A Novel Approach for Embedded based Process Automation of Ilizarov Fixator used for Limb Lengthening

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Abstract: We propose and experimentally evaluate an 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. The system comprises of a micro-controller, dc motor, Bluetooth and a secondary storage device (EEPROM). 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 EEPROM for future reference by the doctor. Additional features include automatic setting of angle according to the gap required depending on the type of callus formed (normotrophic, hypotrophic and hypertrophic). The system attains the goal of 92% - 98% accuracy in creating the required gap automatically.

Key Words: limb lengthening, Ilizarov fixator, automation

1. INTRODUCTION

Engineering is the potential field related to many applications which are useful to human beings. Distraction osteogenesis is a mechanical induction of new bone between bony surfaces that are gradually pulled apart [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 two phases of lengthening until the bone is fully healed: the distraction phase and the consolidation phase [9]. The device (i.e. Ilizarov fixator) shown in fig. 3 and fig. 4, designed for implementation of distraction phase is traditionally manual (the manual turns are performed by the patient or the doctor).

To eliminate this manual work and increase the overall efficiency of the technique automation of fixator is done. Use of microcontroller and DC motor interface is employed to create a 0.25mm gap four times a day i.e. 1mm (millimeter) per day [1]. 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 doctors and the patient’s time and also makes the system user-friendly.

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]. Hence here, we are comparing the callus (soft new bone) formation with these three types of bone formation and accordingly adjusting the rotations (clockwise and anti-clockwise).

Figure 1. External Fixator [6]  Figure 2. Rail Fixator [7]
2. PROPOSED DESIGN OF AUTOMATION OF FIXATOR

Design part consists of hardware and software. An embedded system is designed to automate the rotations of the fixator by using a DC motor, interfaced with ATMEGA16 microcontroller, storing the real time data of the operation being performed and simultaneously displaying it on the LCD display [4]. Furthermore, we are comparing the callus (soft bone) formation using the DIP concept and accordingly varying the rotations.

2.1 HARDWARE DESCRIPTION

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.3.

![Figure 3. Block Diagram of the system](image)

2.1.1 Power Supply

Power supply is the first and the most important part of our project. For our project we require +5V & +12V regulated power supply with maximum current rating 500mA. Following basic building blocks are required to generate regulated power supply.

The AC mains supply is applied to 12v step down transformer. The transformer output is 12v AC which is rectified using Diode Bridge W10M. The output of W10M is DC 12v which is further filtered by a 1000uf capacitor, and then regulated using IC 7805. The output of 7805 is +5v dc which is required for microcontroller operation. Also an LED in series with 220 Ohms resistor is used for power on indication.

2.1.2 Bluetooth Module

Bluetooth transmitter and receiver module provide Bluetooth interface via serial communication. It is connected with microcontroller and acts as serial interface as a mean of communication. Here we have used AUBTM-20 Bluetooth Module which is (w/l/h) 14mm*30mm*2mm in dimensions. The module is designed to be embedded in a host system which requires cable replacement function.

2.1.3 Micro-controller
The microcontroller ATMEL is provided with all necessary connections and its operations. It is the heart of our circuit. The 12 MHz crystal along with two capacitors provides the clock circuit to microcontroller. This Microcontroller is 40 pin IC, having some inbuilt functions such as ADC, DAC etc.

2.1.4 DC Motor and DC driver
Since microcontroller cannot provide sufficient power required to drive the DC motor, we have used a driver circuit to drive the DC motor. DC motor required high power so there must be isolation between microcontroller and DC motor. For DC motor Driver we have used L293D IC.

2.1.5 Secondary Storage Device
Here we are using EEPROM as a storage device. The real time data is stored and can be retrieved using a computer or mobile via Bluetooth technology.

2.1.6 Real Time Clock
We are using 64*8 serial real time clock, DS1307. Real time clock counts seconds, minutes, hours, date of the month, month, day of the week, and year with leap year compensation valid up to 2100. It has 56 byte non volatile RAM for data storage, 2-wire serial interface, programmable square wave output signal, automatic power-fail detect and switch circuitry and also consumes less than 500 nA (nano-ampere) in battery backup mode with oscillator running.

2.1.7 LCD Module
The display section consists of 16*2 LCD, which used to display the real time date and time of the operation being performed and also displaying a message of remaining stable 10 min. prior to the process. LCD interface is a parallel bus which allows simple and fast reading/writing of data to and from the LCD. It needs +5V supply.

2.2 HARDWARE IMPLEMENTATION
The flow of the proposed system is as shown in Fig. 4. 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. 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.

![Figure 4. Flowchart of hardware implementation](image-url)
2.3 SOFTWARE DESCRIPTION

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 the fig. 5, fig. 6 and fig. 7. Further, we are comparing the callus (soft bone) formation using the concept of DIP and accordingly adjusting the rotations (clockwise and anti-clockwise). The flow of software is shown in fig. 8.

![Figure 5. Normotrophic [1]  Figure 6. Hypertrophic [1]  Figure 7. Hypotrophic [1]](image)

3. APPLICATIONS
- To increase the height of Dwarfs.
- Bone infections.
- Limb lengthening and correction of deformities.
- Treatment of non-unions and malunited factures.
- Correction of deformities of limbs.
- Lengthening of foot stumps, limb stumps and fingers.
4. 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. 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.

The following table a. 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.; $360^\circ$.

<table>
<thead>
<tr>
<th>Angle</th>
<th>Gap (in millimetre)</th>
<th>No. of rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>45$^\circ$</td>
<td>0.125 mm</td>
<td>1/8$^\text{th}$</td>
</tr>
<tr>
<td>90$^\circ$</td>
<td>0.250 mm</td>
<td>1/4$^\text{th}$</td>
</tr>
<tr>
<td>135$^\circ$</td>
<td>0.375 mm</td>
<td>3/8$^\text{th}$</td>
</tr>
<tr>
<td>180$^\circ$</td>
<td>0.500 mm</td>
<td>½</td>
</tr>
<tr>
<td>360$^\circ$</td>
<td>1 Mm</td>
<td>1</td>
</tr>
</tbody>
</table>

5. 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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7. REFERENCES