DEVELOPMENT OF A RECEPTIONIST ROBOT: MECHANICAL AND CONTROL SYSTEM DESIGN

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Abstract - The paper focuses on the mechanical and control system development of a receptionist robot. This is the result of a 4-month cooperation project between FPT Global Automation Company and the participation of students in Mechatronic Engineering and Electronic & Telecommunication Engineering programs of The University of Danang, University of Science and Technology (UD-UST). Robot body is based on a two-wheel self-balancing system. The movement direction is given by obstacle detection and localization systems using a Kinect camera. The humanoid robot arm can perform basic gestures, grasp object. Experiments demonstrate the effectiveness of the control system in keeping robot stability.

Key words - Receptionist robot; two-wheel self-balancing robot; humanoid robot arm; PID; DFM.

1. Introduction

Recently, many mobile service robots have been deployed in human environments including the robot for elderly and patient care [1], security tasks [2], receptionist [3] and so on. Due to the demand of Danang FPT Complex to have a receptionist robot that can flexibly move indoors, recognize employee faces and perform some basic gestures, a cooperation project is launched with the participation of students in Mechatronic Engineering and Electronic & Telecommunication Engineering programs, university and company tutors. For 4 months, a low-cost, high flexibile receptionist robot with required functionalities are designed, created and tested.

This paper concentrates on the development of mechanical structure and control system of the robot. The remainder of this paper is organized as follows. Section 2 is devoted to the description of the system overall structure, interactions between the functional blocks and hardware configuration. Section 3 and 4 focus on the mechanical and control system design, respectively. The performance of the systems in real situations are illustrated by some experiments in Section 5. Finally, the conclusion drawn from this work and possible ways for further studies are given.

2. Overall structure of robot

The receptionist robot is a complex system whose general structure can be represented in Figure 1(a). The hardware configurations of 6 principal sub-systems are detailed in Figure 1(b).

Using data collected from a Pi camera, the recognition system deployed on a Raspberry Pi board recognizes the human faces as well as the number on the elevator keypad. Besides, obstacle detection & 3D mapping systems using Kinect locate the robot position in space and determine its movement direction to avoid obstacles. The obtained information is then transmitted to the data processing and control center (TI C2000 Launch Pad board) via UART, CAN communication protocols. Here, a control program based on the TI-RTOS operating system divides and schedules robot tasks in a sequential, fast and efficient way. Then, the appropriate information such as location, movement direction, hand gesture, number on the elevator... are sent to balance-moving system and arm system to operate the desired commands.

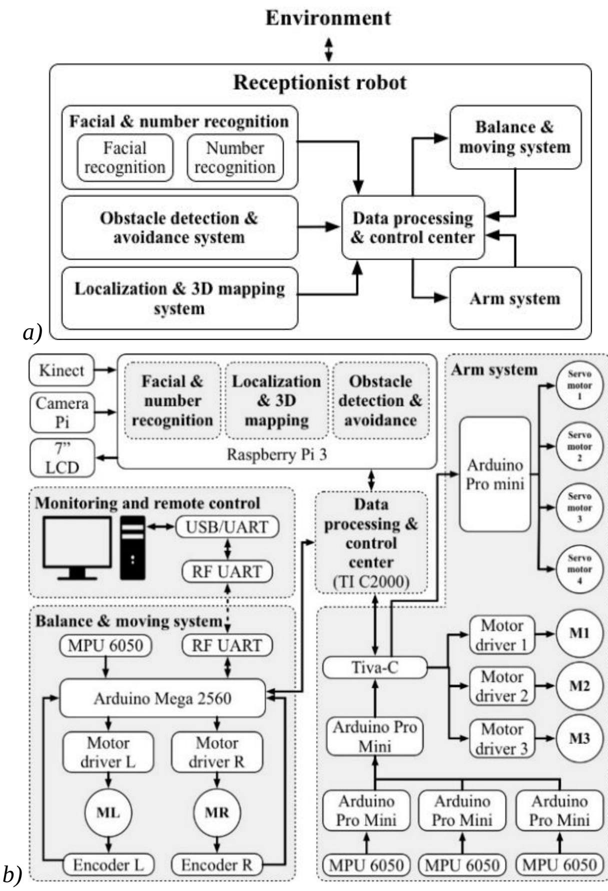


Figure 1. *Receptionist robot: (a) general structure and (b) hardware configuration*

3. Mechanical system design

3.1. Mechanical structure of the arm

One of the most important parts of receptionist robot is its arm. A high DOF robotic arm allows the robot to perform complex gestures similar to real human hands. In this work, the designed 4-DOF robot arm can perform gestures such as hand-waving, handshake, pressing a number button on elevator pad, holding the object. Figure 2 shows the kinematic diagrams of arm.The length of the links is chosen according to a real human body which are summarized by Table 1.

