Humanoid to Tele-Operate Human Actions for Industrial Applications

Naman Jain, Yogesh Mohan Gupta, and Rajat Mishra

Abstract—**A humanoid can be controlled wirelessly, for tele-operating human actions to stimulate activities in hazardous environments. A human wearing a jacket with accelerometers mounted over his arms and flex sensors on the fingers can control the motion of humanoid, to obtain the desired actions. The humanoid is customized to walk, hop, climb stairs and do other human like motions to interact with the real world. A continuous visual feed is also given to the user for the enhanced control and feedback for the task to be performed. Such humanoids can be used in boilers of chemical industries, nuclear reactors etc. where humans cannot go. Thus, helping us to control various parameters in such inappropriate environments without going ourselves. We have made humanoid robot which can wirelessly transfer real time data from sensors to the servo motors in the humanoid to achieve desired motions.**

Index Terms—**Accelerometers, arduino, camera, flex, humanoid, sensors, servo motors, zigbee**

I. Introduction

A humanoid can help to tele-operate the desired motions like walking, climbing stairs, moving hands with high accuracy. This can be useful at inaccessible places or the places where life is at threat. These could prove to be useful in industries where conditions are not suitable for humans like nuclear reactors, chemical boilers etc. The humanoid would be fully controlled by a person at a remote location who would be receiving continuous visual feed from the site through a camera on the humanoid's head [2]. He would wear a jacket with accelerometer sensors mounted over his arms. These sensors are used to determine the tilt of the hand which helps in reproducing the same gesture. He would also wear gloves having flex sensors to monitor the finger movements; each unique motion is decrypted to perform specific functions. The data from the user is transferred to the humanoid via ZigBee 802.15.4 protocol and the video feed to the user via wireless camera [10]. There may be a need to customize the system for particular industrial applications.

A. Humanoid Robots

Humanoids overall appearance is based on humans. It is capable of walking forward, backward or sideways. It is able to climb stairs where wheeled robots lack. We can make it do anything we want.

We can use it to shift/ push things, regulate knobs or take readings from the meters at inaccessible places. We made the humanoid using 19 servo motors, that is, it has 19 DoF. It is made stable with concept of Zero Moment Point (ZMP), the point where total of vertical inertia and gravity forces equal zero [1], [3], [4], [7].

B. Accelerometers

An Accelerometer measures proper acceleration, which is the acceleration it experiences relative to free-fall and is the acceleration felt by people and objects. Or we can say, at any point in space-time the equivalence principle guarantees the existence of a local inertial frame, and an accelerometer measures the acceleration relative to that frame. Such accelerations are popularly measured in terms of g-force.

The sensor is a surface-micro machined polysilicon structure built on top of the silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces. Deflection of the structure is measured using a differential capacitor that consists of independent fixed plates and plates attached to the moving mass. The fixed plates are driven by 180° out-of-phase square waves. Acceleration will deflect the beam and unbalance the differential capacitor, resulting in an output square wave whose amplitude is proportional to acceleration. Phase sensitive demodulation techniques are then used to rectify the signal and determine the direction of the acceleration.

The output of the demodulator is amplified and brought off-chip through a 32 kΩ resistor. At this point, the user can set the signal bandwidth of the device by adding a capacitor. This filtering improves measurement resolution and helps prevent aliasing.

An accelerometer is most sensitive to tilt when its sensitive axis is perpendicular to the force of gravity, that is, parallel to the earth's surface. At this orientation, its sensitivity to changes in tilt is highest. When the accelerometer is oriented on axis to gravity, that is, near its +1g or -1g reading, the change in output acceleration per degree of tilt is negligible. When the accelerometer is perpendicular to the gravity, its output would change nearly 17.5 mg per degree of the tilt. At 45°, its output changes at only 12.2 mg per degree, and resolution declines.

Dual Axis Tilt Sensor Converting Accelerometer to Tilt: When the accelerometer is oriented so both its x-axis and y-axis are parallel to the earth's surface, it can be used as a 2 axis tilt sensor with a roll axis and a pitch axis. Once the output signal from the accelerometer has been converted to an acceleration that varies between -1g and + 1g, the output tilt in degrees is calculated as

$$\begin{aligned} \text{PITCH} &= \arcsin(A_x/1\ g) \\ \text{ROLL} &= \arcsin(A_y/1\ g) \end{aligned} \tag{1}$$

Manuscript received August 1, 2012; revised September 12, 2012. The work is supported in part by VIT University, Vellore.

The authors are with School of Electronics Engineering, VIT University, Vellore 632014, India (e-mail: namanjain2009@vit.ac.in, yogesh.mohangupta2009@ vit.ac.in, rajat.mishra2010@vit.ac.in).

