‘AZ’ Humanoid Robot Head with Object and Color Tracking Capabilities

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***Abstract*—In this project, ‘AZ’ humanoid robot head is developed to assist elderly person in their daily life as a personal assistance. This paper provides the modeling and design of an electrically actuated head mechanism. Object and color tracking are considered in the design process. Considering performance of tracking capabilities leads to a total number of four degrees of freedom for the head mechanism, which are split into two main sub-mechanisms: the neck and the eyes. Modeling each sub-system is carried out and taken as inputs of the design process. The ‘AZ’ humanoid robot head using combination of two cameras and kinematics revolute joint movement which is actuated by servo motor that perform robot head movements concurrently. The tracking action of robot head is managed through graphical coding interface i.e labVIEW. The final outcome of this project will enable the robot to receive process and execute the command received from the elderly people.**

***Index Terms*—robot head, humanoid, design, modeling, vision, object tracking**

I. Introduction

The design of robotic system is the major concern in designing a humanoid robot. This leads to the development of a wide range of humanoid prototypes which fall into three categories. a) Full size of humanoid robot such as ~~is~~ ASIMO (Hirai et al., 1998), WABIAN (Ogura et al., 2006), ATLAS (Banerjee et al., 2015) and other prototypes. b) Middle size of humanoid robot i.e iCub (Beira et al., 2006) and Poppy (Lapeyre et al., 2013) and c) Small size of humanoid robot which are NAO (Gouaillier et al., 2009), DArwIn-OP (Ha et al., 2011), and NimbRo-OP (Schwarz et al., 2013). Usually, the small size of humanoid robot are used for entertainment or educational applications.

These three categories of humanoid robots provide perception capabilities, mostly based on vision as well as the tracking, detecting and controlling object of human face. The vision system should mimic that of human beings. The robot must have manlike appearance and dexterity. Basically, there are two main challenges in designing a humanoid robot head; which is to get a robotic head as a “copy” of a human head and to obtain a more optimized technical mechanism or so called a technomorphic head.

The superiority of a technomorphic head is that there is no restriction in design parameters, which includes head parameters or shape. Thus, this greatly reduces the effort for the mechanical design of humanoid robot head. On the other hand, development of humanoid robotic head has the potential to be used as a research platform in studying fields such as; social interaction between human and robots, artificial intelligence and virtual reality.

Another challenge in the design of humanoid heads deals with the choice of sub-mechanisms in face-human part in order to reach acceptable human-like and emotional capabilities. The four main sub-mechanisms are the neck, the eyes, the mouth and the eyebrows. The analyzing main functional components clearly present in ARMAR III (Asfour et al, 2008), i-Cub, FLOBI, WE-4RII, and Kismet prototypes.

Most of existing humanoid head prototypes are based on electrical actuation due to lightweight construction, minimal risks to users, compact motion space design, low cost, easiness in usage, and control contrary to hydraulic or pneumatic actuation. Such features make electric actuation the most suitable technology as stated by Arent et al. (2008).

Since the aim of this project is to trace object and color tracking for humanoid robot, the choice of the kind of actuation of the proposed robotic head needs to be justified by both mechanism design and visual servo system. This humanoid robot head using combination of two cameras and kinematics revolute joint movement which is actuated by servo motor. The movement of pan (left and right) and tilt (up and down) on humanoid robot head lead to four total degree of freedom. The final outcome of this project will enable the robot to receive process and execute the command received from the elderly people.

Thorough analysis of possible practice design of robotic head leads us to the idea of developing a new humanoid head which can be used either as a necessary sub-mechanism part to complete 'AZ' humanoid robot or as a separate test bed for research on humanoid head or so called "desk version" of the head prototype.

This paper discussed the whole project in several parts. A bio-mechanical study of the human head mechanisms concerning human neck and human eye is detailed in Part II. A mathematical model for the head subsystem is then realized in Part III followed by control design in Part IV. An experimental evaluation of the proposed robotic head

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mechanism is shown in Part V where a visual tracking experiment of a moving target is described. Finally, the conclusion and the future works are presented in Part VI.

