International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:5, No:10, 2011

Development of a Low Cost Haptic Knob

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***Abstract*—**Haptics has been used extensively in many applications especially in human machine interaction and virtual reality systems. Haptic technology allows user to perceive virtual reality as in real world. However, commercially available haptic devices are expensive and may not be suitable for educational purpose. This paper describes the design and development of a low cost haptic knob, with only one degree of freedom, for use in rehabilitation or training hand pronation and supination. End-effectors can be changed to suit different applications or variation in hand sizes and hand orientation.

***Keywords*—**haptic, microcontroller, real time, virtual reality, rehabilitation

I. Introduction

HAPTIC technology has found its way into many different applications, in particular, virtual reality simulation, surgery, education and training, rehabilitation, exploration of environments, manufacturing and design. In virtual reality applications, haptic enables a user to feel the texture and interaction with their surroundings to generate a more realistic environment. With additional sense of touch, educators find it easier to teach abstract scientific theories to students due to the combination of multiple modalities to represent information [1]. In the medical field, haptics is being explored to improve skill acquisition [2] and actual surgical performance based on realistic haptic feedback of tissue movement and interaction of tools [3]. Rehabilitation robots used the haptic sensation extensively for enabling more efficient and effective training. For example, Gentle/S [4] uses Haptic Master to provide the haptic feedback during arm training. Tele-haptics allows safe exploration of a hazardous or remote environment, even remote surgery, providing tactile feedback over a network [3,5].

Haptic devices are the mechanical interfaces that relate tactile information between human and computer [6]. Haptic devices permit input-output communication, where a user's physical movement is tracked (input) and then a realistic tactile feedback is provided, coordinated with on-screen changes (output). Haptic devices currently available in the market include basic consumer peripherals equipped with motors and sensors, such as joysticks and steering wheel with force feedback. The PHANTOM devices [7] are highly sophisticated haptic devices commonly acquired for medical and scientific research, product design, computer-based sculpturing and gaming. The Haptic Master [4] has been widely used as a robotic rehabilitation device for the upper limb. Research-based haptic products are generally very costly, and may not be easily modified to cater for various applications.

This paper will describe the design and development of a low cost haptic knob as shown in Figure 1. The haptic knob will be used in the training of hand pronation / supination, as part of physiotheraphy exercises for stroke patients. The knob can be replaced with other forms of end effectors, using a coupling to suit different training objectives.

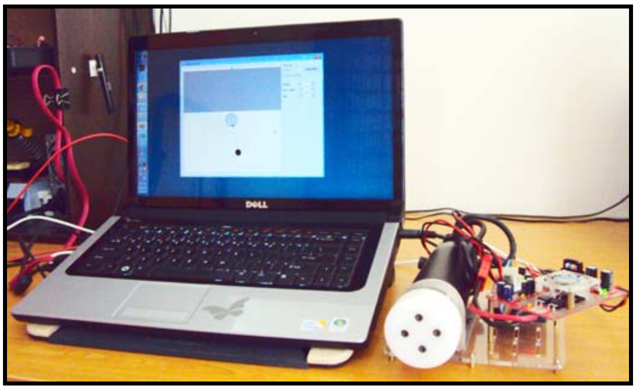

Fig. 1 Low cost Haptic Knob

II. System Design

A. Hardware

This project aims to develop a simple haptic device for training hand pronation and supination. Luvidoc has developed a haptic knob currently being used for hand rehabilitation [8]. Yeong has developed ReachMAN for upper limb rehabilitation, that also uses 1 DOF to train hand pronation and supination [9]. Both systems used the Maxon RE40 motor with gear reduction to create haptic capability. This project will adopt similar design concept utilizing a single motor as actuator, but without gear reduction. A different motor will be selected to reduce cost.

The required torque generated from the motor is about 1.5Nm with 500rpm. The motor should have the capability to record the position, has low inertia and small in size. Figure 2 shows the CAD drawing of the proposed design. A DC motor equipped with encoder is used and attached firmly to a base. Motor driver, controller and other components are attached to the same base allowing small size design and portability.

Different handles or knob can be interchanged easily by using a custom-made coupling attached to the DC motor.

