Gemini Telepresence Robot System Design: A Low-Cost Solution for Manipulation and Enhanced Perception of Telepresence Robots

Trevor R. Smith
West Virginia University

Current telepresence robots are costly and only allow the operator to see the environment on a 2D screen and move around on a wheelbase. Thus, these telepresence devices are severely limited because of the high barrier of entry, and the operator is unable to manipulate objects or easily perceive the world in 3D. Therefore, to address these gaps in capabilities, Gemini, an open-source telepresence humanoid robot and interface station, was designed to grant the operator the ability to manipulate objects, expand the human interface by putting the user in the 3D world with the use of a virtual reality (VR) headset, and be low-cost. The simplistic, low-cost, and intuitive controls of Gemini promote early adoption by businesses and medical personnel to grant increased telepresence needs. In addition, this platform can be utilized by robotics enthusiasts and university researchers studying humanoid robotics or human-robot interaction. This paper presents an overview of the Gemini robot's mechanical, electrical, and programmatic systems. Upon completion of this study, it was found that Gemini was able to grant the ability to manipulate objects, increase user perception with intuitive controls, in addition to costing approximately 30% less than commercial telepresence robots. Furthermore, the paper is concluded with remarks on future iterations of the project.

Introduction

Due to the recent effects of COVID-19, remote teleoperation has been increasingly important to businesses and medical care. However, current telepresence robots are costly and only allow the operator to see the environment on a 2D screen and move around on a wheelbase. Therefore, they severely limit the operator's perception and lack the ability to manipulate objects. Thus, to address these gaps in capabilities, Gemini, a telepresence humanoid robot and interface station was developed to provide the operator with increased perception, the ability to manipulate objects, and utilize intuitive controls. In addition, Gemini was designed to be a low-cost open-source alternative to commercial products to promote widespread use. Furthermore, since mobile platform telepresence devices commercially exist, Gemini's design (shown in Figure 1) focuses on the manipulation aspect of telepresence robots and the mobile platform is abstracted.

Figure 1. Lower right quadrant of the mural. An inscription on the cartouche dates the its competion (1941-42)

One example of an existing first-person perspective robot is the Bimanual Dexterous Robotic Platform (BDRP) Explosive Ordnance Device (EOD) disposal robot from John Hopkin's University1. BDRP is a two-armed robot on a wheelbase that is controlled in first person with a VR headset and serves as the foundation for Gemini. However, BDRP was designed for rugged outdoor environments and

utilizes high-cost components for EOD1. While Gemini, is designed to be low cost and in indoor environments for telepresence.

In addition, human machine interfacing has also been extensively studied. For example, the De Vito human mimicry interface consists of a passive exoskeleton to measure the operator's pose2. The exoskeleton is a backpack device that has two passive 7 DOF arms that attach to the human operator. At the joints of this device, potentiometers are used to provide the joint angles that get sent to the robot2.The main benefit of this design is the increased information frequency and accuracy that potentiometers have in comparison to other sensors used to measure human pose. Furthermore, J. Koenemann used a human mimicry interface that consisted of a body suit of straps that housed electronic sensors which transmit data to the robot3. A major drawback of these designs is that it is inconvenient and awkward to have the operator wear a full body suit when controlling the robot. Therefore, to eliminate the body suit from the human interface a depth camera was utilized to perceive the human pose.

Furthermore, camera research has been conducted to grant depth perception with monoscopic cameras. Z. Kuang describes the use of two cameras to create a stereoscopic view of the world4. Stereoscopic vision has the benefit of being able to discern distance based on the angles of the camera. Furthermore, if the human operator was to look through this camera view it would feel more natural4 due to humans naturally have stereoscopic vison. The difficulty of this design is that the robot would have to determine what the human operator is looking at without tracking the operator's eyes due to the VR headset. Therefore, a single 360-camera will greatly simplify the design.

Gemini consists of a humanoid robot with a 360° camera connected over the internet to an interface station that utilizes a Red Green Blue Depth (RGBD) Camera and a VR headset, as shown in Figure 1. The interface station utilizes the RGBD camera to discern the operator's pose and then transmit that information to the humanoid robot. The robot then mirrors the user and transmits the 360° video back to the operator's VR headset. This grants the operator the robot's perspective and effectively allows the operator to become the robot. Furthermore, Gemini was manufactured using a 3D printer and common household products for a low-cost solution. The advancements of telepresence robots from this study are:

- Ability to manipulate objects
- Enhanced operator 3D environment perception via 360 camera and VR headset
- Intuitive and unencumbering control interface via Xbox One Kinect® camera
- 30% reduction in cost compared to commercial telepresence devices

The author contributions to this paper are TS mechanical, electrical, and programmatic design, construction, and implementation.

