ROBOTIC ARM USING HAPTIC INTELLIGENCE- A REVIEW

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ABSTRACT

A robotic arm is a manipulator based system that operates based on the assigned degrees of freedom. In this paper, we study and inspect the various technologies that our modern manipulators are moulded from and conclude what we learn from the data that we collected. The robotic arm is now the basis of any talk of future innovations in the automation world. The objective of this paper is to analyse the haptic technology in robotic arm used in modern day manipulators to provide a more effective performance. The haptic feedback system imparts sensory feedback to the user controls and permits them to effectively manipulate three dimensional objects without actual manual interference. This type of feedback system is ideal in all fields where human error can occur especially in the medical field of surgery. This research assess the extent of machine intelligence and human-machine interaction in the present years as well as the capability of extending these research possibilities in the future generations.

Keywords: Sensory feedback, machine intelligence, haptic technology, human-machine interaction, robotic manipulator

1. INTRODUCTION

In this generation, robots are integrated over a large variety of tasks designed for human activities. A robot is an actuated operational contrivance in three or more axes with its motion capabilities defined in degrees of freedom of the manipulator moving within its environment to perform calculated tasks. With relevance to a robotic arm, common tasks like welding, cutting, lifting, sorting and bending are applied to industrial usage whereas intense tasks like surgery and carrying out military duty is also achieved by it. Most of the industrial robots look like mechanical arms and many actually function as human arms and are clinically termed as "articulated" in scientific literature [4]. This paper centers on studying the advanced method of controlling the robotic arm using haptic feedback technology. Hence a need for the haptic intelligence is introduced where the term is defined as the science that recreates the sense of touch by enabling the creation of a controlled virtual environment.

Manipulation in robotic system can be categorized into three main types:

- Autonomous controlled- These type of manipulators have the ability to make their own decisions, similar to the actions of humans. An autonomous robot grasps its environment, makes decisions based on what it understands and is programmed to recognize and then actuate a movement within that environment.
- Remotely controlled- Remotely operated robots are a type of manipulator that can be controlled from a
- Manually controlled- Manual robots are a type of robotic system that requires complete human support for its operation. This type of robotic system requires a distinct kind of human control, a system rarely found in any other type of robotic systems.

In haptic form of automation, sensor technologies are used to detect the input from the user and generates information that is required for the operation of the arm. This sensory feedback will provide the user information about properties of the target which will make the user experience real and additionally informative.

The haptic technology itself is a broad category and can be subdivided into three main topics [3].

1. Human Haptics- understanding of human sensing characteristic
2. Machine Haptics- study of designing and building machines to duplicate the human sensory system.
3. Computer Haptics- implementing algorithms and software associated with feel of virtual objects [3].

Haptic feedback is a combination of both Tactile and Kinesthetic feedback which therefore makes it an intelligent and improved form of science. Kinesthetic explains about the motioning and movements in the position of the body and Tactile tells us about the body impressions in the skin [2]. The possibilities of haptic sensory feedback in the future will have the ability to directly animate the focal sensory system to duplicate the touch experience, which in turn means medical advancement like cerebrum nerve persuasion and mechanical interfaces that coordinate with human bodies. This paper gives an overview of the development, design and applications of the haptic feedback system of a

A robotic arm can be designed along several parameters out of which a few are discussed in this paper. Here, we observe that the design and specifications of the arm vary depending upon the applications of each system and the dynamics that these technologies follow:

2.1.1 Robotic Gripper in no-gravity conditions using haptics

The gripper is widely used in the area of space application. This technology aims to substitute the actions of the astronauts in periodical operations with, in this case; a semi-autonomous robotic device [5]. The device establishes manipulation of the object held by the gripper, similar to the actions of a human hand. Particularly, the two-jaw gripper is servo operated, where the two jaws are controlled by a servo whose rotation angle can be changed to close or open jaws. The mechanical structure has been designed considering as basic specifications the possibility of simultaneous application of the contacts and a limited complexity of the kinematic architecture, with not more than three controlled degrees of freedom [6]. **The system has three fingers, each with one D.O.F** whose distal phalange can move on a linear trajectory [6]-[8]. In fig.1, joint 3 represents the elbow which portraying a revolute joint for flexible in all coordinate axis of the frame and joint 4 represents the gripper or the sensory input of the robot.

