Measuring and Implementing Lower Limb Motion Using Inertial Measurement Unit

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Abstract - Realistic virtual training system has attached great attentions for decades in the field of military simulation. In this system, we aim in the development of a low cost wireless real-time inertial limb tracking system for virtual training. The system is designed to provide highly accurate human body motion capture by combining low cost inertial measurement units (IMUs). The 9 Degrees of Freedom (DOF) Inertial Measurement Unit (IMU) sensor is used for sensing motion and is an ideal sensor system for motion control of systems that require to control the pitch, roll and yaw. The 9DOF Razor IMU sensor incorporates three sensors - an ITG-3200 (MEMS triple-axis gyro), ADXL345 (triple-axis accelerometer), and HMC5883L (triple-axis magnetometer) - to give nine degrees of inertial measurement. First, MEMS IMU sensors are placed on user's body and limbs according to human skeletal action, and each sensor performs 9 degrees of freedom (DOF) tracking at a high-speed update rate. Second, the collected sensor's data are transferred through Microcontroller. The inner communication between the MCU and the IMU is I2C. Finally, the IMU sensor values is serial communicated with Mat lab based PC Program for Motion detection.

I. Introduction

Optical Mocap systems are expensive and require very complicated calibration process, making them not feasible for non-professional and inexperienced users. An alternative low cost and non-obtrusive optical Mo cap solution for simple virtual training is to use one or multiple Microsoft RGB- D camera Kinect as the tracking sensor. The Microsoft Kinect for Windows Software Development Kits (SDK) takes the Kinect data from the sensor and provides a skeletal representation of recognized users. However, all Kinect- based Mocap solutions suffer from a vital restriction which is that the user must face forward to the sensor, making Kinect not capable of performing complex motion capture, e.g., 360 degree freedom motion. Recently, low cost miniaturized MEMS inertial sensors, e.g., accelerometer, gyroscope, and magnetometer, have been successfully utilized in real-time human motion tracking. Due to their acceptable accuracy, relative low cost, light weigh compact in size, and easy to use, these wearable MEMS inertial sensors rapidly become one of the most promising solutions for human motion tracking.

II.Embedded systems

Sophisticated embedded systems have enormous hardware and software complexities and may need scalable processors or configurable processor s and programmable logic arrays. They are used for cutting edge applications that need hardware and software co-design and integration n the final system; however, they are constrained by the processing speeds available in their hardware units. Thus the Embedded is used in any fields such as Automobiles, Telephones, Appliances and Peripherals for computer systems. These are called embedded systems. It is a dedicated computer-based system for an application(s) or product. While some embedded systems are very sophisticated.

III. Inertial measurement unit

An inertial measurement unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the magnetic field surrounding the body, using a combination of accelerometers and gyroscopes, sometimes also magnetometers. A inertial measurement unit works by detecting the current rate of acceleration using one or more accelerometers and detect changes in rotational attributes like pitch, roll and yaw using one or more gyroscopes and some also include a magnetometer, mostly to assist calibration against orientation drift. Inertial navigation system contains IMUs which have angular and linear accelerometers to measure changes in position. Some IMUs also have a gyroscopic element for maintaining an absolute angular reference. Angular accelerometer measure how the limb is rotating in space. Generally, there is at least one sensor for each of the three axis: pitch (up and down), yaw (left and right), and roll (clockwise or counter-clockwise). Linear accelerometer measures non-gravitational acceleration.

IV. ARM 7

ARM was an acronym for Advanced RISC Machine. ARM7 is one of the widely used micro-controller family in embedded system application. The ARM was originally developed at Acorn computers limited of Cambridge, England between 1983 and 1985. It was the first RISC microprocessor developed for commercial use and has some significant difference from subsequent RISC architectures. LPC2148 is the widely used IC from ARM-7 family. It is manufactured by Philips and it is preloaded with many inbuilt peripherals making it more efficient and a reliable option for the beginners as well as high end application developer. ARM describes a family of computer processor designed in accordance with a RISC CPU design developed by British company ARM holdings. It is 32-bit microcontroller architecture. This generation introduced the Thumb 16-bit instruction set providing improved code density compared to previous designs. The most widely used ARM7 designs implement the ARMv4T architecture, but some implement ARMv3 or ARMv5TEJ. ARM7TDMI has 37 registers. All these designs use Von Neumann architecture, thus the few versions comprising a cache do not separate data and instruction caches.