Methods

Gemini consists of two main components: the robot and the base station. The body was built out of a salvaged steel rack to create a high moment of inertia of the body promoting a stable frame for mounting the dynamic manipulators, electronics box, and the 360-camera shown in Figure 1. While the base station simply consists of a computer and Xbox Kinect.

The manipulator of the Gemini robot, shown in Figure 2, was designed to mimic the motion capabilities of human arms to allow the operator to use their natural movements to control the robot. Therefore, each manipulator is composed of six degrees of freedom separated evenly into the shoulder, elbow, and wrist. In addition to the arm of the manipulator, the end-effector is a humanoid hand composed of five individually controlled fingers and an additional actuation on the thumb is utilized to improve dexterity.

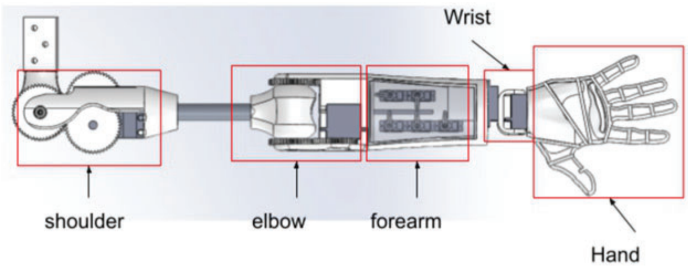

Figure 2. Components of Manipulator. The manipulator consists of a spherical shoulder, elbow, and wrist joints. Connected to a hand with 5 individually controlled fingers with an additional thumb actuator. The motors for the hand are housed in the forearm.

The shoulder and elbow joints of the manipulator are differential spherical joints to mimic the ball-socket joint and the roll / pitch motion of human shoulders and elbows, respectively. Differential spherical joints as shown in Figure 3 utilize a backwards driven differential to control the roll and pitch of the joint.

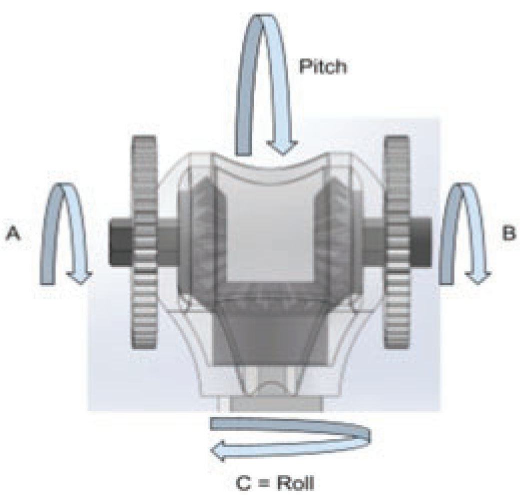

Figure 3. Components of Manipulator. A and B serve as the motor input angles to the joint, with the output angles of Roll, on axis C, and Pitch angle about the joint housing.

To control this type of joint, the forward kinematics of differentials are described in Equations (1 and 2).

$$\text{Roll} = (A-B)/2 \quad (1)$$
$$\text{Pitch} = (A+B)/2 \quad (2)$$

Where the output angle of middle shaft C (Roll) is half the difference between motor inputs A and B (shown in Figure 3). While the pitch angle of the housing is the average of A and B. Furthermore, the inverse spherical kinematics are shown in Equations (3 and 4).

$$B = \text{Pitch}-\text{Roll} \quad (3)$$
$$A = \text{Pitch}+\text{Roll} \quad (4)$$

Combining both the shoulder and elbow together an anthropomorphic spherical arm workspace is generated with each major joint (shoulder and elbow) consisting of local Roll-Pitch spherical coordinate frame kinematics.

Counter to the shoulder and elbow joints the wrist joint was simplified to a direct roll and pitch motor configuration to fit the smaller form factor required to accurately mimic the geometry of humanoid arms and to provide housing space for the electronics and hand motors in the forearm (as shown in Figure 2). In addition to this the humanoid hand is actuated by a nylon line attached to the fingertips and runs through the fingers and hand to the motors in the forearm, similar to tendons in a human hand5.

Gemini's base station consists of an Xbox® Kinect that interprets the pose of the operator and transmits the data over a USB serial cable to a computer. The computer then connects to the robot over Wi-Fi to send commands. The base station electronics diagram is shown in Figure 4.

Gemini is initially powered by U.S. standard 120V 60Hz AC power so battery lifetime can be abstracted from the design. Furthermore, the AC power is first converted to a variety of DC voltages to be supplied to the main components as shown in Figure 5. Therefore, to convert Gemini to a mobile platform simply replace the wall power and AC/DC converters with batteries and voltage regulators.