They can be used for measuring both dynamic and static measurements of acceleration. Tilt is a static measurement where gravity is the acceleration being measured. Therefore, to achieve the highest degree resolution of a tilt measurement, a low-g, high-sensitivity accelerometer is required. All of these accelerometers will experience acceleration in the range of +1g to -1g as the device is tilted from -90 degrees to +90 degrees [2].

C. Flex Sensors

Flex sensors are sensors that change in resistance depending on the amount of bend on it. They convert the change in bend to electrical resistance that is, more the bend, more is the resistance value. They are usually in the form of a thin strip from 1"-5" long that vary in resistance from approximately 10 to 50 kΩ. The membrane construction is both resilient and somewhat durable [14], [15].

D. Servo Motors

We have used *Dynamixel MX-28* Servos. They are capable of sweeping 360° and gives Stall Torque of 24kgf.cm at 12V, 1.5A. They use half-duplex asynchronous serial protocol and have *ST Cortex – M3* controller.

II. Working

We have used 3 accelerometers in each arm. One to control the forward motion, one for sideways and the remaining sensor for the elbow motion of the arms.

The sensors are provided with 5V V_{cc} and Ground. The X-axis, Y-axis (or Z-axis) inputs from the accelerometers (*ADXL203*/ *Freescale MMA7361L*) are provided to 10 bit resolution ADC pins of the Microcontroller board.

The accelerometers are aligned according to the motion required by the humanoid's arm at a distant place. For example, if change in sensors X-axis tilt is to be determined, then X-axis of the sensor is oriented parallel to the plane whose tilt is to be measured.

Eight flex sensors are placed parallel to respective fingers of both hands. They are interfaced to user's Microcontroller board. The different combination of bends in each finger is decoded as a specific task/ instruction. For example, when the flex sensor's resistance change due to bend in the ring finger, the humanoid will be instructed to walk front.

The accelerometers are only used to synchronise the arms of humanoid with the user and rest all instructions like walking, getting up when fallen etc. are implemented by interfacing the flex sensors.

The Microcontroller board we used is *Arduino Mega* which uses *ATMEGA 2560* whereas on the humanoid's end we use *Robotis CM-700* board which uses *ATMEGA 2561* as the controller.

There are a total of 1023 different instructions possible to send via ZigBee protocol. When a particular instruction is generated at the user's end it is encoded to 6 byte word and is then sent to the humanoid's end. The microcontroller there decodes the instruction and executes the command promptly.

The Camera at the humanoid's end continuously sends the visual feed for the user. The video is also processed by *NI LabVIEW* (Vision and Motion Module), to determine the readings accurately on the instruments present at inaccessible locations. These readings can help the user to control and maintain parameters in the industry. The basic algorithm is shown in Fig. 1.

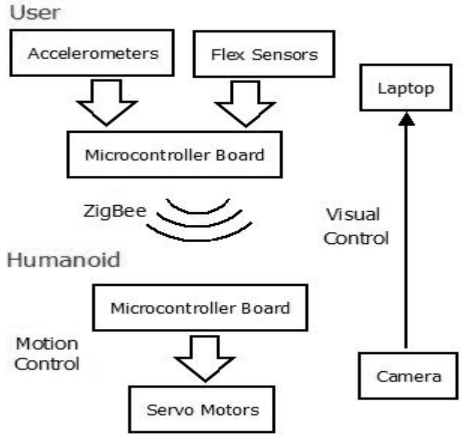


Fig. 1. Basic algorithm followed

III. Process

To determine the angle of tilt due to movement of arms, θ, the A/D values from the accelerometer are sampled by the ADC channel on the microcontroller. The acceleration is compared to the zero g offset to determine if it is a positive or negative acceleration.

$$V_{out} = V_{offset} + \frac{\Delta V}{\Delta g} \times 1.0\,g \times \sin\theta \qquad (2)$$

where:

V_{out} = Accelerometer Output in Volts
V_{offset} = Accelerometer 0g Offset
$\Delta V/\Delta g$ = Sensitivity
1g = Earth's Gravity
θ = Angle of Tilt

$$\theta = \sin^{-1}\left(\frac{V_{out} - V_{offset}}{\frac{\Delta V}{\Delta g}}\right) \qquad (3)$$

From the datasheet of *Freescale MMA7361L*, we get sensitivity as 800mV/g, therefore using these equations we get,

$$\theta = \sin^{-1}\left(0.006249 \times \left(A - 160\right) - 1\right) \qquad (4)$$

where, A is the analog input from the sensor. The analog value varies from 160 to 480 for the angles -90° to 90° in X axis. The graph is plotted in Fig. 2.

