



Non-Invasive Measurement of Stress Levels in Knee Using IOT

Jayakumar S^{1*}, Martin Joel Rathnam²

¹ Associate Professor (Department of Electronics and Communication Engineering, Sri Sairam College of Engineering, VTU)

² Assistant Professor (Department of Electronics and Communication Engineering, Sri Sairam College of Engineering, VTU)

ABSTRACT

As Knee replacement surgery has become widely prevalent with a high success rate in the short to medium term. However, over the long term, implant degradation may occur due to wear and tear. To address this issue, a potential solution involves using a PIC controller to monitor and compare pressure levels, displayed on an LCD. This system employs a load cell to detect stress, which causes changes in inductance. Additionally, Internet of Things (IoT) technology, through wireless connectivity such as Bluetooth, is integrated with an Android mobile app for continuous monitoring of knee pain based on the weight applied.

Keywords: IOT, Keypad, LCD, LCD PIC Controller, Load Cell.

1 Introduction

Knee pain is a common issue that affects many people, with various factors contributing to its development. It can either be referred pain or pain directly related to the knee joint. A sedentary lifestyle and certain work environments can contribute to knee pain, as reduced physical activity weakens the muscles around the knee. This, in turn, can affect blood circulation and lead to painful conditions. In this system, the primary objective is to assess the condition of the knee and determine whether the pain is treatable. A keypad is used to input the person's weight, while a load cell measures the stress on the leg. The controller then compares the weight data from the keypad with the stress readings from the load cell and provides an accurate assessment of the knee's condition, which is displayed on an LCD screen.

2 Recent Works

A prospective randomized study was conducted to investigate whether a design modification in the articular surface geometry of the Optetrak total knee prosthesis—intended to enhance joint conformity and further reduce polyethylene stress—affected implant survival, especially with the all-polyethylene version. The study included 47 patients undergoing bilateral simultaneous total knee arthroplasty, who were randomly assigned to receive a polyethylene tibial component and followed for an average of 11.6 years.

In the monitoring system, the affected knee is subjected to pressure on a load cell, chosen for its high coupling coefficient and sensitivity to stress. Thin 25 μm ribbons were cut into rectangular strips (48 mm $\times$ 7 mm), with four strips stacked and bonded using epoxy resin to



form a solid core. To replicate the femoral condyles, a model with spherical articulating surfaces (20 mm radius) was fabricated from polypropylene.

A key advantage of this approach is that it eliminates the need for secondary windings, allowing for in vivo monitoring without requiring additional circuitry. Timely and accurate monitoring of implant stress can help extend the lifespan of knee implants, reducing the costs associated with replacements. The increasing number of total knee replacement surgeries is driven by factors such as an aging population, higher life expectancy, and a trend toward younger patients undergoing the procedure

3 Proposed Work Explanation

When external stress is applied to the material, it causes the realignment of its magnetic domains, which in turn introduces magneto-elastic anisotropy. This change in the material's structure results in a variation in its permeability. As a consequence, there is a shift in the flux density, which can be detected through an induction coil placed in close proximity to the magnetic material. Essentially, this setup allows us to observe how the stress-induced changes in the material affect its magnetic properties—akin to watching a magnetic "dance" with every tweak of external pressure.

This phenomenon is not just a scientific curiosity but a powerful way to measure stress in materials, offering insight into the subtle yet significant interplay between mechanical forces and magnetic behaviors. Think of it like a secret handshake between physics and materials science!

