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DESIGN AND DEVELOPMENT OF A LEG REHABILITATION SYSTEM FOR PARALYSED PERSON – AN INNOVATIVE APPROACH

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ABSTRACT

The success of post-operative and post-traumatic therapy, as well as rehabilitation of disorders involving major joints, often necessitates ongoing passive mobility of those joints. Exercises used in physiotherapy are performed to heal broken joints. These can also be utilised by paralysed persons. Some technologies, such as Continuous Passive Motion (CPM), are routinely used to assist people suffering from paralysis, osteoarthritis, or other knee injuries. However, the current CPM gadget only conducts a specific common flexion and extension exercise, which aids in muscle tissue regeneration. Humans walk bipedally, which is an important attribute. Therefore, following physiotherapy, the human knee regains its flexibility, but it takes some time for the muscle to retrain itself to function in the gait cycle. This study facilitates the integration of precise gait cycle biomechanics into training mechanisms, enabling patients to replicate the exact gait motion during CPM machine exercises. As a result, the gait cycle not only lengthens the time it takes for patients to recuperate but also takes into account how easily people walk.



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I. INTRODUCTION

In recent scenario injuries related to human musculoskeletal system plays a vital role and it is increasingly at faster rate. One of the most significant issues with occupational health in both developed and developing nations is musculoskeletal illnesses. Among the different musculoskeletal system, most common injuries and defects that occur in the knee joint [1]. The complex interactions between these disparate structures—each of which is dependent upon the others for correct function power the musculoskeletal system, which is made up of muscles, ligaments, tendons, intervertebral discs, and the nerves and blood arteries that connect them. [1]. The musculoskeletal system's tissues can experience damage from abrupt overloads as well as from repeated or prolonged loading. Conversely, insufficient exercise can cause the health of bones, cartilage, tendons, ligaments, and muscles to deteriorate. This may be induced by the following: pathological alterations in the knee joint (e.g., modifications due to pharmacological interventions or conditions such as diabetes), congenital anomalies, injuries and microtrauma incurred over a lifetime (e.g., minor injuries resulting from high-impact sports that excessively strain the knee joint, such as football, skiing, or skating), and overload-induced degenerative changes arising from the aging process of the human body [2]. In severe instances, a patient may require surgery, during which the surgeon does a total joint replacement (knee arthroplasty) or substitutes the damaged components of the joint with prosthesis (implant) [3]. Most of the knee injuries or disease ends up in surgical resections or reproductive surgeries, while surgical resection deals with removal of damaged parts of the joint and latter involves in replacing the damaged parts with new set of joints. Treatment steps often involve treating meniscus injury, treating degenerative changes surgically, and treating patellar instability. Coastal and offshore regions offer significant opportunities for wind energy utilization; however, conventional fixed offshore wind turbine installations are associated with high costs, complex structural demands, and maintenance challenges [4], [5]. To address these limitations, floating wind energy systems and buoy-supported platforms have been introduced as practical solutions, allowing power generation in deeper waters and remote marine locations.

These systems are particularly advantageous for supplying energy to independent offshore applications such as navigation lights, marine sensors, and environmental monitoring equipment.

II. LITERATURE REVIEW

Knee replacement surgery is one of the main treatments for significant orthopaedic knee problems. Effective therapy to lessen pain and enhance functioning is the recommended course of treatment for knee complications. Treatment steps often involve treating meniscus injury, treating degenerative changes surgically, and treating patellar instability. In most of the rehabilitation process, CPM machines have been utilized for therapy [6]. Application of CPM machines is to avoid arthrofibrosis that involves joints to have limited mobility in knee and elbow joints [7]. Knee flexion therapy can be improved in weeks after arthroplasty by utilizing both physical therapy and CPM techniques [8]. Continuous passive motion (CPM), enables joints to move passively by a preset arc of motion [9]. Range of motion (ROM) is the critical parameter which the CPM machines focuses and in general for adequate knee flexion ranges from 90° to 120° for performing day to day activities like sit and stand, climbing stairs etc [10]. Three-dimensional computerized gait analysis or flexible electrogoniometry have been used to measure knee kinematics during walking and stair climbing (5). In order to increase knee range of motion, CPM therapy is carried out as limited motion arc, ranging between 30° to 40° and increased by 10° to 20° each day [11]. It is challenging to carry out several types of tasks when knee stiffness is present, such as getting up from a seated posture. Following surgery or a joint injury, stiffness progresses via four stages: fibrosis, granulation tissue, edema, and hemorrhage [12]. One of the human body's most highly loaded moveable joints, the knees permit comparatively complicated motions that facilitate movement. [13]. Many individuals suffer from Osteoarthritis and other knee injuries and it is degenerative joint disease [13], [14].