II. Overview of Humanoid Head Mechanism System

The specification of actual human head shall be identified in order to design a humanoid head. These specifications or parameters deal with dimensions, motion speeds and rotation ranges of human head. Thus, a study of bio-mechanical will be carried out in order to provide the inputs of the mechanical design process. The analysis focuses on neck and eye of the human head which is detailed in the following two main sub-sections; A and B.

In order to describe the human head precisely, the head length, width, the circumference, the eyes dimensions, and the eyes separating distance need to be measured. The human head has an average length range from 19.5 to 23.3 cm with an average width varying from 15.4 to 15.9 cm. The circumference varies from 56.5 to 58.5 cm. Based on Haley (1988), the human head has an average height, excluding the neck, varying from 22.3 to 23.3 cm.

A. Human Neck Bio-Mechanical Study

According to Haley (1988), the average human neck circumference varies from 36.5 to 40.6 cm. Meanwhile, the average neck length varies from 8.3 to 8.5 cm. The human neck motions include flexion/extension (pitch rotation), the vertical rotation (yaw rotation), and the lateral bending (roll rotation) (Fitzpatrick, 2010).

The flexion movement comes with range of 50 ° which allows the head to bend towards the chest, while the extension movement comes with a range of 57.5 ° until it ensures the head to tilt back. Another movement is yaw rotation. This vertical neck rotation is described as turning motion of the head to the right and to the left. The range of rotation is 70 ° from the main head axis. The lateral bending is the motion that allows the head to bend towards the human shoulder. The bending angle of motion is 45 °. This motion can be considered as the roll rotation of the neck. All of these human neck motions are illustrated in Fig. 1.

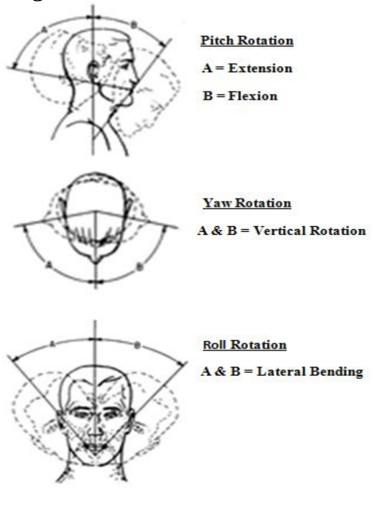

Figure 1. Human neck motions

In order to complete the mechanical design of humanoid head, the speed specifications for each joint need to be identified. The neck velocities reach value of maximum for pitch rotation is 430 °/s, the yaw rotation is 467 °/s and the roll rotation is 360 °/s as stated by Fitzpatrick (2010).

B. Human Eye Bio-Mechanical Study

For human eyes, the average eye dimensions differently according to the human age (Gross et al., 2008). At 13 years old, the eyeball reaches its full-size diameter of 24 mm. The inter-pupillary distance (IPD) which is the distance between the centers of the two pupils has an average range of 56 to 72 mm. The pupil diameter has an average range of 2 to 8mm. The eye motions perform approximately a range of 35 ° up and down, and to the right and to the left.

Based on Jacob (1993), the eye performs sudden and fast motion called saccades. It moves in 1–40 ° in 30–120 ms. Then, followed by a period of stability called fixation, needed to recognize the objects. This period is estimated by 200–600 ms.

Fig. 2 shows the approximate field of view of the eye. The distance with 105 ° away from the nose, 85 ° downward, 70 ° toward the nose, and 50 ° upward. The total forward field of view of the human eye, with the movement of the neck, is almost 180 ° stated by Fitzpatrick (2010). In terms of eyes movement, for yaw and pitch, a maximum angular velocity of 570 °/s can be determined.