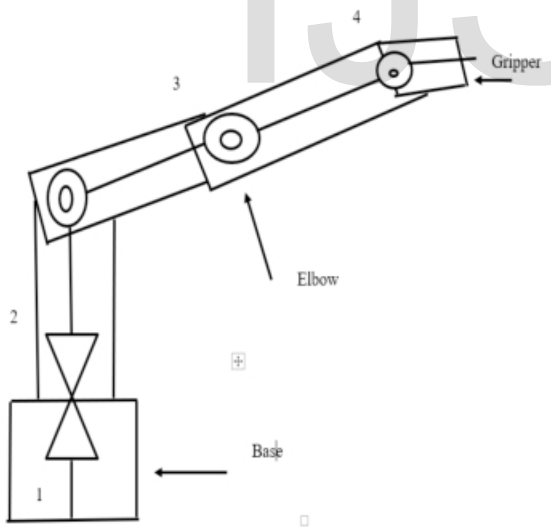

Fig1: Schematic diagram of gripper [5]

The use of the DC motor can be directly coupled with a gear that has a step- down configuration. The design is robust because only by changing the end effectors, it can be made to grip any kind of shape. Each finger of the gripper is prioritized with a position sensor, proximity sensor and miniaturized force or torque sensors to control the motion of each finger and its distance from the object for grasping with limited or normal pressure. Each articulated finger will possess a distal phalanx, that will be in contact with the object, including two intermediate phalanx that are coupled by means of internal transmissions so that the pure translation of the distal link can be produced [9]. Among some of the major factors in choosing a pneumatic gripper and jaw design, the one that stands out is the orientation, dimensional variation and part shape; it is designed keeping in mind the retention or encapsulating grip that requires less force than the actual friction grip [10]. Depending on the air pressure loss, the gripper relaxes its grip on the held object and hence it may be dropped. The complexity of the simple actions of picking up and placing the given object is the whole idea behind the mechanism.

Let us move on to the integral role of haptic technology, where the haptic identification of the objects is used for granting detailed robustness to uncertainty for manipulating objects in addition to conferring leniency towards interactions with the still environment. Modelling the sensor noise as a part of haptic object identification is given as noisy readings. The haptic intelligent robot here is aimed to be able to pick up objects based on the internal sensing data collected by the sensors embedded in each finger which are resistive flex sensors. Due to how the sensors was constructively built, the relative change in resistance increases periodically as the curvature of the sensor increases [11].

In a case where we use a zero mobility parallel-jaw gripper for picking up objects, we look at end-effectors with or without actuators. It is known that a grasp of two objects that oppose each other can resist another external wrench applied to the object hence enabling it to be stable.

2.1.2 Shadow Dextrous Hand

This prototype of the human hand has the flexibility to move all the joints. On an approximated range, the dextrous hand has 24 joints with 24 degrees of freedom concluding 4-DOF per finger and 5-DOF for the thumb, plus 2-DOF for the wrist and 1-DOF for the palm flexure. The distal phalanges of the fingers are under actuated from medial joints, hence obtaining a total of 20-DOF controllable [12].

The robotic hand can be applied by electrically and pneumatically actuating versions and has the capability to grasp objects. This system can be applied to intrinsic and complex tasks that a human hand or a normal simplified robotic arm finds rather strenuous to perform.

The development of dextrous robotic system is a compound process of an interdisciplinary nature which involves consecutive actions like motion planning, grasping defined objects, sensor fusion, digital signal and image processing, human machine interaction and tactile sensing. Among discerning modalities tactile sensing holds an important role in the physical interactions of the robot with human beings. Task related requirements of in-hand manipulation include response where tactile sensors functionally provide information of presence of obstacles that could hinder contact and contact force [16]. Exploration being a task-related requirement must provide information about the surface properties detected by measurement of texture, hardness, temperature and

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shape of the object. Tactile data is used as a control parameter in slip detection, estimation of graph stability, contact point estimation, surface normal and curvature measurement, contact force measurement for finger tips force control [16].