V.MATLAB

MATLAB (Matrix laboratory) is a fourth generation high –level programming language and interactive environment for numerical computation, visualization and programming. MATLAB is developed by Math works. It allows matrix manipulation; plotting of functions and data; implementation of algorithms; creation of user interfaces; interfacing with programs written in other languages, including C. C++, JAVA and FORTAN; analyze data; develop algorithms and create models and applications. It has numerous built – in command and math functions methods. MATLAB is used in every facet of computation mathematics, some commonly used mathematical calculation calculations are dealing with matrices and Arrays, 2-D and 3-D plotting and graphics, linear algebra Algebraic equation, Non-linear functions, Numerous calculations, Integration, Transforms Curve fitting

VI. PWM

Pulse-width modulation (PWM) is a modulation technique used to encode a message into a pulsing signal. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. In addition, PWM is one of the two principal algorithm used in photo-voltaic solar battery charges, the other being maximum power point tracking. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load. The PWM switching frequency has to be much higher than what would affect the load which is to say that the resultant waveform perceived by the load must be as smooth as possible. The rate at which can vary greatly depending on load and application.

VII. ZIGBEE

Zigbee is a low-cost, low-power wireless mesh network standard targeted at the wide development of long battery life devices in wireless control and monitoring applications. Zigbee devices have low latency, which further reduces average current. Zigbee chips are typically integrated with radios and with microcontroller that have between 60-256KB of flash memory. Zigbee operates in the industrial, scientific and medical (ISM) radio bands: 2.4 GHz in most jurisdictions worldwide; 784 MHz in china, 868 MHz in Europe and 915khz to 250 Kbit/s (2.4 GHz band). The Zigbee network layer natively supports both star and tree networks, and generic mesh networking. Every network must have one coordinator devices, tasked with its creation, the control of its parameters and basic maintenance. Within star networks, the coordinator must be the central node. Both trees and mesh less allow the use of Zigbee routers to extend communication at the network level. Zigbee builds on the physical layer and media access control defined in IEEE standard 802.15.4 for low rate WPANs. The specification includes four additional key components: network layer, application layer, Zigbee device objects (ZDOs) and manufacturer-defined application objects which allow for customization and favour total integration. ZDOs are responsible for some tasks, including keeping track of device roles, managing requests to join a network, as well as device discovery and security. Zigbee is one of the global standards of communication protocol formulated by the significant task force under the IEEE 802.15 working group. The fourth in the series, WPAN Low Rate/Zigbee is the newest and provides specifications for devices that have low data rates, consume very low power and are thus high data rate applications such as voice, video and LAN communications.

VIII. EXISTING SYSTEM

The existing methodology uses three MARG (Magnetic Angular Rate Gravity) sensor for measuring the acceleration, angle, and orientation. Initially, the sensors are placed on user's body and limbs according to human skeletal action. This system uses gradient descent algorithm for obtaining the 3D orientation of the human lower limb on the monitor. The data collected are transferred to the X Bus which is placed in the waist of the human and it stores the sensor data temporarily. Then these data are transferred to the PIC controller via the Bluetooth. Finally, The IMU sensor values is serial communicated with Mat lab based PC Program for Motion detection. The fig 3 shows the block diagram of existing system.

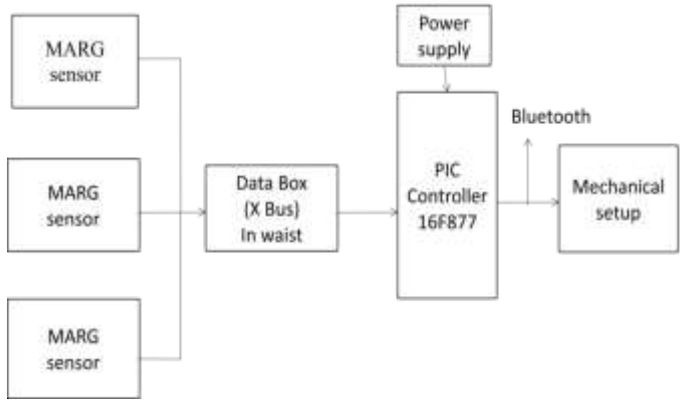

Fig:1 Block Diagram of existing system

IX. MARG Sensor

MARG (Magnetic Angular Rate Gravity) sensors (3DM-GX1) consist of three angular rate gyros, three orthogonal DC accelerometers, three orthogonal magnetometers, multiplexer, 16 bit A/D converter, and embedded microcontroller. When the sensor is operated over the full 360 degrees of angular motion on all three axes, the sensor provides orientation in rotation matrix, quaternion, and Euler formats. 3DM-GX1 measures static and dynamic orientation. It utilizes the tri axial gyros to track dynamic orientation and the tri axial DC accelerometers along with the tri axial magnetometers to track static orientation. The embedded microprocessor contains a unique programmable filter algorithm, which blends these static and dynamic responses in real-time. This sensor has a fast response about vibration and quick movements, while eliminating drifts and providing stabilized output. This stabilized output is helpful in eliminating unwanted jitter or noise from the read data. The fig 3.2 shows the sensor used in the existing system.

