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A Novel Approach for Emerging Fusion of Biomedical and Advanced Engineering for Automation of Ilizarov Fixator

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Abstract **– We experimentally evaluate software and embedded solution for the limb lengthening procedure using Ilizarov fixator. The proposed system is an innovative approach over the existing procedure of manual rotations. The embedded system is used for real time limb lengthening, correction of deformities and treatment of non-unions; safe and easy for patients who currently have to manually turn the screw to lengthen their limb. Automation of fixator is done using a microcontroller and DC motor interface to create a 0.25mm gap four times a day i.e. 1mm (millimeter) per day, which will increase the efficiency of limb lengthening process and save the time. The patient will be informed to remain stable, 10 min prior to the process. For continuous display of real time data (i.e. date and time) LCD display is employed. The data will be sent either to the patient's mobile or to the computer (hyper terminal) via Bluetooth and is simultaneously stored in secondary storage for future reference of the doctor. The designed circuit is stimulated using control techniques of Atmega16 microcontroller which are analyzed by mainly focusing on "Modeling and Simulation of DC Motor using MATLAB". Control System Design and Analysis technologies are very useful to be applied in real-time development which is solved by hardware technology comprising of a micro-controller, dc motor, Bluetooth and a secondary storage device (EEPROM). Additional features include automatic setting of rotation of angle according to the gap required depending on the type of callus formed (normotrophic, hypotrophic and hypertropic).The system attains the goal of 92% - 98% accuracy in creating the required gap automatically.**

Keywords **– Automation of Ilizarov Fixator, Limb Lengthening, Simulink Model of DC Motor.**

I. Introduction

Biomedical Engineering is the potential field related to many applications which are useful to human beings. The Principle on which Limb Lengthening works is "Distraction osteogenesis" which was developed by Prof. G. A. Ilizarov. This revolutionary concept is a mechanical induction of new bone formation (osteogenesis) between bony surfaces that are gradually pulled apart (Distraction) [1]. The desired bone is cut surgically and gradually distracted, leading to a biological bridge between the gaps at the site of the lengthening [1].

There are four phases of Limb Lengthening technique until the bone is fully healed: the surgery, the distraction phase, the consolidation phase and the removal of fixator [8]. For lengthening and deformity correction, the bone is usually cut through a very small incision by the doctor. The distraction phase is the lengthening phase where the bone is actually pulled apart from each other to give space for new bone formation (callus). After the desired length is obtained, the newly regenerated bone is very weak because of lack of calcium within it. The hardening and calcification of the new bone is called the consolidation phase [8]. Finally, the fixator is removed and usually a cast is provided for additional protection.

The device designed for implementation of distraction phase (i.e. Ilizarov fixator) is traditionally manual. The ideal distraction rate should be 0.25mm four times a day i.e. 1mm (millimeter) per day [1]. These manual screw rotations are performed by the patient or the doctor or the relatives who introduced lack of efficiency, increased number of irregularities and risk.

To eliminate this manual work and increase the overall efficiency of the technique automation of Ilizarov's rail fixator is done. Use of microcontroller and DC motor interface is employed to create a 0.25mm gap four times a day. Furthermore, we are storing this real time data in a secondary storage device (EEPROM) which includes date and time of the operation being performed. This data will also be displayed on the LCD screen. The patient is informed by sending a message on the mobile via Bluetooth about the operation being performed, 10 min prior to the process. This further saves doctor's and patient's time and also makes the user-friendly.

The designed circuit is stimulated using control techniques of Atmega16 microcontroller which are analyzed by mainly focusing on "Modeling and Simulation of DC Motor using MATLAB". The microprocessor computes the actual speed of the motor by

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sensing the terminal voltage. It then compares the actual speed of the motor with the reference speed and generates a suitable control signal which is fed into the triggering unit. By using the User Interface Module (UIM) the operator can view and/or change all the control and monitoring variables of the controller program.

