The A.R.M.E.D. Project

A biomechanics project in real-time human arm motion capture and reproduction

Contents:

Abstract:-

The focus of the A.R.M.E.D. project is at capturing and reproducing the kinematics of a human arm in real-time.

Current methods of human motion capture involve large processing requirements or are otherwise restricted or low in accuracy.

The goal of the project is at providing a tether-free setup for the human subject (by means of strap-down sensors) thus providing the subject full freedom of movement. Concurrently, the attempt is to reproduce the motion with stability and high levels of accuracy. The entire system is controlled using the processing power of a ubiquitous desktop processor.

Auxiliary objectives of the project are to achieve touch reciprocation to the user (via haptic feedback) and to achieve the dexterity of the human hand.

Understanding the design constraints:

Since, the project aims at providing a tether-free setup for the user, the choice of sensors must be appropriate. The sensors must be small and light (so that they may be worn or 'strapped' down) and at the same time – accurate and stable.

The algorithms used must be fast and efficient in order to provide real-time response while keeping computational requirements low.

The construction and actuation of the robotic arm must account for real-life problems such as inertia, frictional losses, transient behaviour, etc.

All of the above must be achieved in such a way that the end product is a cost effective solution.

MEMS technology:

The human vestibular system (fig.1) measures head movements, without the need for a reference. The system is essential for stable posture control and it enables humans to move freely because it is not earth bound.

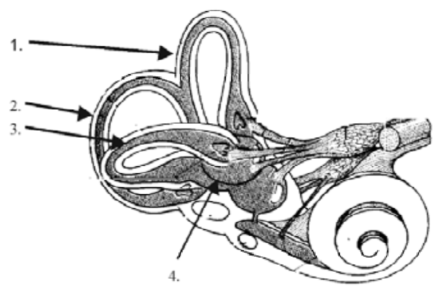


Figure 1: *The human vestibular system. The three semicircular canals (1, 2, 3) are mainly used for obtaining a measure of 3D angular acceleration. The otolith (4) measures the acceleration and gravity.*

Over the last few years, Micro-machined Electro-Mechanical Sensors (accelerometers and gyroscopes) have become more widely available. Because they are small in size, they can be worn on the body. Like the vestibular system, the working principle of these sensors is based on the omnipresent inertia, enabling measurement anywhere without the need for a reference.

A concise list of features of MEMS sensors:

- Rate Gyroscopes
  - Micro-machined MEMS technology
  - Up to 1500deg/s , 140Hz bandwidth
  - Integrated low pass noise filtering and temperature compensation
  - Selectable amplification
- Accelerometers
  - Micro-machined MEMS technology
  - 3-axis, 150Hz sampling frequency
  - Programmable sensitivity (up to 6g) with 800mV/g
  - Onboard Signal Conditioning via Low Pass Filter
  - Can also be used as inclinometer (1.5g mode)

The amalgamation of accelerometers and gyroscopes into a single small and light-weight unit is christened an Inertial Measurement Unit (IMU). The IMU is the primary tool used in the project to capture human arm motion.

Features of an IMU:

- Very small size & high integration of features
- 3 single-axis MEMS gyroscopes + tri-axial MEMS accelerometer
- Onboard 8bit microcontroller (ATmega8)
  - Reprogrammable sensor interface/ basic signal conditioning
  - Basic algorithm execution capability
- Onboard data transmission support
  - ATmega8 linked to an onboard XBee for wireless transfer
  - UART and SPI pins brought out for wired setup.