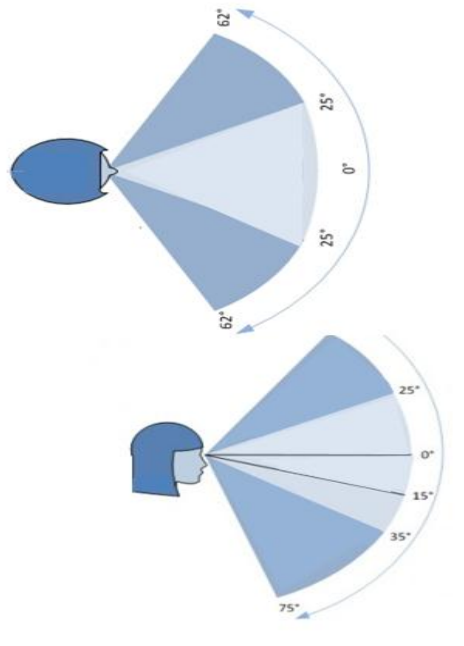

Figure 2. Eyes fields of view

III. Mathematical Model of the Head Mechanism

The purpose of this part is to establish the mathematical model in order to get the equation of motion, the frequency response, and the transfer function. Based on the bio-mechanical analysis carried out in the previous part, there is four total number of degrees of freedom (DOF). These DOF are split into two sub-mechanisms as follows; two DOF for the neck and two independent DOF for each eye mechanism.

For pitch and yaw movements of the neck and the eyes of humanoid head, there are similarities for both movements. Hence, to avoid repetition, the neck pitch movement is given in detail, while only the outcome of the neck yaw is shown. The equations of motion as well as the transfer functions of the eye movement can also be concluded from the neck ones due to the similarities on both mentioned.

The mathematical model for the pitch movement for both neck and eye can be established as shown in Fig. 3, which is considered between the input electric motor and the corresponding head block (leads pitch movement) mechanism.

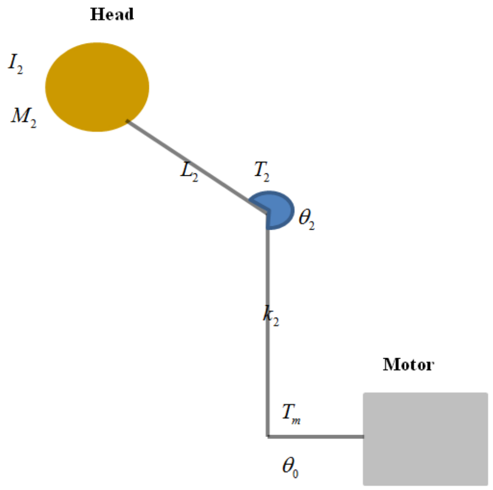

Figure 3. Model for pitch rotation

Firstly, two following dynamic equations on the motor axis shall be considered:

$$I_m\ddot{\theta}_0 + k_2\left(\theta_0 - \theta_2\right) = T_m \tag{1}$$

$$I_2\ddot{\theta}_2 + k_2(\theta_2 - \theta_0) - M_2 g L_2 sin\theta_2 = T_2 \tag{2}$$

Where;

$\ddot{\theta}_0$ acceleration of the motor

$\ddot{\theta}_2$ acceleration of the subsystem

T_m motor torque

T_2 applied torque on the subsystem

k_2 stiffness

θ_0 angular position of the motor

θ_2 angular position of the subsystem

I_m moment of inertia of the motor

I_2 moment of inertia of the subsystem

M_2 mass of the subsystem.

The n_2 be the reduction ratio between the motor axis and the output axis,

$$\ddot{\theta}_0 = n_2\ddot{\theta}_2 \tag{3}$$

$$\theta_0 = n_2\theta_2 \tag{4}$$

For the term $sin\theta$, Taylor expansion is considered for small angles, and $sin\theta$ can be approximated to $\theta - \frac{\theta^3}{6} + \frac{\theta^5}{120} - \ldots$ however, only the first term is taken into account.