Based on clinical experiences of more than 800 limb lengthening cases, classification of different radiographic morphologies related to healing time and weight bearing capacity has been distinguished in normotrophic, hypertrophic and hypotrophic bone regeneration [1]. Hence here, we are comparing the callus (soft new bone) formation with these three types of bone formation and accordingly adjusting the speed of rotations (clockwise or anti-clockwise).

II. Literature Survey

Limb lengthening using Illizarov Fixator is possible and has been performed successfully for about 50 years in Kurgan Russia since 1951 [1] [6]. Limb lengthening and reconstruction techniques are being used to increase the height of dwarf, replace missing bone and lengthen deformed bone segments [6] [7]. The procedures may be performed on both children and adults who have limb length discrepancies due to birth defects, diseases or injuries [5] [6].

Prof. Gavriil Abramovich Ilizarov first developed an external fixation frame that was placed around the leg and he thus instructed a patient to gradually compress the non-union by turning a rod. However, the patient turned the rod the wrong way and which caused separation of the fracture instead of union. After which Prof. Ilizarov noticed that a new bone was formed in the gap between the bone ends which were separated [1]. Recognizing the potential significance of this observation the beginning of much researched and developed technique of limb lengthening was initiated.

Fig.1. Ilizarov Fixator [6]

Fig.2. Rail Fixator [7]

The external fixator used for Limb Lengthening was thus named after Prof. Ilizarov as "Ilizarov's Fixator". The Ilizarov Apparatus is a set of external fixators comprising rings, rods and wires (Fig. 1). It is different from the conventional external fixators in that it encases the limb as a cylinder-the limb itself being shaped like one and it uses wires instead of pins to fix the bone to the rings [7]. Advances have been made and the fixator used in recent times is Ilizarov's rail fixator (Fig.2).

III. DC Motor Modeling

A. System Equation

To perform the simulation of the system, an appropriate model needs to be established. Therefore, a model based on the motor specifications needs to be obtained. Fig. 3 shows the DC motor circuit with Torque and Rotor Angle consideration.

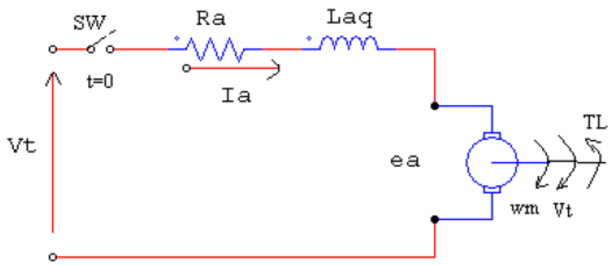

Fig.3. Schematic Diagram of DC Motor [2]

The motor torque T is related to the armature current, i , by a torque constant K;

$$T = Ki \quad (1)$$

The generated voltage, e_a , is relative to angular velocity by

$$e_a = K\omega_a \quad (2)$$

$$K = \frac{d\theta}{dt} \quad (3)$$

From Fig. 3 we can write the following equations based on the

Newton's law combined with the Kirchoff's law:

$$J\frac{d^2\theta}{d^2t} + b\frac{d\theta}{dt} = Ki \quad (4)$$

$$L\frac{di}{dt} + RI = V - K\frac{d\theta}{dt} \quad (5)$$

Using the Laplace transform, equations (3) and (4) can be written as:

$$Js^2\theta(s) + bs\theta(s) = KI(s) \quad (6)$$

$$LsI(s) + RI(s) = V(s) - Ks\theta(s) \quad (7)$$

where's' denotes the Laplace operator. From (7) we can express I(s):

$$I(s) = \frac{V(s) - Ks\theta(s)}{Ls + R} \quad (8)$$

Now, substitute it in (5) to obtain:

$$Js^2\theta(s) = bs\,\theta(s) = K\frac{(V(s) - Ks\theta(s))}{R + Ls} \quad (9)$$

This equation for the DC motor is shown in the block diagram in Fig. 2. From equation (8), the transfer function from the input voltage, V(s), to the output angle θ, directly follows:

$$G_a(s)=\frac{\theta(s)}{V(s)}=\frac{K}{\{s[(R+L_s)(J_s+b)+K^2]\}} \qquad (10)$$