The power system then feeds into the body electronics which consists of two computing resources: a raspberry pi 4, an android phone, and a 360 camera all of which receive 5V DC power. The raspberry pi serves as the main computer for the robot, while the android

phone solely serves to transmit the video from the 360-camera by connecting to the camera over Bluetooth. Furthermore, the raspberry pi receives input from the base station computer over Wi-Fi and transmits commands through a USB serial cable to each Arduino Mega that serve as the main computing resource of the arms. In addition to receiving serial commands the Arduino Mega also receives 9V power from the power subsystem. The Arduino Mega then sends PWM signals to the motors to specify their rotational position. The shoulder, elbow, and wrist motors all receive 7V DC power while the hand motors receive 5V power from the Arduino Mega. The full electronics diagram for Gemini is shown in Figure 5.

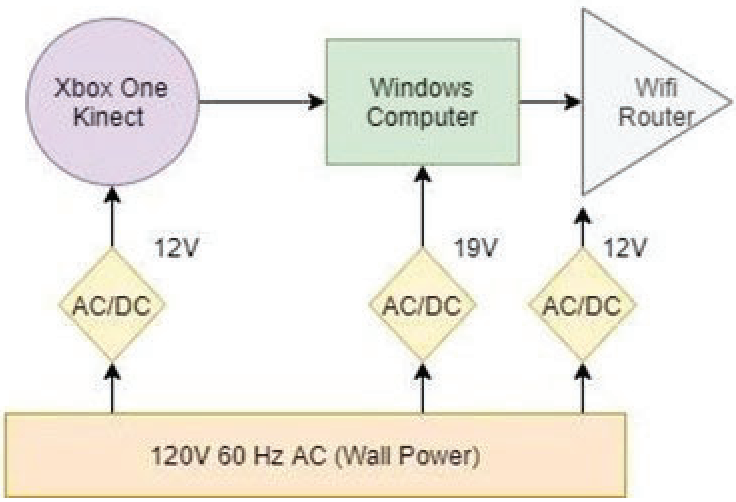

Figure 4. Base Station Electronics Diagram. Consists of standard United States wall power that is supplied to the Xbox one Kinect, windows computer and Wi-Fi router. In addition, the communication links from the Kinect to the computer then to the Wi-Fi Router are also shown.

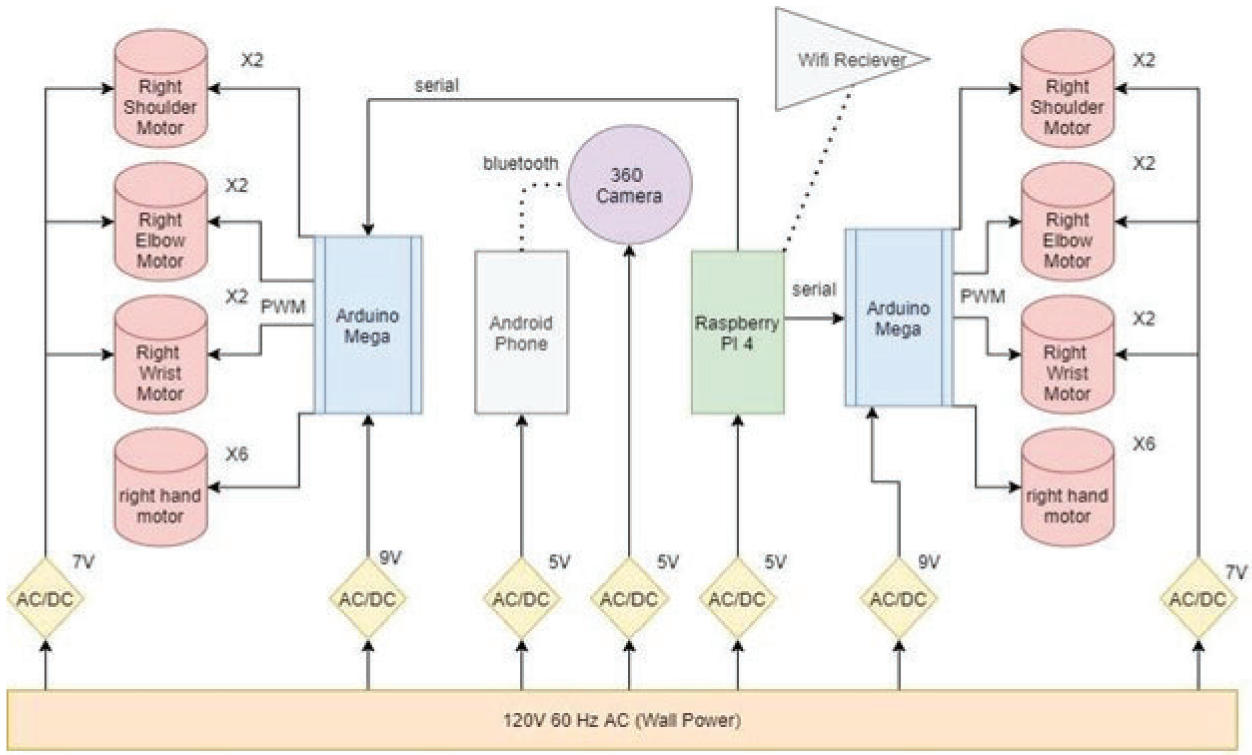

Figure 5. Gemini Robot Electronics Diagram. Starts with standard United States wall power supplied to each of its main components. The Raspberry PI serves as the main computer that sends signals to left and right Arduinos that control the left and right arm motors. In addition, an Android phone is used to control and transmit the 360 video from the camera.

