A Novel Communication Architecture and Control System for TeleBot: A Multi-Modal Telepresence Robot for Disabled Officers

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Abstract

There is an incredible need to help disabled veterans and police officers to remotely perform patrolling and law enforcement duties. Currently a disabled officer is medically retired following a severe duty related injury, depriving the individual of a career and the force of an experienced officer in his/her prime. This result in billions of dollars of wasted talents and resources.

As an ongoing effort at the Florida International University (FIU) Discovery Lab, researchers are designing, developing and testing a new telepresence robot designated as "TeleBot" to assess how it can be used to help disabled officers return to duty. More specifically, the work has been focused on the design and implementation of a smart telepresence robot with enhanced functionalities.

This paper presents a detailed development and analysis of TeleBot and provides a field evaluation (demonstration/validation) of the current capabilities. The principal contribution of this paper comprises of robust communication architecture for efficient human interaction with the robot that almost resembles a law enforcement officer and capable of receiving commands that are issued by an actual disabled officer from a remote location. Two high definition cameras in the head assembly of TeleBot wirelessly transmit live video stream of the TeleBot's visual field to the remote operator wearing a virtual reality based stereoscopic display. Additionally, a voice recognition system enables the TeleBot to greet people and accept voice based commands from the operator. The user-friendly software embedded on the system provides a seamless communication between the officer at a remote location and diverse population through TeleBot.

The striking factor of this design is affordability in terms of cost.

Keywords: TeleBot, Telepresence robot, Voice Recognition, Virtual Reality, Mobility and Data Distribution Service

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Introduction

With recent advances in computer and sensor technologies in the last few decades, the use of robots for various applications has increased enormously. Globally, many research organizations are concentrating in research and development of various types of robots based on their requirements and applications. Telepresence robotics is one such area of robotics that allow human controllers to operate in remote locations through a real-time multimedia and mobility interface in a wireless mode. Remote teleoperation of advanced robotic technologies has great potential in many areas, including applications in education, deep sea exploration [Forrest et al. 2010], dangerous military missions, hazardous environments [Parker et al. 1998] off-shore projects [Heyer et al. 2010; Mazzini et al. 2011], space exploration [Fong, 2012], health care [Vermeersch et al. 2015; Becevic et al. 2015; Guillian et al. 2010; Scassellati, 2009] and tele-surgery [Hannaford et al. 2013; Kong et al, 2006; Lum et al. 2009; Newman et al. 2011; Tinelli et al. 2011]. Robert Leeb et al., [2015] had designed a Telepresence robots to assist people with severe motor disabilities

Telepresence robots are controlled by a computer and accept instructions from a trained human operator to perform user specific operations based on its design. Currently NASA and a few other space agencies are planning to use such robots for future space exploration programs. The Advanced Robotics Research Centre, UK, in their *VERDEX Project* (Virtual Environment demote Driving Experiment), has developed an experimental test bed for investigating telepresence and virtual reality technologies in the design of human-system interfaces for tele-robots. [Stone, 1992]. Recently Nagendran et. al, [2015] had explored the possibility of symmetric three dimensional telepresence where both sides (participants) are "teleported" simultaneously to each other's location. Lee et al., [2015] has investigated the effects of telepresence robot types on the perceived presence of a remote sender.

Returning military veterans who have been disabled during their duty are often released from active duty and/or medically retired from the military and unable to find civilian employment due to their disabilities. In addition to military veterans, every year hundreds of police officers are forced to retire because of a disability. TeleBots offer one of the best solutions to use the skills and capabilities of the disabled veterans and police officers and maintain them in the force, without requiring the use of the officer's physical presence in the field.

In this paper, we present the design aspects of a TeleBot developed at the Discovery Lab in Florida International University (FIU). Here the researchers are working to build a TeleBot that will allow disabled veterans and police officers to reconnect with the workforce and simultaneously give them the opportunity to use their skills to remotely conduct patrol duties in urban streets through the TeleBot.

TeleBot Management System (TMS)

The novelty of the TeleBot management system lies in its, light weight, optimized usage of bandwidth for video streaming, modular approach in data communication, maintaining the stability of the TeleBot by using the PID control system, a user friendly voice recognition system and stable power system. These features makes it easier for trouble shooting and maintenance. In the following sections we present in detail all the subsystems associated with the TeleBot for its normal operation. In section 1 we describe the engineering design of the TeleBot. The sub-section 1.1 describe the wire frame model and its stress analysis. The sub-section 1.2 describes about the TeleBot's head assembly. This section also presents the TeleBot's vision control system and the obstacle detection subsystems that are enclosed inside the head assembly. TeleBot arm manipulation subsystem is discussed in the sub-section 1.3. In section 2 we present the three layered communication architecture and control system of TeleBot. The motion planning of the TeleBot during its operation is discussed in section 3. The implementation of user friendly voice recognition system is described in section 4. Finally, in section 5, we have presented the power system from which all the electronic modules are powered when TeleBot is in operation.

1. The Engineering Design

In this section, we present the details about the designing of both the internal and external mechanical body frame work of TeleBot. A simulation study on stress analysis of the wire frame model is also discussed. In this section, we also present the vision control system of the TeleBot.

1.1 Wire Frame model

The entire body frame work was modeled and optimized using 3D CAD engineering programs [Solid works Corp. MA, USA] to make it viable for physical construction based on feasibility, limitations of manufacturing, materials, budget, and time. The skeleton of the TeleBot was engineered by focusing on two main aspects, simplicity for remotely operated motions and weight distribution of the hardware. Similar to human anatomy, the TeleBot has a spine and rib cage to protect the internal hardware. The structure of the metal frame has a foundation of a continuous backbone [Cibert and Hugel, 2013], which bears most of the robot's weight. For increased stability, the heavy lithium-ion rechargeable batteries have been placed in the lower compartment located at the bottom of the TeleBot.

