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# Development of a New Mobile Humanoid Robot for Assisting Elderly People

Zulkifli Mohamed[a,b,]*, Genci Capi[a]

[a]*Intelligent Robotic Lab, Dept. of Electrical & Electronic System Eng., Faculty of Engineering, University of Toyama 3190 Gofuku, 930-8555, Japan*
[b]*Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450, Shah Alam Selangor, Malaysia*

**Abstract**

This paper presents a new mobile humanoid robot for assisting elderly people. The humanoid robot is equipped with a visual sensor to recognize objects. The Laser Range Finder placed in the lower part of mobile platform makes it possible to detect obstacles. After determining the target object, the robot starts moving toward it and then the grasping motion is generated. We address the kinematics, mechatronic and robot specifications. Our goal is to use the mobile humanoid robot for assisting the elderly and work interactively with humans in real environment such as hospitals or homes. Experimental preliminary results are presented for object grasping in real environment.



*Keywords*: mobile humanoid robot; kinematics analysis; design mechanism;

**Nomenclature**

| | |
|---|---|
| LRF | laser range finder |
| DOF | degree of freedom |
| DC | direct current |
| AC | alternating current |
| $c_1$ | $\cos\theta_1$ |
| $s_1$ | $\sin\theta_1$ |
| $c_{23}$ | $\cos(\theta_2 + \theta_3)$ |
| $s_{23}$ | $\sin(\theta_2 + \theta_3)$ |
| $d_1$ | base to shoulder length (mm) |
| $a_2$ | upper arm length (mm) |
| $a_2$ | lower arm length (mm) |
| *Greek symbols* | |
| $\theta_1$ | shoulder angle (deg) |
| $\theta_2$ | upper arm angle (deg) |
| $\theta_3$ | lower arm angle (deg) |

* Corresponding author. Tel.: +81-0764-45-6744.
*E-mail address:* zulkifli127@salam.uitm.edu.my

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## 1. Introduction

The research in humanoid robots has started since the era of Leonardo da Vinci [1]. Since then, there are numbers of humanoid robots that had been developed by private companies and universities. Among mobile humanoid robots that were developed are Waseda University's TWENDY-ONE [2], Karlsruhe Institute of Technology's ARMAR III [3], University of Bonn's Dynamaid [4] and Snackbot from Carnegie Mellon University [5]. These platforms are by far much advanced to compare to the newly developed mobile robot; however it has the simplicity and the basic function of a human being.

In 1990, Japan population was approximately 124 million and 12 percent was 65 years and older. In 1986 the percentage is increased to 23.6 percent and it is estimated to be 30 percent in 2020 [6]. It can be read in the newspapers and reports that the number of ageing people in Japan will further increase and it is going to be 40 percent in 2050. This problem is getting worse with the decreasing number of birth rate and expected to be more than 20 percent by 2050. This scenario will lead to many problems such as economics, housing and health. The needs of assisting and taking care of the elderly become greater every year. In order to solve the problem, many private companies that deal with the elderly had been established. As an alternative, service robot can be used to assist the elderly in their everyday life such as eating, drinking, cleaning and for emergencies. The only problem with service robot is the cost of owning them. Today, the need of having a service robot in each of the elderly house is a must. Researches in this area need to be continued in order to make the service robot more affordable and flexible.

Different robots have been developed for helping elderly people for example, a nursing robot system that is called DO-U-MI to assist elderly and disabled people to move independently in indoor environments such as nursing home. Substantial research has been done in recent years to apply robotic technologies, particularly embeddable, miniaturized computer and electronic systems and sensors, to develop intelligent mobility aids for the disabled. This research has focused primarily on the needs of the blind and of individuals with physical mobility problems [7-9]. Far less work has addressed the problems of the elderly. A number of intelligent wheelchair-type aids are being designed for people who cannot walk and have extremely poor dexterity [8-9]. The interfaces of these aids have been designed to make them easy to control despite the user's limited dexterity. Users command the aid using voice or breath-activated interfaces, or three channel joysticks. However, most of previously developed systems assist elderly people to navigate in the environment. In this work we propose a new upper torso mobile humanoid robot for assisting the elderly. It has the basic of human motion and sufficient enough to do house hold chores. The upper part is attached to a mobile platform for more flexibility and mobility. Mobile platform is chosen based upon the stability and its simplicity over a pair of leg. We present some preliminary results where the robot reaches and grasp an object.