Programmatically, Gemini utilizes distributed computing to separate the computation power across multiple devices to improve the modularity of the design and to allow repurposing of different components. One example is the manipulator can be removed from the body and still have full functionality if the proper signal and power is supplied. Furthermore, Gemini can be completely separated from the base station and function autonomously. Thus, allowing it to be a test platform for other humanoid robotic studies. The full programming architecture is shown in Figure 6.

Starting from the base station Windows computer, the Xbox Kinect observes the pose of the operator. It is important that the computer is running Windows due to the Xbox Kinect software development kit (SDK) only being available on Windows. Next the skeleton of the operator is extracted and published to a Robot Operating System (ROS) topic, using M. Peng's skeleton tracking package6. ROS is an opensource robotics library that aids users sending information between software processes called nodes via topics. Furthermore, the software then transmits the topic over local Wi-Fi (LAN) to Gemini, as shown in Figure 6.

Gemini then receives the operator's pose on the raspberry pi 4 running Ubuntu 20.04 and ROS Debian on the Kinect bridge node. This node then extracts the shoulder, elbow, and wrist xyz coordinates of the left and right arm, transforms them from the Xbox Kinect's coordinate frame to Gemini's coordinate frame, and publishes them to the left and right Arduino bridge nodes that forward the topics to Arduinos on each of the arms. This is done by using the rosserial python package.

Each of the Arduinos then computes the inverse kinematics and required motor commands to mimic the operator by first transforming the cartesian xyz shoulder, wrist, and elbow points to the local roll-pitch spherical coordinates of the shoulder and elbow joints. The transforms are computed using homogeneous transformation matrices, which are a mathematical tool used to convert coordinates from one frame to another and shown in Equation 5.

H12= R3x3 V3x1 0 0 0 1 (5)

Where H is the 4x4 homogeneous transformation matrix from coordinate frame 1 to coordinated frame 2, R is the 3D rotation matrix that describes the angular difference between the coordinate frames and V is the 3D displacement vector that describes the difference of the position of the origins of the frames. The next step is to define the elbow's position from the shoulder's point of view. This is done by transforming the elbow position from the robot's coordinate frame to the shoulder's coordinate frame using the homogeneous transformation matrix and elbow position vector, as shown in Equation 6.

ES=HRS-1*ER (6)

Where ES is the elbow's xyz position column vector in the shoulder frame and ER is the elbow's xyz position column vector in the robot frame. Now that the elbow position is defined with respect to the shoulder, the cartesian xyz coordinates can be converted to Roll-Pitch spherical coordinates of the mechanical joint using Equations 7 and 8.

RollS=EsyEsx2+Esy2 (7)

PitchS=Esx2+Esy2Esx2+Esy2+Esz2 (8)

