CONCEPTUALIZATION OF DESIGN OF PROSTHETIC ROBOTIC LINKAGE FOR HUMAN LIMB REHABILITATION

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Abstract:
The first phase work of the project involving the conceptualization of mechanical design of an active knee prosthesis linkage mechanism is proposed in this paper. For patients needing limb movement rehabilitation with impaired upper or lower limb joint functions and also for otherwise healthy persons suffering muscle weakness syndrome, this paper proposes an active linkage mechanism along with its actuation. The aim of this study is to demonstrate a theoretical basis for the design of linkage mechanism having stance phase control as well as swing phase fluidic kinematic behavior in conformity with natural legs. Proposed “Knee Mimicking Prosthetic Robotic Linkage Mechanism (KMPLRML) for Human Joint” will have flexion angle up to 60°. This paper includes the conceptual design of “Knee Mimicking Prosthetic Robotic Linkage” which will be used for rehabilitative and assistive purposes. The mechanical design of knee prosthesis linkage mechanism, its mathematical modeling and kinematical analysis is outlined here. It is to be worn on lateral side of lower or upper limb and will provide naturalistic movement of elbow or leg joint. Linear actuator based motion is proposed which can be further put under myoelectric control. KMPLRL is designed to follow the trajectory tracking which corresponds to a typical rehabilitation exercise and is an able knee mimicking assistive device. Thus confirming to effectiveness in rehabilitation therapy and post-surgery recovery treatment. While earlier generation limb rehabilitation used dead weight passive attachment, the proposed KMPLRL has advantage because it is an active device linkage mechanism. This can be very conveniently used in the active rehabilitation and therefore resulting in shortening of recovery period of a patient. In this paper first phase of research project work comprising of conceptualization of design, prototype development of an active knee prosthesis linkage mechanism as proof of concept has been presented. The proposed prototype is to act as test bed for further improvement, analysis and refinement and optimizations.

Keywords: Robotic linkage, human Joint, limb Rehabilitation, Knee mimicking, powered knee prosthetics

1 Introduction

It is common to replace the amputated limb by an artificial limb; a prosthesis. The selection of prosthesis is highly dependent on the individual needs and abilities of the patient. Its function can vary from according to functional necessity for a patient to retrieve independence in performing daily life activities. In case of a TT (Transtibial) amputation, the amputee will be fitted with a ‘lower leg’ prosthesis, which enables the prosthetic user to achieve normal walking after rehabilitation period. While transtibial prostheses are comparatively simpler, transfemoral prostheses are more complex and costly due to additional knee equivalence mechanism. The characteristics of a TT prosthesis directly influence walking pattern and thus, ample attention needs to be given to the prosthetic replacement of part of the amputated limb. Over the
past decades several researchers have examined prosthetic gait in terms of kinematics, kinetics and energy expenditure. Exoskeletons for human lower-limbs are robotics devices worn by user that fits closely and operate in parallel with the human legs, augmenting human performance. In this paper a mechanism design of Knee mimicking robotic prosthesis is presented as proof of concept to be explored and refined further. This linkage mechanism uses polycentric design methodology which is quite different from other polycentric linkage mechanism available in market. Use of prosthetic robotic mechanism in gait rehabilitation applications have evolved in last decades with development in automation technology. These robots with knee mimicking ability can be used as mechanism in the physiotherapist training devices, and are particularly more suitable when the physiotherapy exercises are very intensive. So, the prosthetic robots can reduce the therapist’s work load intensity and also can increase the convenience of patients suffering from Muscular Dystrophy, Cerebral Palsy, Muscle Atrophy due to ageing, or injuries caused to joints with unexpected sudden or repeated loads imposed upon it. Also they can increase exercise time [1] which will ultimately result in faster recovery during rehabilitation exercises. The complexity of proposed polycentric model gives way to innovative analytical technique of evolutionary algorithm to be developed. So, a analytical method of linkage mechanism proposed can be developed further to be used for other similar cases of applications in analogy such as finger joint rehabilitation, shoulder and hip joint rehabilitation, as well as in design of robotic gripper with new actuation mechanism. This mechanism design can also be used in semi active or active rehabilitation and gait rehabilitation treadmills. Over the years many robotic orthosis devises have been developed for gait rehabilitation such as ALEX [2], Lokomat [3] and LOPES [4]. Robot with pneumatic actuators was also proposed such as POGO [5]. Each of the robotic devices developed do have their own draw backs and advantages. Each of the previously presented robots have their own pros and cons performance wise. However some knee prosthesis is quite successful in market as such C- legs, Hossur knees. Some are not as popular due to their own drawbacks. For example, Lokomat has limited degrees of freedom which prevent it from possibility of natural walking. Also its mechanism has high inertia. Also in robot LOPES, using cable has caused some problems such as cable friction and cable sliding at high torques [3, 6-7]. Pneumatic actuators are used in robot POGO. Due to nonlinear behavior of these actuators, their force control causes different problems.