The angles now obtained is compared with itself after every 100ms, if the angles increases then a particular instruction is sent which increases the goal position/angle of the respective motor by 1° else the goal position keeps on decreasing by 1°. Therefore, for each accelerometer we require one instruction to increase the angle and the other to decrease. Thus, six accelerometers output require 12 different instructions for the humanoid.

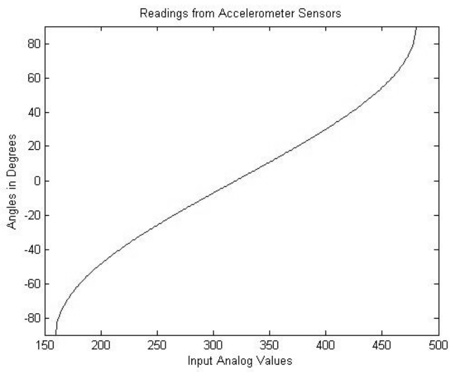


Fig. 2. ADC Values v/s angles of the servos

The flex sensors mounted on the fingers would enable the bot to walk front, back and sideways, when user makes different combinations with his fingers. It will also be used to make the bot stand up on the feet, when it falls either with chest or back facing the ground. Therefore, at most ten different instructions would be required for flex sensors output. On totalling up we get 22 different instructions that can be sent to the humanoid for our application.

These instructions are then encoded as data packet as in Fig. 3.

FF	55	Data_L	~Data_L	Data_H	~Data_H

Fig. 3. Data packet

where, Data_L is LSB of the Data, Data_H is MSB of the Data, ~Data_L and ~Data_H represent 1's complement of Data_L and Data_H respectively.

For example, if data is 0x1234 then the packet would be0xFF 0x55 0x34 0xCB 0x12 0xED

CM 700 Microcontroller board on receiving this data packet at the humanoid end decodes to an instruction. This instruction obtained is compared with the pre-built instruction library present in *CM 700* to perform the specific task.

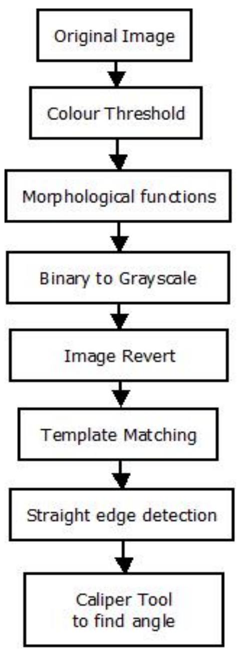


Fig. 4. Algorithm to detect readings on instruments

For example, if the decoded instruction is 0x1234, then the controller understands to load a particular portion of the main source code. Similarly, various data packets can be converted into instructions and command controller to perform specific tasks. The visual feed from the wireless camera is fed to the laptop in front of the user. This would help him guide the humanoid at a distant place.

At many times our eyes are not able to perceive the readings on the instruments accurately, so for these purposes we have used NI LabVIEW for image processing. This would enable the user to know the accurate readings. The algorithm of the image processing is shown in Figure 4.[8]

Firstly, we capture a frame from the feed. Then, we take threshold of the RGB image. The value of RGB during thresholding depends on the colour of the gauge.

Next, we apply morphological functions like dilate, to thicken the objects and then fill holes to avoid unnecessary void spaces [5]. Then we convert the binary image to grayscale and revert the image. During thresholding the image converts from RGB to binary image.

To detect the needle we perform pattern matching using needle alone as a template image.

Finally, to know about the angle suspended by needle from zero point, we perform edge detection followed by calliper function. This gives us the angle suspended by the needle taking horizontal axis as reference.

Once we get the accurate value, the user can adjust the parameters accordingly [6].

IV. Implementation

We made a humanoid robot with 19 Servo Motors and controlled it through *CM 700* controller. It can walk, climb stairs and move arms as we desire.

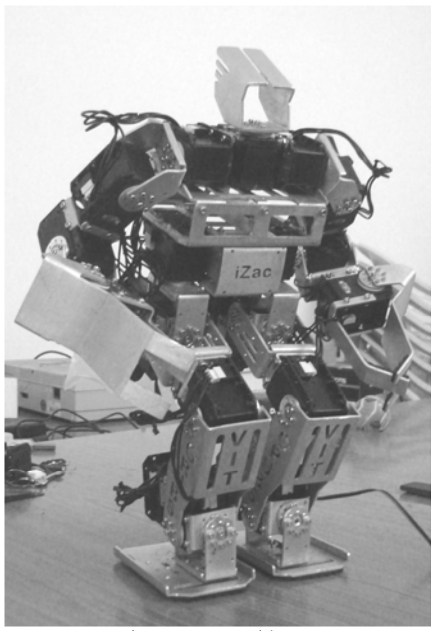
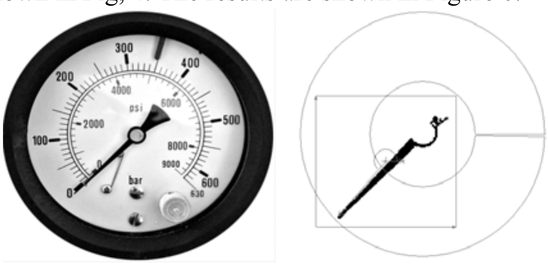


