A LOW-COST THERAPEUTIC EXERCISE MACHINE FOR MECHANIZED KNEE REHABILITATION

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Abstract- Knee Osteoarthritis (OA) is a degenerative joint disease that causes pain, stiffness, swelling, and reduced mobility, particularly in older adults. Obesity is a significant risk factor for developing knee OA. This leads tosurgery such as total knee replacement (TKR). Rehabilitation therapy becomes more crucial after surgery to achieve a normal knee or leg recovery. High costs and limited access to traditional physical therapy and continuous passive motion(CPM) machine necessitate a more affordable and accessible rehabilitation solution. A low-cost therapeutic exercise machine is designed for mechanized knee rehabilitation, providing controlled, repetitive movements that mimic the natural motion of the knee joint. The machine offers a practical alternative to traditional physical therapy methods. The widespread adoption of this device could reduce healthcare costs and increase accessibility to effective rehabilitation for knee injury patient

Keywords- Rehabilitation, Osteoarthritis (OA), Total Knee Replacement(TKR), Continuous Passive Motion (CPM)

INTRODUCTION

Modern society is increasingly vulnerable to various ailments, including musculoskeletal disorders. Common injuries include arthritis, osteoporosis, fractures (especially in the femur),and podiatric problems like bunions and calluses. Traumatic incidents throughout life can lead to reduced mobility, muscle weakness, stiffness, and, in severe cases, deformities or paralysis. These conditions range from minor aches to permanent disabilities.

Osteoarthritis (OA)is a major health issue, causing pain, fatigue, and functional limitations. It commonly affects joint cartilage and is expected to rise due to obesity and aging. While OA is more prevalent in older adults, many are diagnosed by age 55, often due to sports injuries from activities like football, skiing, and skating.**Work-related musculoskeletal diseases (MSDs)** arise from occupational risks such as repetitive movements, awkward postures, and heavy lifting. Nurses, for example, frequently strain their backs and joints while handling patients, increasing their risk of joint pain.

Sedentary lifestyles and obesity also contribute to these disorders.

Primary Treatments and Management

Exercise is crucial in managing OA, strengthening muscles, improving posture, and reducing stress. Doctors may prescribe NSAIDs to relieve inflammation. Severe cases may require a combination of therapies, including physical therapy, assistive devices, or **joint replacement surgery (arthroplasty)**—where damaged joints are replaced with prosthetics that last up to 20 years.TKR involves resurfacing damaged cartilage and bone surfaces with artificial implants. However, TKR can be life-changing for severe OA patients but requires significant recovery time and potential

complications. Physical therapy strengthens weak muscles and joints, and physiotherapy is also used in cases of neurorehabilitation and paralysisPost-surgery **rehabilitation therapy** is essential to regain mobility, strengthen muscles, and ensure proper recovery. While OA cannot be fully cured, proactive measures like maintaining an active lifestyle, weight management, and good posture can help improve joint health and quality of life.

I.PROBLEM STATEMENT

The cost of attending a single knee rehabilitation therapy session in India is estimated to range from Rs. 400 to Rs. 1,200. Along with this, patients face several challenges, such as traveling to rehabilitation centers (portability issues), financial constraints, and time consumption, leading to significant expenditure of both time and money.Additionally, the physiotherapy method must be modified and determined based on the patient's condition (i.e., age, weight, and severity of the problem). After post-operative surgery, patients are required to stay in the hospital until a physician is assigned to them. Furthermore, the CPM (Continuous Passive Motion) machines used in hospitals are highly advanced, making them difficult to operate for anyone other than professionals, and they lack portability.Moreover, these CPM machines are not widely available in all hospitals; they are mostly found in select multispecialty hospitals located in prime areas, making them difficult for many patients to access.

II. LITERATURE SURVEY

A variety of medications like nonsteroidal anti-inflammatories and opioids can cause severe side effects with limited benefits. Total knee arthroplasty, although a definitive management, comes with risk such as postoperative infections, revisions, and chronic pain. Newer injectable therapies are gaining attention as alternatives to medications because of a safer side effect profile and are much less invasive than a joint replacement. Platelet-rich plasma is beginning to replace the more common injectable therapies of intra-articular corticosteroids and hyaluronic acid, but larger trials are needed to confirm this effect. Small studies have examined prolotherapy and stem cell therapy and demonstrate some benefits. Trials involving genicular nerve block procedures have been successful. As treatments evolve, injectable therapies may offer a safe and effective pathway for patients suffering from knee osteoarthritis.[1]