The Mechanical design of the active knee prosthesis having a knee mimicking mechanism is reported in this paper with intension of providing the possibility of natural walking for patient. The design and kinematics of prosthesis mechanism is presented in the paper. As said above different orthosis and prosthesis device have been proposed are based on different design principles and architecture. Some of different design architecture knees are manual locking knee, single axis constant friction knee. Weight activated stance control knee, polycentric knee, Ossur knee, C-Leg, hydraulic knee. Also there is UT Knee, a four-bar knee mechanism with an inverted (as compared to the regular knees) trajectory of points of rotation [8]. In this paper polycentric knee architecture based knee mimicking linkage mechanism design is proposed. The advantage of polycentric knees is that it has variable center of rotation allowing for stability in all phases of gait. In contrast to earlier 4 bar linkage mechanism with polycentric knee architecture prevalent, in this paper author has come up with new 10 bar polycentric knee architecture. In continuance with its architectural advantage, the presented 10 bar polycentric knee allows the knee to collapse better during the swing phase of gait, essentially allowing the foot to clear the ground conveniently. This collapsing feature also allows the knee to bend easily for sitting and is the ideal knee for knee disarticulation or above knee amputees. The swing phase control will be again by same electrical servo motor. The instantaneous center of rotation remains behind TKA (Total Knee Anthroplasty) line for initial few degrees of flexion, enhancing stability during mid- late stance/toe-off.

The experimental results indicate that for walking with a more stable knee, as the symmetry increases the net hip moment of force, required to stabilize the knee reduces. The mechanical work however, performed at the hip joint at the prosthetic side, remains about equal. With the Knee Mimicking Prosthetic
Robotic Linkage Mechanism (KMPRLM) for human joint the a concept for powered Trans-femoral prosthesis is discussed herein as proof of concept.

As the benefits of robotic systems are not limited to healthcare only, the proposed methodology can be applied to multitude of applications such as in military applications to allow soldiers to carry more and walk further. However as the style of recent wars creates additional needs for robotic assistance: as while the death toll has been dramatically reduced (10% of injured died in Iraq compared to 30% in World War II), 6% of injury survivors required amputation (compared to 3% in previous wars) and 20% of injury survivors will need assistance for the rest of their lives. Robotic systems for assistance and rehabilitation focus on providing missing movements and sensing, providing safer environments, and providing environments that makes in regaining movement-related function easier and faster. Robotic prosthetics and exoskeletons is able to provide dexterity, natural mobility, and sense of touch to missing or paralyzed limbs. Individuals suffering from hip or knee disability conditions can use a robotically intelligent walker or wheelchair to help prevent from commonly occurrence of accidents like slipping, tumbling etc. Finally, biorobotic rehabilitation provides consistent and efficient therapy. When this field reaches its zenith, the benefits to society will be enormous. We will be able to replace entire limbs with prosthetics that can replicate one's own biological functions precisely, with a natural outward appearance and requiring minimal upkeep.