Osteoarthritis (OA), is a chronic condition that leads to pain, fatigue, decreased mobility and structural changes in and around the knee joint [14]. The Knee injuries can be repaired by reconstructive surgery [15]. Injuries and its reconstructive surgery are (Anterior cruciate ligament (ACL), knee arthroplasties, arthrofibrosis are commonly knee joint problems [16]. Restoring the knee's normal range of motion requires physical treatment to minimise joint stiffness and oedema. Physical therapist uses manual pressure or mechanical devices for attaining the knee flexion or extension [16]. After surgery, intense physical therapy and rehabilitation are necessary to fully restore joint function and range of motion. The goal of post-operative physical therapy is to lessen joint stiffness and restore the knee's natural range of motion. Muscle activation is not necessary for passive motion, which is movement produced by an external source. Repetitive passive motion for rehabilitation can be done by either a physical therapist or a continuous passive motion (CPM) machine [17]. Worldwide, chronic illnesses, trauma, violence, and ageing all contribute to the more than 600 million individuals who live with various forms of disability (World Health Organisation, 2007). One of the more prevalent disabilities brought on by a brain injury or stroke is hemiplegia. The total loss of muscle function in one or more muscle groups is known as paralysis. It mostly happens as a result of abnormal muscle function, which typically causes sensory loss in the affected area of the body and damages the spinal cord, which impacts the body's central nervous system. There are many types of paralysis and one type of generalized paralysis is Hemiplegia. This type just affects the one side of the human body [4].

It results in muscle stiffness, weakness, and issues with muscle control. The site and severity of the damage can affect the degree of hemiplegia symptoms. Either the left or right side of your body might be affected by hemiplegia; symptoms on the affected side of the brain correspond to the opposite side of the body. The affected people have symptoms like muscle weakness, muscle spasticity, trouble during walking, poor balance, trouble grabbing object, seizures [5]. In order to address potential side effects of paralysis, enable the paralysed person to live as independently as possible, and enhance their quality of life, rehabilitation is frequently advised. Those who are paralysed may also benefit from the following rehabilitation techniques. Heat, massage, and exercise are common physical therapy treatments used to stimulate muscles and nerves. Occupational therapy, on the other hand, emphasizes performing daily activities. Examples of mobility aids include scooters and both manual and electric wheelchairs. Assistive technology like voice-activated computers, as well as supportive devices such as walkers, canes, and braces, also play a key role in therapy.

II.1 CONTINUOUS PASSIVE MOTION (CPM)

A tool called Continuous Passive Motion (CPM) is used in physiotherapy and rehabilitation to give the limbs and joints movement. It is mostly used to support postoperative therapy and improve knee joint mobility. CPM devices are generally utilised in the early stages of recovery after trauma or soft tissue surgery. Depending on the joint in question, these devices gradually improve the range of motion of the joint by continuous movement [18]. For a passive-assist strengthening exercise, the patient can be guided to provide a little amount of resistance against the moving attachment, or they can choose to remain relaxed and allow the device to move passively through its range of motion. To optimise patient benefits and improve physician outcomes, it is imperative to preserve range of motion following medical operations. Early in the rehabilitation process, it is beneficial to combine Active Assisted Range of Motion (AAROM) with Targeted Force and Continuous Passive Motion (CPM) to enhance muscle strength, control, coordination, and endurance. Range of motion (ROM) is the critical parameter which the CPM machines focuses and in general for adequate knee flexion ranges from 90° to 120° for performing day to day activities like sit and stand, climbing stairs etc [10]. From the literature review it is identified as the knee injuries is the main factor for reduced range of motion and commonly affected muscular skeletal degenerative joint disease. In the work an attempt is made to reduce the joint stiffness and restore the normal range of the knee flexion or extension through CPM machine.

III. DESIGN AND METHODOLOGY

From the literature finding, skeletal degenerative disease is more common against knee. In order to reduce the knee stiffness, joint function and improve the range of motion of knee flexion and knee extension, by incorporating gait analysis a modified CPM machine is to be designed. Designed CPM machine, incorporates the gait analysis of human leg and it is automated with the cam design. The designed CPM machines, considers the design calculations of gait, incorporating the gait analysis to design the cam profile.