Where Esx, Esy, and Esz, are the elbow's

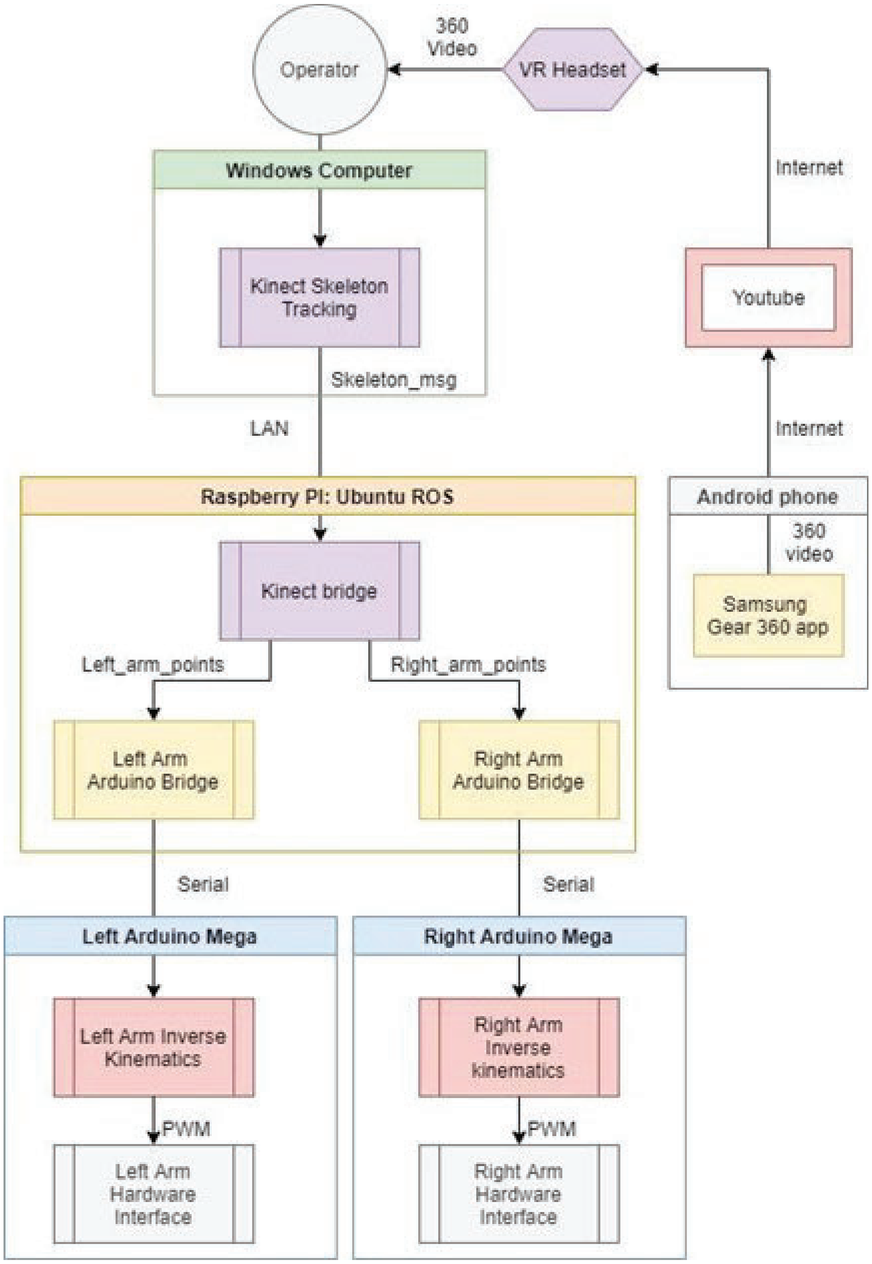

Figure 6. Gemini Programming Architecture. Starts with the operator, whose skeletal pose is measured by the Kinect on the windows computer. THen transmitted to the robot's Ubuntu computer that sends the left and right arm coordinates to each manipulator's Arduino. That then controls the motors positions.

xyz coordinates in the shoulder frame and RollS and PitchS are the roll and pitch spherical coordinates of the shoulder joint. Now that the shoulder spherical coordinates (RollS and PitchS) have been found the process is then repeated for the elbow to calculate its spherical coordinates. After the shoulder and elbow roll and pitch values are found, they are input into Equations 3 and 4 to calculate the motor rotation angles A and B. Which in turn are converted to motor control Pulse Width Modulus (PWM) signals using a linear empirical fit and sent to the motors in the Arm Hardware Interface on the Arduino Mega as shown in Figure 6.

Next to transmit the 360 video of the camera the android phone runs the Samsung Gear 360 app that live streams the video to a private YouTube channel. The operator then views the private live stream at the base station

through the VR headset.

Results

From this design the Gemini robot was able to mimic the human operator from a first-person perspective. Therefore, the Gemini robot was able to allow the manipulation of objects following the intuitive controls of the human operator, via the Xbox Kinect. While also providing enhanced perception to the operator through the VR headset and 360-camera. Figure 7 displays Gemini actively grasping and holding on to a ball and Figure 8 displays Gemini being controlled by the operator's movements.

Furthermore, Gemini costs approximately

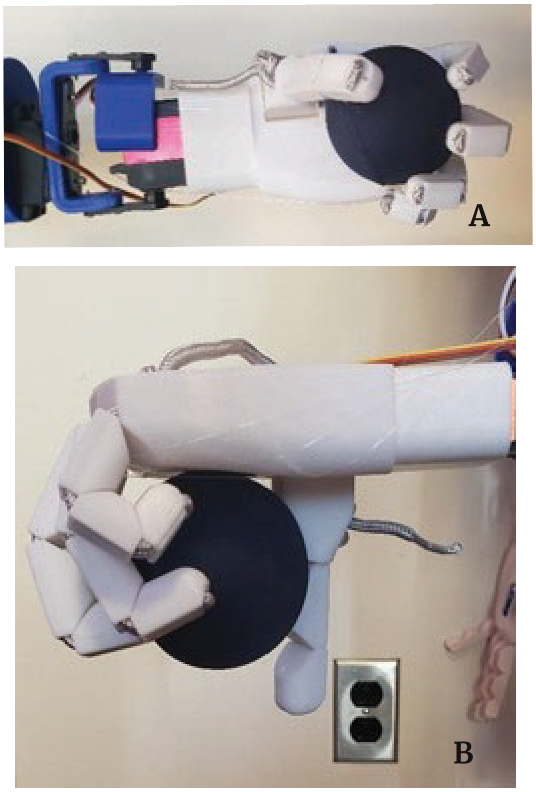

Figure 7. Gemini Grasping a Ball Front View (A) Side View (B). Gravity is acting downwards in both photos, as the hand grasps around the ball due to the nylon strings pulled taught.