Fig. 5. Humanoid *iZac*

The humanoid's height is 42 cm. and weighs 2.7 kg only. The maximum walking speed obtained is 1 cm/s and can climb stairs of 3 cm. height.

We have successfully implemented the tele-operation of the human motions. The visual images from the wireless camera are viewed on the laptop and in case of reading a meter on the instrument; we have implemented the algorithm as shown in Fig, 4. The results are shown in Figure 6.



(a) (b)

Fig. 6. (a). Original meter image; (b). Processed Image to determine angle

V. Conclusion

This paper proposed the wearable teleoperation system and explained the implementation of the prototype. Furthermore, we conducted the experiments using the humanoid robot, *iZac* as a slave robot to confirm the system performance and effectiveness. The humanoid's height and functionality may be customized according to the application.

Acknowledgment

We would like to thank Prof. Z. C. Alex and Prof. V. Arunachalam for their support and guidance throughout our project. We also thank VIT University, Vellore for their support in providing labs and other necessities to implement and test the humanoid.

References

[1] I. Ha, Y. Tamura, H. Asama, J. Han, and D. W. Hong, "Development of Open Humanoid Platform DARwIn-OP," *SICE Annual Conference*, Tokyo, Japan, 2011

[2] N. E. Sian, K. Yokoi, S. Kajita, F. Kanehiro, K. Tanie, "Whole Body Teleoperation of a Humanoid Robot -Development of a Simple Master Device using Joysticks-," In *Proc. IEEE/RSJ Intl. Conference on Intelligent Robots and Systems*, Switzerland, 2002

[3] C. Dube and J. Tapson, "Kinematics design and human motion transfer for a humanoid service robot arm," South Africa.

[4] Robot Arm Tutorial, Society of Robots, [Online]. Available: http://www.societyofrobots.com/

[5] R. Kumar, R. C. Tripathi, and M. D. Tiwari, "Morphological Pattern Based Approach for Trademark Retrieval," In *Proc. International Conference on Advanced Science, Engineering and Information Technology*, Malaysia, 2011

[6] T. Lovell and D. Litwhiler, "Teaching a Computer to Read: Image Analysis of Electrical Meters," *American Society for Engineering Education*, 2006

[7] I. Ha, Y. Tamura, H. Asama, J. Han, and D. W. Hong, "Development of Open Humanoid Platform DARwIn-OP," *SICE Annual Conference*, Tokyo, Japan, 2011.

[8] T. Klinger, "Image processing with Lab VIEW and IMAQ Vision," *Prentice Hall*, 2003.

[9] B. L. Luk, D. S. Cooke, S. Galt, A. A. Collie, and S. Chen, "Intelligent legged climbing service robot for remote maintenance applications in hazardous environments," *Robotics and Autonomous Systems*, Elsevier, vol. 53, no. 2, no. 30, 2005, pp. 142–152.

[10] N. G. Herlitz, K. I. Iglehart, and J. S. Sentell, "all of Baton Rouge, La, Video Inspection System for Hazardous Environments," US Patent 5068720, Nov. 26, 1991.

[11] A. M. Khamis, F. J. Rodr´Iguez, and M. A. Salichs, "Remote Interaction with Mobile Robots," *Autonomous Robots 15*, pp. 267–281, Kluwer Academic Publishers, 2003.

[12] J. Triesch and C. V. D. Malsburg, "Robotic Gesture Recognition, Automatic Face and Gesture Recognition," In *Proc., Killington VT*, pp. 14-16 Oct, 1996.

[13] N. Kita, "Visual Attention Control for Nuclear Power Plant Inspection," Pattern Recognition, In *Proc., Barcelona*, 2000

[14] T. G. Zimmerman, J. Lanier, C. Blanchard, S. Bryson, and Y. Harvill, "A Hand Gesture Interface Device," In *Proc. CHI '87 Proceedings of the SIGCHI/GI conference on Human factors in computing systems and graphics interface*, pp. 189 – 192

[15] J. Hong and X. Tan, "Calibrating a VPL DataGlove for teleoperating the Utah/MIT hand, Robotics and Automation," In *Proc. , Scottsdale*, pp. 14-19 May 1989.