Fig. 1a shows the physical TeleBot exterior frame work for the real world. The internal frame work of the TeleBot is shown in Fig. 1b and Fig. 1c shows the present TeleBot model that is comprised of internal lightweight aluminum metal tubes frame work and with an exterior cover fabricated with a durable and lightweight aluminum metal sheet. The covers were designed with maintenance and convenience factors in mind [Oh et al. 2006]. Through the use of 3D printers, machining, and Computer Numerical Control (CNC) routers, the TeleBot prototype was manufactured at FIU Discovery Lab, showing feasibility of the design. The backbone frame was angled to match the final TeleBot exterior. Due to the chosen lightweight materials and

hardware, the TeleBot structure is stable and withstands the given loads. Stress analysis simulation using Finite Element Analysis (FEA) [Reddy, 2006; Gilbert, 1973; Zienkiewwicz, 2005; Babuska et al. 2004] was conducted to validate its structural integrity. SolidWorks Simulation was used to perform the design analysis. The frame was designed to meet all physical requirements and the aesthetic design concept. The actual weight of the TeleBot is about 32 kg. For analysis, the weight of the entire TeleBot is set to 60 kg. This is 28 kg heavier than the predicted TeleBot weight, thus providing a better factor of safety. The vertical waist beam from analysis is replaced by a powerful linear actuator that is welded to the frame for added structural support and functionality. Fig.2 shows the simulation results of the stress analysis. From the Fig.2 it can be seen that the stress is minimum and zero at the bottom and is maximum at the waist beam support.
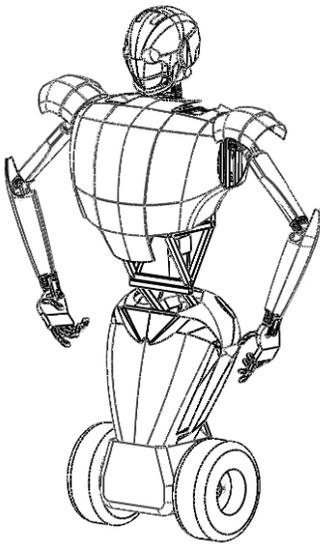

Fig. 1a Modified physical TeleBot exterior with frame for the real world
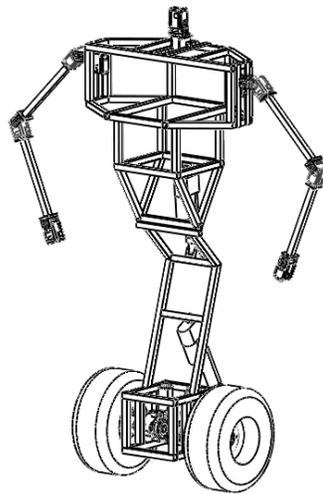
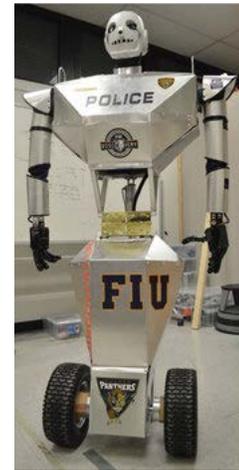Fig. 1b TeleBot lightweight metal wire frame angled to maintain TeleBot shape
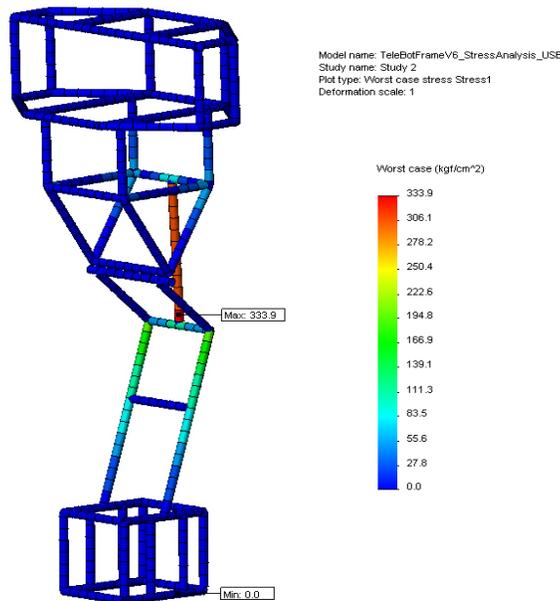
Fig. 1c Present TeleBot model

Fig. 2 Weight on upper TeleBot frame – stress analysis of worst case scenario

Table 2: Degrees of Freedom

Degrees of Freedom (DOF)	
Head	2DOF
Shoulder	3 DOF X 2
Elbow	1 DOF x 2
Wrist	2 DOF X 2
Fingers	3 DOF x 10
Main Wheels	2 DOF x 2
Body Balance	1 DOF
Third Wheel	2 DOF
Waist	1 DOF
Total	52 DOF

Table 1. TeleBot Dimensions

TeleBot Specifications	
Height	180 cm
Width	85 cm
Depth	55.0 cm
Total Weight	32 kg

Table 1 gives the physical dimensions of the TeleBot and the Table 2 gives the various degrees of freedom of the TeleBot.

1.2 TeleBot head assembly

The TeleBot's head assembly is made in house by using Makerbot® Replicator Desktop 3D Printer [MakerBot® Industries, LLC, NY, USA]. Polylactic acid (PLA) based thermoplastic filament is used for designing. PLA is a bio-degradable polymer and is harder than ABS (*Acrylonitrile Butadiene Styrene*) thermoplastic. It melts at a lower temperature (around 180°C to 220°C), and has a glass transition temperature between 60-65 °C, so is potentially a very useful material for 3D printing applications for making robotics parts. The head assembly encloses the vision subsystem and the associated electronics for obstacle detection.

1.2.1 Vision

Video information transmitted from the TeleBot is critical for conversation and navigation. During the field operation the TeleBot will be in motion, so the information must be transferred wirelessly. Two high definition cameras act as the eyes for TeleBot similar to humans. Video transmission of the remote environment produces the largest set of sensory data to the operator. The primary difficulty faced by the TeleBot's Vision system is its susceptibility to communication problems from network failure, a reduction in networks bandwidth, latency and packet loss. The operator receives the transmitted video information of the TeleBot's visual field by wearing a virtual reality based head mounted display (HMD). The TeleBot's intelligent vision control system adjusts image quality to prevent excess delay and jitter during video transmission. The vision control system accounts for network quality, camera movement and the operators region of interest. During the peak network traffic, the video quality is optimized by maintaining the quality of the video to be high only in the operators region of interest (ROI) while degrading the quality of the surrounding environment. The ROI detection is based on the eye movements of the operator. Fig. 3 shows the implementation of vision control system in the TeleBot.