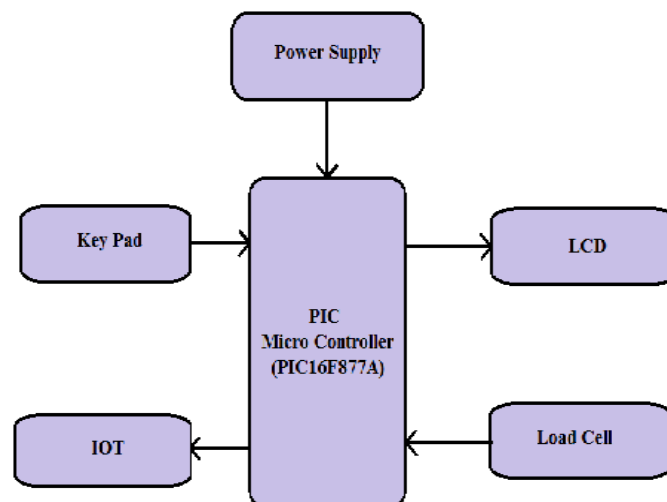


Figure 1: Block diagram of the proposed methodology

3.1 PIC16F877A Microcontroller

The PIC16F877A is an 8-bit microcontroller based on CMOS FLASH technology and is compatible with the PIC16C5x, PIC12Cxxx, and PIC16C7x families. It offers fast 200 ns instruction execution, 256 bytes of EEPROM data memory, self-programming, in-circuit



debugging (ICD), two comparators, 8 channels of 10-bit Analog-to-Digital (A/D) converters, two capture/compare/PWM modules, a synchronous serial port supporting both 3-wire SPI and 2-wire I2C communication, a USART, and a parallel slave port. The Program Counter (PC) tracks program execution by holding the address of the current instruction, which is automatically incremented during execution. The PIC16F877A series features an 8-level, 13-bit deep hardware stack that is used exclusively for subroutine calls and interrupt handling. The stack operates separately from the program and data memory and cannot be directly read or written to. The CALL instruction pushes the return address onto the stack, and the RETURN instruction pops the address when the subroutine completes.

3.2 Load Cell

A load cell is a transducer that converts a physical force into an electrical signal proportional to the measured force. Common types include hydraulic, pneumatic, and strain gauge load cells, with strain gauge load cells being the most widely used due to their stiffness, high resonance, and long lifespan. Strain gauge load cells operate on the principle that the resistance of a strain gauge changes when it deforms as the load on the cell changes.

Typically, four strain gauges are used in a full-bridge configuration to enhance sensitivity and temperature compensation. Two gauges (T1 and T2) are placed under tension, and two (C1 and C2) under compression. When a force is applied, the gauges in compression (C1 and C2) decrease their resistance, while those in tension (T1 and T2) increase their resistance. This differential change in resistance produces a measurable voltage difference, which is proportional to the applied load.

3.3 Keypad

Keyboards are commonly organized in a matrix of rows and columns. The CPU accesses both rows and columns through ports, and with two 8-bit ports, an 8x8 matrix can be connected to a microcontroller. In a 4x4 keypad, the rows are connected to output ports, and the columns are connected to input ports. When no key is pressed, the input ports read high (1s), as they are connected to the voltage supply (Vcc). When a key is pressed, it creates a connection between a row and a column, causing one column to read low (0). The microcontroller continuously scans the keypad to detect which key is pressed, identifying the active key by determining the corresponding row and column.

3.4 IoT (Internet of Things)

Wireless connectivity is a fundamental component of the Internet of Things (IoT), enabling the communication between embedded systems in various sectors such as healthcare, smart buildings, transportation, and industry. These systems, often referred to as Machine-to-Machine (M2M) communication, use a variety of wireless data transfer technologies such as Wi-Fi (802.11), Bluetooth (3.0 and 4.0), and ZigBee. While IoT devices may include both new and legacy equipment, they rely on wireless protocols to connect to each other and share data. Effective IoT communication is rarely a direct link between two machines; instead, it typically



involves a network of devices, sensors, controllers, and servers. Centralized intelligence is often located in a gateway server, simplifying the devices themselves. The RS9113 M2MCombo chipset by Redpine provides an ideal solution for IoT, supporting dual-band Wi-Fi, Bluetooth, and ZigBee, enabling efficient M2M networking.

3.5 LCD (Liquid Crystal Display)

An LCD is a type of display technology commonly used in devices like digital watches, portable computers, and monitors. It consists of two layers of polarizing material with a liquid crystal solution between them. When an electric current passes through the liquid crystal, the crystals align, blocking or allowing light to pass through. This ability to control light transmission enables LCDs to display images. Over time, advancements in LCD technology have improved their brightness, resolution, and response times, making them more efficient and cost-effective.