## 2. Mechatronic Design

This mobile humanoid robot has sixteen degree of freedom (DOF) using 6 dc motors and 8 servo motors. It consists of an autonomous two wheel mobile platform, a pair of arms having 12 DOF each, two simple grippers and 2 DOF head. The total weight of the upper part is 8.4 kilogram. This section will describe the robot's upper part, mobile platform and computer architecture.

### *2.1. Upper Part*

The upper part of the humanoid robot consists of the arms, grippers and head. It is also where all the electronic parts are placed. The arm has 6 DOF on each side and a total length of 610 mm from the shoulder to the gripper. A simple gripper is attached to the arm for manipulation purpose. Potentiometers are used as the angle encoder for each joint with a resolution of $0.1^{o}$. Details of the kinematics analysis will be discussed in next section.

The head of the robot is consists of 2 DOF for tilt and pan. Two webcams are used for stereo vision with 1.4 mega pixel resolution. It is used for tracking and detecting the environment. A small microphone is used for voice recognition and receiving command.

The basic movements that can be achieved by this robot are extension, flexion and hyperextension of the head, flexion, hyper-flexion, extension, hyper-extension, abduction, hyper-abduction, adduction and hyper-adduction of the arms, flexion and extension of the lower arms, flexion, extension and hyper-extension of the gripper [10]. The limit angles of each arm are shown in Table 1 and Fig. 1.

Table 1. Lower and upper angle limit of the arms

| Arms | Min. Angle | Max Angle |
|---|---|---|
| Left & Right Shoulder | $-20^0$ | $200^0$ |
| Left & Right Upper Arm | $-10^0$ | $190^0$ |
| Left & Right Lower Arm | $-20^0$ | $90^0$ |
| Head Tilt | $-90^0$ | $30^0$ |
| Head Pan | $-60^0$ | $60^0$ |
| Left & Right Hand Pitch & Roll | $-60^0$ | $60^0$ |

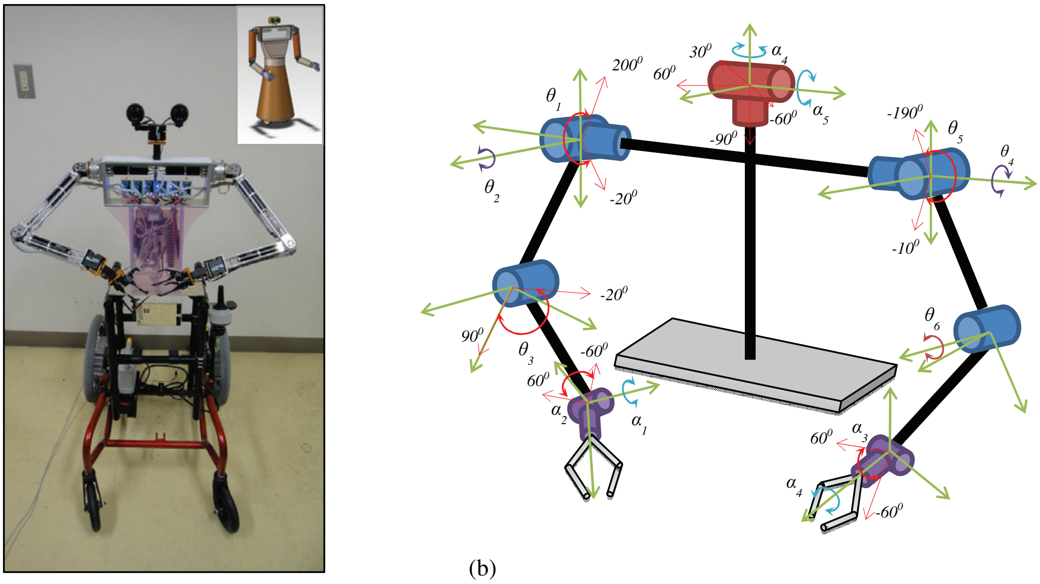
### *2.2. Mobile Platform*

The proposed robotic system is shown in Fig. 1. It consists of a PC, one Laser Range Finder (LRF), two Yamaha AC motors to drive the right and left wheels. The PC and sensors are placed in a trolley walker produced in collaboration with Kanayama Machinery. The laser sensors scan the environment in front of the trolley walker, in the horizontal plane. The PC analyzes the sensor's data continuously. In our system, the LRF sensor is made by HOKUYO AUTOMATIC. The URG-04LX-UG01 ([11]) is a small and light LRF sensor. Its high accuracy, high resolution and wide range provide a good solution for 2D scanning. It has low-power consumption (2.5W) for longer working time and can be powered by the USB bus.