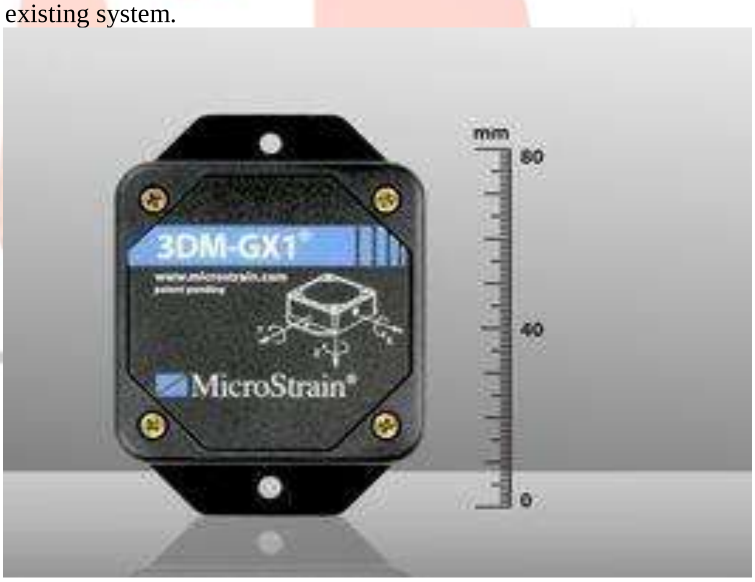

Fig 2 MARG sensor

X. PROPOSED SYSTEM

Transmitter Section

The proposed system uses MEMS (Micro Electro Mechanical Systems) Inertial Measurement Unit (IMU) sensor. Initially, MEMS IMU sensors are placed on user's body and limbs according to human skeletal action, and each sensor performs 9 degrees of freedom (DOF) tracking at a high-speed update rate. Then, the collected sensor's data are transferred to Microcontroller, The inner communication between the MCU and the IMU is I2C. Then the data is transferred to the level analyzer via the UART. The analyzed data are transferred via Zigbee. The block diagram of the transmitter section is shown in fig 3.4.