In the C5 type hand being the older model of the shadow robot arm, all the joints are tendon driven and these tendons are actuated by a pair of air-muscles for each controllable joint [12]. The elastic muscles provide complete passive conformation, resulting in appreciable grasp stability for a large composition of static grasp poses.

Looking onto to the C6 type hand constituting the newer model, the same mechanical structure is observed. In *fig2* given below we deduce that the variables J1,J2,J3,J4 and J5 correspond to the joints in this bionic model of the hand. However, the tendon on all the joints of the hand are electrically driven by motors hence resulting in faster actuation.

In this dextrous tendon driven under actuated anthropomorphic robotic hand, the first joint is coupled with the second creating a so-called virtual joint such that the first joint does not flex until the second joint that it is coupled with undergoes full flexion at 90° [13].

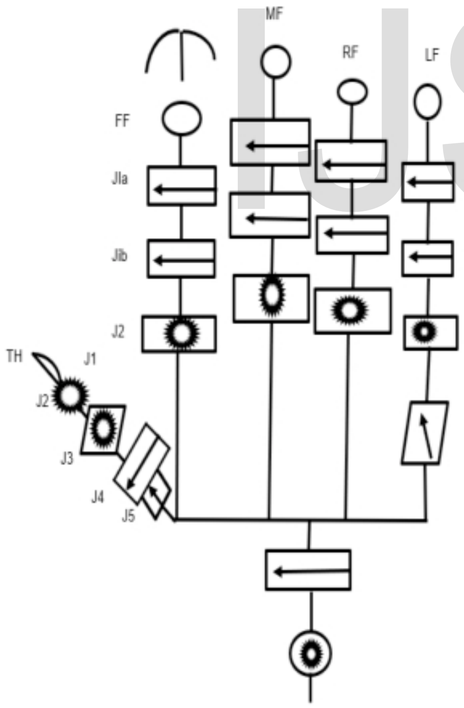

Fig2: Sensors C6M joints [13]

Completing the mechanical structure of the dextrous hand the mechanism of grasping a virtually defined objects would be the next aspect. The capacitive force sensor namely the fingertip tactile sensor is used for sensing the contours of the body of the object. The capacitive force sensor consists of two conductive layers clinically separated by a soft dielectric material made up of Nitrile rubber. Flexible conductive silicon is used for the outer ground layer to get a compliant and deformable fingertip skin [14]. The i-LIMB is the world's first multi -fingered prosthetic hand developed by Touch Bionics Inc. It comprises of optical sensor embedded in a silicon bionic glove and a control algorithm. To prevent objects from slipping out of grasp, the grip control is reflexive, and processing occurs at the spinal cord level where the initial gripping forces rely on prediction of the load and modify reflexively based on sensation feedback from sensors in the hand glove [15].

2.2 **SYSTEM DESIGN**

2.2.1 Hardware

A. <u>Microcontroller board: Arduino Uno/Arduino Mega 2560</u>

The Arduino Mega 2560 is a simple i/o board with 54 digital input and output pins out of which 14 are used as Pulse Width Modulation (PWM) outputs, 16 pins as

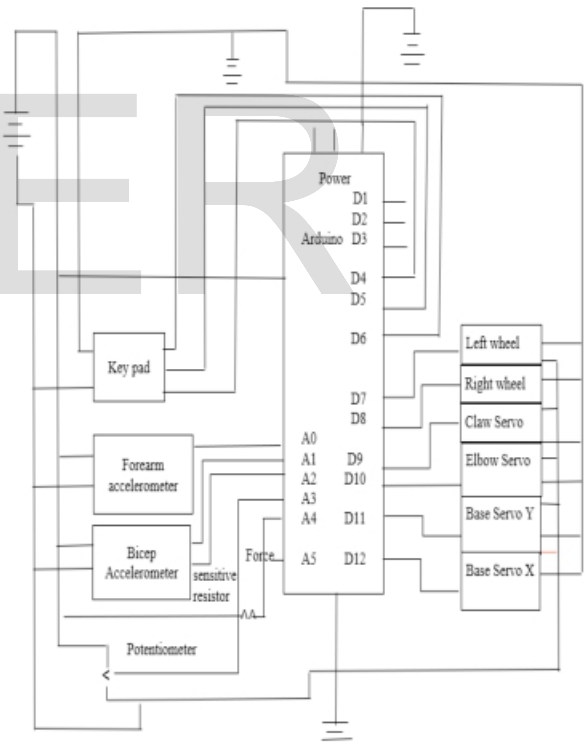

Fig3: Arduino Schematic Pin Layout [19]