### *2.3. Computer Architecture and Software*

The mechanical design of the mobile robot is done using Solidworks program. It allows the arm to be checked and visualized at the same time. This is to make sure that the mechanism, mechanical part and the electrical parts is in the best position. The drawing will be used later for the simulation purpose.

The manipulation and maneuverability of the robot are depending on the computer architecture and software. MATLAB is used for its flexibility and ability to interface with controller board via USB connector. The board is compatible to drive 8 dc motor, 6 servo motor and read 6 potentiometers and provides the interface between computer and mobile robot.




(a) (b)

Fig. 1. (a) The mobile humanoid robot and Solidworks model (b) minimum and maximum angle of the robot

## 3. Kinematics Analysis

### *3.1. Denavit-Hartenberg Analysis and Forward Kinematics*

Denavit-Hartenberg (D-H) analysis is one of the method can be used to determine direct kinematics of the robot. By using this method, homogeneous transformation matrix is determined, which specifies the position and orientation of the robot with respect to the base as in Fig. 2 [12]. D-H parameters of the robot are defined in Table 2.

Table 2. D-H parameters for mobile humanoid robot

| Joint, *i* | $\alpha_i$ | $a_i$ | $d_i$ | $\theta_i$ |
|---|---|---|---|---|
| OA | $90^0$ | 0 | $d_1$ | $\theta_1$ |
| B | 0 | $a_1$ | 0 | $\theta_2$ |
| C | 0 | $a_2$ | 0 | $\theta_3$ |
| D | 0 | 0 | 0 | Gripper |

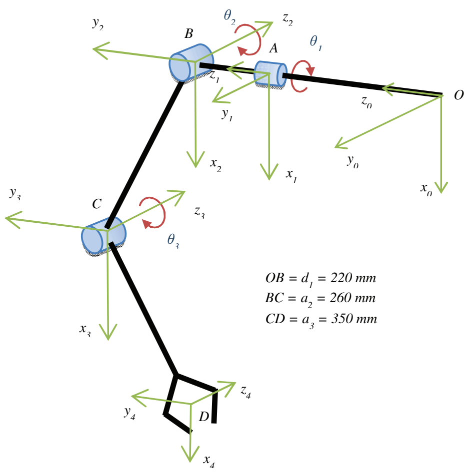



Fig. 2. Coordinate frame of the mobile humanoid robot

By substituting parameters from Table 2 into Eq. (1), the transformation matrices of designated frames T1 to T4 can be obtained as in Eq. (2).

$$T_i^{i-1} = \begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$T_1^0 = \begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_2^1 = \begin{bmatrix} c_2 & -s_2 & 0 & a_2c_2 \\ s_2 & c_2 & 0 & a_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_3^2 = \begin{bmatrix} c_3 & -s_3 & 0 & a_3c_3 \\ s_3 & c_3 & 0 & a_3s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_4^3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Forward kinematics is used to determine the position and orientation of the end effectors with given position. It is generated from the total transformation matrices as in Eq. (3).

$$T_4^0 = \begin{bmatrix} n_x & o_x & a_x & d_x \\ n_y & o_y & a_y & d_y \\ n_z & o_z & a_z & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad T_4^0 = \begin{bmatrix} c_1c_{23} & -c_1s_{23} & s_1 & c_1(a_3c_{23}+a_2c_2) \\ s_1c_{23} & -s_1s_{23} & -c_1 & c_1(a_3c_{23}+a_2c_2) \\ S_{23} & C_{23} & 0 & a_3s_{23}+a_2s_2+d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

The first three columns of Eq. (3) represent the orientation of the end effector whereas the last column represents the position of end effector. Both position and orientation of the end effectors can be calculated in terms of joint angles.