From the block diagram in Fig. 2, it is easy to see that the transfer function from the input voltage, V(s), to the angular velocity ω is:

$$G_v(s)=\frac{\omega(s)}{\upsilon(s)}=\frac{K}{\{s[(R+L_s)(J_s+b)+K^2]\}} \qquad (11)$$

B. MATLAB Representation

To represent the model with m-file, we can perform the Fig. 4 data as follows:

Power P = 0.37 kW
Speed N = 100 rpm
Rotor Inertia J is assumed to be 0.01
Supply voltage = 12 volts.
Calculate the torque constant K:

$$\omega_m=\frac{V_t}{K}=\frac{2\pi N}{60} \qquad (12)$$

K=1.4

By using equation (3) for $\omega=\frac{d\theta}{dt}$

$$Ki=\frac{d\omega}{dt}+b\omega \qquad (13)$$

At the steady state (used as analyzed data), both I and ω are stabilized:

$$\frac{d\omega}{dt}=0$$

$$T=\frac{P}{W} \qquad (14)$$

$$b=\frac{Ki}{\omega} \qquad (15)$$

Following values are assigned to be used for our desire DC Motor Model:
Vt = 12V; J=0.01; b=0.02; K=1.4; Ra=0.0135 Ω; La=1.3 mH. By calculating and assuming the required data as above.

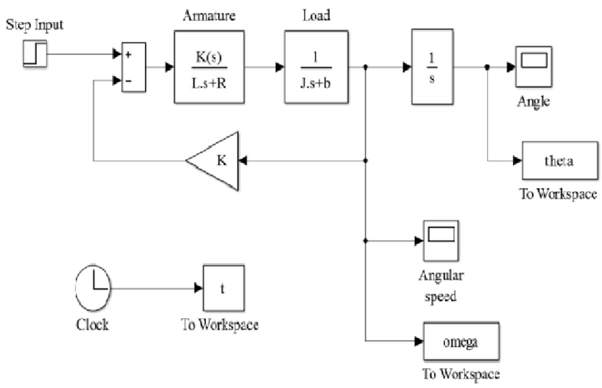

Fig.4. DC Motor Closed Loop System

C. Simulink Model

The block diagram can be represented and created as a model as shown in Fig. 5. The approach to construct this model can easily be done by using Simulink Library. The M- file and Simulink model can be combined by the commands used in M-file.

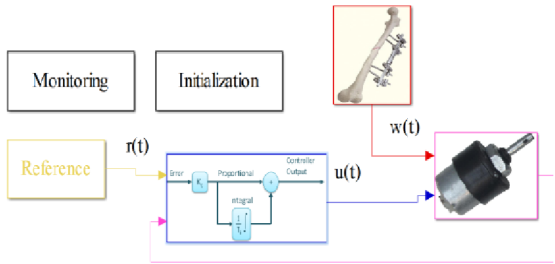

Fig.5. Simulink Model

IV. Hardware Description

A. System Overview

Initially, the fixator is attached to the bone invasively and the bone is cut surgically by the doctor. The motor is made to rotate four times a day by the distance of 0.25mm so as to achieve 1mm gap per day [2]. Rotations are done by the motor which is driven through a relay using a microcontroller [4]. Rotations are also controlled according to the formation of new bone. The system also consists of Bluetooth for viewing the data on the computer using hyperlink or a mobile and EEPROM for storing the data. Moreover a message would be sent to the patient to remain stable before the process starts. The block diagram of the proposed system is shown in Fig. 6.