By combining the previous equations, the two following relations can be derived:

$$\ddot{\theta}_2 = \frac{T_m - k_2\left(n_2 - 1\right)\theta_2}{n_2 I_m} \tag{5}$$

$$\ddot{\theta}_2 = \frac{T_2 - \left(k_2\left(1 - n_2\right) - M_2 g L_2\right)\theta_2}{I_2} \tag{6}$$

By equating (5) and (6) and considering the relation between the output system torque T_2 and the input motor torque T_m ($T_2 = \mu n_2\, T_m$ with μ the efficiency coefficient), the following θ_2 expression is set up:

$$\theta_2 = \frac{T_m\left(I_2 - \mu n^2{}_2 I_m\right)}{\left(n_2 - 1\right)k_2\left(I_2 + n_2 I_m\right) + n_2 I_m M_2 g L_2} \tag{7}$$

Equation (7) can be generalized to produce the transfer functions of all the other DOFs of the head which is yaw of the neck sub-mechanism and pitch and yaw of the eyes. For the yaw rotations (neck and eye sub-mechanisms), there is no effect of gravity and the corresponding term in equation (7) need to be avoided. Consequently, the yaw motion transfer function of the neck can be generated as below:

$$\theta_1 = \frac{T_m\left(I_1 - \mu n^2{}_1 Im\right)}{\left(n_1 - 1\right)k_1\left(I_1 + n_1 I_m\right)} \tag{8}$$

Where;

I_m motor moment of inertia

I_1 yaw sub-system moment of inertia

T_m input torque

θ_1 neck yaw angle

k_1 stiffness of the flexible element

μ corresponding efficiency coefficient.

The above generated equations (7) and (8) will be carried out for the position control of the neck pitch and yaw rotations of humanoid head.

IV. Control Design

The software that was used in the control and image processing was LabVIEW. Basically, the experiment is divided into three levels; started with image processing followed by object tracking and finally object identifying.

A. Stereo Vision

The stereo vision can be defined to recognize the coordinates of the object and color. A calibration was done using LabVIEW build in function. The algorithm used in the calibration was based on the procedure described in Fig. 4.

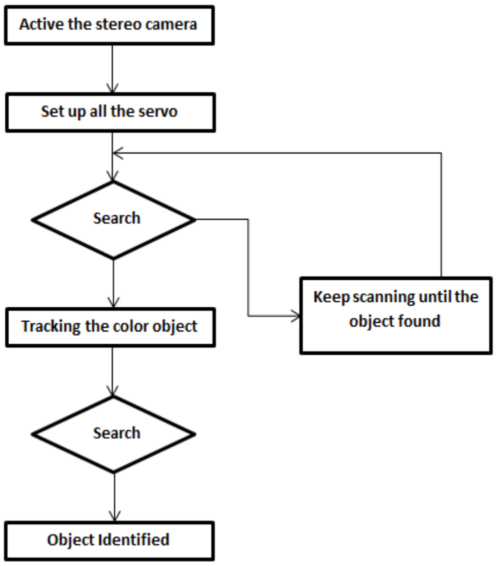

Figure 4. Algorithm process flow

A simple shape with different color was used in the calibration due to its simple structure. The dimension of shape was about 7 cm by 7 cm. Twenty images were taken from each camera in order to use them in the calibration for the purpose of finding the camera parameters. A few shapes with different color were presented in different orientations and translations during images taken to enhance the accuracy.

LabVIEW generates a file contains the parameters of the camera. When the parameters of the camera are identified, the stereo camera process takes the place. Since a video processing was used, the algorithm shown below was done repeatedly for each frame. This algorithm started by images rectification using the calibration results.

B. Tracking the Color Object

The process of tracking is by identifying the object via color threshold in image processing. The image threshold passes through series of processes in order to identify an object. Firstly, the object color needs to be placed in front of the camera. The users select the object by drawing shape circle, rectangle and triangle with different color of wanted object. Then, the mean color value of the selected area will be calculated. Finally, the image will be transformed to the LAB color space to find the true color of the object detected. The mean color's value of selected object was used to threshold the image and the result is generated in a binary image.