2. Problem Statement

The main design requirement for the active knee prosthesis is that “Kinematics of the linkage mechanism of designed prosthetic knee mechanism should match that of natural knee kinematics. Prosthetic knee should provide range of motion which rival natural leg during normal walking with linear actuator”. The Linear actuator should be able to produce the kind of motion similar to quadriceps and hamstring muscles produce to achieve physiological walking gait patterns. We have to design first prototype of prosthesis as proof of concept and as platform for evaluation of design optimization concepts and further improvement and refinement.

3. Design characteristics requirement

Knee prosthesis should not exceed the size and weight of the missing limb and should exhibit similar kinematics to those of a biological knee joint. The ideal knee prosthetic should be capable of replicating the full range of motion of the human knee as well as the ranges of torque and stiffness which are observed in normal routine life. Functional requirements (FRs) of prosthetics related to comfort, fatigue, stability, and falling are of high importance, while sitting appearance and adequate knee flexion are not as much significant but are desirable.

4. Design and development of knee Prosthesis for exoskeleton

It is sensible to reduce the scale and complexity of the problem in order to identify and address technical problems at an early stage, and to assess mechanical design and concepts. This is why the first phase of the project involves the mechanical design and development of an active knee prosthesis linkage mechanism. The Mechanical design of this active knee prosthesis is to be resolved in this paper. Mechanical design problem statement is concerned with the architecture of the linkage mechanism to be adopted. Options are there to be explored along lines of single axis knee architecture, polycentric knee, hydraulic knee, geared knee, weight activated stance control knee, single axis constant friction knee, and many others architecture and design base. As in the first phase of project the research work involves design and development of linkage mechanism for active knee prosthesis. And, once a design with knee mimicking ability different from commonly existing prosthesis mechanism in market is conceptualized then model is developed, and presented as proof of concept rather than end product at user end.

5. Mechanical modeling of human joints

Before proceeding towards mechanical design of knee mimicking mechanism, getting familiarity with various joints of the human skeleton and their biological, anatomical and kinematic orientation is important. The different joints of human skeleton from top to bottom location wise is shown in fig 1. The Exoskeleton needs to have knee joints, wrist, fingers ,which are all flexion- extension joints . So if we
are. So if we are able develop a mechanism for such knee and its actuation, same can be used for rehabilitation most of joints such as ankles, hips, shoulders with orientation wise adjustment rehabilitation executing similar movements.

![Hierarchical structure of human joints](image)

Fig. 1. Hierarchical structure of human joints [9]

On observing day to day motion of limbs we observe that most of the movement of limb in the sagittal plane is one of the most common movements as it is clear from the reference plane depiction shown in Fig. 2.

![Reference planes of the human body](image)

Fig. 2. Reference planes of the human body [10]

### 5.1 Biomechanics of knee and its kinetics

For design of knee mimicking linkage mechanism the complete understanding of knee mechanics is must. Coming to anatomy of the knee joint from mechanical forces view point, knee is made up of three bones and four main ligaments. The knee is formed by the femur (the thigh bone), the tibia (the shin bone), and the patella (the knee cap) as is clear from fig 3.

![Knee made up of three bones](image)

Fig. 3. Knee made up of three bones [11]

Different pair of muscles and ligaments controls the motion of the knee and protect it from damage at the same time. As shown in fig. 4.

![Four ligaments acting in sync to keep knee in right position and orientation](image)

Fig. 4. Four ligaments acting in sync to keep knee in right position and orientation [12]

Two ligaments on each either side of the knee, called the medial and lateral collateral ligaments, stabilize the knee from side-to-side displacement. Then there is Anterior Cruciate Ligament (ACL), a pair of ligaments in the center of the knee joint that forms a cross, and this is where the name "cruciate" comes from. There is Posterior Cruciate ligament (PCL) which prevents slide of femur on tibia bone in sagittal plane. Inspired from natural configuration of ligament forces natural linkage mechanism designed for knee equivalence looks like something as shown in fig. 5.
5.2 Movement of the knee

The main muscles that move the knee joint are the quadriceps and hamstring muscles. The quadriceps attaches to the patella, and the patellar tendon connects this muscle to the front of the tibia. When the quadriceps muscles contract the knee extends.

