MECHANICAL DESIGN OF DUAL-ARMS FOR SOCIAL SERVICE ROBOT BASED ON NONVERBAL INTERACTION

Nguyen Duc Tai[1], **Nguyen Truong Thinh**[1,*]

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ABSTRACT

Robots have become increasingly popular for fulfilling various tasks in different fields to reduce labor, increase productivity, and replace humans in hazardous and dangerous environments. Currently, service robots are designed as humanoids. The robot serves the community in public environments and has the ability to interact with humans through nonverbal communication. Robots with receptionist functions can interact with customers, which is one way to impress and arouse curiosity among customers. This contributes to attracting and encouraging more customers to visit the store. Recognizing the high potential and practicality in reality, this paper presents the mechanical design of dual arms for a humanoid robot that allows the robot to replicate human-like movements and gestures based on nonverbal interaction. The system consists of 1 pair of arms with 4 dof each. Each arm weighs 1.5kg and has a reach of 645 mm. The robot's movements are optimized by mechanical design for the two arms of the robot during the interaction. In the experiment process, the robot's dual arms work flexibly in nonverbal interactions with the surrounding communicators.

Keywords: *Dual arms, Humanoid Robot, Service Robot, Social Robot, Human-Robot Interaction.*

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[1] Institute of Intelligent and Interactive Technologies, University of Economics Ho Chi Minh City(UEH), Vietnam

[*] Email: thinhnt@ueh.edu.vn

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1. INTRODUCTION

The development of robotics and artificial intelligence has transformed the way people engage with technology, opening the path for the creation of advanced social service robots that can integrate smoothly into human-centered environments. These robots have enormous promise for solving societal issues ranging from supporting the elderly and disabled to improving the quality of life in a variety of care situations. One of the most important characteristics of social service robots is their capacity to successfully communicate with humans. While verbal communication is undeniably important, nonverbal interaction is similarly important in creating authentic and empathetic connections between humans and robots. Nonverbal cues such as gestures and body language play an important role in communicating intentions and responses, making them essential components of human-robot interaction (HRI) [1]. The mechanical design of dual arms for a social service robot is the focus of this paper, with a particular emphasis on facilitating nonverbal interaction. The robot's arms flexibility, range of motion, and adaptability are essential aspects that directly influence its capacity to perform gestures and engage in intuitive and empathetic interactions with humans. Currently, the design of the arm for the robot is in development. There are many robot arm configurations designed and used in community, as shown in [2, 3, 4]. These robot arm configurations are designed to serve in the factory, so in general, the design cannot meet the design requirements to resemble humans. This has also prompted later studies to create robotic arms integrated into humanoid robots to increase the aesthetics and effectiveness of interactions, especially interactions through gestures. There are several subsequent robot configurations that have done this and are presented by the authors in [5, 6, 7]. These designs for these robotic arms on humanoids have been improved, but they are still crude and do not provide an accurate shape or description of the actual human arm structure. Therefore, we have presented a mechanical design for dual arms that is more innovative and solves the above problems with the aim of increasing the non-verbal interoperability of the robot. The primary objective of this project is to create a dual-arm system that allows the robot to replicate human-like movements and gestures. Furthermore, the mechanical design must take safety and robustness into account, ensuring the robot's adaptability for real-world deployment in a variety of social service contexts. We delve into the kinematic analysis [8] and engineering approaches used in the creation of the dual-arm structure in the next sections of this work. We also go through the integration of sensors and actuators, which allow the robot to comprehend human movements and change its reactions accordingly. We contribute knowledge in the field of social robots by addressing mechanical design issues and implementing nonverbal interaction capabilities into the dual-arm system. The ultimate goal is to improve the robot's emotional engagement with humans, creating trust, acceptance, and productive collaboration in a variety of social service domains. This research aims to bridge the gap between robotics, nonverbal communication, and social service applications, while also providing vital insights into the future of human-robot interaction. Understanding and optimizing the mechanical design of social service robots will surely bring us toward human-robot cooperation as technology advances.