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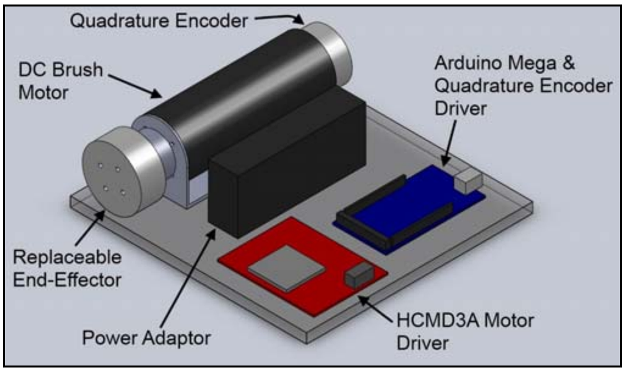

Fig. 2 CAD Drawing

B. Control

Most of the existing robots use a computer with Labview RT or Matlab RT for real time processing, which incur higher cost. This project proposes the use of a low cost solution with a microcontroller as the main controller, without jeopardizing the real time control. Microcontroller will function as the main controller to process the motor control commands for real time applications and the GUI running from a separate laptop computer (PC) will be the display for virtual reality output and environment setup input.

III. Implementation

A. Hardware

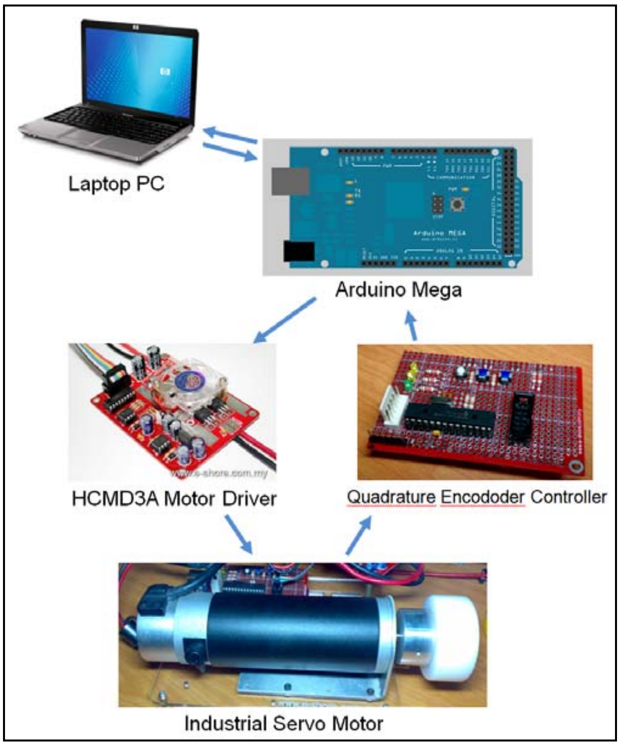

Fig. 3 System overview

Figure 3 shows the system overview. Arduino Mega is the main controller for the system, which communicates with PC for the GUI virtual environment output and also environment setup input (*Weight, StickLength and WallThickness*). For motor control, Arduino Mega interfaces with a high current motor driver (HCMD3A) for the motor PWM and direction control, while the Quadrature Encoder Controller is used for the motor position sensing.

1) Industrial Servo Motor

The motor chosen for the haptic knob is a DC brush motor without gear reduction, which is used as industrial servo motor. The reason for using DC brush motor without gear reduction is to minimize friction caused by the gear head and thus maximizing the virtual reality tactile sensation felt by a user. This industrial servo motor comes with a built-in quadrature encoder system for position sensing.

2) Arduino Mega

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [10]. The USB connection creates a virtual COM Port on the PC for UART communication link between Arduino Mega and PC.

3) Laptop PC

Function of Laptop PC in the system is to run the GUI for virtual reality output and environment setup input for the Haptic Knob. The updating of the display is run from the PC to separate it from motor commands processing at the microcontroller, to ensure faster response rate of the motor for real time haptic applications. Display rate is being set to lower frequency, at about 50Hz because human sensorial capabilities impose much lower refresh rate for visual feedback than for haptic feedback.

4) HCMD3A Motor Driver

HCMD3A is a high current DC brushed motor driver that supports up to 40A peak current [11]. This enables Arduino Mega to directly control the motor using a simple 3-pin interface: Direction, PWM and Enable.

5) Encoder

The built-in encoder support Quadrature Encoder Output that allows up to 4000 step per revolution for precise position sensing of the motor movement in both directions.

6) Quadrature Encoder Controller

To efficiently read the position of the motor, a Quadrature Encoder Controller has been designed using a microcontroller (PIC18F2431) for the signal processing from the Quadrature Encoder. The reason of using a separate controller for the Quadrature Encoder signal processing is to reduce the processing burden on Arduino Mega.

