Mechanism. Finally, a working prototype is also produced using 3D printer, which is the Klann Prototype A.

5.2 Recommendation

The following are the few recommendations that will help to improve this project

i. Atomization the process of finding the limitation of the Klann mechanism.

In this project, the process in done manually to determine the limitation of Klann mechanism where a value is added and then observation is done to ensure angle of leg and angle of power link remain in required value. In addition, observation need to be done on the frame and walking curve to ensure that that did not collide or touch with each other.

ii. Changes done all link, crank and pinned joints.

In this project, there are only two changes that are made, that are link_1 and pin_2_y. In the future, since the framework is there, analysis on all links should be done. In addition, the radius of crank, the position of pin 1 and pin 2 should also be experimented to know their effect toward the Klann mechanism. First change the length of the links, the radius of crank and the positions for the pinned joints.

iii. Addition or reduction toward the mechanism and see effect on walking curve.

Add or reduce is done in the mechanism and see which will get better walking curve in term of x step and y step. Bigger x step and y step is always the goal.

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APPENDIX A

Drawings for Klann Prototype A

APPENDIX B

Assemble Drawing for Klann Prototype A

APPENDIX C

Matlab Coding for Klann Mechanism