Figure 8. Gemini in Operation. Gemini mirrors the operator's hand moving up, while the operator views from the VR headset.

$1,000 which is at a minimum 30% cheaper than current telepresence robots such as PadBot P2 and BotEyes-Pad. The cost breakdown of Gemini is displayed in Table 1.

Table 1. Cost Breakdown of Gemini. Note that a majority of these parts are common components hobbyists would have on hand.

Discussion

From this work, it is shown that Gemini grants the operator the ability to remotely manipulate objects in first person perspective with advanced perception and control. Using a VR headset and Xbox One Kinect, respectively. Thus, solidifying Gemini as a 30% cheaper opensource† alternative to commercial telepresence robots. The current limitations of Gemini are "jittering" and back driving servo motors under heavy loadings. To further improve this work, the shoulder and elbow motors will be replaced with worm-gear driven DC motors with encoders. This change will prevent back driving of the joints under loading, in addition to lowering the cost. However, this will require an additional motor control electronics board and more in-depth controls programming. In addition, a passive elastic support would be added to the joints similar to tendons on the human body to reduce the loading on the motors to allow the operator to lift heavier objects. Furthermore, lack of touch feedback, as seen in BDRP1, presents a limitation in operator's ease of manipulation. Therefore, ergonomic gloves with haptic touch feedback will be developed to allow the operator touch perception and the ability to have individual finger control over the current open / close hand control. Gemini is also currently limited to local Wi-Fi connections, while commercial products can be accessed globally. This limitation will be mitigated by using a remote server to allow global access.

Competing Interests

The authors declare no competing interests.

References

1. J. L. Graham, S. G. Manuel, M. S. Johannes and R. S. Armiger, "Development of a multi-modal haptic feedback system for dexterous robotic telemanipulation," 2011 IEEE International Conference on Systems, Man, and Cybernetics, Anchorage, AK, 2011, pp. 3548-3553.
2. Falck, F., Larppichet, K., & Kormushev, P. (2019). DE VITO: A Dual-Arm, HIGH Degree-of-Freedom, lightweight, inexpensive, Passive UPPER-LIMB Exoskeleton for ROBOT TELEOPERATION. Towards Autonomous Robotic Systems, 78–89. https://doi.org/10.1007/978-3-030-23807-0_7
3. J. Koenemann and M. Bennewitz, "Whole-body imitation of human motions with a Nao humanoid," 2012 7th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Boston, MA, 2012, pp. 425-425.
4. Z. Kuang, Y. Yang, T. Hau and Y. He, "Research on Biomimetic Coordination Action of Service Robot Based on Stereo Vision," 2018 2nd IEEE Advanced Information Management,Communicates,Electronic and Automation Control Conference (IMCEC), Xi'an, 2018, pp. 769-773.
5. Gross, R. (2017). Humanoid Robotic Hand [Computer Aided Drawing]. Retrieved from https://www.thingiverse.com/thing:2269115
6. M, Peng. (2018). Skeleton Tracking Based on Kinect Sensor V2 [Computer software]. Retrieved from https://github.com/msr-peng/kinect_v2_skeleton_tracking
7. S. Hasan, K. Al-Kandari, E. Al-Awadhi, A. Jaafar, B. Al-Farhan, M. Hassan, S. Said, and S. Alkork, "Wearable Mind Thoughts Controlled Open Source 3D Printed Arm with Embedded Sensor Feedback System," Proceedings of the 2nd International Conference on Computer-Human Interaction Research and Applications, 2018.
8. S. Rader, L. Kaul, H. Fischbach, N. Vahrenkamp and T. Asfour, "Design of a high-performance humanoid dual arm system with inner shoulder joints," 2016 IEEE-RAS 16th International Conference on Humanoid Robots (Humanoids), Cancun, 2016, pp. 523-529.
9. K. Kaneko, K. Harada, F. Kanehiro, G. Miyamori and K. Akachi, "Humanoid robot HRP-3," 2008 IEEE/RSJ International Conference on Intelligent Robots and Systems, Nice, 2008, pp. 2471-2478.
10. A. Albers, S. Brudniok, J. Ottnad, C. Sauter and K. Sedchaicharn, "Upper Body of a new Humanoid Robot - the Design of ARMAR III," 2006 6th IEEE-RAS International Conference on Humanoid Robots, Genova, 2006, pp. 308-313.
11. S. Park, H. Lee, D. Hanson and P. Y. Oh, "Sophia-Hubo's Arm Motion Generation for a Handshake and Gestures," 2018 15th International Conference on Ubiquitous Robots (UR), Honolulu, HI, 2018, pp. 511-515.
12. M. R. Motamedi, J. Chossat, J. Roberge and V. Duchaine, "Haptic feedback for improved robotic arm control during simple grasp, slippage, and contact detection tasks," 2016 IEEE International Conference on Robotics and Automation (ICRA), Stockholm, 2016, pp. 4894-4900.