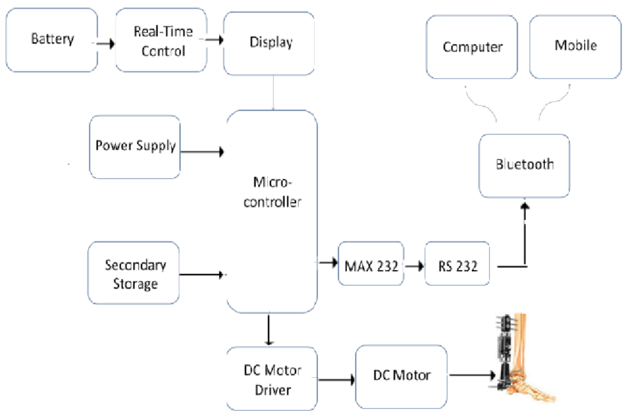

Fig.6. Block Diagram of the system

B. System Flow

The flow of the proposed system is as shown in Fig. 7. As the power supply is turned ON, the LCD is initialized and it displays the date and time. Ten minutes prior the process begins a message is send to the patients mobile for being stable and the process is about to begin. After 10 minutes, the operation is performed and message is send to patient's mobile informing that the operation is successful.

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The microcontroller also checks for the interrupt if any through Bluetooth. If an interrupt is detected then it checks for the alphabet, if C-change of angle is can be made; if R-Database can be retrieved and also date and time can be updated; if A-anticlockwise rotations can be performed.

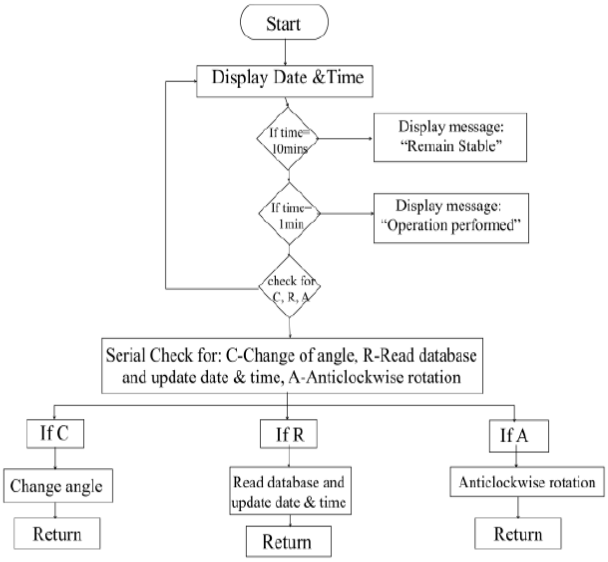

Fig.7. Flow of the hardware system

V. Software Description

A. System Overview

In software part of our project we are including image processing. Based on clinical experience of more than 800 limb lengthening catagni has classified different radiographic morphologies related to healing time and weight bearing capacity. Based upon these observations it is distinguished between normotrophic, hypertrophic and hypotrophic bone regeneration [1]. For this we have collected database which includes x-rays of various bone formation of these three types shown in Fig. 8. Further, we are comparing the callus (soft bone) formation using the concept of DIP and accordingly adjusting the rotations (clockwise and anti-clockwise).

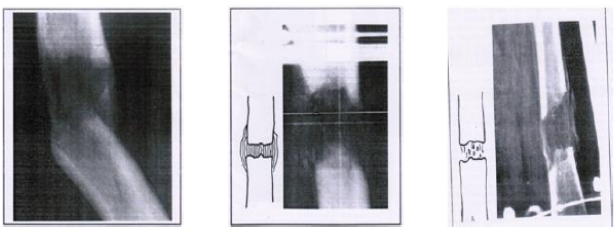

Fig.8.a) Normotrophic b) Hypertrophic c) Hypotrophic [1]

B. System Flow

The flow of Software system proposed is as shown in Fig. 9.