### *3.2. Inverse Kinematics*

Inverse kinematics analysis is important in finding the joint angles if the position and orientations of end effectors are known. By using geometric approach, the inverse kinematics of the mobile robot is determined. The length $d_1$, $a_2$ and $a_3$ are constant. The angles $\theta_1$, $\theta_2$ and $\theta_3$ are determined using inverse kinematics analysis for a given end effector position, $P_x$, $P_y$ and $P_z$ [13].

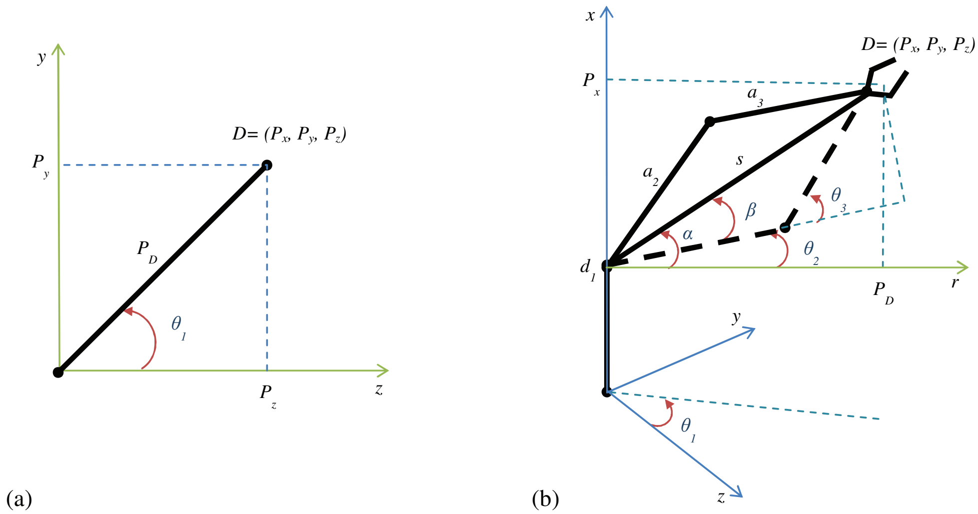



Fig. 3. Inverse kinematics of right hand (a) top view (b) planar view

Fig. 3(a) shows that the first angle, $\theta_1$ can be obtained by taking the arctangent of $P_y$ and $P_z$ as in Eq. (4).

$$\theta_1 = A\tan 2(P_y, P_z) \tag{4}$$

The planar view of the mobile robot is shown in Fig. 3(b) and the rest of the angles can be obtained using Eq. (5) and Eq. (6).

$$\theta_3 = \cos^{-1}\left(\frac{(P_z^2 + P_y^2) + (P_x - d_1)^2 - a_2^2 - a_3^2}{2a_2^2 a_3^2}\right) \tag{5}$$

$$\theta_2 = \alpha \pm \beta = \tan^{-1}\left(\frac{(P_x - d_1)^2}{(P_z^2 + P_y^2)^{1/2}}\right) \pm \cos^{-1}\left(\frac{a_2 + a_3\cos\theta_3}{((P_x - d_1)^2 + P_d^2)^{1/2}}\right) \tag{6}$$

## 4. Experimental Results

In order to evaluate the performance of the developed mobile humanoid robot, we conducted an experiment where the robot has to recognize, reach and grasp a bottle with red marker placed on the table (Fig.4). From the starting position, the robot moves while keeping the red color in the center of the visual sensor and stopping near the table. Fig.4 shows both cameras tracking the red object at a pre-determine position. Once the position is determined, the left arm moves from its reference position to the bottle and grasps it. The bottle is picked and placed back at to its initial position. The left arm returns to its reference position once the bottle is released. The readings of left arm joint angle are taken for further analysis.