analog inputs, 4 pins as UART which hardware serial ports are, one 16 MHz crystal oscillator, one USB connection, one power jack, an In-Circuit Serial Programming (ICSP) header, and lastly a reset button. It's application varies through its use in control of speed of the Brushless DC Motor [17]. Now, the speed control implementation of permanent magnet DC motor is purely based on the Arduino Mega 2560. The applications vary from the control of CNC cutting machine model using the motor to the responses of the DC motor controlled through the PID in real time conditions under real constraints [18].

The use of an Arduino uno as a microcontroller board for the functioning of the robotic arm is based on the ATmega328P. Comparing to the Arduino Mega 2560, the Arduino uno stands separately having 14 digital input/output pins where 6 of these pins could be used as Pulse Width Modulation, 6 analog inputs, one 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button [19].

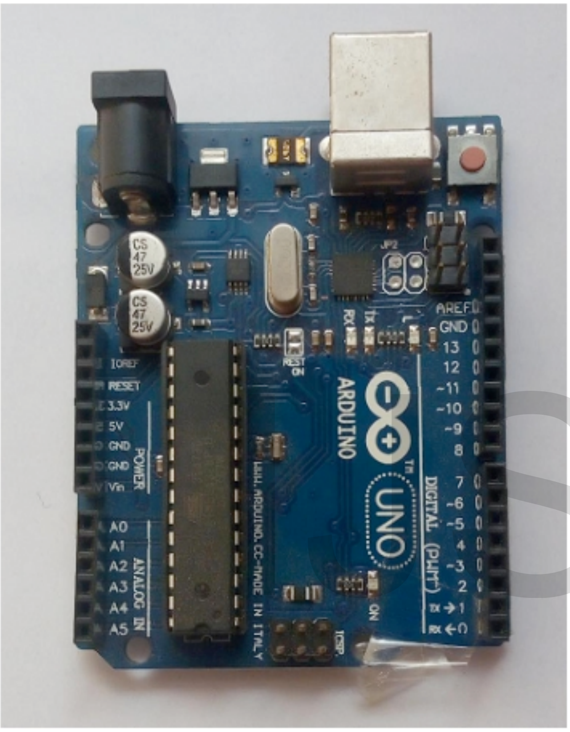

Fig4: Arduino Uno

The below figure represents Arduino Uno:

B. Flex Sensors

Flex sensors present on the fingers change the movement of the hand into motion of the Robotic Arm. Flex sensors change the resistance depending on how much it's bent which in-turn rotates the servo motors connected to the wrist and hand of the robotic arm. Application of this technology is mainly implemented in wireless control robotic hand for picking and placing operation. Three flex sensors are used to control the position of the arm, where one flex sensor is used to control the opening and closing of the robotic gripper, second flex sensor is utilized for the up and down movement of the robotic system and the third sensor is employed for circular position [20]. Flex sensors operating in the two directions, are passive resistive devices which on bending in the compressing direction, decreases resistance and bending along ensile direction increases the resistance of these flex sensors. The sensors are attached to the glove worn by the user so that the angle of the bending and position of the object is calculated and fed to the Arduino in which values are already recorded, requiring a change. Therefore, the information and the output voltage value displayed by the Arduino varies with the user [21].

Now why is the flex sensor preferred to tactile or pressure sensors which are commercially used in robots since they are associated with robot sensing technologies? Certain disadvantages like complex structure hence; operation which in turn increases the fabrication costs along with making them unmanageable to replace in case of any damage, drop in sensitivity of the sensor with time; since these sensors are attached to the robot, on degradation of their properties they undergo glitches in their working [22].