C. Object Coordinate Findings

Considering the relation of the object with the stereo camera, the coordinated was calculated as follows:

$$O_{object} = T_m{}^A{}_1 \times T_m{}^m{}_2{}^1 \times T_{m2}{}^{camera} \times O_{camera}{}^{object} \quad (9)$$

Where:

O_{object} vector from the world coordinate to the object

$T_m{}^A{}_1$ transformation between robot coordinate and motor 1 coordinate

$T_{m2}{}^{m1}$ transformation matrix between motor 1 and the motor 2 coordinates

$T_{m2}{}^{camera}$ transformation between robot between Motor 2 and the camera coordinates

$O_{camera}{}^{object}$ vector between the camera and object.

The transformation between motor 1 and motor 2 are function of their angular positions θ_{m1} and θ_{m1}, where these values depend on the object position in the world.

The operating system was divided into five stages. The system starts by scanning the surrounding area to find the target. Once the target is identified, the transformation from the object to the fixed world coordinate is calculated.

The important result of the transformation was the translation coordinate [X Y Z 1]' of the object with respect to the world coordinate. The orientation of the object was discounted in this experiment. The fixed world coordinate is the robot center.

The camera will keep following the target object until the object stay stills. The system checks the position of the object.

V. 'AZ' Humanoid Head Mechanism

The mechanical design of the 'AZ' head mechanism has taken several criteria with considering the four degree of freedom, the range of motion for each sub-system, torque and speed. These parameters have been taken from the previously mentioned bio-mechanical study in Part 2. We focus on simplicity, compactness, and the easiness in installation on this humanoid head with eyes mechanism of vision based on object color tracking capabilities.

The neck mechanism builds with two degree of freedom. Pitch and Yaw rotation shall be taken on consideration. The serial mechanism is more simple, robust, and easy to be controlled compare to the parallel mechanism. The serial mechanism used when high load capacity is required project and some more interference between the various parts especially when small space is allowed (Beira et al., 2006).

The neck mechanism is formed from three pulley and a belt system. Fig. 5 shows the neck part drawing using Catia software and Fig. 6 shows the neck part installation. Using belts and pulleys, allows us to distant transmission in any direction of the neck parts. Moreover, belts are cheap for small systems and it has a unique ability for vibration isolation. Belt transmission system is also able to avoid the gear trains induce, such as backlash, noise, and vibration of the system. We can also use mechanical chain. But since its high mass and instability of velocity which may causes vibration, noise, and limitation in position, the mechanical chain was not selected in the proposed neck mechanism. Nevertheless, the use of timing belts allows us to avoid slipping during installation.

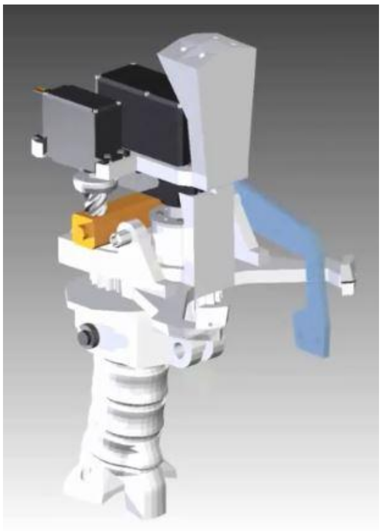

Figure 5. Catia software

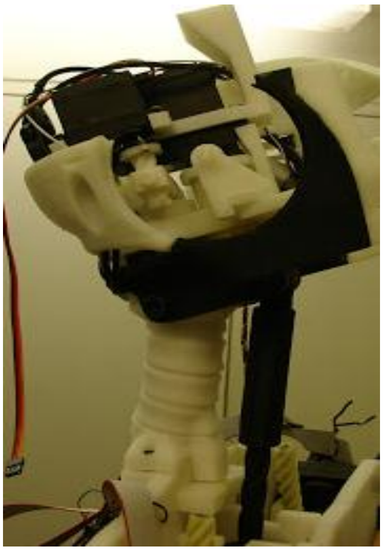

Figure 6. Neck Prototype

VI. EXPERIMENT STUDIES

In order to evaluate the ability of tracking the object color smoothly, experiments of color detection are performed. The experiments are done by placing the object color shape in front of the camera. When the camera systems started, it turns motor move to keep the object within the limited range of head movement.