This cam profile designed will cater the functionality of the CPM machine and it satisfies the range of motion needed for the therapy used for Hemiplegia treatment of the post-operative assistive techniques used for physical therapy. Further discussion will focus on gait cycle and calculation of gait cycle.

III.1 GAIT CYCLE

As seen in Figure 1, a gait cycle is the interval of time between consecutive, repeating walking activities. The same sequence of events occurs in both legs, but with a half-cycle phase shift. The stance phase, which makes up 60% of the gait cycle, and the swing phase, which makes up the remaining 40% [19], are the two primary stages of the cycle. Gait combines both closed-chain and open-chain operations.

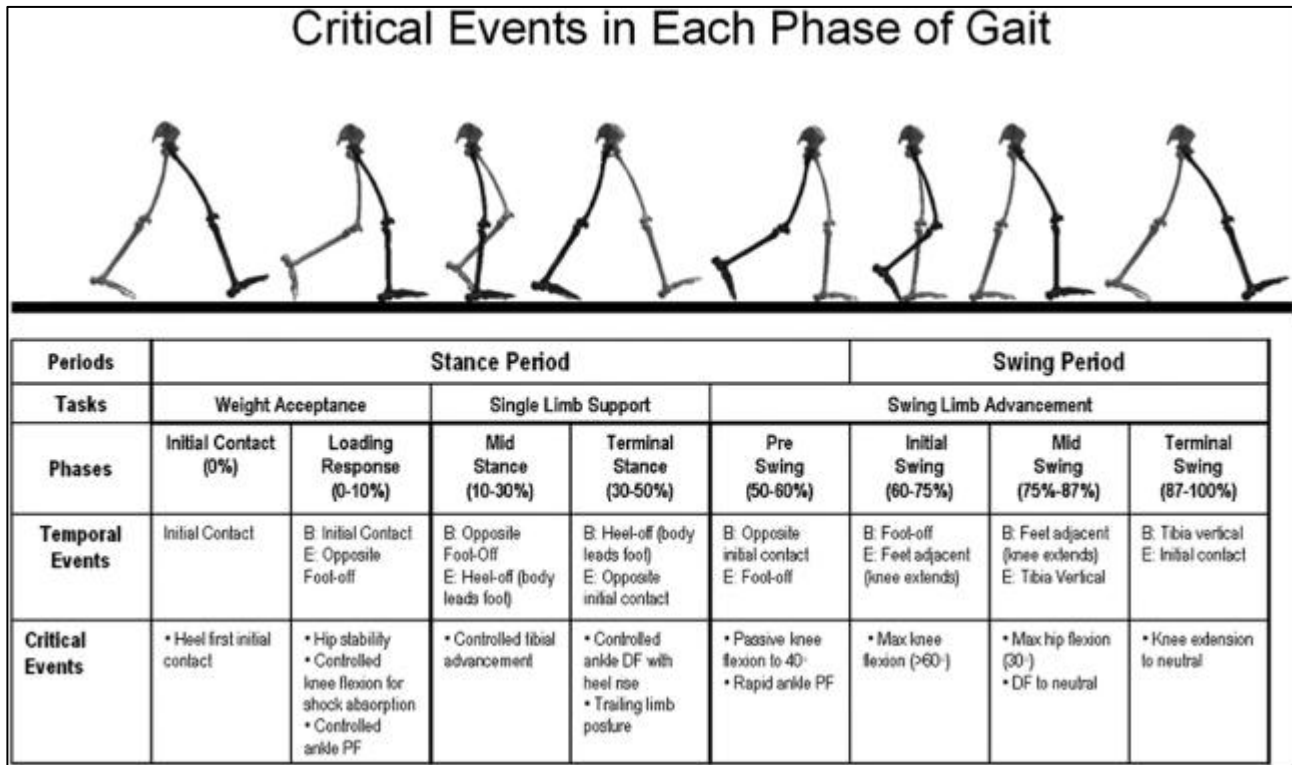


Figure 1: Stages of Gait Cycle.

Source: Authors, (2026).