In contrast, when the hamstring muscles contract, they pull the knee into flexion. This contraction behavior of quadriceps muscle and hamstring muscles and consequent movement will be clear from observing the anatomy of muscles as shown in fig. 8. This against – antagonist action of two muscles, quadriceps and hamstrings result incomplete gait cycle comprising of 6 phases - Initial stance, mid stance, terminal stance, initial swing, mid swing and terminal swing. With execution of complete six phases of gait cycle the complete movement behavior of knee comprising of rotation is executed and forward movement of human body is executed. The quadriceps contraction action causing extension is shown in the fig. 8 with associated muscle orientation.
While hamstring contraction causing flexion is shown in fig. 9 with associated muscles orientation. This way agonist – antagonist behavior of muscles producing mobility torque is clear. The detailed study of biomechanics on knee has indicated that it is single degree of freedom mechanism. The MCL and LCL control undesirable motion between femur and tibia in the transverse plane. In complete extension – flexion movement the ACL and PCL do not stretches or contracts.

![Hamstring muscle](image)

Fig. 9. Hamstring muscle contracts to action leg to cause flexion leg bends (Antagonist)[14]

Instead a complete instantaneous center of rotation is formed resulting in envelop of motion. The instantaneous center of rotation is located along path of cross points of two ligaments ACL-PCL traced during extension and flexion motion. Instantaneous center of rotation during flexion- extension is same as during extension- flexion motion. This situation vindicates the assumption that the knee mimicking linkage can designed to be 4 bar linkage mechanism with single degree of freedom. The different orientations of femur and tibia bones between from straight( Extension ) orientation to bend orientation (Flexion ) are shown in fig.10(a), (b), (c) and (d) which are achieved through contraction of quadriceps and hamstring muscles individually. This gives clear visualization of extension - flexion cycle.

![Knee joint orientations](image)

Fig 10 . Different stages orientation of Femur and Tibia bone of leg from straight (Extension) orientation to bend orientation (Flexion). [15]

### 5.3 The musculoskeletal structure of lower limb from kinematic viewpoint

As the proposed mechanical design is inspired from the natural biomechanics of human lower limb knee. Hence it is important to decipher the working of the musculoskeletal structure of lower limb to come out with new mechanical design proposed. As shown in Fig.11 how the actuating muscles are attached to the lower limb skeleton system. First, we need to understand and distinguish the muscles applying the governing forces to the knee joint that predominantly provides necessary torques to support the human body weight and rotations of the knee joint in sagittal plane. This will be important to us in design procedures. As shown in the figure10, the hamstring is attached between the pelvis and the tibia near back side of the knee joint. In addition, the hamstring is the longest muscle within the part of lower limb. The mechanical functioning of these muscles resembles to linear actuation type.

![Knee joint muscles](image)

The quadriceps is found between the middle part of femur and the front side of tibia near knee joint. The behavior of quadriceps is different as compared with the hamstring as shown by Fig.11. As mentioned earlier, the quadriceps plays an important role of fixing the angle of knee joint underbody weight. The mechanical functioning of these muscles resembles to linear actuation type.
movements as can be seen from the figures. Hence, these muscles can be mechanically represented identical to linear actuator as shown in Fig.11. In addition, it can be recognized that it determines the angle between the femur and the tibia with the contraction of quadriceps. The mechanical structure of knee joint is also important in the analysis.