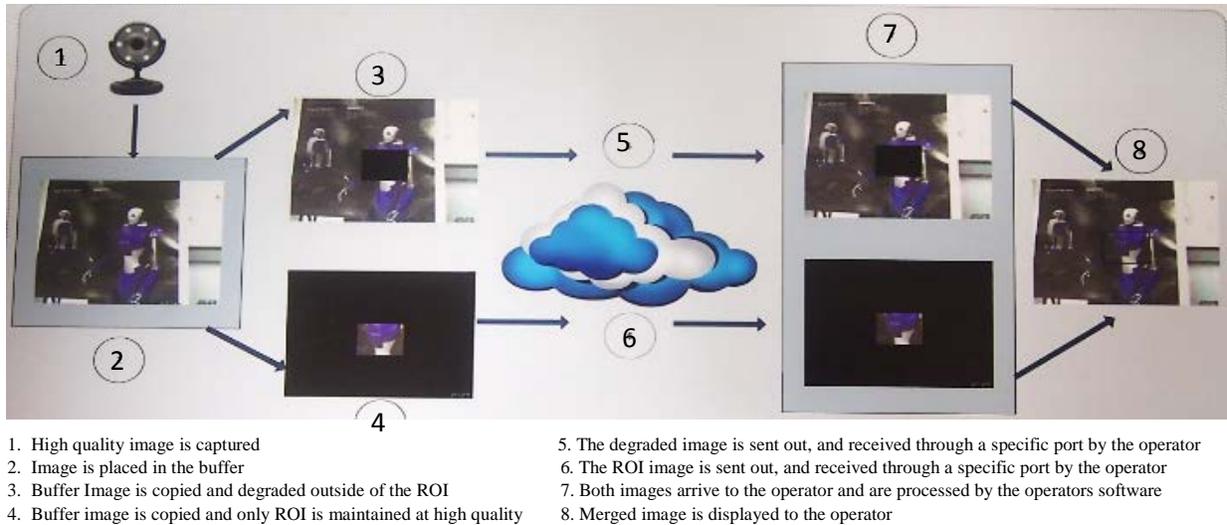|	
1. High quality image is captured	5. The degraded image is sent out, and received through a specific port by the operator
2. Image is placed in the buffer	6. The ROI image is sent out, and received through a specific port by the operator
3. Buffer Image is copied and degraded outside of the ROI	7. Both images arrive to the operator and are processed by the operators software
4. Buffer image is copied and only ROI is maintained at high quality	8. Merged image is displayed to the operator

Fig. 3 TeleBot vision control system

1.2.2 Detection of Obstacles

TeleBot uses a Maxbotix LV-EZ1 sensor [MaxBotix Inc., MN, USA] as shown in Fig. 4 for detecting the obstacles in its path. This unique sensor uses sound pulses to detect obstacles. LV-EZ1 sensor sends out pulses of ultrasonic sound at a frequency of 41KHz and listens for the reflection of the sound off nearby objects. The distance of the object is determined by calculating the total time between the transmission and reception of ultrasonic pulses. For example, the round trip time for an obstacle located at 10 feet away from the sensor will be about 17.8 ms (velocity of sound is assumed to be 1126 feet/sec). The LV-EZ1 requires a power supply from 2.5V to 5.5V at 3mA current. We have used an Arduino microcontroller board for converting the total time taken between the transmission and reception of ultrasonic sound pulses into distance in terms of inches (distance between the TeleBot and the obstacle). The minimum distance at which the TeleBot should stop when it finds an obstacle can be set in the Arduino module.

Fig. 4 Ultrasonic Sensor

1.3 TeleBot Arm Manipulation subsystem

In this section, we demonstrate the feasibility and benefits of a low-cost open-source TeleBot arm manipulation subsystem. A decentralized, modular arm control subsystem is based on Blue tooth sensors so that officers with different disabilities can seamlessly switch devices in order to manipulate the robotic arms in a way that is suitable to their operational needs. In the present version of the TeleBot, the tools used for arm operation were the YEI Technology 3D-

Space Sensor wireless inertial measurement unit (IMU) [YEI Technology, OH, USA] sensors, the windows-based YEI MoCAP Studio [YEI Technology, OH, USA] motion capture software (modified for data transmission over TCP/IP network communication), the open source Real-Time Innovations (RTI) [Real-Time Innovations, CA, USA] Data Distribution Service (DDS) software, the Robotis CM-700 Controller [ROBOTIS INC, CA, USA] and SUB Board, and the Robotis Dynamixel MX-106R [ROBOTIS INC, CA, USA] and MX-64 servo actuators [ROBOTIS INC, CA, USA].

To operate TeleBot's arms, the Operator securely straps the 3D-Space wireless IMU sensors along the hands, lower and upper arms, back shoulders, chest, and head. As the Operator moves the arms, data from the triaxial gyroscope, accelerometer, and magnetometer embedded within these IMUs are transmitted to a listening dongle connected to a laptop/computer, which relays the data to the motion-capture software, the YEI 3D-Space MoCAP Studio. This software, uses a set of algorithms to calculate angles in order to process the orientation of each sensor. Real-time angular coordinate data (X, Y, and Z) is calculated from the sensor input for the head, elbow, shoulder joints and the wrist, of both the right and left arms. This data is formatted and locally transmitted via TCP/IP to a Master program on the same laptop/computer. Simultaneously, this software also maps each sensor to the corresponding anatomy of a virtual skeleton to visually aid the Operator, to confirm whether all the sensors are correctly mapped according to the movements of the operator. Fig. 5 shows the MoCAP software window that is used for calibrating the sensors.

Fig. 5 Screenshot of the MoCAP studio window

The operating system used for TeleBot is Linux, UBUNTU, Ver. 14.4. [Canonical Group limited, London, UK] The Master program, employs a Java-based framework utilizing the RTI DDS publish-subscribe message-passing protocol. This program formats and packages the

collected co-ordinate data from the sensors. These data are given as an input to a mapping formula, which produces a respective servomotor position unit. The unique servo identification number, servo position unit, and servo speed unit for each joint movement, is then published onto a "topic," or a message "mailbox" in accordance to the publish-subscribe protocol.