Modern LCDs often feature a backlight for better visibility, and improvements such as pixel-level light control have enhanced their ability to display sharp images and small text.

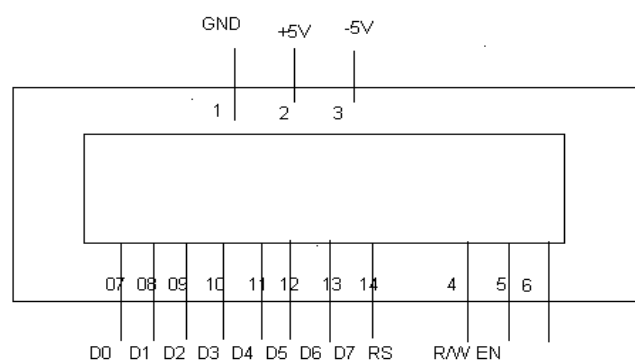


Figure 2: Pin Configuration of LCD

3.6 Power Supply

The power supply unit in this system consists of several key components: a step-down transformer, bridge rectifier, input filter, voltage regulators, output filter, and an indicator unit. The step-down transformer reduces the mains voltage of 230V AC to lower voltages, which are required by the ICs used in the project. A diode bridge, composed of four diodes arranged in a bridge configuration, ensures that the output voltage maintains the correct polarity regardless of the input voltage's polarity. This bridge rectifier is primarily used to convert alternating current (AC) into direct current (DC) output. Capacitors are employed as filters to smooth out any ripples in the DC voltage, providing a steady and pure DC output. The capacitors charge and discharge to perform this filtering action effectively.



3.7 Software Description

Embedded C

Embedded C is an extension of the C programming language designed by the C standards committee to address the unique challenges of embedded systems. Embedded C adds features such as fixed-point arithmetic, memory management for multiple distinct memory banks, and direct hardware I/O operations—extensions not typically found in standard C. In 2008, the C Standards Committee introduced updates to the C language to standardize these embedded system-specific features, providing a unified approach for all implementations. Embedded C retains the core syntax and semantics of standard C, including the `main()` function, variable definitions, data type declarations, conditionals (`if`, `switch`, `case`), loops (`while`, `for`), functions, arrays, structures, unions, bitwise operations, and macros.

Keil Software

Keil Software is a leading provider of development tools for 8/16-bit microcontrollers, holding the top spot in the 2004 Embedded Market Study by Embedded Systems and EE Times. Since its introduction in 1988, the Keil C51 Compiler has become the industry standard, supporting over 500 variants of 8051 microcontrollers. Keil now offers development tools for ARM-based microcontrollers as well, including compilers, assemblers, real-time kernels, debuggers, simulators, integrated development environments (IDEs), and evaluation boards. The Keil μ Vision Debugger simulates the complete ARM instruction set and on-chip peripherals for ARM devices, such as the Atmel AT91 family, offering full peripheral simulation. New features in the μ Vision Debugger include an integrated Software Logic Analyzer to measure I/O signals and program variables, and an Execution Profiler that tracks the time spent on each function, source line, and assembler instruction. These tools allow developers to create detailed simulations of their target hardware, optimizing code and signal processing algorithms without requiring additional test equipment. The Logic Analyzer and Execution Profiler aid in refining performance by pinpointing bottlenecks in program execution.