![Fig.11. The illustration of musculoskeletal system [18]](image)

The placement of patella is between the quadriceps tendon and the patella tendon. The roll of patella is transmitting force which is produced by quadriceps contraction. The force is transferred from patella to tibia by sliding motion of femur on the knee joint. The two tendons of knee joint can be represented as equivalent springs [16]. In addition, we can see the four-bar mechanism in center of knee joint. All this signify us that knee joint cannot be solely represented as revolute joint in a simple way [17]. The primary concern is the prosthesis’ ability to move closely resembling that of natural motor. As knee mimicking mechanism which is central to prosthetics to be developed has already been conceptualized as 4-bar binary linkage, further understanding of working of hamstring and quadriceps gives way to conceptualization of design of actuating system to 4 bar BL. The role of patella in active biomechanics is clear from fig. 12, whether it be transmitting compressive force from quadriceps muscles or force from hamstring muscles.

![Fig12. Compressive force of patella as quadriceps contracts leg will straighten human’s lower limb & when hamstring contracts knee will bend. [18]](image)

6. The conceptual design of knee prosthesis

The conceptual design of the proposed active knee prosthesis has been realized by taking into account the considerations of human’s bio-mechanics as explained in previous sections. With the proposed design, it is attempted to contain the unique kinematic structure of lower limb and knee arrangement with their characteristics. Fig.15 shows the complete active knee prosthesis design for use of patients to support normal walking of gait cycle and variable lower limb movement in the real life or in rehabilitation practice. Basic approach guideline towards development of knee mimicking linkage mechanism is towards modeling the various possible linkage mechanism on CAD software, then studying the kinematic behavior of the models. Then deciding for zero-in on particular mechanism having kinematic similarity with the natural knee & potential to be further developed for KMRP-LM. For studying kinematic behavior the mathematical formulation is developed to model the behavior of linkage mathematically in form of equations.

Whether it is about augmenting abilities or improving disabilities, purpose of assistive prosthetic devices to be used for knee joint is to provide useful mechanical power by means of synchronous operation with the person that is wearing it [19]. The human–robot interface is quite crucial for a safe and comfortable interaction with a wearable robotic device [20].
6.1. Modeling of KMRP_LM and its structural details

The complete designed for bio inspired knee linkage mechanism for knee prosthetics can be divided into four parts.

(a) Linkage mechanism for ACL &PCL equivalence

(b) Linkage mechanism for hamstring and quadriceps which has been achieved by linkage mechanism which is divided into two parts –

(i) Upper four bar linkage mechanism

(ii) Lower four bar linkage mechanism

(c) Actuator providing power to cause mobility as muscles (hamstring and quadriceps)

Linkage mechanism for ACL&PCL equivalence is designed as instinctively inspired from natural alignment of Anterior Cruciate Ligament (ACL), Posterior Cruciate ligament (PCL), Lateral Collateral Ligament (LCL) and Medial Collateral Ligament (MCL) as shown in fig. 13.

In this Linkage design the MCL and PCL has not been considered. Thereby simple cross linkage structure is obtained while collateral linkage equivalence is omitted. For Upper four bar linkage mechanism Linkage mechanism for hamstring and quadriceps we have used another four bar linkage which is not independent, but works in sync with other two four bar mechanism. Though This ACL-PCL equivalence linkage mechanism direct link with the link attached to the thigh bone link a10. The ACL-PCL equivalence mechanism is a four bar linkage mechanism comprising a1, a2, a4. Linkages a2 and a4 form cross members. Link a1 is grounded. Link a1 is treated as reference link for all calculations. The upper four bar binary linkage mechanism is shown in fig. 14.

Fig 14 Upper four bar linkage mechanism

The hamstring and quadriceps works similar to springs. Like springs the hamstring and quadriceps contract to cause flexion and extension respectively. So the two muscles can be represented by springs as mechanical equivalent with proper orientation. With two springs it will actuate prosthetics similar to agonist - antagonist working principal. However for current design purpose we have opted for the spring less linkage design at this stage. The link a10 is attached with grounded link a1. The two link forms T-shaped solid rigid link together. Others links comprising the Upper four bar linkage mechanism are a6, a7, and a7. Lower four bar linkage mechanism acts in tandem with upper four bar mechanism and ACL- PCL equivalent mechanism. it is comprised of a2, a6, a7, and a8 links as shown in fig. 15 below.

