The 2009 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 11-15, 2009 St. Louis, USA

Self-balancing Control and Manipulation of a Glove Puppet Robot on a Two-wheel Mobile Platform

Jwu-Sheng Hu, *Member, IEEE,* Jyun-Ji Wang and Guan-Cyun Sun

***Abstract*—This video shows a continuing work of the glove puppet robot presented before [1]. The major improvement from the previous work is to mount the 9-DOF mechanism, which mimicking a glove puppet manipulation, on a two-wheel mobile platform. The platform provides agile movements of the robot but itself is an unstable system. Hence, a self-balancing controller is implemented by considering the motion as well as configuration variation of the upper body (the 9-DOF mechanism). The control law utilizes the principle of computed torque method with online identification of related parameters using various sensors including an accelerometer. The incline angle is obtained by fusing a gyroscope and a tilt sensor. Under the balancing control, the forward motion of the robot is achieved by giving a desired tilt angle profile. To minimize the footprint of electronics, the controller is implemented using an 8-bit single-chip microcontroller. Further, to enhance the interaction capability of the system, a simple gesture coding using dynamic time warping[2] identification method with Markov model is implemented for the data glove to recognize the puppet gesture by human hand.**

I. INTRODUCTION

A previous attempt was reported [1] to robotize the glove puppet art. In [1], a 9-DOF mechanism which mimicking the puppet movement was made along with a data glove that is able to manipulate the robot wirelessly. However, the robot is mounted on a stationary base which has limited manipulation.

This paper presents a continuing work to mobilize the puppet robot. The mobility is achieved by a two-wheel platform which provides an agile yet unstable motion without feedback control. Fig. 1 shows the photo of the robot and its kinematic model. From dynamic control viewpoint, this robot is an inverted pendulum with a variable pendulum configuration. To simplify the controller design effort, the upper body (the 9-DOF mechanism) is considered relatively rigid to the motion of the wheeled platform. This is possible because all joints in the upper body use gear motors which essentially reduce the dynamic forces when moving the wheels.

Jwu-Sheng Hu is currently a Professor in the Department of Electrical and Control Engineering, National Chiao Tung University, Hsinchu 300, Taiwan, ROC. (phone: 886-3-5712121 ext. 54318; e-mail: jshu@cn.nctu.edu.tw).
Jyun-Ji Wang is a Ph.D candidate in the Department of Electrical and Control Engineering, National Chiao Tung University, Taiwan, ROC. (e-mail: bboy.ece95g@nctu.edu.tw).
Guan-Cyun Sun is a Master in the Department of Electrical and Control Engineering, National Chiao Tung University, Taiwan, ROC. (e-mail: gcs.ece97g@nctu.edu.tw).

An adaptive computed torque method is implemented for the balancing control of the wheeled platform. To identify the related parameters, an accelerometer is mounted on the platform to remove the inertia effect in the dynamic equation of motion. To measure the tilt angle, it is found that the low-cost gyroscope sensor gives bias while the tilt sensor oscillates during fast angular variation. Therefore, a Kalman filter is implemented to fuse these two sensors for an unbiased and smooth measurement. It is shown that the control law can be implemented by an 8-bit microcontroller and effectively balance the robot with upper body manipulation. To enhance the interaction of the puppet robot, the signals of a data glove [1] is coded according to the puppet manipulation by hand. The glove measures 5 signals related to the movements of fingers. A database is established in advance to record meaningful dynamic gestures. Dynamic time warping method with Markov model is proposed to determine the closest gestures from the manipulation.

The robot is self-powered by a battery and can be controlled remotely through the Bluetooth wireless network. Various control scenarios are presented in the video to show the effectiveness of the proposed control methods.

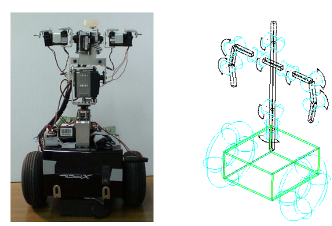

Fig. 1. X-puppet overview: (Left) the picture of the robot; (Right) the kinematic

II. THE HARDWARE PLATFORM

The robot has 11 DOF in total and use three types of servomotors (Fig. 1). The hardware schematic is shown in Fig.2. It consists of two parts: auto-balancing system and robot control system. The auto-balancing control board will update the state of robot and transit command to wheel driver to keep balancing, it also receives the data from robot control system and calculate the variation of the upper body. The robot control system consists of the master board, motor control board and power module. The master board receives the command from the computer or the data glove through the RS-232 protocol and then sends the encoded data to the motor control board through the I2C protocol.

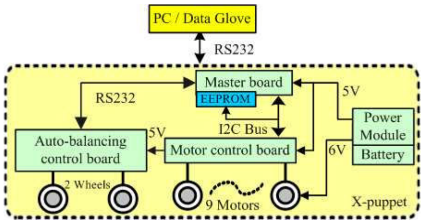

Fig. 2. The schematics of the control hardware

III. THE BALANCING CONTROL ALGORITHM

The robot has a two-wheel mobile platform with self-balanced control. To defend the torque from upper body, we implement the computed torque method rather than LQR control, because it's difficult to linearize the equation of system and then hard to design the controller.