A subscribing Java-based Slave program listens and reads the data from the topic, and passes this data to the Robotis CM-700 controller, which communicates with six daisy-chained Robotis Dynamixel servo actuators on each robot arm and two in the robot neck. These servomotors rotate to the position given in the sent data, mimicking the arm movements of the Operator. If the Master or Slave program is prematurely terminated, the other side will continue to publish data to the topic or listen for data from the topic without termination or interruption; the Master and Slave are unaware of the presence of each other, which is key to the reliable, remote operation of TeleBot.

2. The Communication Architecture/Control System

For an effective deployment of TeleBot, several communications need to be supported between the operator at a remote site and TeleBot. Further, these communications interface a variety of devices over different communication media such as Bluetooth, wireless, etc. Moreover, the system should support communications from the operator to TeleBot as well as from TeleBot to the operator. A modular framework is essential for the implementation of this heterogeneous communication to minimize software development and maintenance, and to improve communication reliability.

We propose a three layer communication architecture as shown in Fig. 6. The operator interface layer associates communication with devices that are at the operator site to the communication system. Some of them are input devices such as IMU Bluetooth sensors, Kinect, voice command input, etc. and others are output devices like head mount stereoscopic display, haptic feedback sensors on fingers, etc. Similar to the operator interface, the TeleBot interface bridges the communication system with TeleBot components. To modularize this diverse communication, we introduce a middle layer known as Data Distribution Service (DDS) that forms the communication platform between the operator interface and the TeleBot interface. Any communication from an input device/component will be published at the DDS layer as an article. Any device/component that is a recipient of a communication will subscribe to the article at the DDS layer.

This publish-subscribe modular approach also supports multiple devices for concurrent subscription to the same article. Additionally, this framework facilitates a multi-modal interface (Bluetooth, wireless, voice command, etc.) that would improve fault tolerance and reliability of the TeleBot operation. Addition of any new device requires a simplified development of the plugin for the device to DSS either as a publisher or a subscriber. This modular feature reduces the complexity of the system and enhances the reliability and performance.
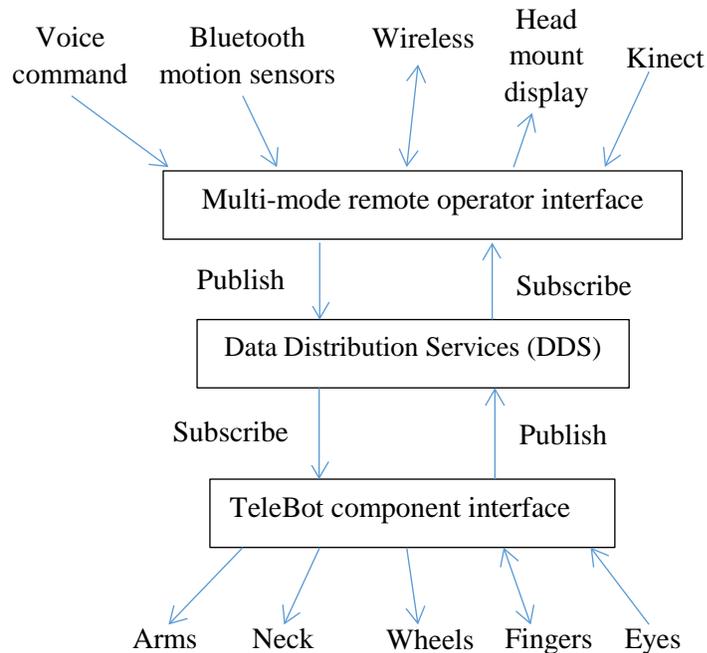
Fig. 6 TeleBot Communication Architecture/Control System

3. The Motion Planning

In this section we describe the implementation of motion planning in TeleBot. The TeleBot Mobility System currently operates as a three-wheeled platform, comprised of two drive wheels at the front of the TeleBot and a swiveling caster wheel suspended by a linear actuator from the back of the TeleBot. The TeleBot uses differential steering powered by an Arduino Mega and a VNH5019 motor driver [Pololu Corp. NV, USA], that communicates with TeleBot through USB and deciphers input commands from an array of various control devices.

The design of the TeleBot Mobility System is based on two wheels during the normal terrain condition and uses a third small tail wheel in very rough terrains. While the three wheeled platform provides optimal stability, the two wheeled platform adds an increased maneuverability and a smaller turning radius, allowing for TeleBot to perform more precise drive maneuvers in tighter spaces. This added capability requires an increase in system complexity, motor capability, and intricate tire design.

Mobility System has two main components: an mbed LPC1768 [Creative Commons, CA, USA] microcontroller, powered by an ARM Cortex M3, and a CHR-UM6 IMU sensor. The mbed runs a proportional-integral-derivative controller (PID controller) to control a feedback loop that sends pulses to the motors. These pulses are proportional to the offset reading of the pitch angle, as read from the UM6 IMU. The Mobility System was developed using a small test assembly, in order to test the algorithm and response of the wheel motion before it is actually implemented on TeleBot. The UM6 IMU unit runs an Extended Kalman Filter that outputs quaternion values and the converted Euler angle representation. A set point value defined by the pitch value read from the UM6 IMU at an upright, balanced state is used to calculate the offset value, representative of the tilt forward or backward of the mobile assembly. The PID control

loop has preset constants that are tuned during calibration to match the specific conditions of the mobile assembly, i.e., mass distribution, or slop in the wheel assembly. The PID output is sent to the VNH5019 motor driver to pulse the motors at a value directly proportional to the output given.

The mobile assembly used 12V DC brush motors and a Parallax wheel hub assembly [Parallax Inc CA, USA] of the same kind that exists on TeleBot's current Mobility System. During the demonstration/validation testing, the precision of the Denso motors was called into question, as improvements in the mass distribution of the assembly designed to even out the stresses on the motors as the assembly tilted forward or backward, didn't improve the reactivity of the PID control. The addition of optical encoders to read more absolute offset differences and to improve the quality of the set point may lead to greater responsivity of the control and more finite adjustments. Following PID control algorithm is currently used for motion control.