The two primary phases of the gait cycle are the stance phase and the swing phase. The stance phase, which accounts up 60% of the gait cycle, commences with the heel strike, in which the toes are still elevated above the ground at the time of the heel strike. The foot settles near the lateral border during the midstance phase. The stance phase ends and the swing phase (also referred to as the propulsive phase) begins with the toe-off phase [5]. In the swing phase, the toe-off and heel hitting phases are separated. The swing phase also includes the acceleration and deceleration subphases. From toe-off to mid-swing, the body is driven forward by the swift forward motion of the swing leg during the acceleration period. From mid-swing to heel strike, the following stage is the deceleration. Forward motion is controlled throughout this stage to ensure the foot lands softly [20], [21]. The mid-swing phase, which occurs between these two sub-phases, is when both feet are beneath the torso and the heels are in alignment.

III.2 CALCULATION OF GAIT CYCLE

Initial contact, loading reaction, mid-stance, terminal stance, pre-swing, initial swing, mid-swing, and late swing are the eight different phases that make up the gait cycle. Every stage involves movement of the whole body and leg. Forward leg movement is made easier by an anterior-posterior displacement in the pelvic region that alternates from left to right. This displacement is roughly 4-5° on each side [4]. The foot moves in a certain way in the frontal plane between heel strike and foot flat, and between heel-off and toe-off. Between heel-off and foot flat, a small valgus movement is also seen. During the gait cycle, which is a typical time frame for periodic human walking, the hip displays additional lateral motions. On level ground, the cycle is determined by the interval between consecutive heel strikes. When the foot strikes the ground, the leg moves into 5° of supination, increasing by 5° increments, marking the beginning of the gait cycle, or initial contact. During this phase, the knee flexes 15% to 20%. With lateral rotation, the hip flexes to 20° after extending to 10° during the swing phase. The ankle shifts from 20° of plantar flexion to dorsiflexion, while the knee flexes to 40°-60°. During the mid-swing phase, the adductors contract to cause the hip to flex to 30°, and the tibialis anterior muscle contracts to dorsiflex the ankle. With a locked extension of the knee, a neutral ankle position, and 25°-30° hip flexion, the late swing or terminal phase starts.

Incorporating the gait cycle into the design of a Continuous Passive Motion (CPM) machine is crucial to the design process. To develop a modified CPM machine, components such as links, a slotted bar, and a cam are needed. The motion of the human leg, including the up-and-down movement triggered by the knee joint and the forward movement initiated by the hip joint, must be considered as a mechanism in the CPM machine. The positioning of the leg within the CPM machine is illustrated in Figure 2.

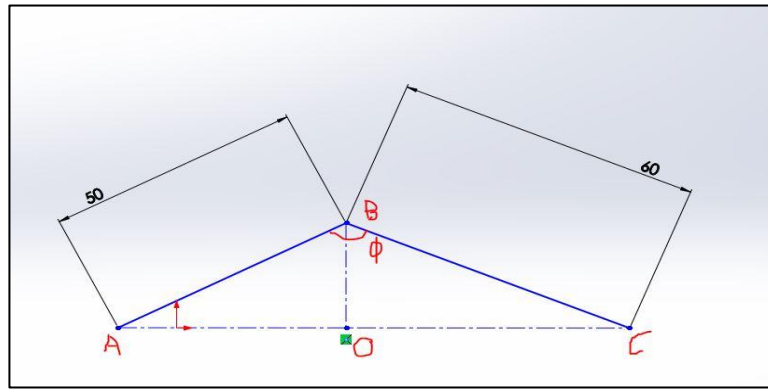


Figure 2: 2D drawing schematic of model leg in COM.

Source: Authors, (2026).

From the Figure 2, let us consider the following assumptions;

Consider AC as the base of the machine which is the travel length of the leg.

AB represents thigh portion.

BC represents below knee portion.

$\emptyset$ represents the total angle between the thigh and the crus.

Line AOC represents ground (rest position of leg)

AB=50 cm and BC=60 cm.

Calculation:

BO –distance from the ground

$\cos \emptyset = \text{adjacent side/hypotenuse side}$

$\cos(\emptyset/2) = BO/BC$

$BO = BC \cos(\emptyset/2)$

$BO = 60 \cos(\emptyset/2)$

To find AC:

$AC = AO + OC$

$AO = 50 \sin(\emptyset/2)$

$OC = 60 \sin(\emptyset/2)$

So, $AC = 50 \sin(\emptyset/2) + 60 \sin(\emptyset/2)$

Based on the above calculations, linear displacement as tabulated in Table 1 for each gait angle and the distance from the center of the cam are shown in the Table 1.