Block Diagram of μ Vision3 IDE

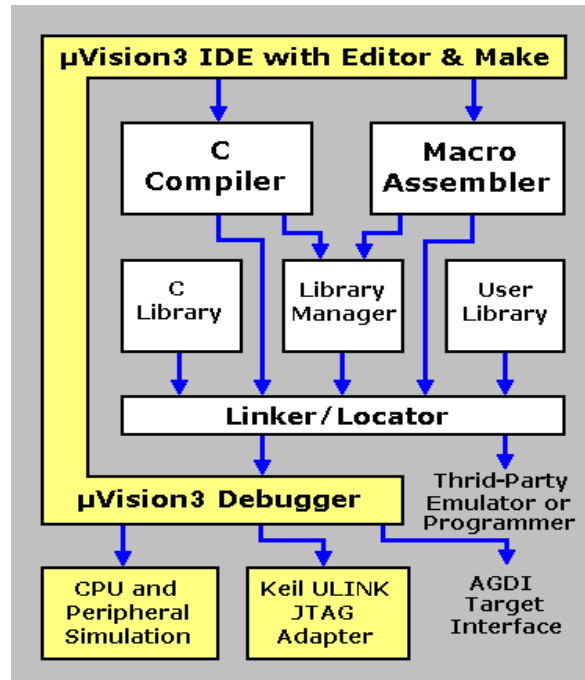


Figure 3: Block Diagram of the Micro vision 3 IDE

4 Results and Discussion

This approach eliminates the need for secondary windings, making it suitable for in vivo monitoring without the need for additional circuitry. By enabling effective and timely monitoring of implant stress, it can help extend the lifespan of knee implants, ultimately reducing the costs associated with replacements. The number of total knee replacement surgeries is steadily increasing due to factors such as a growing population, higher life expectancy, and a general trend of younger patients undergoing the procedure.

The system is designed to assess whether knee pain is improving or not. The keypad allows the user to input the person's weight, and the load cell measures the stress on the leg. The controller compares the weight input from the keypad with the stress measured by the load cell and determines the condition of the knee. This information is then displayed on an LCD screen. In the case of knee pain, the user enters their approximate weight on the keypad, and the affected knee is pressed onto the load cell. The pressure applied to the load cell is compared to the weight entered on the keypad by the PIC microcontroller. The pressure is then converted into a voltage, transforming a non-electrical quantity into an electrical signal. The final result is shown on the LCD for immediate feedback, and through an IoT module, the data is transmitted via Bluetooth to an Android mobile app for continuous monitoring of the knee's condition.



Figure 4: *Knee replacement*

Experimental Results

The outputs verified from the experimental setup are noted down and presented below;

Table 1: *Representation of weight laid (in Kg) versus force sensor outputs*

Sl.no	Weight laid (in kg)	Force Sensor Output (ADC Units)
1	0	0
2	2	32
3	5	60
4	7	85

Graph 1: *Graphical representation of weight laid versus force sensor outputs*

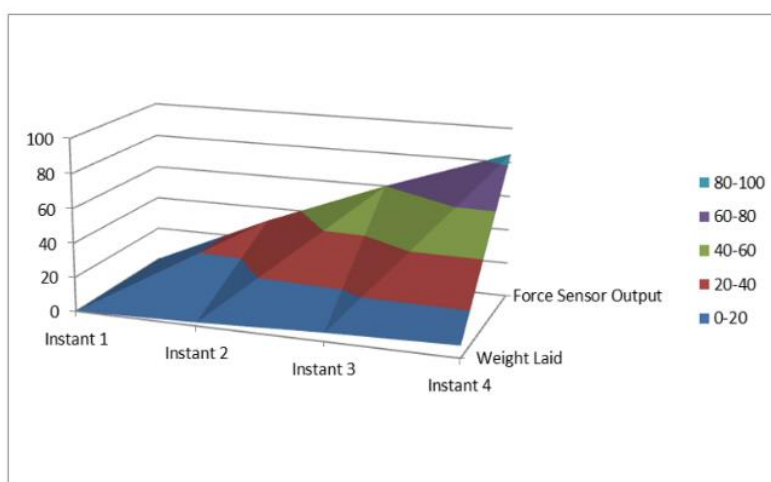
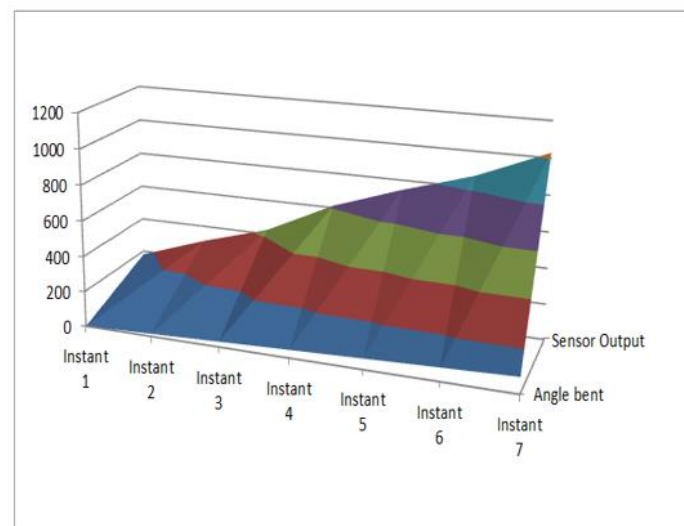