B. Control

The Motor Control for the Haptic system is based on the equation listed below:

$$MotorControl = WallControl + WeightControl \quad ...(1)$$

$$WallControl(t) = \begin{cases} K_P e(t) + K_D \frac{d}{dt} e(t), wall\_collision \\ 0, wall\_collision\_not\_happen \end{cases} \quad ...(2)$$

$$WeightControl = Weight \times StickLength \times \sin(\theta) \quad ...(3)$$

All variables to control the Haptic Knob e.g. *Weight*, *StickLength*, and *WallThickness* are configurable using the Haptic System GUI and will be transferred from the GUI to Arduino Mega for the motor control processing. The equation will be processed by Arduino Mega every 2ms under interrupt powered routine for stable processing result, and the output of the *MotorControl* value will be fed to the Motor PWM.

1) Communication Between Laptop PC and Arduino Mega

Arduino Mega communicates with the PC by sending and receiving standardized data packet through UART. The basic data packet consists of Start Bytes, ID, Length, Data(s) and Checksum.

Start Bytes	**ID**	**Length**	**Data(s)**	**Checksum**
Two 0xFF as the start byte	ID for the receipient	Length of the Data(s) + Checksum	Data(s)	1 Checksum byte for the verification

a) Start Bytes

The two 0xFF bytes indicated the start of an incoming packet.

b) ID

The unique ID of the receipient allows the Arduino Mega to communicate with more than one receipient.

c) Length

The length of the packet where the value is number of data(s) plus one for the Checksum Byte.

d) Data(s)

The data array consists of the information needed to be sent to the receipient.

e) Checksum

The computation for the checksum is as following:
Checksum = ~ (ID + Length + Data1 + Data1 + … DataN)
(if calculated value is larger than 255, the lower byte is defined as the checksum value).
(~ represents the bitwise NOT operation)

Data packet sent from Arduino Mega to PC consist of the Encoder reading and the Motor PWM output, to be displayed on the Haptic System GUI. Conversely, data packet from PC to Arduino Mega consist of all the environment setup variables including *WallThickness*, *StickLength* and *Weight* for the motor control processing.

IV. Results

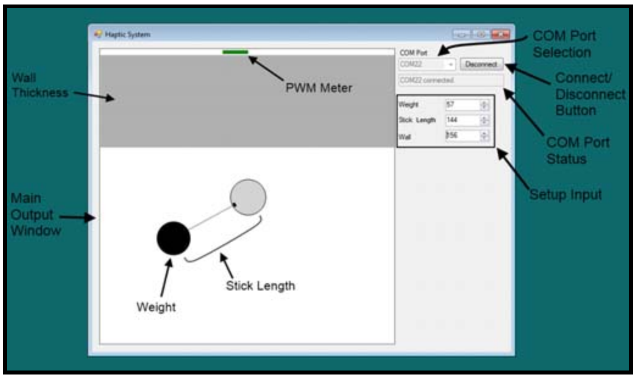

Fig. 4 Haptic System GUI

Figure 4 shows the GUI of the Haptic System. Currently, the Haptic System supports three setup variables which are *Weight, StickLength* and *WallThickness*. The motor control processing by Arduino Mega will change the response of the knob according to these given setup variable.

The motorized knob provides haptic feedback to user. For example, if collision happens between the wall and the weight, user will feel that the knob is being blocked or stopped as if there is a real wall preventing the weight from moving further to the collision side. A higher value for *Weight* or *StickLength* gives a heavier feeling to the knob, as if a heavier weight has been tied to the knob and user will have the feeling of lifting this heavier weight attached to the knob.

This design has been able to provide realistic haptic sensation although more systematic and thorough experiments are required to quantify the quality of the haptic feedback, and to vary the haptic sensation provided by the system.

V. Conclusion

This paper described the design and development of a low cost haptic knob. The design of this haptic knob is similar to several other available designs, except that the controller used in our system is a microcontroller but still able to provide real time control at 250Hz, sufficient to generate realistic haptic feedback. This reduces the cost and size compared to other conventional haptic devices that depend on a desktop computer to run real time processing. However, the drawback of this system is that programming the microcontroller is slightly more inconvenient compared to programming using high level language program on a desktop computer.

ACKNOWLEDGMENT

This project is funded by the Universiti Teknologi Malaysia Research grant 03J64.

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