5.0. CONCLUSION

An anthropomorphic robotic head has been designed and developed to comply with the biometrical data of adult humanhead. The developed robot head has 3 degree of freedoms inthe neck section. The developed robotic head is capable ofascertaining natural human like neck movements into a greaterextent. A novel cost effective mechanical design for the necksection of the robot has been introduced. This design is capableof minimizing the displacements between the moving axes andfacilitating for a compact modular design. Commonly availableDC motors in the market can be used as actuators instead of custom-made actuators. Therefore, the design is cost effectivewhile providing adequate performance. The developed robotic head is capable of identifying the direction of an external force applied on it and appropriate acting to the force. Therefore, the robotic head has a novel attentive feature. Force attentive mechanism could be further developed by introducing more parameters for the reactionfunction. Apart from that, the robot head has been developed in sucha way that it can be used as a research platform that can be used for further research purposes.

5.1. Contribution

Contribution of my research can be discussed under main two areas as below. In the bio mimetic force attentive robot head developed, below force based reactions were incorporated to the robot head as my contribution.

5.1.1. Reactions based on direction of external force acting on the head

Direction of the external force is a main key factor that decides the mode of reaction for that force by the human head. When any external force acted on human head or something hit on the head, stresses or impacts induces on muscles of head or neck will send signal to brain to identify the direction of force acted to the head. Then brain will decide to take the head away from the force and will send signals to the muscles of the head, neck to act accordingly. In human anatomy each and every cell works as individual

sensor to send stress signal to the brain. The robot head developed in this also same principle was used to detect the direction of external force. Instead of stresses generated in muscles of human head, four force sensor mounted on robot head base will sense the external force. According to the algorithm written on controller direction of external force will be determined by the controller and robot head will instantly move his head away from the force like human. This function was verified with 8 case studies that applied forces on the head in different 8 directions.

5.1.2. Reactions based on magnitude of external force acting on the head

When we analyze reactions of human head for different magnitude of external forces, it is a complex function of human brain. As an example if something hit gently on our head the reaction will be vary differ compared to if same thing hit hardly on the head. It is obvious that when human head react to an external force, magnitude of that force is a decisive factor in all aspect. Normally if something hit on the head, taking away speed of head will proportional to the magnitude of the external force. In less significantly, angle of rotation also will approximately proportional to the magnitude of the external force. So, same reaction function was applied to this robot head.

Reaction functions on magnitude of the external force were developed for this robot head for 2 magnitude limits for main for directions as shown in table 4.1

5.2. Problems Encountered and corrective measures taken

5.2.1. Problems of unexpected vibration at end of movement

Robot head was mounted on the base by means of 4 springs placed at each corner. When external force is applied on the head, robot head will move away from the applied force. But in the instant motors are stopping sudden jerk is acting due to momentum of the robot head. This sudden jerk is causing to induce forces on force sensors which may mislead the controller. So in some instants when robot head moved and stopped at a point again it will start to move even without having any external force acting. So, robot head had to be tuned very precisely to eliminate subjected vibration effects. Springs of the bases were mounted so that they can be adjusted easily to vary its length.

5.2.2. Slight play in gear motors due to weight of structure

There was a slight play in gear motors even after DC power cut-off due to weight of the brass ring gears those were used in head structure. After stopping the head movements by the controller, if this stop position is making a movement of any axis motor, that motor tend to rotate in very little amount. Especially when we consider the rolling motor this issue was significant since maximum moment is coming around rolling axis of then robot head. As corrective action some tolerance limit had to be introduced in the Arduino program for the encoder signals.

5.2.3. Difficulty of finding zero position of the head

Sometimes when resetting the robot head by pressing the reset button, it was not coming to rest position at once. It will pass its rest position and again will come back to the rest position. This is happening because of due to momentum of the head, it will go beyond the encoder limits defined in the controller program. This was fine-tuned so that frequency of this fault happening is minimum.