C. *Servomotors*

Servomotors are rotatory or linear actuators since they have a mobility angle of around 180° which is best suited for a flexible robotic arm. The purpose of implementation of this system is allow the robot to operate with precision in control, position, velocity and acceleration. The type of servomotor that can be used is dependant on their power applications. For low power applications, AC servo motors which are two-phase squirrel cage induction motors are used; newly developed and modified version are the three-phase squirrel cage induction motors that are now applied to servomotors [23]. For simplified method of administration, the use of DC servo motor is also carried out in this paper. DC servo motors consist of a miniature DC motor, feedback potentiometer, gearbox, motor drive electronic circuit and electronic feedback control loop [23].

D. Accelerometers

Accelerometers are activated for the movement of the robotic arm in three-dimensional space (XYZ axes directions of movement). Accelerometer in a pneumatic gripper is used for monitoring the exact instant when contact between the gripper and the object, also when combined with the force sensor can regulate the grasping force [24]. Accelerometers provide acceleration and deceleration movements to the gripper for tracking processes. The deceleration of grasping can be used to track position of the fingers of the gripper and estimate the force of grasping. Accelerometer measurements for a robotic vehicle on an irregular terrain need to be eliminated [25]. The information calculated from the accelerometer readings attached to the gripper of the robot arm are then formulated to the Arduino for further display of results.

2.2.2 Software

A. *Interface Design*

The information fed to the microcontroller board embedded in the technology must be now relayed to the rest of the system. The analog input pins in the Arduino Uno/Arduino Mega 2560 is used to extract information from the hardware components like the flex sensors, accelerometers and servomotors. A four-layer architecture involving user interface, function block, functional modules and hardware is proposed where the function block with embedded algorithms and knowledge and driven by events to provide a dynamic link to the relevant application interface (APIs) of the functional modules in terms of case requirements [26].

B. Algorithm Design

The algorithm of the Arduino can take up to 11 inputs in order of controlling servomotors. The flex sensors attached to the gripper claw and the accelerometers proved analog inputs to the Arduino. Since the Arduino has the capability for both; digital and analog inputs, the digital input is given by push buttons that control the forward, reverse, left and right movements of the robot.

2.3 **CONTROL METHODS**

· *Neural network control*

The motions and orientation of a manipulator is controlled by many methods, one such is by using means of neural networks. Artificial neural networks is a deep learning algorithm derived from the aspirations of the human brain and designed to imitate the learning methods of the neurons present in the human brain. In an artificial neural network, there are present three main layers comprising of an input layer, a hidden layer and an output layer. Now how do these learning procedures provide to be useful in training our robotic arm? A set of parameters is trained to review the mappings by the inputs given from the user to the inputs sent to the manipulator.

Two main types of training algorithms of artificial neural networks as a solution to the controlling of the manipulator is classified as on-line training and off-line training. The training of the off-line is more- simpler as the users receive feedbacks from manipulator readings and compare to the in-stored outputs.

Proposed method of training of neural networks is the on-line training method to achieve real dynamics of the manipulator. In this procedure, a sensor is responsible for measuring the real output which would then pass this result extracted from the user's input to the neural network. Thus, online feature is enables thus introducing the ability to modify its parameters until it fits training samples [27].

Another problem solved by this efficient method of controlling the manipulator is inverse kinematic dynamics of the robotic arm. Here, in order to produce the training data for the neural network, arbitrary joint angle values that monotonously cover the ranges of the coordinated are generated. The procedure begins with finding inputs from the joint parameters which would yield a desired output referencing to the localization of the end-effector [28]. The next stage would be the training stage, here the user input is simply the localized vector resulting from the forward kinematics and the target data is its corresponding joint parameters set of randomly generalized values [28].

· *PID control*

PID control is implemented for the motion of a robotic manipulator. A PID controller has three tunable parameters where the controller gains are defined by variables Kp,Ki,Kd. Here, Kp corresponds to proportional gain, Kd represents derivative gain and Ki represents the integral gain. The control law for PID is shown as-

$$u = Kve(t) + Kpe(t) + Kie(t)$$

General approach to error is defined as:

$$e(t) = x\text{^}des(t) - x(t)$$

Where we require e(t) to converge exponentially to zero.