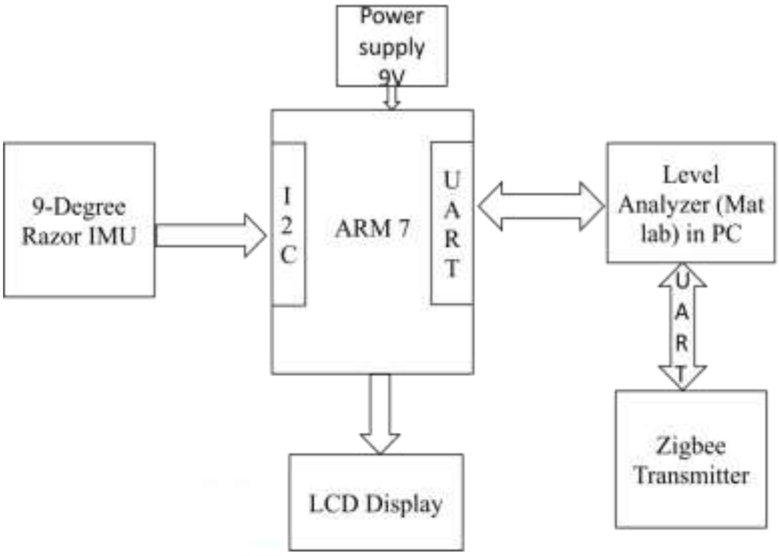

Fig 3 Block diagram of the transmitter section

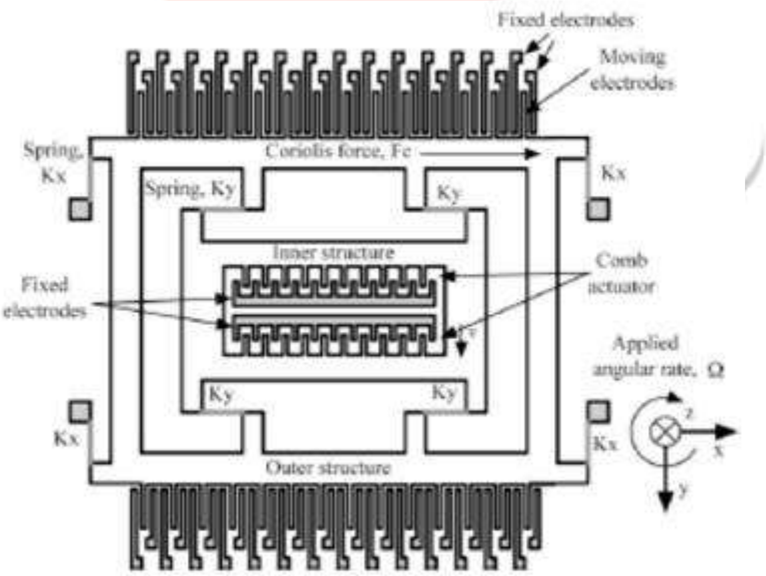

Fig 4 Block diagram of the transmitter section

The fig 4 shows the operation of gyroscope. When the mass is moving in a particular velocity, the angular rate is applied on the mass which produce a force causing a perpendicular displacement of mass. So this displacement is calibrated as the rotation value.

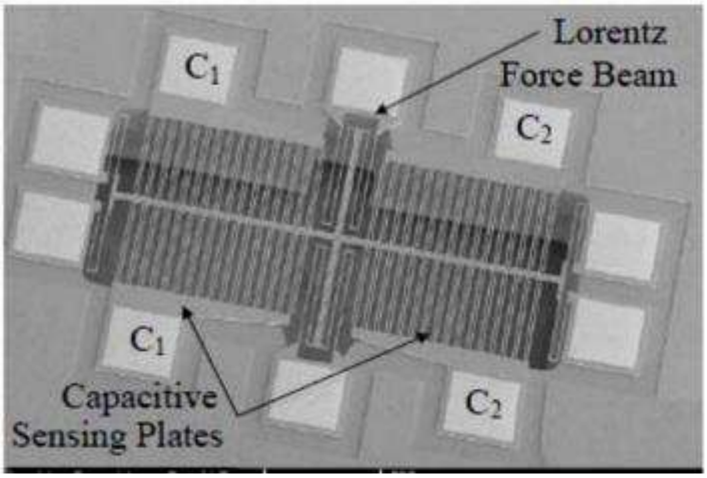

Fig 5 Operation of Magnetometer

Fig 5 shows the operation of magnetometer which measures the earth magnetic feild by hall effect or magneto-resistive effect.It consists of a conductive plate with supply through which the electrons move. If a magnetic feild is applied, the electrons will not move in straight line thus accumulating the electrons on one side and protons on other side thus producing voltage value.

XI CIRCUIT DIAGRAM

The circuit diagram of the transmitter section is shown in fig 4 and the receiver section is shown in fig 5.The ARM LPC2148 is used here. The sensor values are connected to the pin po10 and pin po11. The sensed values are processed and are transferred to the Zigbee in the transmitter section.

The Zigbee receiver receives the signal and given to the LPC2148 which gives out PWM signals to run the motor placed in the mechanical setup according to the sensed values. The motor interface is done in the pins 2,3 and 11.