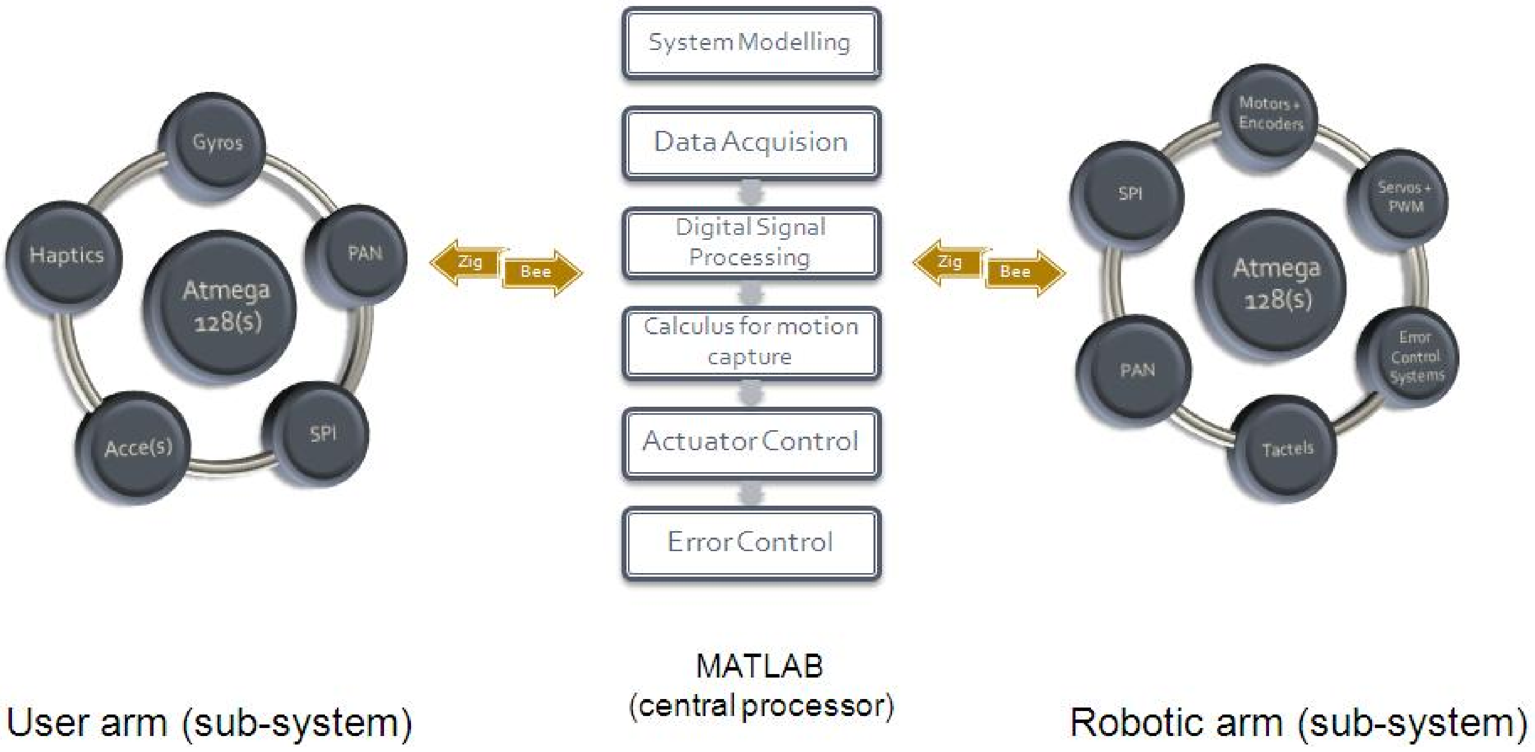
Sensor Fusion:

Sensor fusion refers to the process of integrating accelerometer and gyroscope data into a single unified data structure. Extensive testing of the MEMS based IMU has revealed the merits and demerits of each individual component sensor. Based upon these observations, a complementary filter algorithm for sensor fusion has been developed.

It has been observed that the gyroscopes provide excellent dynamic response. But, they are victim to integration drift in static conditions. On the other hand, accelerometers have very stable static response but are comparatively poor in dynamic conditions.

In light of the above, the following approach which employs the merits of both sensors and rejects their demerits is used. In static or low frequency conditions, the more stable accelerometer data is given higher priority and the gyroscope data is preferred in high frequency/ dynamic conditions. This arrangement is akin to a complementary filter (which passes one signal at low frequencies and the complementary signal at higher frequencies) and the implementation of this filter is done in software.