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_d \frac{de}{dt}$$

where $e(t)$ is the error offset from the set point and K_P, K_I, K_D are the PID coefficients. Initially the desired angle of zero pitch degrees is set, which is the pitch angle when TeleBot is upright. The current pitch angle is read from the IMU device on the TeleBot. The pitch angle is then passed through the Kalman filter to remove noise. The filtered pitch angle is subtracted from the desired angle to get the error in the TeleBots position. This error is used to calculate the Proportional, Integral and Derivative terms of the PID controller. Then each term is multiplied by the respective gain coefficients. Tuning of PID coefficients are done as follows. First all the PID coefficients were first set to zero. In the next step the P-gain (K_p) was increased until the robot began to oscillate in a consistent manner. Then the D-gain (K_I) was increased until overshooting was decreased and finally the I-gain was slowly increased until the system gets completely stabilized. The block diagram of the PID control algorithm is shown in Fig. 7.
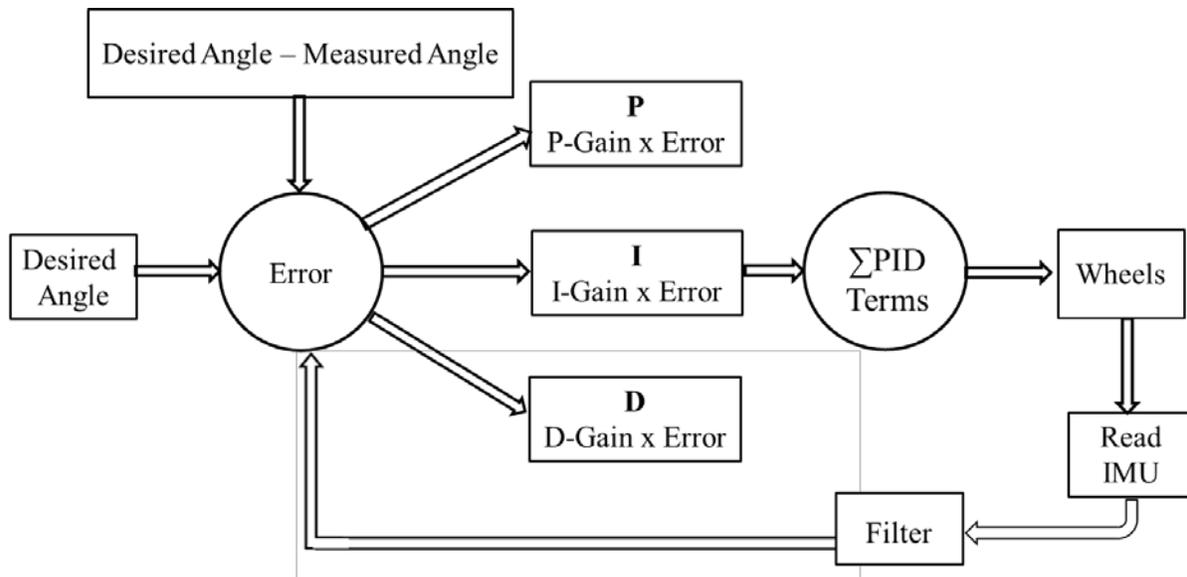

Fig. 7 Block diagram of the PID Controller

4. Voice Based Greeting/Control System

During field operations, TeleBot needs a complete, well advanced ground control system to operate efficiently and to improve the performance and productivity gains. Such ground systems should be robust without any complexity. The systems should also be compact and portable, as well as user friendly, enabling the disabled operator who is controlling the TeleBot to smoothly operate the TeleBot. Finally the system should also be economical and easily sustainable in the field. A. In the case, where the operator has a disability with his/her arms, the calibration of the IMU sensors and arm control of the TeleBot becomes difficult. We overcome this problem by adding the feature of human voice based Greeting/Control system to the TeleBot.

In the current version of TeleBot, we have tested two types of voice systems:

1. Android, Bluetooth, Arduino microcontroller and an EMIC2 [Parallax Inc CA, USA] based greeting system.
2. TCP/IP and Free TTS open source based greetings/control system.

4.1 Android, Bluetooth, Arduino microcontroller and EMIC2 based greeting system.

In this section we describe the human voice based greeting system that was developed for the TeleBot. The motivation of the voice based greeting system is to enable the TeleBot to greet the people when it is in field operation (e.g., greeting drivers or road side commuter's when TeleBot is used in traffic control). In this greeting system we have used an AMR voice recognition application that translates voice to text data and sends that data via Bluetooth module. The AMR voice recognition application is an android operating system (OS) based free application that generally comes along with all types of Android OS based smart phones. HC-05 type Bluetooth module is used for receiving the text data sent from the AMR voice recognition application. For the HC-05 to receive the text data, it needs to be paired with the smart phone. Pairing can be done by using the default factory set password of "1234" for the Bluetooth module. Once the Bluetooth module is paired with the smart phone, the built in microphone in the smartphone receives the voice input and sends the voice data to the AMR voice recognition application. The AMR voice recognition application in turn converts the voice data to text and the resulting text data is sent to the Bluetooth module. Now, HC-05 module transmits the received data through the T_x pin to the R_x pin of the Arduino UNO microcontroller board. Arduino UNO board has an ATMEL's "ATmega328P" [Atmel Corp. CA, USA] microcontroller for processing the data.

The format of text strings that are sent from the AMR voice recognition application to the Arduino has a leading "*" symbol and an ending "#" to indicate the start and ending of the text data. For example if anyone speak the word "*hello*" the AMR voice recognition application converts the voice to text and sends it to the Bluetooth module as "*hello#*". In the Arduino program, the ending "#" symbol is used as a stop symbol for accepting the data from Bluetooth. A simple Arduino program for the TeleBot greeting system is given below.

```
#include <SoftwareSerial.h>
#include <AltSoftSerial.h>   //AltSoftSerial library is used for sending
                             // serial data instead of Tx and Rx of the Arduino
String readString = "";
String Voice = "";
AltSoftSerial altSerial(50,48); //Pins in Arduino used for Tx and Rx
void setup() {
  Serial.begin(9600);
  altSerial.begin(9600);
  Serial.println("Discovery Lab, TeleBot Greeting System");
}
void loop() {
  while (altSerial.available()) {
     delay (3);
     char c = altSerial.read();
     if (c == '#') {break;} //Exit the loop when the '#' is detected
     readString += c;
  }

  if (readString.length() >0) {
    if (readString == "*hello") {
      Serial.println("Swelcome  to  Discovery  Lab "); // sends message to Tx of
                                            //the arduino Leading "S" enables
                                            //the EMIC2 to start reading the
                                            //text
      readString = "";
    }
    else if (readString == "*how are you"){
      Serial.println("SI am fine thank you "); //sends msg to Tx of the arduino
      readString = "";
      altSerial.flush();
      Serial.flush();
    }
  }
}
```