5.2.4. Issues related to material, machinery selection

Since we have used brass material to machine ring gears for rolling and pitching mechanisms the weight of the structure was increased up to considerable amount. Further, used ring gears were custom made especially for this project and those had to be machined in milling machines which has minimum size of gear teeth. As the result, gear ring gears made for rolling and pitching mechanisms were somewhat heavy and robust. This was caused to form a large momentum of rotational parts which cause to make some unexpected issues as explained above.

5.3. Recommendations and Further developments

We have implemented reaction function only for external force acting on the head and it also implemented only for main eight directions as discussed above chapters. But control algorithms can be developed to sense impulsive forces and many more reaction functions can be implemented for various modes of external forces.

Also force sensing methodology can be improved further by introducing more force sensors to the model. When the model is consist of more force sensors means accuracy of detecting the external force is going high.

If we consider the mechanical features of the model it can be implemented some corrective methods to eliminate issue arise during testing and tuning of the robot head. In order to eliminate vibration effect of the robot structure some set of dampers can be introduced to the base. This will ensure smooth functioning of force sensing mechanism and will caused to eliminate false sensor readings caused due to vibration of the robot head.

Also more sensitive types of force sensors can be used for better results for future implementations. Also impulse sensors, torque sensors can be used to sense different modes of external forces. Further, more advance attentive features like human can be incorporated to this robot model by introducing more DOF to the shoulder area of the robot head assembly.

References

[1] T. Fong, I. Nourbakhsh, and K. Dautenhahn, “A survey of socially interactive robots: Concepts, design, and applications,” The Robotics Institute, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213, Tech. Rep. CMU-RI-TR-02-29, November 2002.

[2] C. Becker-Asano, K. Arras, B. Nebel, and H. Ishiguro, “The effect of anthropomorphism on social tele-embodiment,” in *IROS 2012 WorkshopHuman-Agent Interaction*, Vilamoura, 2012.

[3] James Manyika, Michael Chui,Jacques, Bughin,Richard, Dobbs,Peter, Bisson,AlexMarrs, "Disruptive technologies advances that will transform life, business and the economy," McKinsey & Company, 2013.

[4] R.PLATFORM, "Classification of robots," 2015. [Online]. Available: http://www.robotplatform.com/knowledge/Classification_of_Robots/Classification_of_Robots.html.

[5] Hiroyasu Miwal, Tetsuya Okuchi, Hideaki and Takanoba .” Development of a New Human-like Head Robot WE-4” IEEE/RSJ International Conference on Intelligent Robots and Systems, 2002,pp 2443-2448

[6] Hashimoton T and Kabayashi H **“**Study on natural head motion in waiting state with receptionist robot SAYA that has human-like appearance” *IEEE workshop on Robotic intelligence in informational structured space,*2009,pp 93-98

[7] TamimAsfour , Kai Welke , Pedram Azad , Ales Ude and RudigerDillmann “The Karlsruhe Humanoid Head” *IEEE-RAS International Conference on Humanoid Robots*,2008,pp:447-453

[8] Erich Schneider, Stefan Kohlbecher, Klaus Bartl and Frank Wallhoff,”Recognition of intersection scene by attentive observation for a mobile robot” *IEEE/RSJ International Conference on Intelligent Robots and Systems*, 1996,pp:1648-1654

[9] Stasse .O,Telle .B” 3D segmentation using interval analysis and pre-attentive behavior for a humanoid robot” *Robotics and Bio mimetic (ROBIO).IEEE International Conference,*2005,pp:284-289

[10] SeiichiroKatsura,Member, IEEE, Yuichi Matsumoto, and KouheiOhnishi “Modeling of Force Sensing and Validation of Disturbance Observer for Force Control*“ IEEE Transactions of Industrial electronics*, VOL. 54, NO. 1, Feb 2007, pp: 530-537

[11] Aaron Edsinger-Gonzales and Jeff WeberofMIT Computer Science and Artificial Intelligence Laboratory “Domo: A Force Sensing Humanoid Robot for Manipulation Research “International Journal of Humanoid Robotics, May 2004

[12] Kai Xu and Nabil Simaan, Member, “An Investigation of the Intrinsic Force Sensing Capabilities of Continuum Robots “IEEE Transactions on Robotics (TRO),Vol 23, No. 3, pp. 576-587