2. DUAL ARMS MECHANICAL DESIGN

Fig. 1. The structure of the service robot

The social service robot is placed in a public space and will be responsible for interacting with humans through both nonverbal and verbal interactions. Therefore, in the design, it is crucial to ensure that the hardware and software components are capable of high-level control decision-making. The main components of the robot include the mobility base, the robot body, two robot arms, and the head. Two active wheels powered by DC servo motors allow the robot to move, and it also features a castor wheel for more flexible movement and balancing. The robot is surrounded by sensors and cameras that enable it to move, avoid obstacles, and simultaneously recognize human faces in order to provide information. A touch screen can be fitted to the robot's body to allow for human contact. A welcoming atmosphere is also created by the robot arm's four degrees of freedom, which allow it to move flexibly and be programmed to perform various simple dance routines like a person. Mechanical is an extremely important part of the robot, this part is like a solid backbone responsible for supporting the entire mass and ensuring the flexible operation of the robot. A precise, stable mechanical design makes programming easy. The form of the robot is based on the assumption that the nature of the nonverbal interaction task is consistent throughout. We designed with the concept of a young lady with pleasant characteristics in mind, using curves, corners, and gourd forms to create a sense of closeness for consumers. Furthermore, the texture and proportions of the torsos, pedestals, and shoulder joints give the robot a feminine appearance. To make the robot interact nicely and be approachable, touch displays and screens with flat blocks are utilized to receive information, restricting organic designs with curves. The human hand is one of the most challenging body parts to translate into mechanical parts from a design perspective. Imitating the human hand is difficult due to the restricted geometric space, variety of touch input, and 22 degrees of freedom. This project's service robot arm was designed using the human arm as a model. The arms and hands are designed to be as similar to a human hand as possible in terms of size and weight. Two servo motors on the forearm and five servo motors on the hand are used to flex the fingers. For quick prototyping, the complete system is 3D printed with plastic. Many changes have been made from a bio-anatomy and mechatronics perspective to reduce the bulk of issues with the hand. The project design takes into account the need to retain biological dimensions; the complete system must fit drivers, motors, sensors, and other electronics that must be contained within the geometry space constraint. Forearms, fingers, and other parts are modularized for simple assembly, upkeep, and repair. For precise control, position feedback at the joints is crucial. The team looked at the human arm's golden ratio when designing the forearm, and they came up with a design that fit the size and shape of the human arm. The robot features two arms. Nine degrees of freedom, including four degrees for the arm and five for the hand. A hinge joint joins the base body and the arm. The robot has a wider work area with two robotic arms. The control system combined and coordinated the movements of the manipulator and platform. Tasks are carried out by the robot using data from an automatic camera system or by interacting with a human operator. The body coupling is a crucial joint because it is here that the engine carries the bulk of the arm's weight, making it crucial to build it in such a way that it is both small and strong. important. Since this is where the arm module and robot body are assembled, the mounting of the details must make sense. We must determine the maximum torque at the shoulder joint in order to select the motor to be used. The arm's design and material choices have resulted in a mass for the entire arm of roughly 1.5 kg. The proportions of a woman's hand served as inspiration for the hand's design, which was then used to determine how the robot's arm and body should fit.

3. KINEMATICS ANALYSIS

A social service robot is a mechatronic device that operates autonomously in space, carrying out various tasks under computer control. It has the capability to manipulate objects or move its own components to perform the required work. The mathematical representation of a robot typically involves a reference coordinate system, which is often mounted at a specific point to establish a precise relationship with the robot. Each component of the robot is connected to this reference coordinate system, allowing for accurate tracking of position and orientation, thereby creating a complete model of the robot. Kinematics is concerned with studying the mechanical motion of objects, focusing on geometric aspects without considering the specific causes or sources of motion. When applied to robot kinematics, it involves describing the motion of the robot. Forward kinematics examines the geometric relationships that influence the robot system, including the connection between control parameters and the resulting behavior of the robot in its workspace. This allows us to determine how the robot moves and where it will go for specific combinations of joint parameters. In contrast, inverse kinematics calculates the required joint parameters to achieve a desired position in a given direction, allowing us to plan the robot's motion toward a fixed position.