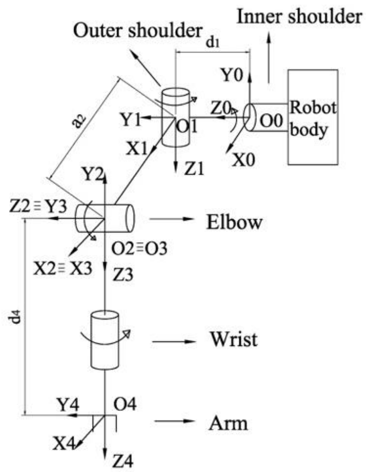


Figure 2. *Kinematic diagram of robot arm*

Table 1. *Dimension of arm links*

Symbol	Value [mm]	Description
d1	110	Distance from inner shoulder to outer shoulder
a2	240	Distance from outer shoulder to elbow
d3	190	Distance from elbow to wrist
d4	240	Distance from elbow to arm

The three-fingered hand has the same dimension as a real human hand that can hold simple shape objects and light-weight objects. Fingers are controlled using drawstrings actuated by servo motors as presented in Figure 3.

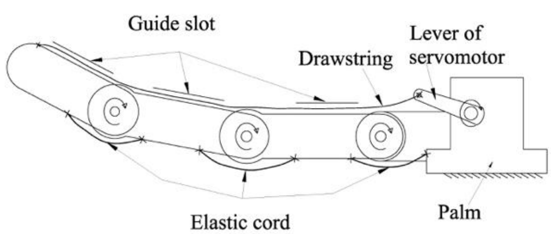
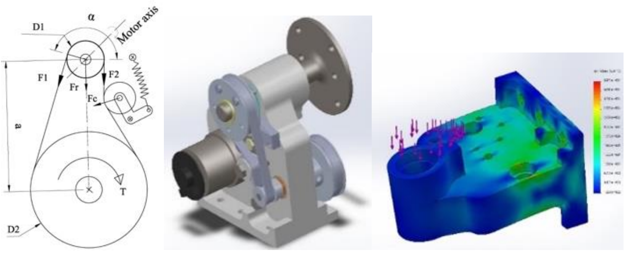


Figure 3. *Kinematic diagram ofrobot finger*

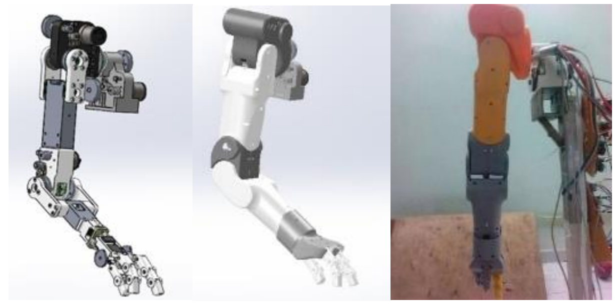


a) *(b)* *(c)*

Figure 4. *Shoulder joint: (a) timing belt (b) CAD model and (c) force analysis on a main part*

The working conditions (load, speed, working space), required mechanical strength of arm and its aesthetics are considered in design process. Indeed, parts are modeled and assembled in Solid Works. Parts' mass estimation in this software is then used to determine static load of joints. Combining this information with the dynamic load, one can compute the required torque for each joint. Relying on that, appropriate motors and transmissions can be chosen. Besides, important parts, which are subjected to heavy load, are examined by FEA (*Finite Element Analysis*) and DFM (*Design for Manufacturability*) toolsto guarantee manufacturability on CNC machine and 3D printer (see Figure 4).

ABS plastic and aluminum are used to build the robot arm and body due to their light-weight, mechanical properties, and easily manufactured capabilities. Figure 5 represents the CAD model and real model of robot arm.



(a) *(b)* *(c)*

Figure 5. *Robot arm: (a) CAD model without case, (b) CAD model with case and (c) real prototype*

3.2. Mechanical structure of the body

The robot body based on a two-wheel self-balancing structure which has small footprint can help robot to move flexibly in narrow area. Figure 6 represents the robot body kinematic diagram and frame. The body frame is built by iron plate and tube in order to achive the required rigidity. Two wheels of the robot are arranged coaxially and are controlled by two independent motors.