Fig. 4. Experimental setup

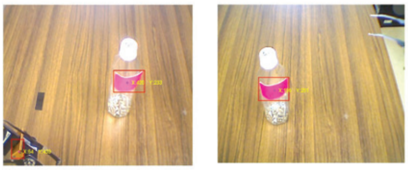


Fig. 5. Stereo camera tracking

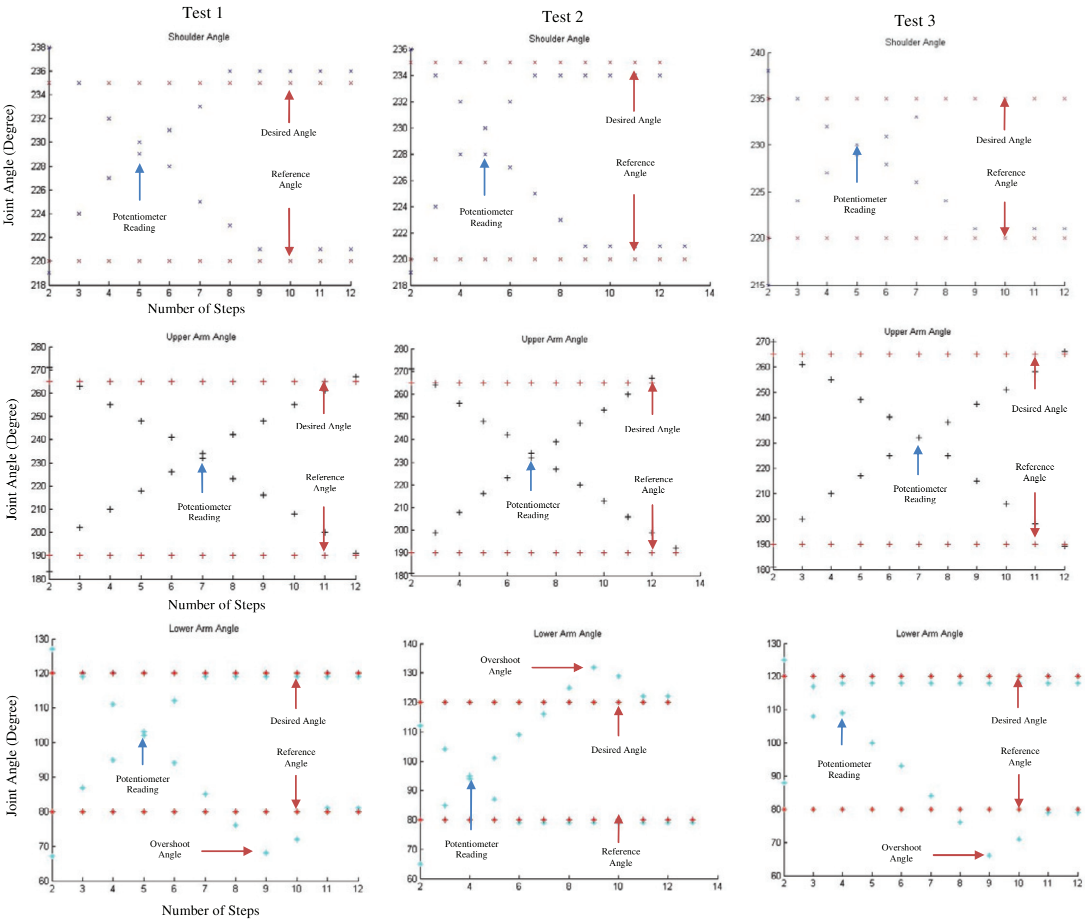



Fig. 6. Left Arm Joint Angle

The joint angles of the left arm are shown in Fig. 6. In this preliminary experiment, the accuracy of the arm is tested. It shows that the shoulder and upper arm moves from its reference position to the desired position with high accuracy but the lower arm is having some difficulties to reach the desired position. In each of the three tests, the lower arm is overshooting more than ten degree. Mechatronic design, programming, motor speed, controller parameters and connection speed between the robot system and computer are among the consideration need to be further studied and analyzed in order to have a high accuracy and robust mobile humanoid robot system.

## 5. Conclusion and Future Work

This paper proposed a new mobile humanoid robot platform for assisting elderly people. The robot specifications, mechatronic design and the computer architecture of the mobile humanoid robot are described. In our system, we integrated the visual and LRF sensor data for robot navigation. In addition, the arm motion is generated based on the visual sensor. Preliminary results for reaching and grasping the object showed a good performance of the system. However, the system needs further improvements in order to increase its robustness. For example, the lower arm motion. In addition, application of intelligent algorithms for better robot performance needs to be considered.

## Acknowledgements

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