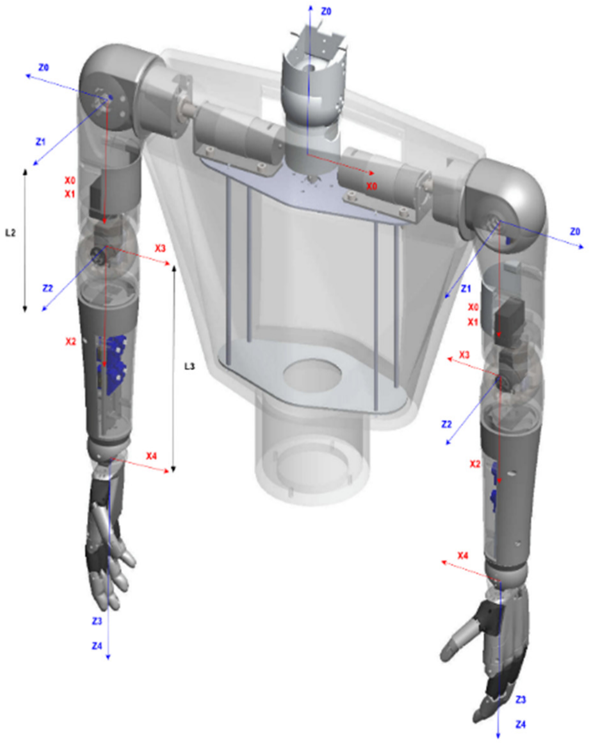

Fig. 2. Coordinates assigned in dual-arms for kinematics

The number of degrees of freedom for the arm must first be modeled, and each joint must have a reference system of axes that includes the z and x axes. Since the arm is totally built as a swivel without a translational joint, the z-axis will be established using the right-hand rule in the direction of displacement brought on by the rotation. We can model the coordinate system of the dual-arms (Fig. 2) according to the rotation using the anatomy and representation of the coordinate system and the rotation joints in the human body. Each joint is given a set of coordinate axes. Finding the ending position of the endpoint on the arm based on the rotation angles of the arm joints is how the forward kinematics problem is solved. The parameters of the D-H table must first be established in order to calculate the position and orientation from the set of values for the matching variables. From there, we may determine the gripper's or final actuator's position and orientation conversion matrices in relation to the robot's reference axis system. The coordinate transformation between two consecutive frame i and frame i + 1 is obtained as follows:

$$ {}_{n+1}^{\;\;n}T=\begin{bmatrix} \sin(\theta_{n+1}) & -\sin(\theta_{n+1})\cos(\alpha_{n+1}) & \sin(\theta_{n+1})\sin(\alpha_{n+1}) & a_{n+1}\cos(\theta_{n+1}) \\ \sin(\theta_{n+1}) & \cos(\theta_{n+1})\cos(\alpha_{n+1}) & -\cos(\theta_{n+1})\sin(\alpha_{n+1}) & a_{n+1}\sin(\theta_{n+1}) \\ 0 & \sin(\alpha_{n+1}) & \cos(\alpha_{n+1}) & d_{n+1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

The robot arm is constructed using the D-H table to obtain the coordinate transformation between the two successive frames. As a result, the following is the coordinate transformation from the frame of the end effector to the frame of the base:

$$ {}_4^0T = {}_1^0T\,{}_2^1T\,{}_3^2T\,{}_4^3T \quad (2) $$

After multiplying all the matrices together and reducing the expression, we finally find out that the coordinates of the hands are:

$$ \rightarrow \begin{cases} P_X = \cos(\theta_1)(L_3\cos(\theta_2+\theta_3)+L_2\cos(\theta_2)) \\ P_Y = \sin(\theta_1)(L_3\cos(\theta_2+\theta_3)+L_2\cos(\theta_2)) \\ P_Z = -L_3\sin(\theta_2+\theta_3)-L_2\sin(\theta_2) \end{cases} \quad (3) $$

The problem of inverse kinematics is a problem we encounter a lot in projects related to robots and all robots that want to be controlled must have an inverse kinematic problem. The inverse problem is a problem that knows the coordinates of a point, thereby deducing the matching variable values so that the robot can move to that point. With the wing model of 4 degrees of freedom as above, we can calculate. The inverse kinematic is calculated by steps below:

$$ \rightarrow \theta_3 = \arccos\left(\frac{P_X^2+P_Y^2+P_Z^2-L_3^2-L_2^2}{2L_2L_3}\right) \quad (4) $$

$$ \cos(\theta_2)=\frac{\begin{vmatrix} \sqrt{P_X^2+P_Y^2} & -L_3\sin(\theta_3) \\ -P_z & L_3\cos(\theta_3)+L_2 \end{vmatrix}}{\begin{vmatrix} L_3\cos(\theta_3)+L_2 & -L_3\sin(\theta_3) \\ L_3\sin(\theta_3) & L_3\cos(\theta_3)+L_2 \end{vmatrix}} \quad (5) $$