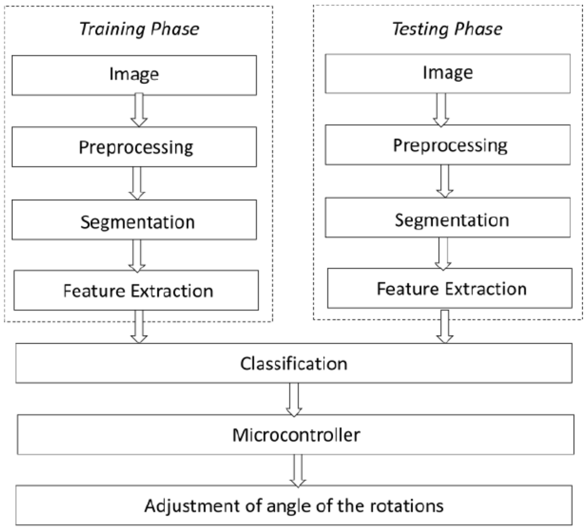

Fig.9. Flow of Software System

VI. Result

After the feasible result obtained from the simulation, automation of the fixator is done, a hardware kit has been developed. The kit consists of a power supply unit, microcontroller, Bluetooth module, dc motor and dc motor driver, LCD module, secondary storage (EEPROM) and a real time clock. The motor is being rotated and the date and time of operation is displayed on LCD module as well as on the patient's mobile or computer. The data is also getting stored in EEPROM for the doctor's reference.

Table I: Result table

Angle	Gap (in mm)	No. of rotation
45^0	0.125 mm	$1/8^{th}$
90^0	0.250 mm	$1/4^{th}$
135^0	0.375 mm	$3/8^{th}$
180^0	0.500 mm	½
360	1mm	1

Table I. shows the angle and rotation for which the gap is being formed. For example, to create a gap of 1mm, we need 1 full rotation of the fixator i.e.; 3600.

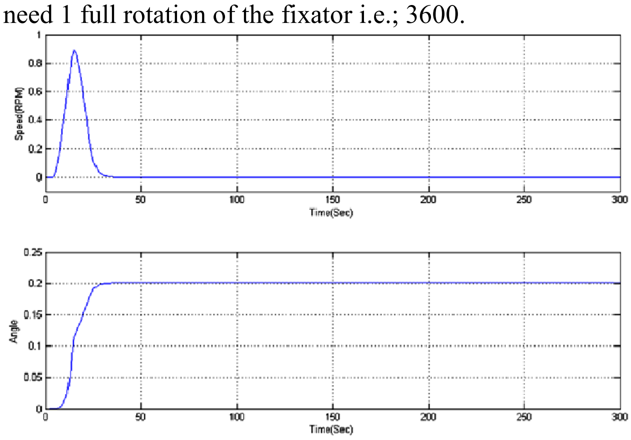

Fig.10. Analysis of DC Motor

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The speed of the D Motor is kept constant while the angle of rotation is changed by 0 for fraction of seconds in an attempt to achieve 0.25mm gap between the bones. The analysis of the same is shown in Fig.10.

In software part, the x-rays of types of bone being formed are collected and further compared with the x-ray of the patient's bone being operated. Here, the type of bone being formed is detected and its result is displayed on the screen and simultaneously a voice output is given.

VII. Conclusion

It is an attempt to automate the process of gap extension in bone. By automating limb lengthening process patient can easily distract the fixator without any mechanical device. It becomes easier for the patient, as there is no need for the patient to always memorize that he has to make a rotation of 1mm a day. Also the efficiency of the unit increases hence the process completes in time. The system has successfully overcome quite a few shortcomings of the existing systems by reducing the maintenance and complexity, at the same time providing a flexible and precise form of maintaining the gap of 1mm daily. The results obtained from the process have shown that the system performance is quite reliable and accurate. Furthermore the data including the real time date and time of operation is being stored for future reference so it is feasible for doctor to analyze. The rotations are further adjusted as and when required after the analysis of type of new bone (callus) formed.

The kit is designed in such a way that it remains lighter so that the patient can carry it along without much load and also it is seen that the cost is kept minimum as according to the medical analysis most of the people undergoing through this treatment are quite poor.

Hence, our project eliminates manual manipulation of the screw, removes the irregularities of the patient if he forgets to rotate the fixator and also makes the process safe and easy for patients.

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