Experimental results presented in Fig. 7 to demonnstrate the efficiency of our tracking system. The result for block diagram is shown in Fig. 8.

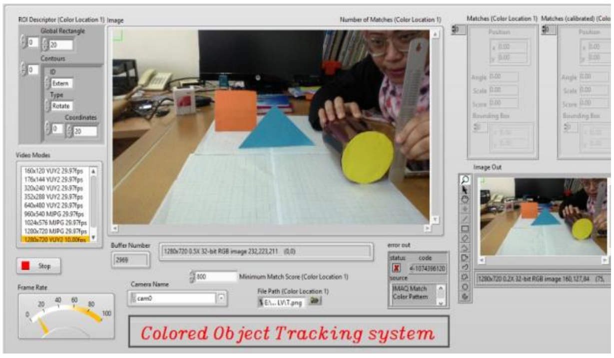

Figure 7. Labview image of color object tracking

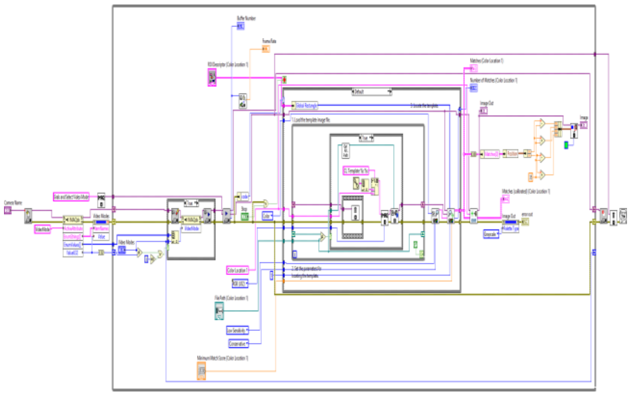

Figure 8. Labview block diagram

VII. CONCLUSION

The main objective of the paper was to develop a model of an electrically actuated head mechanism for stereo vision based on color tracking control system using LabVIEW. The object tracking algorithm is made first, recognize and detecting the object color in both camera images with concurrently actuated by several servo motor. In the same time the acquired pictures are used to estimate the distance between object color and stereo vision system. The proposed system can be improved in the next directions such as size shape, texture object color since LabVIEW software is very well suitable to stereo vision applications.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Each author's contribution to this work is as follows; the first author supervised and analyzed the data, the second author conducted the research and the third author wrote the paper. All authors had approved the final version.

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REFERENCES

[1] K. Arent, Janiak, B. Kreczmer, L. Malek, R. Muszynski, et al. "Toward a robotic companion design," *Warszaw: Oficyna Wydawnicza Politechniki Warszawskiej*, 2008.

[2] T. Asfour, K. Welke, P. Azad, A. Ude, and R. Dillmann, "The Karlsruhe humanoid head," in *Proc. 8th IEEE-RAS International Conference on Humanoid Robots*, Humanoids 2008 (Karlsruhe; Ljubljana), pp. 447–453, 2008.

[3] N. Banerjee, X. Long, R. Du, F. Polido, S. Feng, C. G. Atkeson, et al., "Human-supervised control of the ATLAS humanoid robot for traversing doors," in *IEEE-RAS International Conference on Humanoid Robots* (Seoul: IEEE), 2015, pp. 722–729.

[4] R. Beira, M. Lopes, M. Praga, J. Santos-Victor, A. Bernardino, G. Metta, et al. "Design of the robot-cub (icub) head," in *Proc. 2006 IEEE International Conference on Robotics and Automation*, 2006 (ICRA 2006), vol. 21, 2006.

[5] G. Lacey, K. M. Dawson-Howe, "The application of robotics to a mobility aid for the elderly blind," *Robotics and Automation. Systems*, no. 23, pp. 245-252, 1998.

[6] C. Breazeal, "Emotion and sociable humanoid robots," *Int. J. Hum. Comput. Stud*. vol. 59, pp. 119–155, 2003.

[7] Delaunay, F. De Greeff, J., and T. Belpaeme, "Towards retro-projected robot faces: an alternative to mechatronic and android faces," in *IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)* (Kobe: IEEE), pp. 306–311, 2009.