Table 2: Representation of angle bent versus sensor outputs

Sl.No	Angle bent (approximately)	Sensor Output (ADC Units)
1	0	180
2	15	311
3	30	425
4	45	612
5	60	746
6	75	865
7	90	1029

Graph 2: Graphical representation of angle bent versus force sensor outputs



5 Conclusions

In many cases, knee implant failure is primarily due to insufficient post-operative care. The proposed methodology aims to address this issue by continuously monitoring the patient's implants using multiple sensors and IoT technology.

References

1. Porter; Borroff; Gregg; MacGregor; Tucker; Howard, Year: 2013, "National Joint Registry for England, Wales and Northern Ireland", 10th Annual Report, Vol: 25.
2. Heinlein; Bernd; Ines Kutzner; Friedmar Graichen; Alwina Bender; Antonius Rohlmann; Andreas Halder; Alexander Beier; Georg Bergmann, Year: 2009, "ESB Clinical Biomechanics Award 2008: Complete data of total knee replacement loading for level walking and stair climbing measured in vivo with a follow-up of 6–10 months", Clinical Biomechanics, Vol: 24, no. 04, pp. 315-326.



3. Dlima; Darry; Shantanu Patil, Nikolai Steklov; John E. Slamin; Clifford W. Colwell Jr, Year: 2006, "Tibial forces measured in vivo after total knee arthroplasty", The Journal of arthroplasty, Vol: 21, no.0 2, pp. 255-262.
4. Arami; Arash; Matteo Simoncini; Oguz Atasoy; Willyan Hasenkamp; Shafqat Ali; Arnaud Bertsch; Eric Meurville, Year: 2011, "Instrumented prosthesis for knee implants monitoring", In *2011 IEEE international conference on automation science and engineering*, pp. 828-835.
5. Taylor; Walker; Perry; Cannon; Woledge, Year: 1998, "The forces in the distal femur and the knee during walking and other activities measured by telemetry", The Journal of arthroplasty, Vol: 13, no. 4 pp. 428-437.
6. Kirking; Bryan; Janet Krevolin; Christopher Townsend; Clifford W. Colwell ; Darry Lima, Year: 2006 "A multiaxial force-sensing implantable tibial prosthesis", Journal of biomechanics,, Vol: 39, no. 09, pp. 1744-1751.
7. Heinlein; Bernd; Friedmar Graichen; Alwina Bender; Antonius Rohlmann; Georg Bergmann, Year: 2007, "Design, calibration and pre-clinical testing of an instrumented tibial tray", Journal of biomechanics, Vol: 40.
8. Mohanty; Lipi; Swee Chuan Tjin; Denny TT Lie; Silvino EC Panganiban; Pierce KH Chow, Year: 2007, "Fiber grating sensor for pressure mapping during total knee arthroplasty", Sensors and Actuators A: Physical, Vol: 135, no. 2, pp. 323-328.
9. Hasenkamp; Thevenaz; Villard; Bertsch; Arami; Aminian; Terrier; Renaud, Year: 2013, "Design and test of a MEMS strain-sensing device for monitoring artificial knee implants", Biomedical microdevices, Vol: 15, pp. 831-839.
10. Wang; Yiting; Shah Nazir; Muhammad Shafiq, Year: 2021, "An overview on analyzing deep learning and transfer learning approaches for health monitoring", Computational and Mathematical Methods in Medicine, no. 1.