System model:



The physical system is divided into two broad halves – the user arm and the robotic arm. From the point of view of software, the system consists of a central processing station (MATLAB) and the two subsystems: user arm and robotic arm.

MATLAB for Central Processing:

The major roles of the central processing block are:

- Digital Signal Processing and Conditioning to attenuate noise, jitter etc.
- Data acquisition via the ZigBee wireless interface
- Processing iterative algorithms for mathematical estimations of motion (based on data acquired)
- Implementing sensor fusion algorithm for data correction
- Command generation for the robotic arm sub-system
- Software level error control and master initialization of system
- Dynamic development and debugging platform

Keeping in mind the processing constraints, the platform for software development and implementation has been chosen as MATLAB (The MathWorks Inc.). It provides:

- Extremely fast processing: ability to run the iterative algorithm at up to 100Hz on normal desktop processor.
- Extremely high precision ensures minimal computing errors.
- Powerful environment for system modelling and software based design testing

Auxiliary Processing (ATmega microcontrollers):

The purpose of providing auxiliary processing is to complement the central processing block. Low level algorithms of lesser computation complexity are handled by the auxiliary processors. This enables the central processor to handle the higher and more complex algorithms more efficiently.

The main tasks of the auxiliary processing block are:

- Sensor & actuator interface & setup
- Low level algorithm execution
- Closed loop DC motor control (via encoders)
- Interfacing with peripherals
  - Use of 8 channel, 10bit ADC feature in translating analog sensor values
  - Use of multiple PWM channels for motor control applications
- Handling intra and inter sub-system communications
  - UART (on the ZigBee wireless protocol)
  - SPI (intra sub-system communication)

For the purpose of auxiliary processing, microcontrollers from the ATmega series (Atmel) have been chosen. These microcontrollers are cheap, robust and provide the wide range of peripherals that are required for this role.

Wireless Connectivity:

For providing tether-free setup for the user, it becomes imperative to detach the user from the central processing station. Hence, wireless communication between the central processor and the sub-systems is implemented. This includes wireless connectivity with the robotic arm so that the system is completely flexible in terms of installation.

The wireless link is provided using XBee (Digi) which implements the IEEE 802.15.4 ZigBee protocol of wireless communication. Features of the Xbee are:

- Point to point or multi-point network support
- 250kbps Max data rate @ 2.4GHz

- Up to 300ft (100m) range. Built-in on chip antenna
- 128-bit encryption
- Local or over-air configuration

The final product is envisaged to have a dedicated embedded microprocessor to function as the central processor. This will be positioned at the site of the robotic arm.

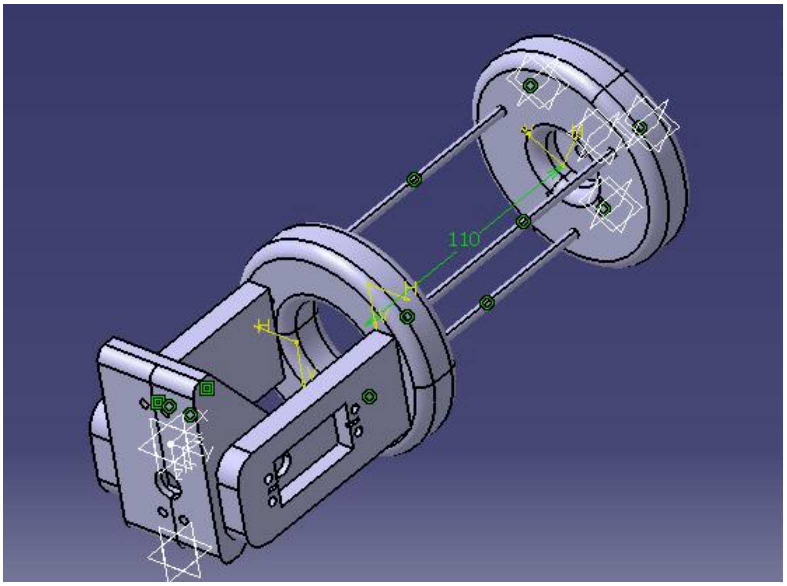
Mechanical Design:

The current prototype design concentrates solely on fidelity of kinematics. It covers a summation of 5 degrees of freedom across the arm.