Figure 3 shows the free body diagram of the robot without the upper body. The reaction force from the upper body is modeled by forces and moment as shown. The governing equation is,

$$\begin{aligned}&\left(I_1+m_1L_1^2\right)\ddot{\theta}-m_1L_1\cos\theta\ddot{x}-m_1gL_1\sin\theta\\&=-(L_1+L_2)\cos\theta F_{x_1}-(L_1+L_2)\sin\theta F_{y_1}+M_1\end{aligned}\quad(1)$$

and

$$\left(m_w+m_1\right)\ddot{x}+m_1L_1\dot{\theta}^2\sin\theta-m_1L_1\ddot{\theta}\cos\theta=F_f+F_{x_1}\quad(2)$$

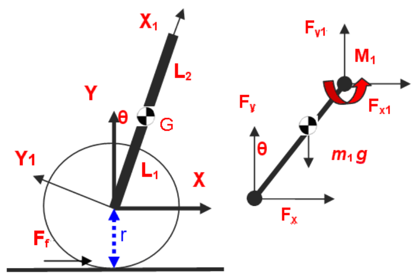

Fig. 3. The free body diagram of the robot

The control law is designed by parameterizing (1) and (2) as,

$$m_\theta\ddot{\theta}+\mathbf{a}_1{}^T\mathbf{b}=k_1F_f\quad(3)$$

where

$$\mathbf{a}_1=\left[\cos\theta\sin\theta\dot{\theta}^2\quad\cos\theta\quad\sin\theta\quad-1\right]^T$$

$$\mathbf{b}=\left[\frac{m_1^2L_1^2}{\left(m_w+m_1\right)}\quad\left((L_1+L_2)-\frac{m_1L_1}{\left(m_w+m_1\right)}\right)F_{x_1}\quad(L_1+L_2)F_{y_1}-m_1gL_1\quad M_1\right]^T$$

$$k_1=\frac{m_1L_1\cos\theta}{\left(m_w+m_1\right)}\text{ and }m_\theta=I_1+m_1L_1^2-\frac{m_1^2L_1^2\cos^2\theta}{\left(m_w+m_1\right)}$$

Let the wheel friction be proportional to the wheel velocity ($F_f=k_uu$). The computed torque control with feedback linearization gives the following control law,

$$\mathbf{a}_2{}^Th=u\quad(4)$$

where

$$\mathbf{a}_2=\left[\ddot{x}\quad\cos^2\theta\ddot{x}\quad\dot{\theta}^2\sin\theta\quad\cos\theta\sin\theta\quad\cos^2\theta\quad-\cos\theta\quad-1\right]^T$$

$$\mathbf{h}=\left[\frac{m_w+m_1}{k_u}\quad\frac{m_1^2L_1^2}{\left(I_1+m_1L_1^2\right)k_u}\quad\frac{m_1L_1}{k_u}\quad\frac{m_1L_1}{\left(I_1+m_1L_1^2\right)k_u}\left((L_1+L_2)F_{y_1}-m_1L_1g\right)\quad\frac{(L_1+L_2)m_1L_1F_{x_1}}{\left(I_1+m_1L_1^2\right)k_u}\quad\frac{m_1L_1M_1}{\left(I_1+m_1L_1^2\right)k_u}\quad\frac{F_{x_1}}{k_u}\right]^T$$

It can be shown the parameters in b can be represented by the parameter in the vector h. Hence, (4) can be used as the parameter identification equation and the control law can be designed from (3) as,

$$u=\frac{1}{k_1}\left(\frac{m_\theta}{k_u}\ddot{\theta}_d+\frac{1}{k_u}\mathbf{a}_1{}^T\mathbf{b}-\frac{m_\theta}{k_u}k_d(\dot{\theta}-\dot{\theta}_d)-\frac{m_\theta}{k_u}k_p(\theta-\theta_d)\right)\quad(5)$$

The resulting error dynamic is,

$$m_\theta\left(\ddot{e}+k_d\dot{e}+k_pe\right)=0\,,$$

where $e=\theta-\theta_d$ is the error signal and θ_d is the desired angle command. Under the balancing control law, the forward motion of the robot can be achieved by designing the desired angle command.

IV. DYNAMIC GESTURE RECOGNITION

Fig. 4 shows the schematic of the data glove made by the authors. The signals from the piezoelectric sensors are used to recognize the gesture of the hand when performing glove puppet manipulation.

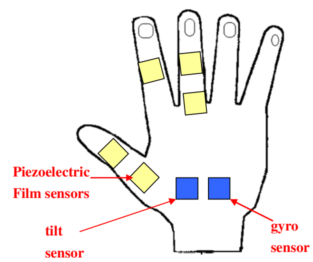

Fig. 4. The data glove and its sensor locations

Each sensor is measured by 8 bits AD converter. The measurement sequences are then recorded to establish a database of meaningful glove puppet gestures. The dynamic time warping [2] is used to compute the similarity of the measured sequences and the database. The Markov model is applied to identify a sequential motion the user play, and each state represents a gesture model. From the recognized gesture, the robot is able to react with related motion as if the human and robot are playing a scenario together.

V. CONCLUSION

A continue work of the glove puppet robot is reported in this video paper. The robot has a two-wheel mobile platform with self-balanced control. Various motion and control system performance are shown to demonstrate the research effort.

REFERENCES

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