After determining the law of the system with the error input, the output is carried out by taking degree of freedom of the controller into view. A conventional PID controller design has one degree of freedom due to a single feedback controller [36]. Now, in a two degree of freedom PID controller, the output is determined with respect to the difference between a reference signal output and measured signal output [36].

· *Coordinated control*

The coordinated control technique is for the three-dimensional recognition of the object to be withheld. Some objects have irregularities or are stacked in a staggered or a disoriented manner, which makes it rather grueling to recognize. The coordinated control strategy based on the task requirements is executed in a master-slave control mode for a dual-arm manipulator. In this strategy, the master arm adopts a bilayer fuzzy force/position hybrid control and the slave arm inhibits position control, added to this, a fuzzy control algorithm is combined with this control scheme to adjust to the changing surroundings [29]. Coordinated control can be vastly applied to spacecraft dynamics at its desired altitude whilst tracking trajectory in the inertial space.

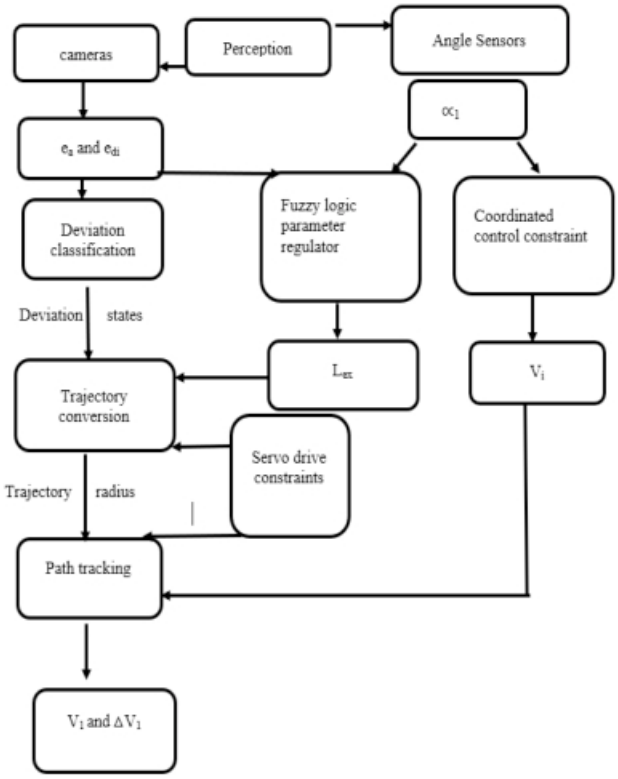

Fig5: Control frame work of coordinated path tracking [32]

Sliding mode control or the SMC, could provide inconsistent solutions to if the altitudes are moderated. Hence control gains can be derived using the simplified Lyaponov function [30]. A decoupled systems projects independent selection of switched control gains in concurrence with instinctive option of the Lyapunov function [30]. Looking at an example of this network, we observe path tracking using coordinated control framework that can be explained by the presentation of two vision guided tractors as shown below [32]:
This exhibits the process in generating motor outputs in accordance with the sensor inputs and several control constraints as mentioned earlier. In the below depicted flowchart it is observed that each of the tractors have parallel processes of vision perception and path tracking represented by variable Lex.

· *Haptic based control*

In haptic based teleoperation, a master-slave approach is catered to monitor the position and movement of the robotic arm. The basic requirements for a master haptic device would be; a six DOF with three DOF translations and three DOF rotations, decoupled and coupled manipulations functions and handle of master haptic