Fig 15 Lower four bar linkage mechanism

In this part of mechanism a1 and a6 are solidly linked together to form T-shapped link. Irrespective of orientation the linkage mechanism the angle between a3 and a4 is always 90 degree. The link a6 is common to both top both upper four bar mechanism and lower four bar mechanism part. The lower four bar mechanism transmits the force the force to lower limb and produces torques at shank end to cause mobility. It is the lower four bar mechanism which receives
actuating force input from the upper four bar mechanism. This linkage receives actuator input and transmits the force without such that minimum loss of energy.

7. Results

The complete Knee prosthetics linkage mechanism visualized is as shown in fig. 16.

Fig 16. Complete Linkage design of Knee prosthesis

And, its CAD model is drawn using Autodesk Inventor is shown in fig. 17.

Fig.17. CAD Model of Proposed Knee prosthesis

7.1 The kinematics of proposed knee prosthesis

Kinematically the complete prosthetic linkage can be described by kinematics of three parts.

(a) Kinematics of four bar ACL–PCL equivalent linkage mechanism

Kinematic design and analysis equation of ‘four member knee cartilages’ equivalence mechanism is developed considering single degree of freedom. With final range of motion being 0° to 60° has form modeled by equation (1) and (2).

\[
\begin{align*}
\alpha_4 \cos \theta_1 + \alpha_5 \cos \theta_2 &= \alpha_4 \cos \theta_3 + \alpha_5 \cos \theta_4 \\
\alpha_4 \sin \theta_1 + \alpha_5 \sin \theta_2 &= \alpha_4 \sin \theta_3 + \alpha_5 \sin \theta_4
\end{align*}
\]

(1) \hspace{1cm} (2)

(b) The lower four bar linkage mechanism again has single degree of free. The lower mechanism is comprised of the penultimate linkage member which provides the actuation force to the link which is in direct contact with the limb member whose motion is to be controlled. The lower mechanism is conceptualized & designed in accordance with the desired range of motion. The kinematic equation of model of lower linkage mechanism for given range of motion is as by equation (3) and equation (4).

\[
\begin{align*}
\alpha_4 \cos \theta_4 + \frac{\alpha_2}{2} \cos \theta_2 + \alpha_5 \cos \theta_5 &= \alpha_4 + \\
\alpha_6 \cos \theta_6 + \\
\alpha_4 \sin \theta_4 + \frac{\alpha_2}{2} \sin \theta_2 + \alpha_5 \sin \theta_5 &= \alpha_4 + \\
\alpha_6 \sin \theta_6 + \\
\alpha_7 \cos \theta_7 \\
\alpha_7 \sin \theta_7
\end{align*}
\]

(3) \hspace{1cm} (4)

Lower linkage kinematics equation (3) and (4) are used with supplied value of different linkages for given anthropomorphic compatible data. The cadaver leg data has been used for reference as and when required. Anthropometric data incorporation in conceptualization of linkage mechanism helps in rendering ergonomic efficiency.