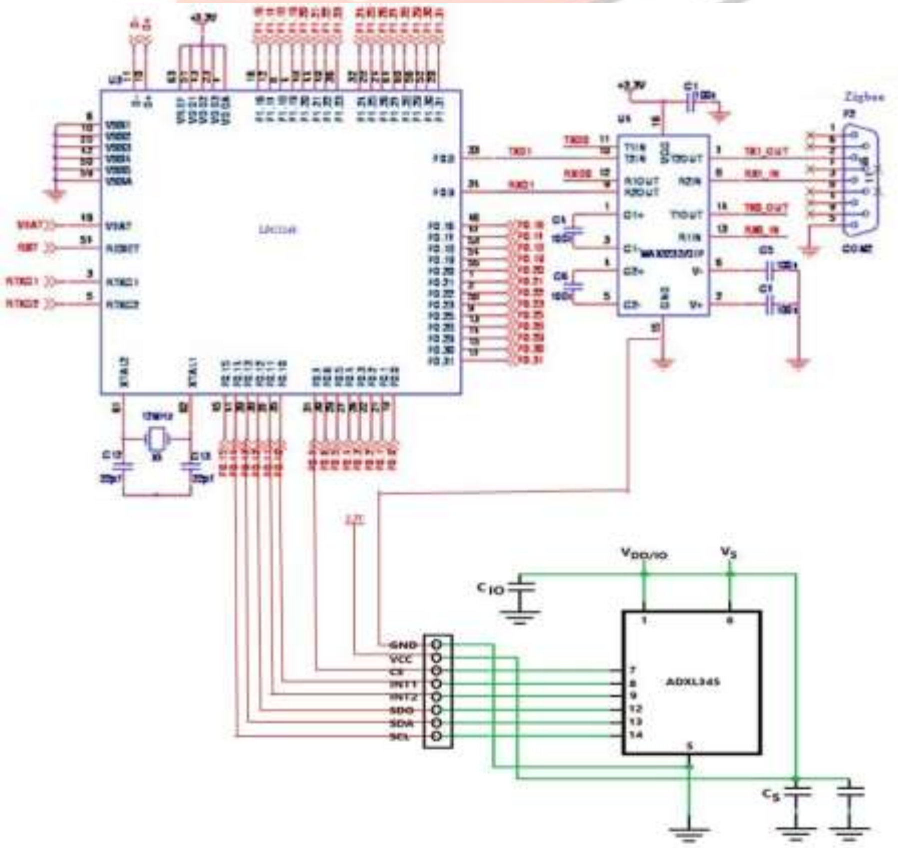

Fig 6 Circuit diagram of transmitter

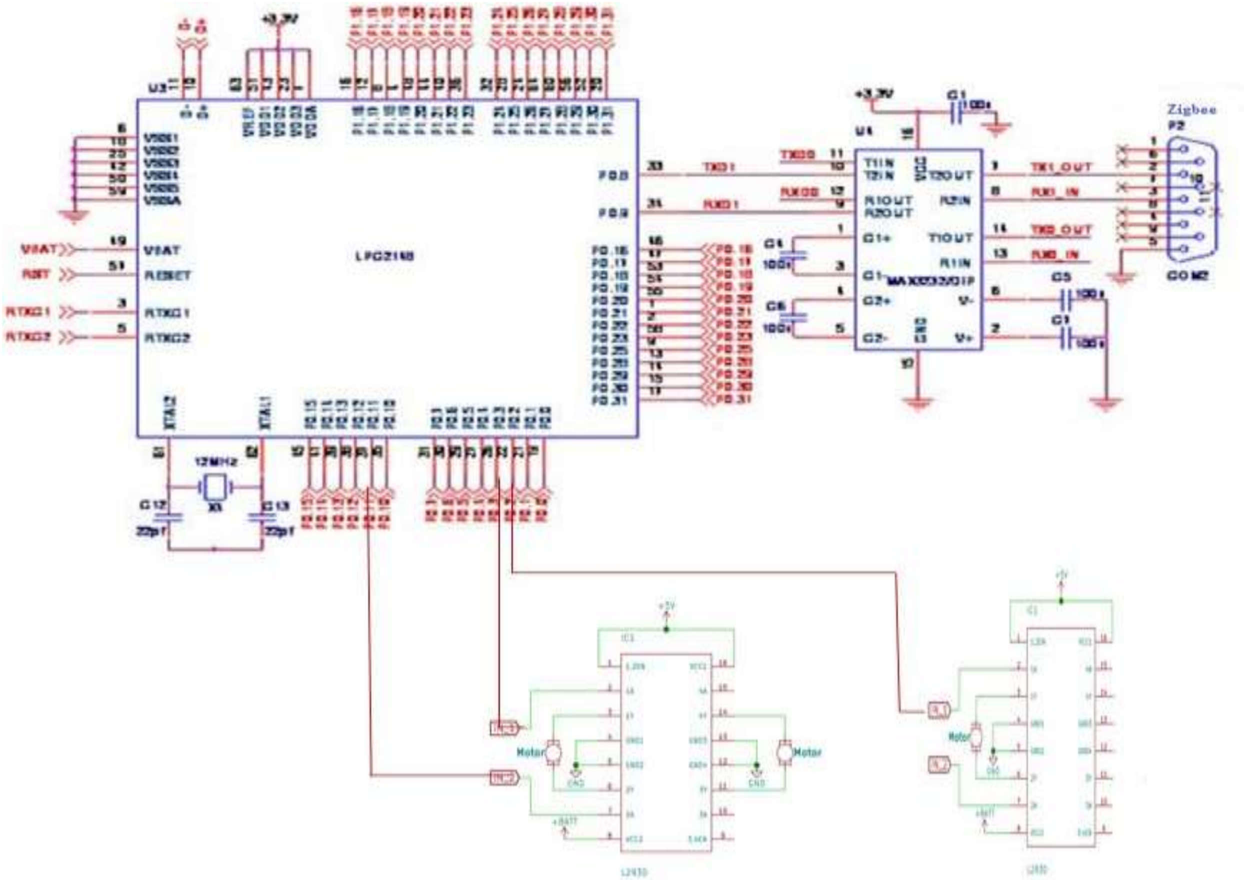

Fig 7 Circuit diagram of receiver

XII. ARM7

The ARM7 is part of the Advanced RISC Machines (ARM) family of general purpose 32-bit microprocessors, which offer very low power consumption and price for high performance devices. The architecture is based on Reduced Instruction Set Computer (RISC) principles, and the instruction set and related decode mechanism are much simpler in comparison with micro programmed Complex Instruction Set Computers. This results in a high instruction throughput and impressive real-time interrupt response from a small and cost-effective chip. The ARM7 is a low-power; general purpose 32-bit RISC microprocessor macro cell for use in application or customer-specific integrated circuits (ASICs or CSICs). It's simple, elegant and fully static design is particularly suitable for cost and power-sensitive applications. The ARM7's small die size makes it ideal for integrating into a larger custom chip that could also contain RAM, ROM, logic, DSP and other cells. The ARM instruction set is a good target for compilers of many different high-level languages. Where required for critical code segments, assembly code programming is also straightforward, unlike some RISC processors which depend on sophisticated