$$ \rightarrow \theta_2 = \operatorname{atan2}(\sin(\theta_2),\cos(\theta_2)) $$

$$ \cos(\theta_1)=\frac{P_X}{L_3\cos(\theta_2+\theta_3)+L_2\cos(\theta_2)} \quad (6) $$

$$ \sin(\theta_1)=\frac{P_Y}{L_3\cos(\theta_2+\theta_3)+L_2\cos(\theta_2)} \quad (7) $$

$$ \rightarrow \theta_1 = \operatorname{atan2}(\sin(\theta_1),\cos(\theta_1)) \quad (8) $$

4. RESULTS AND EXPERIMENTS

The test results of the robot's handshake action, from the observation, the robot arm can respond to the desired speed and position. With other actions, the two robot arms both maintain stability when performing the operation and the shaking of the stitches occurs when controlling the robot arm to move at high speed. Overall, the design and programming of the robot arm and neck meet the requirements set forth earlier. The result of process is shown in Fig. 3.

Fig. 3. Robot's right arm movements to perform the handshake task with the interactor

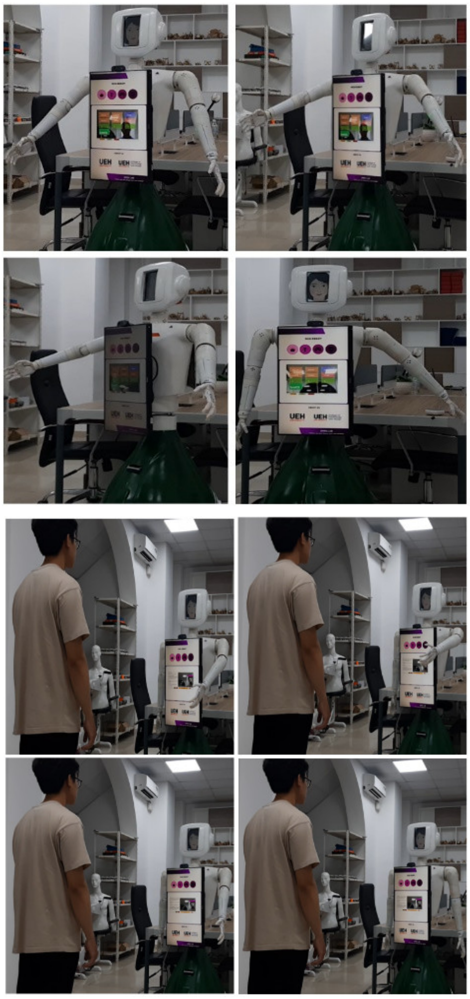

Fig. 4. Robot uses body language while talking with people

The combination of three parts including the base, two arms, and robot head has helped to create smooth movements, that combination helps interactors feel that the robot can be close to humans. We can see as shown in Fig. 4, when the robot base rotates, the neck will rotate along with the two arms creating different movements, creating dance movements. In this particular section, the human-robot interaction process takes place within a real-world environment. The timeliness of the robot's response is a critical requirement in this system, and through rigorous testing, it has been proven that the robot can provide swift responses within a short time. Emotional recognition, due to its computationally intensive nature, typically requires the most time in the recognition process. Apart from response time, it is crucial to ensure that the operation process executes tasks without any conflicts when the robot receives input signals. Fig. 4 illustrates the robot's hand gestures, such as performing a handshake to convey hospitality when users initiate greetings and direct interaction. Moreover, when users request the robot to dance, the robot processes the command and converts it into hardware control signals to carry out the task. Experiments were conducted across various real-life environments, and during system operation, no conflicts were observed.

5. CONCLUSIONS

The study has successfully built and tested the dual-arm of service robot. The experimental results demonstrate the stable operation of the system. The research outcomes include:

- Development of humanoid service robots that operate independently using locally available devices, aiming to attract humans in public areas.
- The robot is capable of providing essential information to users upon specific requests by nonverbal interaction: reminders, recommendations, advice, assistance, and activity provision.
- Complete the design of the social service robot, establish the kinematics models, and intergrate them to achieve the requirements of automatic operation.

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