There is increased interest in nonpharmacological treatments to reduce pain after total knee arthroplasty. Yet, little consensus supports the effectiveness of these interventions. To systematically review and meta-analyze evidence of nonpharmacological interventions for postoperative pain management after total knee arthroplasty. Database searches ofMEDLINE (PubMed), EMBASE (OVID), Cochrane Central Register of Controlled Trials (CENTRAL), Cochrane Database of Systematic Reviews, Web of Science (ISI database), Physiotherapy Evidence (PEDRO) database, and ClinicalTrials.gov for the period between January 1946 and April 2016.Randomized clinical trials comparing nonpharmacological interventions with other interventions in combination with standard care were included. [2]

Adverse knee pain occurs in 10-34% of all total knee replacements (TKR), and 20% of TKR patients experience more pain post-operatively than pre-operatively. Knee pain is amongst the top five reasons for knee replacement revision. Some are Loosening of implant, Instability, Patellar clunk syndrome, Location, and irradiation of the pain, palpation of the periarticular structures is important for identifying neuromas and problems with the size and implantation of the prosthesis. Length of time for which the symptoms have been present. A retrospective study by Erivan showed that in patients with unexplained chronic knee pain following TKR, 4.5% of cases were caused by infection, 2.7% were due to instability without real dislocation, 1.8% were due to placement error from rotational problems, 22.3% were due to loosening in tibia and femoral components, 8.0% were due to polyethylene wear, 33.9% due to periarticular involvement with quadricep deficiency, iliotibial tendinitis, pes bursitis, stiffness.[3]

Knee surgery is a common procedure to treat cartilage defects, soft tissue lesions as cruciate ligaments (ACL/PCL), and osteoarthritis with total or epicondylar knee arthroplasty. After knee surgery, every patient undergoes a long

period of rehabilitation (typically from 6 weeks to 6 months) consisting of long sessions of physiotherapy and medical training therapy carried out by qualified personnel. This procedure is long and expensive and may cause work related pathologies to

physiotherapists. Fortunately, it is generally agreed that robotics may benefit to both patients and physiotherapists due to its ability to repeat tasks with accuracy and its potential to measure the progress of the rehabilitation. This paper aims at providing a critical review of the different proposed robotic solutions and the associated rehabilitation techniques for the knee and for the lower limb in general, with the sake of highlighting the pros and cons and to identify possible promising directions of research. [4]

Because pain, muscle weakness, and physical dysfunction form a vicious circle in OA of the knee, in which muscle weakness is associated with pain and physical dysfunction and influences the progression of the disease, muscle-strengthening exercise may be of primary importance in the prevention and treatment of OA of the knee. Systematic reviews and meta-analyses of studies have established the beneficial effects of exercise in patients with mild to moderate OA of the knee, including muscle-strengthening and aerobic exercises, which have been reported to be effective in reducing pain and improving physical function. Aerobic exercise, walking programs, aquatic exercise, jogging in water, yoga, and Tai Chi have been shown to be effective in improving functional status, gait, pain, and aerobic capacity in people with OA of the knee. Both high- and low-intensity aerobic exercises appear to be equally effective in improving a patient's functional status, gait, pain, and aerobic capacity in people with OA of the knee. It appears that facility-based supervised exercise is superior to independent home-based exercise for pain reduction. [5]

Total knee replacement is one option to relieve pain and to restore function to an arthritic knee. The most common reason for knee replacement is that other treatments (weight loss, exercise/physical therapy, medicines, injections, and bracing) have failed to relieve arthritis associated knee pain. Partial knee replacement —A "partial" or "noncompartmental" knee replacement involves replacing only one part of the knee joint. It may be an option for certain people whose osteoarthritis is limited to only one compartment of the knee. The doctor can repair any damage through small surgical incisions in the skin. Arthroscopy is only helpful for a certain type of knee problems. Arthroscopic surgery has not demonstrated significant benefit for patients with osteoarthritis. Osteotomy is a surgical procedure that involves cutting the leg bone, realigning it, and allowing it to heal. [6]

Despite the advanced age of many patients having total knee arthroplasty, previous attempts to quantify patient function postoperatively have not allowed for normal deterioration of musculoskeletal function that occurs with aging. arthroplasties. A self-administered, validated knee function questionnaire consisting of 55 scaled multiple-choice questions was used in this study. Responses were collected from 243 patients at least 1 year after they had total knee arthroplasties, and from 257 individuals (age- and gender-matched) who had no previous history of knee disorders. Many of these latter subjects reported that they could do most of the activities cited in the questionnaire without symptoms attributable to their knees. Patients who had total knee replacements still experienced substantial functional impairment compared with their age- and gender-matched peers, especially when doing biomechanically demanding activities. [7]