[8] R. Fitzpatrick, "Designing and constructing an animatronic head capable of human motion programmed using face-tracking software," Ph.D. thesis, Polytechnic Institute, Worcester, 2010.

[9] D. Gouaillier, V. Hugel, P. Blazevic, C. Kilner, J. Monceaux, P. Lafourcade, et al. "Mechatronic design of NAO robot humanoid," in *Proc. IEEE International Conference on Robotics and Automation (Kobe: IEEE)*, 2009, pp. 769–774.

[10] T. Asfour, K. Bern, R. Dillmann, "The humanoid robot ARMAR III: Design and control," in *Proc. the First IEEE-RAS Int. Conf. on Humanoid Robots (Humanoids 2000)*, MIT, USA.

[11] R. D. Schraft, C. Schaeffer, M. T. Care-Obot, "The concept of a system for assisting elderly or disabled persons in home environments," in *Proc. of the IEEE 24th Annual Conf*., V.4, 1998, pp. 2476-2482.

[12] H. Tamura, Y., H. Asama, J. Han, and D. W. Hong, "Development of open humanoid platform DARwIn-OP," in *Proc. SICE Annual Conference 2011 (Tokyo: IEEE)*, 2011, pp. 2178–2181.

[13] J. Haley, "Anthropometry and mass distribution for human analogues," vol. 1, Military Male Aviators. Ohio: Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Report No. 88, 1988.

[14] K. Hirai, M. Hirose, Y. Haikawa, and T. Takenaka, "The development of Honda humanoid robot," in *Proc. IEEE International Conference on Robotics and Automation*, vol. 2 (Leuven: IEEE), pp. 1321–1326, 1998.

[15] D. Xu, A. A. Calderon, J. Q. Gan, H. Hu, "An analysis of the inverse kinematics for a 5-DOF manipulator," *International Journal od Automation and Computing 2*. 2005, pp. 114-124.

[16] J. Hirth, N. Schmitz, and K. Berns, "Emotional architecture for the humanoid robot head ROMAN," in *Proc. IEEE International Conference on Robotics and Automation (Roma: IEEE)*, 2007.

[17] R. J. K. Jacob, "Eye movement-based human-computer interaction techniques: Toward non-command interfaces," *Advance Human Computive*, Interact. 4, pp. 151–190, 1993.

[18] N. I. Katevas, et al., "The autonomous mobile robot SENARIO: A sensor-aided intelligent navigation system for powered wheelchairs," *IEEE Robotics & Automation Mag*., vol. 4, no. 4, pp. 60-70 Dec 1997.

[19] K. Kaneko, F. Kanehiro, M. Morisawa, K. Akachi, G. Miyamori, A. Hayashi, et al. (2011). "Humanoid robot– humanoid robotics platform with lightweight and slim body," in *Proc. Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on (San Francisco, CA: IEEE)*, pp. 4400–4407.

[20] M. W. Spong, F. L. Lewis, C. T. Abdallah, *Robot Control: Dynamics, Motion Planning and Analysis*, IEEE Press, 1993.

[21] M. Lopes, A. Bernardino, J. Santos-Victor, C. V. Hofsten, and K. Rosander, "Biomimetic eye-neck coordination," in *Proc. IEEE – International Conference on Development and Learning (ICDL) (Shanghai)*, 2009.

[22] I. Lutkebohle, F. Hegel, S. Schulz, M. Hackel, B. Wrede, S. Wachsmuth, et al. (2010). "The bielefeld anthropomorphic robot head," in *Proc. 2010 IEEE International Conference on Robotics and Automation (ICRA)*, (Alaska: IEEE), pp. 3384–3391.

[23] Y. Ogura, H. Aikawa, K. Shimomura, A. Morishima, H. O. Lim, and A. Takanishi, "Development of a new humanoid robot wabian-2," in *Proc. 2006 IEEE International Conference on Robotics and Automation*, 2006. (Orlando, FL: IEEE), pp. 76–81, 2006.

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