Table 1: Shows the calculation of Linear Displacement based on the schematic model leg.

Knee Angle (In Deg)	Distance of knee joint Angle (In Deg)	BO (Linear Displacement) (In Cm)	Distance from Centre Of Cam (In Cm)
8	164	8.35	25.85
20	140	20.52	38.02
22	136	22.48	39.98
20	140	20.52	38.02
16	148	16.54	34.04
14	152	14.52	32.02
10	160	10.41	27.91
9	162	9.39	26.89
12	156	12.47	29.97
18	144	18.54	36.04
28	124	28.17	45.67
42	96	40.15	57.65
56	68	49.742	67.242
65	50	54.38	71.88
60	60	51.96	69.46
52	76	47.28	64.78
38	104	36.94	54.44
18	144	18.54	36.04
10	160	10.41	27.91
8	164	8.35	25.85

Source: Authors, (2026).

III.3 DESIGN OF MODIFIED CPM MACHINE

After soft tissue surgery, Continuous Passive Motion (CPM) devices are used in the initial phase of rehabilitation. During the first phase of rehabilitation, the main objectives are to control pain following surgery, lower inflammation, enable passive movement in a certain plane, and safeguard the healing tissues. Several elements need to be taken into account when building a CPM machine, including:

- The length and intensity of post-operative physical therapy can be affected by the kind of operation, the extent of the injury, and the patient's degree of activity.
- Gender, size, and weight of the patient are all significant factors in selecting the proper range of motion and velocity for the CPM device.
- Adjusting important factors including knee flexion velocity, range of motion, and treatment time is necessary to maximise the benefits of physical therapy.
- To provide optimal therapy outcomes, it is imperative to examine the knee's biomechanics during passive motion in order to comprehend the interaction between user input settings and the CPM machine.

Table 2 contrasts the improved CPM machine, which incorporates gait analysis into its design, with the current CPM machine. The CPM machine's design considers all of the previously described elements, making sure that it satisfies every need for successful post-operative rehabilitation including knee flexion and extension. The redesigned device has motor-driven velocity control and is made to fit the needs of each user, male or female. Compared to the present CPM machines, this model is more suitable for a larger range of people due to its adjustability to users with different leg lengths.

Table 2 Comparison with existing CPM machine.

S.no	specification	Current CPM description	Designed CPM model
1	Maximum crus length	49cm	60cm
2	Maximum patient weight	160 kg	120 kg
3	Maximum Thigh length	41cm	50cm
4	weight	12kg	22kg
5	length	90cm	110cm

Source: Authors, (2026).

While most existing CPM devices offer just standard exercises, our created model incorporates the knee's unique gait cycle into the exercise mechanism. The gadget attempts to mimic the way the human leg moves naturally, which consists of two main movements: a forward motion started by the hip joint and an upward and downward motion led by the knee joint during a whole gait cycle. We chose to account for this variability by creating a cam profile in the CPM machine that matches gait cycle data because the angle variations that occur over a gait cycle are not uniform. Before deciding on the cam-follower mechanism, a number of mechanisms and their levels of complexity were assessed in order to determine its suitability and efficacy in correctly recreating the gait cycle.

III.4 DESIGN OF CPM WORKING MODEL

For designing the modified CPM machine, above mentioned factors are considered. The design has mechanical components like cam and follower, links to connect, shafts to hold the position of the leg and motor to drive the modified CPM machine. The designed CPM must perform the functionality of CPM machine by incorporating the Gait analysis in to the design. The working model of CPM machine is comprised of 6 components which is assembled together to get the unique modified CPM machine incorporating gait cycle. The components are base, cam follower, roller, links, centre shaft and midshaft. The components of the model are briefed further in the following sections.

III.5 DESIGN OF CAM

For implementing the displacement made by the knee in the design of the cam, cam profile is made into 20 divisions and each division represents the particular gait cycle angle and the displacement of each division is calculated and shown in the Table 1.