Restricted motion range, also known as knee stiffness, is one of the significant complications after intra-articular or extra-articular injury. Postoperatively, it is primarily due to articular fibrosis (intra and extra) and scarring adhesions in the quadriceps-femoral apparatus after ligament reconstruction, patellar tendon repair, burn, and total knee arthroplasty. Knee stiffness is both preventable and treatable with physiotherapy treatment. Physiotherapy includes electrotherapy and exercises therapy playing an important role in reduction of knee stiffness. The aim of the present study to survey the existing literature related to exercise therapy and electrotherapy programs for the management of post-operative knee stiffness. Based on the literature survey undertaken, the best approach for efficient recovery is to plan and start treatment regime preoperatively that should be continued until achieving knee symmetry postoperatively.[8]

Adequate and intensive rehabilitation is an important requirement for successful total knee arthroplasty. Continuous Passive Motion (CPM) should be implemented in the first rehabilitation phase after surgery, there is substantial debate about the duration of each session and the total period of CPM application. In a randomised controlled trial, we investigated the effectiveness of prolonged CPM use in the home situation as an adjunct to standardised PT. Efficacy was assessed in terms of faster improvements in range of motion (RoM) and functional recovery, measured at the end of the active treatment period, 17 days aftersurgery. Sixty patients with knee osteoarthritis undergoing TKA and experiencing early postoperative flexion impairment were randomised over two treatment groups. Results indicate that prolonged CPM use might have a small short-term effect on RoM. [11]

III. METHODOLOGY

A. BLOCK DIAGRAM

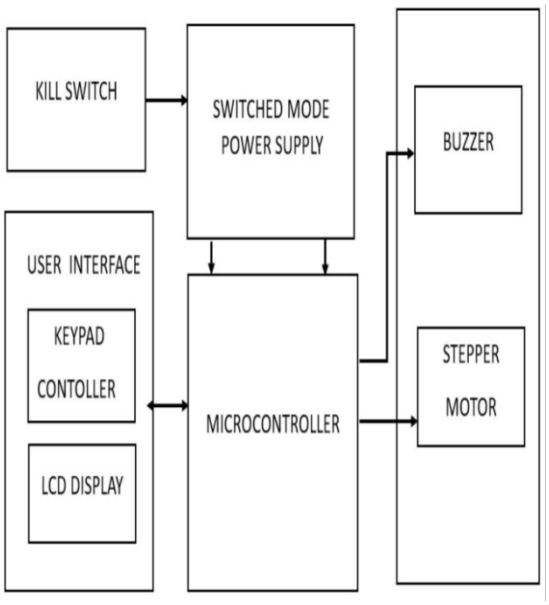

Fig.1 Block Diagram of Proposed System

In order to implement the proposed idea, the block diagram consisting of various blocksbeing used must be configured together as shown in Figure 1. These blocks work in coordination with each other to perform the required task.

B. WORKING

The block diagram mainly consists of two major sides: the transmitting side and the receiving side, which interact with each other through a bridge called a transceiver (a microcontroller in this case). The transmitting block contains a keypad controller and a Liquid Crystal Display (LCD), which are used for input feeding by the user operating the machine. The LCD displays the user's given instructions or iterations.

The receiving side of the block consists of a high-torque stepper motor and a buzzer. The operation of the machine primarily depends on the stepper motor, along with other supporting components. The stepper motor is the main component of the setup and serves as the backbone of the design, enabling movement of the leg-resting part. It performs a specific number of rotations as required by the user. A high-torque stepper motor has been selected to ensure it can efficiently handle the load for which it is designed.

The buzzer alerts the user both before and after key initialization.Regarding the transceiver, a microcontroller is the most suitable device for this application, especially in the embedded systems market and the field of artificial intelligence, which is trending in the modern world. The microcontroller is used to interface hardware components with the user interface by programming the processor/controller in an application-oriented language.

Specifically, these interfaces play a crucial role in ensuring the proper functioning of the machine, which would not be possible without a common programming language for both sides of the block diagram. Therefore, computer-oriented programs and codes are used, typically written in high-level languages such as C, C++, Java, JavaScript, and several others.The blocks in the mechanism require a stable power supply, which is provided by an SMPS (Switched Mode Power Supply) offering 24V DC

C. FLOWCHART

The prototype is activated once the hardware is initialized. A 24V DC supply is regulated through an SMPS (Switched Mode Power Supply) to ensure a stable and reliable power source for the smooth operation of embedded hardware. After powering up, the system enters a standby mode, waiting for user input.