compiler technology to manage complicated instruction interdependencies. Pipelining is employed so that all parts of the processing and memory systems can operate continuously. Typically, while one instruction is being executed, its successor is being decoded, and a third instruction is being fetched from memory. The fig 7 shows the block diagram of ARM7.

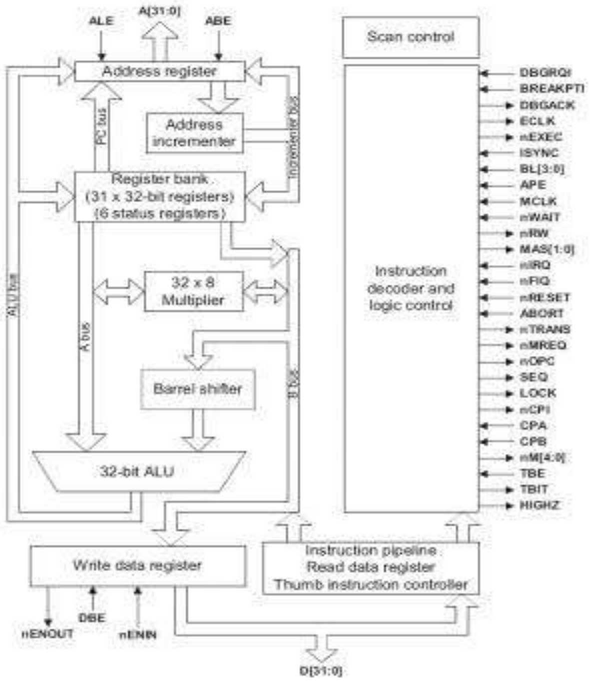

Fig 8 Block diagram of ARM7

Features of ARM 7

- 32-bit RISC processor (32-bit data & address bus).
- Big and Little Endian operating modes.
- High performance RISC 17 MIPS sustained @ 25 MHz (25 MIPS peak) @ 3V.
- Low power consumption 0.6mA/MHz @ 3V fabricated in .8µm CMOS.
- Fully static operation ideal for power-sensitive applications.

XIII SOFTWARE TOOLS

KEIL IDE

Keil provides a broad range of development tools like ANSI C compiler, macro assemblers, debuggers and simulators, linkers, IDE, library managers, real-time operating systems and evaluation boards for Intel 8051, Intel MCS-251, ARM, and XC16x/C16x/ST10 families. Integrated Development Environment popularly known as IDE is a suite of software tools that facilitates microcontroller programming. The Keil IDE enables the embedded professional to develop the program in C and assembly as well. The IDE passes through the source code to check the syntax. The fig 6 shows a sample of Keil software.