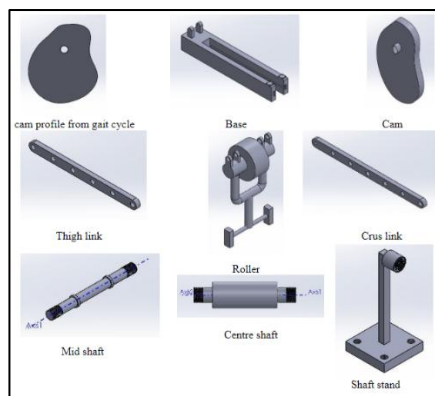


Figure 3: Components of Modified CPM machine.

Source: Authors, (2026).

The profile of the cam is generated with these calculated values and it is shown in Figure 3. The final profile of the cam after proceeding with the above steps will follow the gait cycle pattern because the profile of the cam is designed for each gait angle. The base has a sliding t-slot running through it all along which paves the way for the roller to slide through it. This slot prevents the roller from its up and down movement mainly because it helps the setup to be stable after the loads has been added to the links. Only one translational movement is provided and the rest two kinds of motion are arrested. It has two mounts near the end which helps the links to fix through it like a pin joint. There is a plate with four holes at the front side of the base. The other plate of the shaft stand can be screwed up with this for the ease of removal of the cam if needed. The cam has been designed with a hole shaft inside which supports the rotation of the cam with the rotating motor in it. The gait cycle is incorporated in the cam which moves the leg placed in the machine as accordingly. The major need of the roller is to convert the rotary motion of the cam to linear motion of the roller follower. The roller has a shaft in which the mounts for holding the below knee part is connected and they are affixed through nuts and bolts. There is a center roller which will be connected to the cam and provides the necessary translation motion for the movement of the leg. There are two blocks connected at each end of a shaft which slides through the T-slot.

There are actually four links in which there are two similar thigh links and other two similar links for the below knee part. The links are connected at their ends with bolt and nut while the amidst part is connected with a midshaft. The thigh region is usually smaller when compared with the crus. So, the thigh link is smaller. The two links has slots through which the length of the leg according to the person can be adjusted. Thus, this results that the machine can be used by everyone irrespective of the leg length. In between the two links a soft cloth will be wrapped up as this prevents the direct contact of leg with any part of the machine and the legs will be kept hold in a netted cloth since a plate may be felt uncomfortable for some persons. The cloth takes the shape of the leg and it does not induce any pain while resting on it. The centre shaft is an assembly of two components centre shaft and the shaft stand. They together become the setup for holding the cam. The centre shaft has threads at the end of its step shaft. The threads are provided in order to mate with the shaft stand. The cam will be made concentric with the centre shaft and a very small gap is left between the cam shaft and the centre shaft to rotate the cam. The shaft stand has a cup shaped opening with threads cut inside them to fit into the centre shaft. The shaft stand has a plate at the bottom which fits with the similar plate made at the top of the base. The midshaft has threads at the end and the link has no threads in them because to adjust the length of the leg through the links easily threads are not provided in the links. A stud is kept in the main shaft as shown above to prevent the links from displacing since only the midshaft is locked with the nuts and the links are free to move through the axis when the roller rotates.

III.6 WORKING PRINCIPLE OF THE CPM MACHINE

The cam is mounted on the center shaft which has been supported through a stand attached to the base. The cam has only rotational motion on one axis only and a roller is attached to the cam. The base has a T-Slot running through it which makes the roller part slide against it. The two links connected with the roller forms the below knee part of the leg and the other two links are for the thigh region. They are connected with the base through the mounts. A midshaft is attached between the two links which makes them to move parallel always. When the motor is powered, the shaft attached with the cam rotates. So, the rotation of the cam brings out a translatory motion to the roller which slides through the slot. Hence the link attached with the roller moves up and down resulting in the movement of the leg. The final assembled view of the CPM machine is shown in Figure 4.

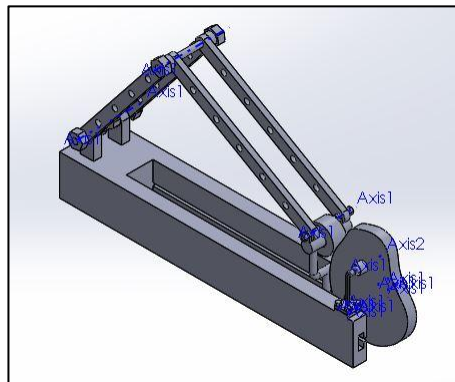


Figure 4: Assembled model.
Source: Authors, (2026).