13. T. B. Sheridan, “Human–Robot Interaction,” Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 58, no. 4, pp. 525–532, 2016.
14. H. Admoni and B. Scassellati, “Social Eye Gaze in Human-Robot Interaction: A Review,” Journal of Human-Robot Interaction, vol. 6, no. 1, p. 25, Jan. 2017.
15. P. Kaiser et al., "An affordance-based pilot interface for high-level control of humanoid robots isupervised autonomy," 2016 IEEE-RAS 16th International Conference on Humanoid Robots (Humanoids), Cancun, 2016, pp. 621-628.
16. A. Saha, A. Kumar and A. K. Sahu, "FPV drone with GPS used for surveillance in remote areas," 2017 Third International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), Kolkata, 2017, pp. 62-67.
17. C. Canning, T. J. Donahue and M. Scheutz, "Investigating human perceptions of robot capabilities in remote human-robot team tasks based on first-person robot video feeds," 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems, Chicago, IL, 2014, pp. 4354-4361.
18. S. Rivera, S. Lagraa and R. State, "ROSploit: Cybersecurity Tool for ROS," 2019 Third IEEE International Conference on Robotic Computing (IRC), Naples, Italy, 2019, pp. 415-416.
19. Q. Gao and H. Cheng, "Design of a CloudROS enabled Mobile Robot," 2018 IEEE International Conference on Robotics and Biomimetics (ROBIO), Kuala Lumpur, Malaysia, 2018, pp. 2487-2492.
20. B. V. S. Krishna, J. Oviya, S. Gowri and M. Varshini, "Cloud robotics in industry using Raspberry Pi," 2016 Second International Conference on Science Technology Engineering and Management (ICONSTEM), Chennai, 2016, pp. 543-547.
21. P. Amontamavut and E. Hayakawa, "ROS Extension of Blue-Sky web based development environment for IoT," 2016 Fifth ICT International Student Project Conference (ICT-ISPC), Nakhon Pathom, 2016, pp. 45-48.
22. J. Seo et al., "Feasibility Evaluation of Mobile Internet based Robot-assisted Tele-echography System,URL:
23. M. Mortimer, B. Horan and M. Joordens, "Kinect with ROS, interact with Oculus: Towards Dynamic User Interfaces for robotic teleoperation," 2016 11th System of Systems Engineering Conference (SoSE), Kongsberg, 2016, pp. 1-6.
24. Z. Wen, Y. Yan and H. Cui, "Study on Segmentation of 3D Human Body Based on Point Cloud Data," 2012 Second International Conference on Intelligent System Design and Engineering Application, Sanya, Hainan, 2012, pp. 657-660.
25. C. Huang, S. Jhang and C. Tsai, "An efficient RGB-D camera based point cloud registration algorithm," 2017 International Conference on Applied System Innovation (ICASI), Sapporo, 2017, pp. 558-561.
26. L. Valgma, M. Daneshmand and G. Anbarjafari, "Iterative closest point based 3D object reconstruction using RGB-D acquisition devices," 2016 24th Signal Processing and Communication Application Conference (SIU), Zonguldak, 2016, pp. 457-460.
27. M. Parzych, A. Dabrowski, D. Cetnarowicz, M. Wroblewski, H. Szwed and M. Staszewski, "Investigation of gesture scenarios for servomotor control using Microsoft Kinect sensor," 2013 Signal Processing: Algorithms, Architectures, Arrangements, and Applications (SPA), Poznan, 2013, pp. 112-117.
28. S. P. K. Arachchi, N. L. Hakim, H. Hsu, S. V. Klimenko and T. K. Shih, "Real-Time Static and Dynamic Gesture Recognition Using Mixed Space Features for 3D Virtual World's Interactions," 2018 32nd International Conference on Advanced Information Networking and Applications Workshops (WAINA), Krakow, 2018, pp. 627-632.
29. D. H. Song and S. Jung, "Geometrical Analysis of Inverse Kinematics Solutions and Fuzzy Control of Humanoid Robot Arm under Kinematics Constraints," 2007 International Conference on Mechatronics and Automation, Harbin, 2007, pp. 1178-1183.
30. J. Zhang, W. Xu and D. Meng, "Inverse kinematics resolution method of redundant space manipulator based on arm angle parameterization," Proceedings of the 32nd Chinese Control Conference, Xi'an, 2013, pp. 6022-6027.
31. K. P. Hawkins, “Analytic Inverse Kinematics for the Universal Robots UR-5/UR-10 Arms,” Dec. 2013.
32. K. Wegner, O. Stankiewicz, T. Grajek and M. Domański, "Depth Estimation from Stereoscopic 360-Degree Video," 2018 25th IEEE International Conference on Image Processing (ICIP), Athens, 2018, pp. 2945-2948.
33. M. Hosseini, "View-aware tile-based adaptations in 360 virtual reality video streaming," 2017 IEEE Virtual Reality (VR), Los Angeles, CA, 2017, pp. 423-424.
34. J. Zhou et al., "A Soft-Robotic Approach to Anthropomorphic Robotic Hand Dexterity," in IEEE Access, vol. 7, pp. 101483-101495, 2019.
35. H. Jeong and J. Cheong, "Design of hybrid type robotic hand : The KU hybrid HAND," 2011 11th International Conference on Control, Automation and Systems, Gyeonggi-do, 2011, pp. 1113-1116.
36. G. Jeong et al., "On the Design of a Novel Underactuated Robotic Finger Prosthesis for Partial Hand Amputation," 2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR), Toronto, ON, Canada, 2019, pp. 861-867.
37. N. S. K. Ho et al., "An EMG-driven exoskeleton hand robotic training device on chronic stroke subjects: Task training