5.2 FLASH MAGIC

Flash Magic is an application developed by Embedded Systems Academy to allow you to easily access the features of a microcontroller device. With this program you can erase individual blocks or the entire Flash memory of the microcontroller. Flash Magic is a tool which used to program hex code in EEPROM of micro-controller. It is a freeware tool. It only supports the micro- controller of Philips and NXP. You can burn a hex code into those controllers which supports ISP (in system programming) feature. The fig 6 shows the sample for flash magic software.

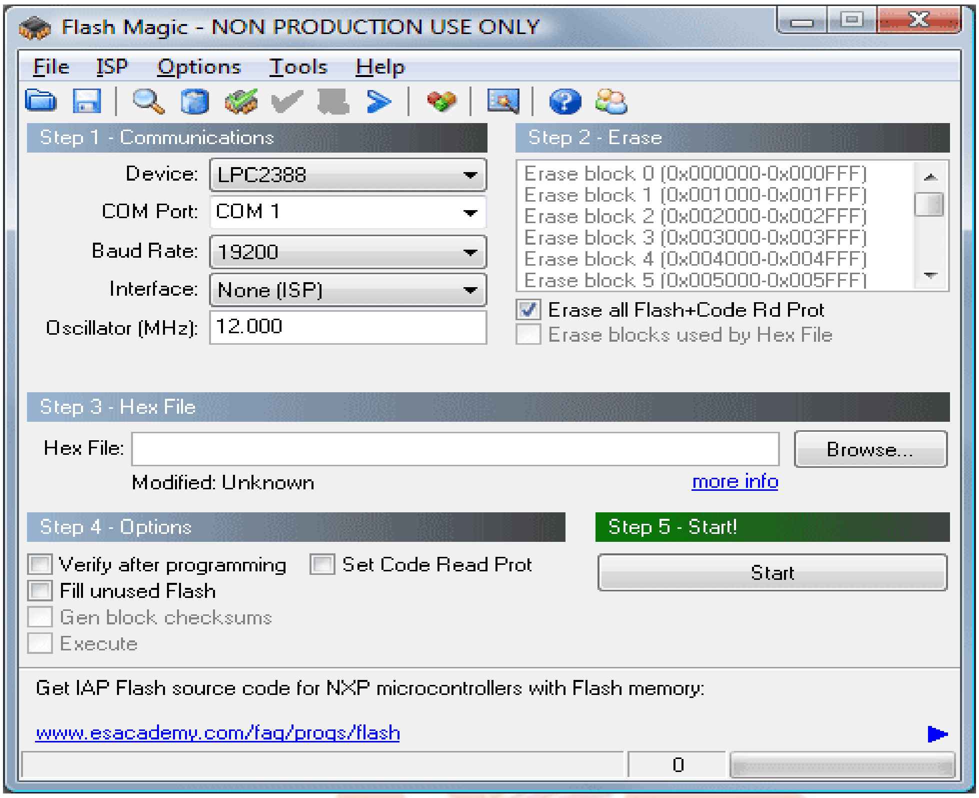

Fig 9 Sample for flash magic software

Features of Flash Magic

- Straightforward and intuitive user interface.
- Five simple steps to erasing and programming a device and setting key options.
- Automatically program checksums. Using the supplied checksum calculation routine your firmware can easily verify the integrity of a Flash block, ensuring no unauthorized or corrupted code can ever be executed.
- Reprogram the Boot Vector and Status Byte with the help of confirmation features that prevent accidentally programming incorrect values Single- click access to the manual, Flash Magic home page and NXP Microcontrollers home page.
- Support programming certain LPC1xxx/LPC2xxx devices via Ethernet.
- Displays information about the selected Hex File, including the creation and modification dates, flash memory used, percentage of the current device used.

XVI .RESULTS AND DISCUSSION

The process that is performed in this system is shown below. The 9 DOF razors IMU track the motion according to the human skeletal motion. It can track the motion in all directions. The motor has 3 sensors in it. It measures the acceleration of the limb. The gyroscope, or gyro for short, adds an additional dimension to the information supplied by the accelerometer by tracking rotation or twist. An accelerometer measures linear acceleration of movement, while a gyro on the other hand measures the angular rotational velocity. And the magnetometer provides with a simple orientation in relation to the Earth's magnetic field. As a result, the sensor always knows which way is North so it can automatically rotate depending on our physical orientation. The input here is the movement of the sensor. The fig 9 shows the movement of the sensor placed on the limb.