IV. RESULTS AND DISCUSSION

Designed CPM machine incorporates the functionality of movement by utilizing gait cycle in to the mechanism. Designed CPM machine is of easy to use and it can be an effective system for post operative physio therapeutical procedures. From the designed CPM machine for effective utilization of the gait analysis was carried out and it is simulated to check the functionality of knee Osteoarthritis.

IV.1 ANALYSIS OF GAIT CYCLE

The analysis of the design is important because it helps to reduce the errors on a system by optimizing and running the iteration several times. The software used for analyzing the designed cam for the gait cycle incorporated is working model 2D. The working model 2D is a real time 2D motion analysis and mechanical system analysis software that can be used to plot graph and arrive at the math data that sequencingly corresponds to the output.

Force is exerted on the roller which is the force exerted when a leg placed on the links connected to the roller. Motor has been connected to the cam and it rotates about the axis. With the rotation of the cam and by tracing the path made by the roller the displacement of the roller according to the velocity of the cam can be calculated. Figure 5 shows the graphical analysis of gait cycle simulation. The graph shows the plot obtained by plotting the roller velocity against the cam. The first graph is obtained when the roller touches the cam at its outer surface. The second graph shows the plot obtained when the centre of mass on the roller rolls over the defined cam path. The graph obtained from the analysis figure is more likely similar to the one obtained in the gait cycle. It can be inferred that for any one cycle in the graph the curve is similar to the gait graph which affirms that it follows the gait cycle.

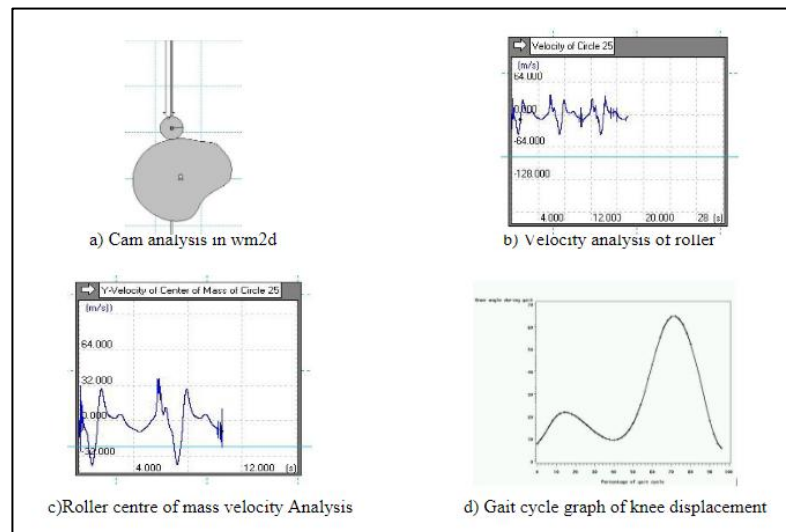


Figure 5: Gait Analysis.

Source: Authors, (2026).

V. CONCLUSION

Focus of the paper is to design a CPM machine for Osteoarthritis (OA), is a chronic condition that leads to pain, fatigue, decreased mobility and structural changes in and around the knee joint. The modelled design can also be used by the osteoarthritis affected persons, leg fractures and knee injured persons. The designed CPM machine should be able to adapt to the human gait cycle pattern and incorporating gait cycle analysis in the CPM machine could be used at the therapy session to reduce joint stiffness and swelling in order to restore the normal range of motion of the knee. The designed CPM model is assembled in such a way that it not only acts as a physiotherapeutic device but also acts as a device for faster reclamation of the leg tissues with the incorporation of the gait cycle. The analysed model is safer to use by any person irrespective of gender, weight and height. The designed model works well for generalised paralysed person for whom the design has been developed.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Vivek Chandrasekaran, Sivasankar Arumugam, Balamurugan Gopalakrishnan.

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Investigation: Sivasankar Arumugam.

Discussion of results: Vivek Chandrasekaran, Balamurugan Gopalakrishnan.

Writing – Original Draft: Sivasankar Arumugam.

Writing – Review and Editing: Vivek Chandrasekaran, Sivasankar Arumugam, Balamurugan Gopalakrishnan.

Resources: Vivek Chandrasekaran, Sivasankar Arumugam, Balamurugan Gopalakrishnan.

Supervision: Vivek Chandrasekaran, Sivasankar Arumugam

Approval of the final text: Vivek Chandrasekaran, Sivasankar Arumugam, Balamurugan Gopalakrishnan.

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