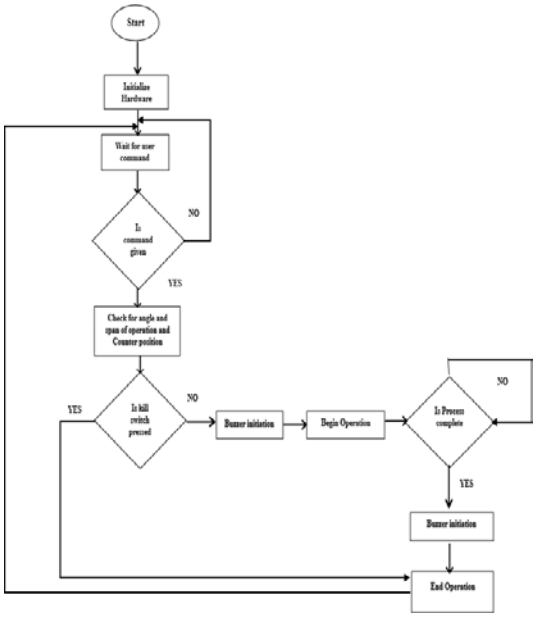

Fig.2 Flowchart of proposed system

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A programmed algorithm processes the user's command, determining its validity. If the command is valid, the system executes the corresponding operation; otherwise, it remains idle until a correct input is received. This ensures that the machine functions only as intended, preventing any unintended actions.

The next phase involves determining key operational parameters, including the angle increments for motor movement, the duration of operation, and the counter's position. A decision-making algorithm assesses the current counter position. If the counter is at C = 0, the system initiates the process with a buzzer alert, followed by controlled angular adjustments for the specified time span.

The operation runs for a set duration, measured in minutes. Throughout this period, the algorithm continuously monitors progress. Once the allotted time is complete, the buzzer alerts the user, indicating that the session has ended and the system is ready for the next set of instructions. If the system is still in progress, it does not interfere with ongoing operations but keeps track of the remaining time.

A crucial safety feature integrated into the system is the kill switch. In case of excessive discomfort or pain, the user can activate the kill switch, which immediately stops the operation, overriding all other processes. This feature is independent of the motor's position, ensuring instant response at any point during motion.

At the end of each cycle, the system resets and returns to the command input stage, awaiting further instructions for the next iteration. The complete process flow is illustrated in Figure 2.

IV. RESULT

Fig. 3 Side View

The side view gives a clear look at how the device is used. A person is seated with their leg placed on the mechanism, interacting with the system comfortably. The strong metal frame provides stability, while the mechanical linkage is designed to guide smooth and controlled movement. The structure isas shown in Figure 3.This provides proper support and alignment, making it easy to use and effective.

Fig.4 Top View

The top view provides a better understanding of the device's overall design. The metal frame holds a cushioned backrest with adjustable straps, likely helping to rest the user's legs with better support and comfort. This view, as seen in Figure 4.Highlights how the components are arranged, ensuring a balance of durability, ease of use, and ergonomic support.

The first position, as defined by the program, is set at an angle of 10 degrees, as shown in Figure 5. When the user inputs a command by pressing key 1 on the keypad, the Arduino initializes the stepper motor to move 10 degrees forward from the initial position (0 degrees).

Once the motor reaches the 10-degree limit, it automatically reverses direction and returns to the initial position. Similarly, the user can select an angle based on the patient's comfort. The program allows multiple key inputs, enabling movement to different positions ranging from 10 degrees to 90 degrees. This is achieved in increments of 10 degrees per step.

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Fig.5 Position1

A patient who has recently undergone surgery is advised to begin rehabilitation a few days after the procedure rather than immediately. During this recovery period, moving a stiff leg, even in small increments, can be quite painful. As a result, an initial movement of 10 degrees may not be the most suitable starting position for every patient.

To accommodate individual comfort levels, the program offers flexibility in adjusting both the speed and the degree of movement. As the patient gradually adapts to the machine, they can modify the settings to increase the range of motion. For instance, by pressing keys 2, 3, or 4, the leg position can be adjusted to 20, 30, or 40 degrees, respectively. This step-by-step progression ensures a gradual and comfortable transition, minimizing discomfort while maximizing rehabilitation effectiveness.

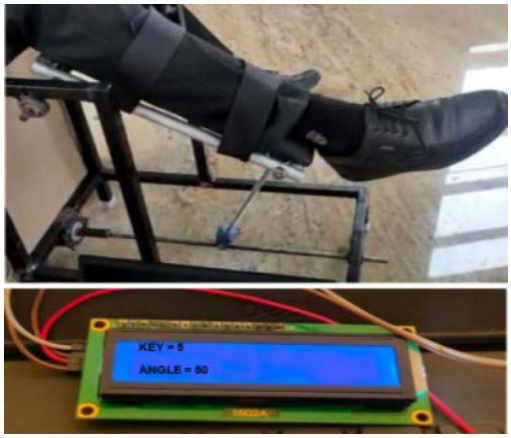

Fig.6 Position2

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As shown in Figure 6, the movement at an angle of 50 degrees is achieved by pressing key 5 on the keypad. Given the patient’s condition, reaching this position may take up to a month. Therefore, during the initial stages of rehabilitation, the speed of movement is deliberately kept slow to ensure a smoother and more effective recovery process.

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