The Arduino program checks for the input string received (including the starting character "*"
from Bluetooth Module and selects the appropriate greeting message and sends it to the EMIC2
module. The greeting message "S*welcome to the Discovery Lab*" will be selected for an input of
"**hello*"and it will be sent to the T_x pin of the Aruduino board. The leading character "*S*" acts as
an activation bit to start the EMIC2 module to convert the text following it in to voice which will
be feed into a speaker output. The Arduino program can be expanded for any number of voice
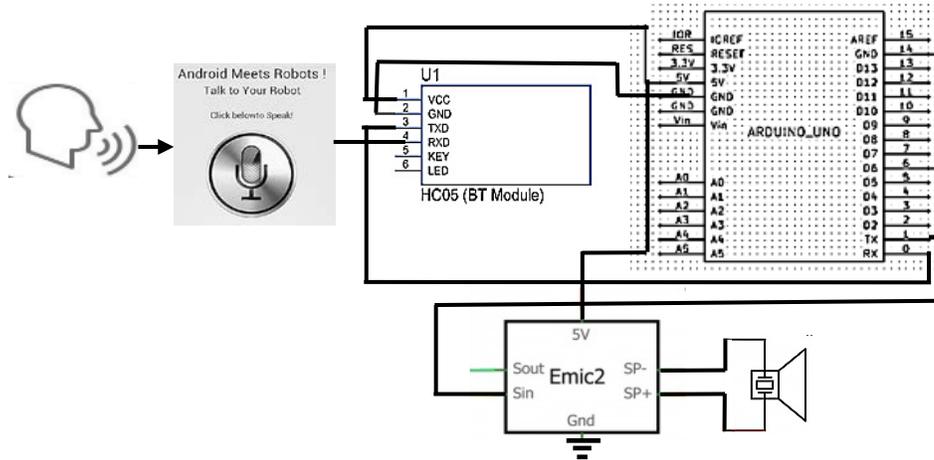inputs. Fig.8 shows the complete circuit diagram for the TeleBot greeting system.

Fig. 8 Circuit diagram of the TeleBot greeting system

4.2 TCP/IP and Free TTS open-source based greetings/control system.

In the section 4.1, we described the greeting system developed for TeleBot, but due to a few constraints based on other subsystem design issues and having in mind the future updating processes, as well as the team's desire to make it very economic, we re-designed the greetings system in such a way that it can also be extended and used as a voice based control system for the TeleBot operations. One of the main constraints in the model described in section 4.1 is that it needs a dedicated serial port for communication, and moreover it needs a Bluetooth module and an EMIC2 module for operation. Also it needs an Android smart phone for voice input. In the redesigned voice recognition subsystem we have used Bitshophia's Bitvoicer software [BitSophia Software Ltd. 2013] for converting the voice to text and a free open source, Free TTS software for converting text to speech (TTS). FreeTTS is a speech synthesis application written entirely in the Java[TM] programming language. Since the free TTS is based on Java, it becomes easier to use this open source software along with the RTI Data Distribution Services software for controlling the TeleBot. In this model TCP/IP is used as the communication protocol for sending the text data obtained as the voice inputs through a microphone. Fig. 9 shows the block diagram of TCP/IP and Free TTS based Greeting/Control system of TeleBot
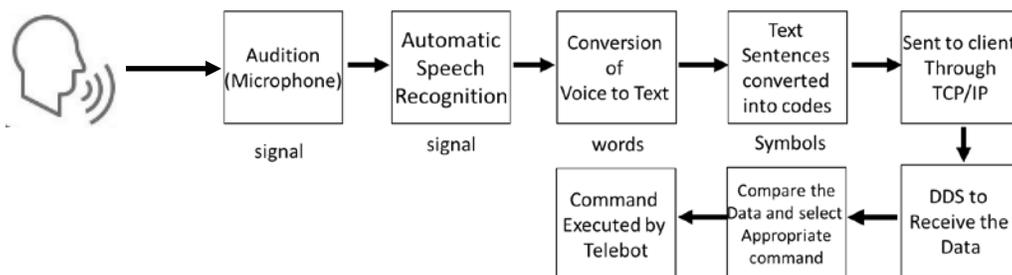

Fig. 9 Block diagram of TCP/IP and Free TTS based Greeting/Control system of TeleBot

Initially, the human voice is captured by the microphone connected to the computer in which the Bitvoicer software is installed. Bitvoicer interprets the voice input and converts the words or sentences into small, two letter codes. The two letter codes are defined by the users. For example, as in Section 5.1, for the word "*hello,*" the two letter code generated would be "*HL*". Now this two letter code is sent to the computer installed inside the TeleBot through TCP/IP. Then this two letter code is published by the Master program for the Voice recognition system through the DDS. The corresponding Slave program for the voice recognition system subscribes the code, taking appropriate action based upon the code words received. Again, if the code word received by the slave is "*HL,*" the message "*Welcome to the Discovery Lab*" will be played in the speaker, located inside the TeleBot. Similarly, we can send commands to the respective master program for motion control. This enables voice operation using commands such as; "Move front," "Move back," "Turn left" and "Turn right," etc. The two letter codes for these commands are MF, MB, TL and TR respectively. When these command are received by the slave program for motion control, it makes the TeleBot move forward, move backward, turn left side and turn right side respectively.

5. Power System

This section describes the redesigned model of the power system for the TeleBot. When redesigning the power system our goal was to create a system that provided a more stable and reliable power source than the original design while offering more flexibility in terms of power distribution and options. This was achieved by redesigning the original system that was comprised of four 12.8V 10Ah LiFePo4 battery packs in parallel. The batteries discharge curve showed in Fig. 10 ranged from roughly 14V maximum to a minimum of roughly 11V. These packs were used for powering wheel motors, servos of the hands and to all other electronic modules in TeleBot. But this design presented several issues.