[13] David Johnston, Ping Zhang, John Hollerbachand Stephen Jacobsen“A Full Tactile Sensing Suite for Dextrous Robot Hands and Use in Contact Force Control “IEEE International conference of robotics,1996, pp:3221-3227

[14] Stramigioli, Rob Reilink, Ludo C. Visser · Dannis M. BrouwerRaffaellaCarloniStefano, "Mechatronic design of the Twente humanoid head," Springerlink.com, 2010

[15] Sherry Turkle, Cynthia Breazeal, Olivia Dasté, Brian Scassellati, "Encounters with Kismet and Cog: Children Respond to Relational Artifacts"

[16] M. Zecca, T. Chaminade, M.A. Umiltà, K. Itoh, M. Saito, N. Endo, Y. Mizoguchi, S. Blakemore, C. Frith, V. Gallese, G. Rizzolatti, S. Micera, , P. Dario, H. Takanobu, A. Takanishi, " Emotional Expression Humanoid Robot WE-4RII Evaluation of the perception of facial emotional expressions by Using fMRI"

[17] Hirth, K. Berns, "Control of facial expressions of the humanoid robot head ROMAN”. Intelligent Robots and Systems, *IEEE International Conference*,2006

[18] T. Fong, I. Nourbakhsh, and K. Dautenhahn, “A survey of socially interactive robots: Concepts, design, and applications,” The Robotics Institute, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, Pennsylvania 15213, Tech. Rep.CMU-RI-TR-02-29, November2002.

[19] C. Becker-Asano, K. Arras, B. Nebel, and H. Ishiguro, “The effect of anthropomorphism on social tele-embodiment,” in *IROS 2012 Workshop Human-AgentInteraction*,Vilamoura,2012.

[20] B. R. Duffy, “Anthropomorphism and the social robot,” *Robotics and autonomous systems*, vol. 42, no. 3, pp. 177–190, 2003.

[21] S. Costa, H. Lehmann, K. Dautenhahn, B. Robins, and F. Soares, “Using a humanoid robot to elicit body awareness and appropriate physical interaction in children with autism,” International Journal of SocialRobotics, vol. 7, no. 2, pp. 265–278, 2015.

[22] H. Robinson, B. MacDonald, and E. Broadbent, “The role of healthcare robots for older people at home: A review,” International Journal ofSocial Robotics, vol. 6, no. 4, pp. 575–591, 2014.

[23] C. Jayawardena, I. Kuo, E. Broadbent, and B. A. MacDonald, “Socially assistive robot healthbot: Design, implementation, and field trials,” IEEESyst. J.no. 99, pp. 1–12, 2014.

[24] A. Causo, G.T.Vo, I.M. Chen, and S. H. Yeo, “Design of robots used as education companion and tutor,” in Robotics and Mechatronics. Springer, 2016, pp. 75–84.

[25] H.E.J. Veeger, “The position of the rotation center of the glenohumeral joint”, International journal of biomechanics, vol 33,pp 1711-1715,2000

[26] K. R. Liles and J. M. Beer, “Ms. an, feasibility study with a robot teaching assistant,” in Proc. 10th Annu. ACM/IEEE Int. Conf. HumanRobot Interaction Extended Abstracts, Portland, 2015, pp. 83–84.

[27] C.Y. Lin, L.-W.Chuang, L.-C.Cheng, and K.-J.Lin, “An interactive finger-gaming robot with real-time emotion feedback,” in 2015 6th Int.Conf. Automation, Robotics and Applications (ICARA), Queenstown, 2015, pp. 513–518.

[28] G.E. Grossman, R.J. Leigh, L.A. Abel, D.J. Lanska, “Frequency and velocity of rotational head perturbations during locomotion” Department of neurology, biomedical engineering,Case western reserve university, Cleveland, 1988,pp 471

[29] L.B.Walker, E.H. Harris, U.R. Pontius, “Mass, volume, center of mass and moment of inertia of head and neck of human body, Tulane university, 1973,pp 530

Rolling Motor – ON (CW

Pitching Motor - OFF

Head starts to move to right