Fig 10 Movement of sensor placed on limb

First, the sensor is placed on the fine limb of the user. This sensor tracks the motion of their fine limb when they move it. This sensor is better than the MARG sensor that was used in the existing system. The sensor measures the pitch, roll and yaw of the fine limb. Pitch is up and down motion; yaw is left and right motion; roll is rotation about an axis. The fig 10 shows the directions of pitch, roll and yaw.

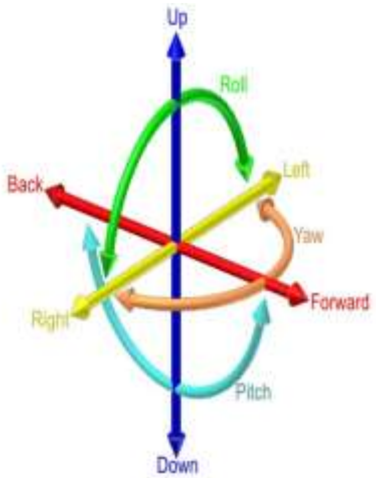

Fig 11 Directions of pitch roll and yaw

These tracked values are transferred to the ARM7 through the I2C. The I2C is Inter Integrated circuit which performs the serial communication. Serial communication is preferred because it is cost efficient. Since we can use one wire instead of two parallel lines. The data transferred to the processor converts the signals into digital data and transmits to the level analyzer.

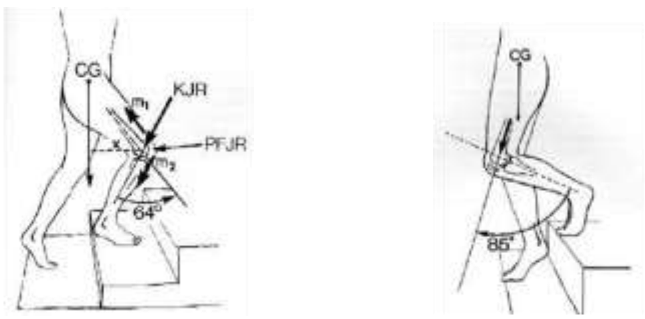

Fig 12 Sample angle while climbing stairs

The fig 12 shows the sample angle while climbing stairs. It will be varied based on the movement of the angle using the threshold level of the analyzer which is set as thirty degree. The work of the level analyzer is to transmit the job that has to be performed by the motors. This level analyzer conveys in which direction and up to how much length and angle the sensor has been moved. The transmission is via the Zigbee module. Until now, any transmission is only in the form of analog not in digital. So, the Analog to Digital Converter in Zigbee converts the signal to analog and transmit it. The Zigbee receiver receives the signal and passes it to the processor using UART.

Fig 13 Sample LCD module to display angle

The fig 13 shows the LCD which is used to display the angle and is interfaced with the microcontroller. The signal from the processor dictates the motors to run according to the sensor movements. This is achieved by the PWM which is pulse width modulation. The main work of the PWM is to control the power supplied to the motors. This is done by using a switch which is between the load and supply. Pulse width modulation speed control works by driving the motor with a series of "ON-OFF" pulses and varying the duty cycle, the fraction of time that the output voltage is "ON" compared to when it is "OFF", of the pulses while keeping the frequency constant.

The fig 13 shows the sample of DC Motor. The motor will be rotated with the help of controller. The power applied to the motor can be controlled by varying the width of these applied pulses and thereby varying the average DC voltage applied to the motors terminals. The longer the pulse is "ON", the faster the motor will rotate and likewise, the shorter the pulse is "ON" the slower the motor will rotate.

XV . CONCLUSION AND FUTURE ENHANCEMENT

The proposed system aims in helping the differently able people to walk with the help of an artificial leg. The sensor used tracks the movement of the limb on which it is placed and transmits it to the motors wirelessly. The sensor values are analyzed in the level analyzer and the motor is controlled by the Pulse Width Modulation and with the help of the motors the patients can walk easily without any difficulty.

The main challenge of this system is that it can only help the motion of the user but can't track the location of the user. To overcome this challenge in future user can try 11 Degrees Of Freedom which has an inbuilt GPS tracking which is Global Positioning System and also a biometric sensor. This would help the patients as well as sports persons to monitor the pressure, heart rate and temperature. These parameters can be measured using a single sensor. Implementing these things in future will make this system more efficient and can have a vast application unlike now where the application is strictly to medical application. If these challenges are overcome, this system can be used in many applications such as medical, police and other users may include astronauts.

XVI .PROTOTYPE