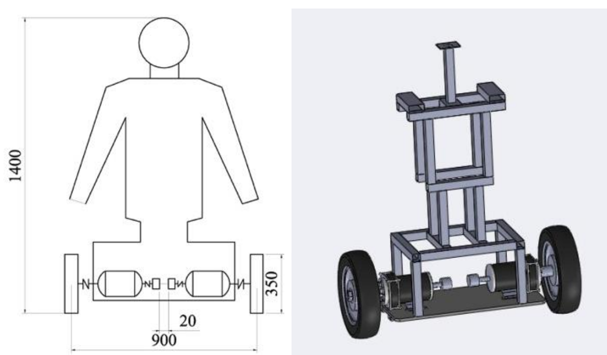
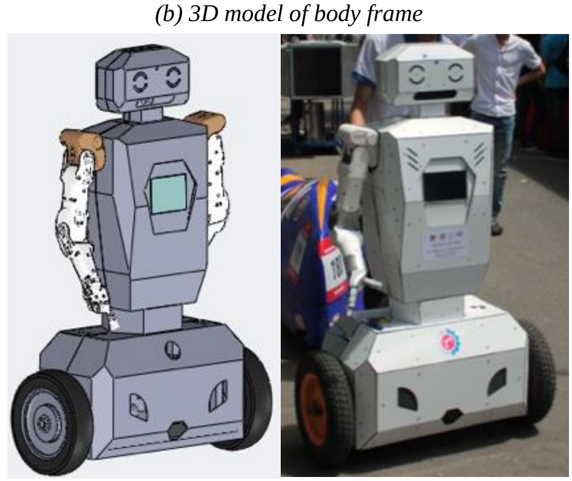


Figure 6. *Robot body: (a) kinematic diagram and (b) 3D model of body frame*



(a) *(b)*

Figure 7. *Receptionist robot: (a) CAD model of robot and (b) Real prototype*

The robot's body case is designed in assembly environment by top-down technology in order to increase the assembly accuracy between case components, and case with the internal frame. Figure 7 illustrates the CAD model and real prototype of the robot.

4. Control system design

4.1. Armcontrol system

The state of arm joints and fingers are monitored by MPU6050 sensors. This information is then transferred to a Tiva-C microprocessor. After processing data, the Tiva-C board send the appropriate command to control fingers and arm joints positions using servo motors system (as presented in Figure 1). Table 2 resumes Denavit - Hartenberg parameters of the arm obtained from the kinematic diagram where link 1, 2, 3 and 4 are the shoulders, biceps, elbows and hands, respectively. The parameters θ_i^* are joint variables.

Table 2. *Denavit-Hartenberg parameters*

Link	θ	α	a	d
1	θ_1^*	90^0	0	d_1
2	θ_2^*	-90^0	a_2	0
3	θ_3^*	90^0	0	0
4	θ_4^*	0^0	0	d_4

From Table 2, the kinematic equation of arm can be derived as follows:

$$\theta_3 = a \times tan\,2\left(S_3, \pm\sqrt{1 - S_3^2}\right) \quad (1)$$

where $S_3 = \frac{p_x^2+p_y^2+(p_z-d_1)^2-a_2^2-d_4^2}{2\times a_2\times d_4}$ and p_x, p_y, p_z are the position of hand.

$$\theta_2 = a \times tan\,2\left(S_2, \pm\sqrt{1 - S_2^2}\right) \quad (2)$$

Where $S_2 = \frac{p_z-d_1}{a_2+d_4\times sin\,\theta_3}$

$$\theta_1 = a\,tan\,2(p_x, -p_y) \pm a\,tan\,2\left(\sqrt{p_x^2 + p_y^2 - S_1^2}, S_1\right) \quad (3)$$

where $S_1 = d_4 \times cos\,\theta_3$.

4.2. Balance-moving control system

The state-spacemodel of two-wheeled self-balancing system can be described as Eq. 4 and Eq. 5.

$$\begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta}_p \\ \ddot{\theta}_p \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & \frac{2k_m k_e(M_p lr - I_p - M_p l^2)}{Rr^2 A} & \frac{M_p^2 g l^2}{A} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \frac{2k_m k_e(rB - M_p l)}{Rr^2 A} & \frac{M_p g l B}{A} & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \theta_p \\ \dot{\theta}_p \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{2k_m(I_p + M_p l^2 - M_p lr)}{RrA} \\ 0 \\ \frac{2k_m(M_p l - rB)}{RrA} \end{bmatrix} V_a \quad (4)$$

$$y = [0\ 0\ 1\ 0] \begin{bmatrix} x \\ \dot{x} \\ \theta_p \\ \dot{\theta}_p \end{bmatrix} \quad (5)$$

where $A = \left[I_p B + 2M_p l^2 \left(M_w + \frac{I_w}{r^2}\right)\right]$,

$$B = \left(2M_w + 2\frac{I_w}{r^2} + M_p\right)$$

and x and θ_p are horizontal position and tilt angle of robot, respectively; the voltage V_a of motor is the control input. The principal parameters of model are summarized in Table 3.