The ball and socket joint at the shoulder is mimicked using a three axes design powered by closed loop actuator systems. The axes arrangement is as follows:

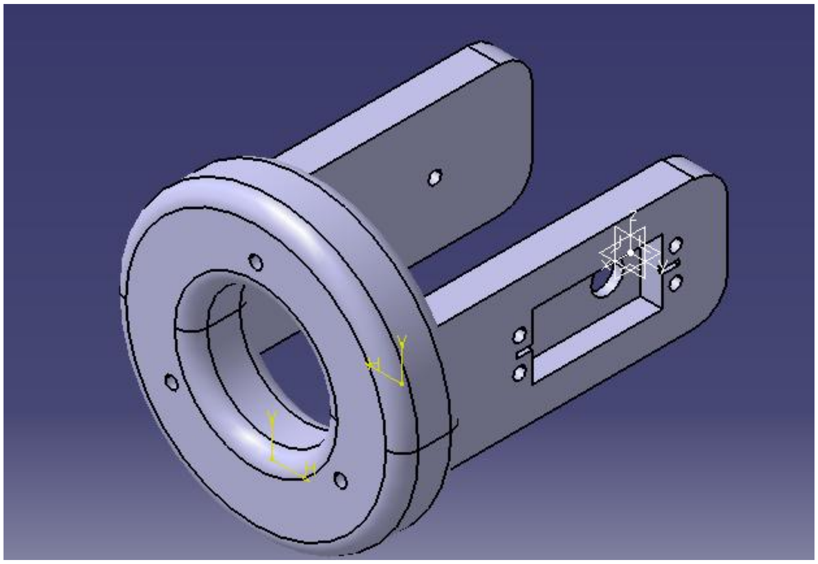
- One vertical axis
- One horizontal axis
- One axis along the arm

Motion about third orthogonal (horizontal) axis is obtained by compound motion of the 2 existing main axes.



The elbow joint is replicated by a 2 axes design similarly powered by closed loop actuator systems:

- One axis for elbow twist
- One axis for elbow curling



The design of the major components has been done using CATIA (CAD software). Screenshots of the design parts are displayed above.

The prototype model is being fabricated using Rapid Prototyping using FDM ABS plastic.

The final design is a 1:1 scale replica of a human arm. The construction of the final model will be based on light weight and sturdy material like Aluminium. Both geared and direct drive closed loop actuation will be employed as and where required. Addition of a powered wrist – a three appendage gripper mechanism completes the design for the final model.

Actuation:

Actuation for the robotic arm is provided using electrical actuators: geared DC motors and servo motors. These motors are chosen such that they can meet the high torque requirements of the system and provide prompt dynamic response.

The feedback for DC motor control is employed using Quadrature encoders with a resolution of up to 500 pulses per revolution to ensure high accuracy of position.

Proposed Applications:

- Bionic arm/ assembly line integration
  e.g.) operator can use the fixed robotic arm on the assembly line for handling heavy objects with equal agility.
- Handling hazardous/sensitive material
  - Handling of materials in nuclear facilities with dexterity of human arm
    e.g.) servicing nuclear power plants, examining radioactive material
  - Handling of materials in contamination free zones. Robotic arm can be sealed into the sensitive work area
    e.g.) silicon wafer manufacturing
  - Handling in other dangerous environment like high voltage hazards, chemically hazardous region, etc.
  - Deep sea exploration
    Remote control of a robotic arm in deep sea where hydraulic pressure is beyond safe limits for divers.
  - Extra-terrestrial exploration/ astronautical engineering:
    Astronauts can use this agile system for commanding robotic arms precisely in space.
- Virtual surgeries/ remote diagnosis
  - Remote motion capture using a strap-on sensor belt on the surgeon
  - Robotic arm with very high precision reproduces the motion. It may employ features like laser scalpels for precision surgery

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