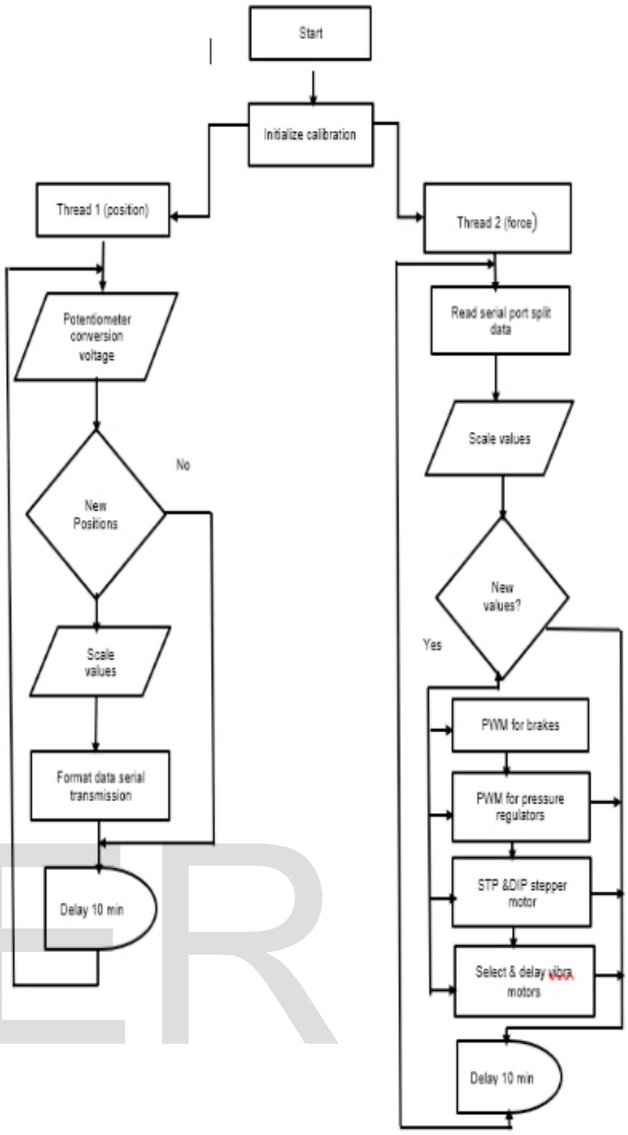

Fig6*: Control program flow chart [34]*

device should be at its initial position and orientation [33]. In exoplanet observations, for the extravehicular tasks that have to be performed, human safety is also a matter of consideration.

For this purpose, the extravehicular robot connected with a haptic robotic arm exoskeleton actuated by the human operator in the spacecraft is implemented. The program control module consists of two parallel independent code branches to provide information taken by the receptors and provided to the transmitters as separate structures and to avoid clashes in their timing [34].

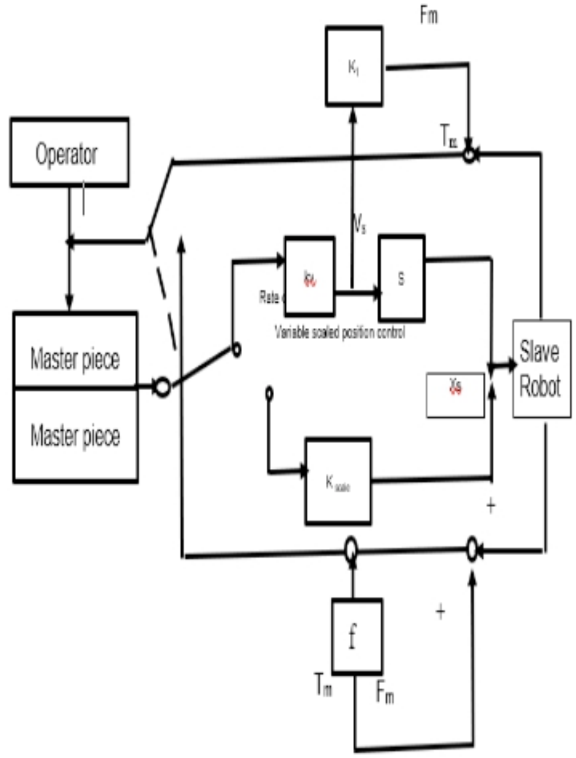

Fig7: Flow chart of haptic feedback generated for operating resistance on the slave side [33]

3. CONCLUSION

The mechanism, structure and the components used to analyse the techniques of this elaborate field of robotics, we can conclude that a haptic based control of the robotic gripper or arm is the recent most evolved technology introduced. This mechanism not only simplifies the assigned tasks but only achieves lengths where a normal human hand or intelligence would interim as a difficult task. In this paper, the components used to build such an efficient high-tech product are modernised to be simpler as well as light weight and highly affable to any human looking forward to accentuate the idea of a haptic robotic arm.

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