Table 3. *Two-wheeled self-balancing system parameters*

Symbol	Description	Unit
k_m	Torque constant	Nm/A
k_e	Back EMF constant	V s/rad
M_p	Mass of the robot's chassis.	kg
l	Distance between the centers of thewheel and the robot's center of gravity	m
r	Wheel radius	m
g	Gravitational acceleration	m/s2
R	Nominal terminal resistance	Ohms
I_p	Moment of inertia of the robot'schassis	kg.m2
I_w	Moment of inertia of the wheels	kg.m2
M_w	Mass of the wheel connected toboth sides of the robot	kg

The manipulation of the robot arm can change of robot center of mass, that causes some challenges for control process. In this work, system parameters estimation [4] and sensor-based control [5-6] techniques are applied to control the robot. In the balance-moving system, along with a MPU6050 sensor, two encoders are used to determine robot position [7]. To ensure the balance of the two-wheeled robot [8], its tilt, position and velocity [9] are controlled using PID control design [10].

In addition, the robot state is transferred to a PC via RF for condition monitoring and remote-control purpose [11] (see Figure 8 for software interface).

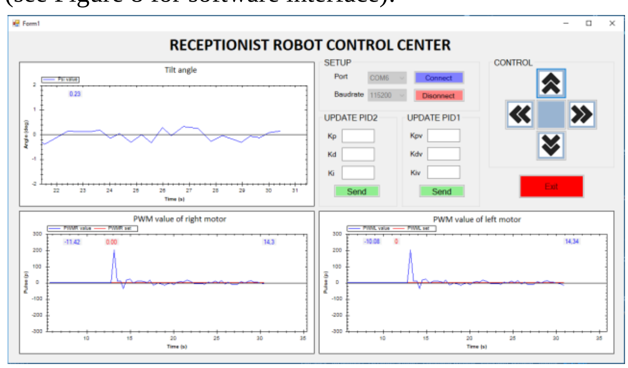
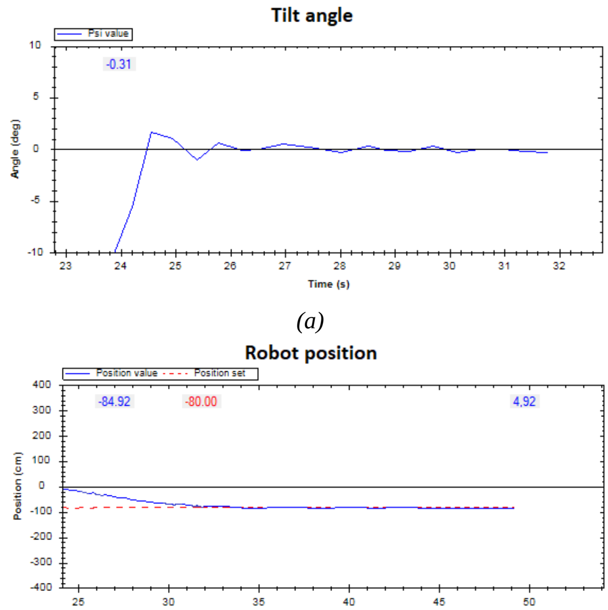


Figure 8. *Monitoring and remote control software interface*

5. Experiment results

The developed robot's height is 1.4 m and weight is 40kg. Figure 8 shows the robot tilt angle and its position when balancing, moving. One can find the the performance of control system with the short settling time and small steady-state error. As presented in Figure 9(a), settling time is less than 1 second when the robot sees a change of its tilt angle. Figure 9(b) shows that it takes a short time (about 2 seconds) for the robot to move 1 m.



(b)

Figure 9. *The response of system when robot is (a) in balance, (b) moving*

6. Conclusion

This paper has presented the current state of a receptionist robot developped for FPT Global Auto-motive. The aim of this work is to develop a low-cost, high flexible indoor robot. This paper briefly describes the development of mechanical structure and control system of the robot. The performance of stability and moving control system is illustrated through experiments.

Future work will focus on when performing complex gesture by using advanced control techniques such as LQR.

Acknowledgment

The authors would like to thank staff of the Danang FPT Complex and 9 students of this project for their support and participation in the development of the service robot. In particular to Pham Ngoc Thach, Nguyen Quang Ha, Bui Van Danh, Van Ba Tai, Nguyen Thi Kieu, Huynh Ngoc Quyen, Nguyen Viet Tuong, Pham Xuan Vinh and Pham Hoang Long for their contributions to this project.

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(The Board of Editors received the paper on 04/12/2018, its review was completed on 23/01/2019)