(c) Third four bar linkage mechanism called upper linkage mechanism is kinematically modeled by equation (5) and (6) as given below. It is upper linkage mechanism which receives driving force input from external power source. So its orientation needs to be adjudged in such a way that input force vector is transmitted with maximum active component.

\[
\begin{align*}
\alpha_4 \cos \theta_4 + \frac{\alpha_2}{2} \cos \theta_2 + \alpha_5 \cos \theta_5 &= \alpha_4 + \\
\alpha_6 \cos \theta_6 + \\
\frac{\alpha_2}{2} \sin \theta_2 + \alpha_5 \sin \theta_5 &= \alpha_4 + \\
\alpha_6 \sin \theta_6 + \\
\alpha_7 \cos \theta_7
\end{align*}
\]

(5) \hspace{1cm} (6)
\[ a_{10} = a_2 \sin \beta_2 + a_2 \sin \beta_1 - a_2 \sin \beta_2 \tag{6} \]

The complete Knee mechanism structure modeled by Kinematic Equation (1), (2), (3), (4), (5) & (6) aptly describes the working of the linkage mechanism. Final complete linkage mechanism is as shown in fig 15. And its CAD modeling is shown in fig 16.

7. Actuation

The actuation system needs to be dimensioned carefully according to the kinematical and dynamical requirements. Representative Clinical Gait Analysis (CGA) data serves as a first estimate of the required output characteristics [20]. A knee joint range of motion of 60° in flexion is sufficient in normal over ground walking. Therefore assistance in sit-to-stand motion has been omitted for the first prototype Torque requirements are predominantly determined by the large peak moment of force occurring at early stance, going up to 50Nm for an average male subject in normal over ground walking [21]. The generated torque is to be transferred to the subject’s lower limb avoiding any excessive load or displacement at the interface. To this end, the knee prosthetics needs to be fitted properly.

In this study we conceptualized a design of mechanism Knee Mimicking Prosthetic Robotic Linkage. Final mechanism (KMPRLM) is as shown in fig 15 and fig. 16. As mentioned in the introductory section, we have designed the (KMPRLM) prototype as proof-of-concept device, primarily intended for the development and testing of design and control concepts for further improvement for which proposed design will act as test bed. For this reason, the design has been tailored to the requirements of an average male subject and for the adjustability of the device only small inter-subject variations have been taken into account. Although aesthetics are important for an end-user product, it is not considered a priority for this prototype. Thanks to its particular mechanical design, the control of the proposed device can remain very simple and basic while the compliant actuation still ensures a safe human-knee joint prosthesis interaction. And last but not least, in case of the actuation, even if the power source fails, the subject remains with a very efficient passive foot.

8. Discussion

The desired result of KMPR-LM is, its kinematics should rival to that of natural knee joint. Minimum flexion angle required for normal walking on plane surface is achieved with knee prosthetics prototype. Adequate range of motion of about 60 degrees supports its utility claim. This is generally achievable through a joint prosthetics which operation is evenly and smoothly spreads over range of its motion.. The optimal KMPR –LM is not one that is kinematically perfect, but one that evenly addresses general design requirement of ergonomics, maneuverability, portability. The mechanical design of linkage mechanism for Knee mimicking robotic prosthesis keeping in mind aforesaid design requirement has been successfully designed and a first prototype/model was developed. In its commercial production format it will have light weight, high strength and stability as well. Above knee amputee (AKA) can use this device for rehabilitation purpose. However it can be used in other walks of common day to day life with convenience. Though proposed design mechanism is mainly for the limb joint rehabilitation, yet with adaptation it can be also used for other joint rehabilitation such as elbow joint rehabilitation, shoulder and wrist also.

9. Conclusion and Future work

A proof-of-concept knee rehabilitation device actuated by linear actuator has been designed for the assessment of mechatronical concepts and as test bed for further improvement strategies. A design of powered transfemoral prosthesis having ability of mimicking able-bodied knee behavior, the KMPRLM is proposed. Currently development of the KMRPLM is ongoing. Next, KMRPLM design is to be subjected to linkage length optimization method based on genetic algorithm. Then simulation validation will to be done to validate design architecture. Once link length is optimized the proposed knee prosthetics will have right shape and dimension according to individual user’s anthropomorphic data. Hopefully with continued improvement to joint prosthetic system, the KMRPLM will become a commercially successful assistive device for joint rehabilitation therapies.

References


[15] https://www.youtube.com/watch?v=bPU9T20qfCD