system for stroke rehabilitation," 2011 IEEE International Conference on Rehabilitation Robotics, Zurich, 2011, pp. 1-5.

38. C. Ishii, Y. Nishitani and H. Hashimoto, "Robotic hand with a new bending mechanism," 2009 International Conference on Mechatronics and Automation, Changchun, 2009, pp. 32-36.
39. J. Zhou, X. Chen, U. Chang, Y. Liu, Y. Chen and Z. Wang, "A Grasping Component Mapping Approach for Soft Robotic End-Effector Control," 2019 2nd IEEE International Conference on Soft Robotics (RoboSoft), Seoul, Korea (South), 2019, pp. 650-655.
40. H. Yin, Y. Yu and J. Li, "Optimization design of a motor embedded in a lightweight robotic joint," 2017 12th IEEE Conference on Industrial Electronics and Applications (ICIEA), Siem Reap, 2017, pp. 1630-1634.
41. Jianguo Zhu, Haiwei Lu, Youguang Guo and Zhiwei Lin, "Development of electromagnetic linear actuators for micro robots," 2008 International Conference on Electrical Machines and Systems, Wuhan, 2008, pp. 3673-3679.
42. M. J. Rahman, D. Prosad Das, O. Islam and H. U. Zaman, "A Novel Design of a Robotic Object Sorter Based on Color Differences using Image Processing Techniques," 2018 International Conference on Computer, Communication, Chemical, Material and Electronic Engineering (IC4ME2), Rajshahi, 2018, pp. 1-4.
43. S. Gandhi and N. Gandhi, "A CMUcam5 Computer Vision Based Arduino Wearable Navigation System for the Visually Impaired," 2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI), Bangalore, 2018, pp. 1768-1774.
44. N. S. Yamanoor and S. Yamanoor, "High quality, low cost education with the Raspberry Pi," 2017 IEEE Global Humanitarian Technology Conference (GHTC), San Jose, CA, 2017, pp. 1-5.
45. N. Alee, M. Rahman and R. B. Ahmad, "Performance comparison of Single Board Computer: A case study of kernel on ARM architecture," 2011 6th International Conference on Computer Science & Education (ICCSE), Singapore, 2011, pp. 521-524.

About the Author:

Trevor Smith is a 2021 graduate of West Virginia University, having finished his Mechanical Engineering BA, Aerospace Engineering BA, and Minor in Computer Science in the Fall. Originally from a small township outside of Johnstown, PA Trevor Smith now lives in Morgantown, WV and working in the Interactive Robotics Laboratory at WVU. Where he currently studies swarm robotics and focuses on developing fundamental elements of robotics to utilize computational methods, though this article was written during his senior year. With his WVU degree finished, Trevor plans on continuing his education to earn a Ph.D. in Robotics to eventually teach and research within the scopes of swarm robotic system design, cooperative morphological computing, and dynamic reconfiguration of swarm networks.

How to Cite This Article:

Smith, T.R. (2022). Gemini Telepresence Robot System Design: A Low Cost Solution for Manipulation and Enhanced Perception of Telepresence Robots. *Mountaineer Undergraduate Research Review*, 7, 19-28.