First, the motherboard began to "brownout" when the voltage in the system dropped below approximately 12.2V which not only cut into the capacity of the battery system, but could potentially cause damage to our sensitive electronic systems such as the motherboard and sensory equipment.

Second, due to the configuration and the high impedance of the mini ITX motherboard the overall amperage that could be delivered to the system when attached to an external power source was limited, thus limiting the ability to charge the batteries, leading to long downtimes and intermittent power failures during testing and operation. Third, the batteries natural discharge curve placed 10-20% of their capacity below the dropout threshold for the systems ITX motherboard causing premature power failure.

To solve these issues we shifted our battery configuration to achieve 24V by creating two separate battery packs, each comprised of two 12.8V packs wired in series, which were then wired in parallel to achieve a constant voltage between roughly 22V and 28V. The 24V supply was then lowered via stepping transformers to the desired voltages. This afforded greater flexibility and consistency of voltage supplies as the stepping transformers corrected for voltage

fluctuations due to battery depletion maintaining a consistent supply voltage regardless of battery capacity. Another benefit being the ability to use higher voltage motors which were not previously options.
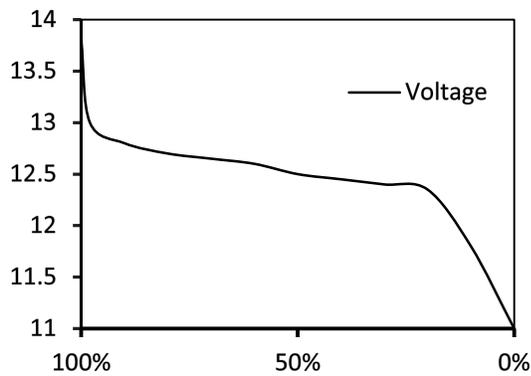

Fig. 10 Voltage discharge curve

Ultimately the power system was divided into three power levels, 24V, 12.8V and 5V (not pictured). For safety, the motherboard was isolated on a separate Stepping transformer from the other parts of the system such as the mobility and arm systems. This was done to lower the risk of surges caused by sudden power drawn due to motor actuation.

Our choice to use stepping transformers was due in large part to cost as well as availability and high efficiency. The low cost and availability of this type of transformer allowed us to implement our system in relatively little time and with a low budget. The high efficiency of this transformer meant that at most we would lose 20% of our battery capacity to power conversion with actual figures closer to 10% - 5%.
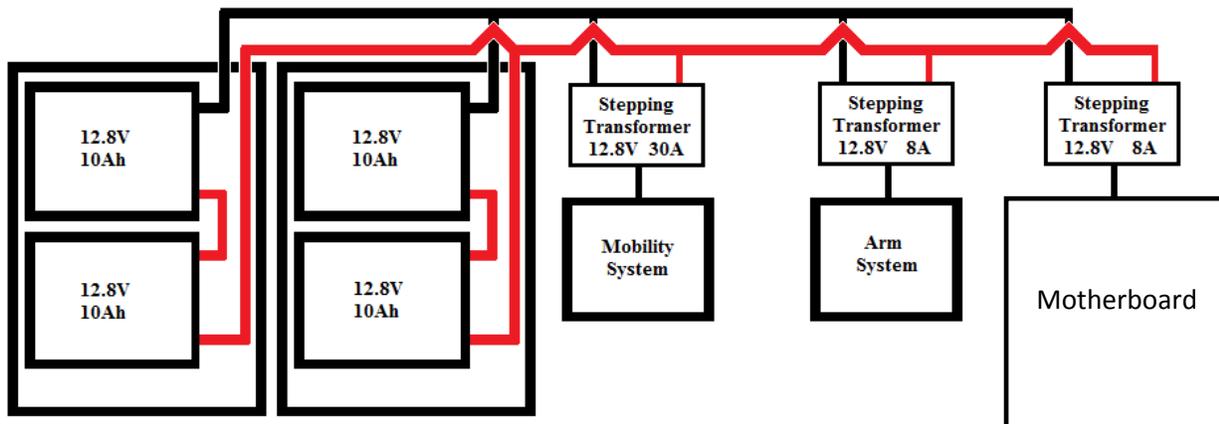

Fig.11 Implementation Scheme of TeleBot E-Stop Switch

For safety reasons a wireless E-Stop switch was implemented using a solid state relay controlled by an Arduino micro controller over Bluetooth. This allowed us to maintain safe function while simultaneously allowing mobility without a tether. With a single press the solid state relay is opened and power to all systems is deactivated until the E-Stop is reset.

Conclusion and Future work

In this paper, we presented the recent research work from the FIU Discovery Lab in designing and building a low-cost, sustainable telepresence robot for use as an avatar for

disabled military veterans or police officers to perform law enforcement duties. The current prototype of TeleBot has many added features compared to its earlier versions. In the present model we adopted a modular approach for each subsystem with a novel three layered communication architecture. Additionally, the integration of a voice recognition system enables the TeleBot to greet and accept commands from the operator. Currently, we are in the process of updating the voice control system by using natural language programing, neural network and deep learning process. We are also in the process of incorporating aesthetic design into TeleBot for its wide acceptance among the general public.

Acknowledgements

References

Atmel Micro-controllers, Atmel Corporation, 1600 Technology Drive, San Jose, CA 95110 United States.

Babuška, Ivo; Banerjee, Uday; Osborn, John E. (2004). "Generalized Finite Element Methods: Main Ideas, Results, and Perspective". Int. Journal of Comp. Methods 1 (1): 67–103.

Barbosa. B. L, BitSophia Software Ltd. 2013.

Becevic. M, Martina A. Clarke, Mohammed M. Alnijoumi, Harjyot S. Sohal, Suzanne A. Boren, Min S. Kim, and Rachel Mutrux, (2015), "Robotic Telepresence in a Medical Intensive Care Unit—Clinicians' Perceptions." Perspectives in Health Information Management", Summer, 1-9.

Cibert C. and Hugel V. (2013), "Compliant intervertebral mechanism for humanoid backbone: Kinematic modeling and optimization", Mechanism and Machine Theory, Vol. 66, 32-35.

Mbed LPC1768 Micro-controller, Creative Commons, 444 Castro Street, Suite 900, Mountain View, California, 94041, USA

Fong, T.W. (2012), "The human exploration telerobotics project." Global Space Exploration Conference, Washington (pp. 1-12).

Forrest, A.L., Laval, B.E., Lim, D.S.S., Williams, D.R., Trembanis, A.C., Marinova, M.M., Shepard, R., Brady, A.L., Slater, G.F., Gernhardt, M.L. and McKay, C.P. (2010), "Performance evaluation of underwater platforms in the context of space exploration." Planetary and Space Science, Vol. **58** (4), 706-716.

Gilbert. S and Fix, George (1973). An Analysis of The Finite Element Method. Prentice Hall. ISBN 0-13-032946-0.

Giullian, N., Ricks, D., Atherton, A., Colton, M., Goodrich, M. and Brinton, B. (2010), "Detailed requirements for robots in autism therapy."Proceedings of the IEEE International Conference on Systems Man and Cybernetics (pp. 2595 -2602).

Hannaford, B., Rosen, J., Friedman, D.C.W., King, H., Roan, P., Cheng, L., Glozman, D., Ma, J., Kosari, S.N. and White, L. (2013), "Raven-II: An Open Platform for Surgical Robotics Research."IEEE Transactions on Biomedical Engineering, Vol. 60, 954-995.

Heyer, C. (2010), "Human-robot interaction and future industrial robotics applications." Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (pp. 4749-4754).

Kong, M.X., Du, Z.J., Sun, L.N., Fu, L.X., Jia, Z.H. and Wu, D.M. (2006), "A Robot-assisted orthopedic telesurgery system." Engineering in Medicine and Biology Society, 2005, 27th Annual International Conference of the IEEE-EMBS 2005.

Lee. H, Jung Ju Choi and Sonya S. Kwak, (2015), "The Impact of Telepresence Robot Types on the Perceived Presence of a Remote Sender." International Journal of Software Engineering and Its Applications, Vol. 9, 107-116.

Leeb. R, Luca Tonin, Martin Rohm, Lorenzo Desideri, Tom Carlson, and Jose´ del R. Milla´n, (2015), "Towards Independence: A BCI Telepresence Robot for People With SevereMotor Disabilities." Proceedings of the IEEE, Vol. 103, No. 6, 969-982.

Lum, M., Friedman, D., Rosen, J., Sankaranarayanan, G., King, H., Fodero, K., Leuschke, R., Sinanan, M., and Hannaford, B. (2009), "The RAVEN - Design and Validation of a Telesurgery System."International Journal of Robotics Research, Vol. 28, 1183-1197.

Makerbot® Replicator (Desktop 3D Printer), MakerBot® Industries, LLC, One MetroTech Center, 21st Fl, Brooklyn, NY 11201 USA.

Maxbotix LV-EZ1 sensor, MaxBotix Inc., 13860 Shawkia Drive, Brainerd, MN 56401.

Mazzini, F., Kettler, D., Guerrero, J. and Dubowsky, S. (2011), "Tactile robotic mapping of unknown surfaces, with application to oil wells." IEEE Transactions on Instrumentation and Measurement, 60(2), 420-429.

Nagendran. A, Anthony Steed, Brian Kelly and Ye Pan, (2015) "Symmetric telepresence using robotic humanoid surrogates." Comp. Anim. Virtual Worlds, Vol.26, 271–280.

Newman, J.G., Kuppersmith, R.B., and O'Malley, B.W. Jr. (2011), "Robotics and telesurgery in otolaryngology.OtolaryngolClin North Am. Vol. 44(6), 1317-1331.

Oh, J.H., Hanson, D., Kim, W.S., Kim, J.Y., and Park, I.W. (2006), "Design of Android type Humanoid Robot Albert HUBO." Proceedings of 2006 IEEE/RSJ Int. Conf. Intell.Robot.Syst., Beijing, China.

Parallax, EMIC2 module, Parallax Inc., 599 Menlo Drive, Suite 100, Rocklin, CA 95765, USA.

Parker, L. E. and Draper, J. V. (1998), "Robotics applications in maintenance and repair."In S. Y. Nof (Ed.), Handbook of Industrial Robotics (2nd ed., Vol. 1, pp. 1023-1036). Hoboken, NJ: John Wiley & Sons, Inc.

VNH5019 motor driver, Pololu Corporation, 920 Pilot Rd., Las Vegas, NV 89119, USA.

Real-Time Innovations, 232 E. Java Drive, Sunnyvale, CA 94089, United States.

Reddy, J.N. (2006). An Introduction to the Finite Element Method (Third ed.). McGraw-Hill. ISBN 9780071267618.

Robotis CM-700 Controller, Robotis Dynamixel MX-106R and MX-64 servo actuators ROBOTIS INC, 1 Technology Dr., Suite F213 Irvine. CA 92618.

Scassellati, B. (2009), "Affective prosody recognition for human-robot interaction." Microsoft Research's External Research Symposium. Redmond, WA, USA.

SolidWorks, Dassault Systèmes SolidWorks Corporation, 175 Wyman Street, Waltham, MA 02451

Stone. R, (1992), "Virtual reality and telepresence." Robotica, Vol.10, 461-467.

Tinelli, A., Malvasi, A., Gustapane, S., Buscarini, M., Gill, I.S., Stark, M., Nezhat, F.R., and Mettler, L. (2011), "Robotic assisted surgery in gynecology: current insights and future perspectives." Recent Pat Biotechnol. Vol. 5(1):12-24.

UBUNTU Operating System, Canonical Group limited, 5th Floor, Blue Fin Building, 110 Southwark Street, SE1 0SU, London, United Kingdom.

Vermeersch. P, Debi D. Sampsel, Carolyn Kleman, (2015), "Acceptability and usability of a telepresence robot for geriatric primary care: A pilot." Geriatric Nursing, Vol. 36, 234-238.

YEI Technology 3D-Space Sensor and MoCAP Studio, YEI Technology, 630 Second Street, Portsmouth, Ohio 45662.

Zienkiewicz, O.C.; Taylor, R.L.; Zhu, J.Z. (2005). The Finite Element Method: Its Basis and Fundamentals (Sixth ed.). Butterworth-Heinemann. ISBN 0750663200.