Haptic Device
For Human Virtual Environments

- period of practical training -

presented by

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1 ABSTRACT

The paper aims to present a human hand haptic device for virtual environment. The nature of the sensations expected from a hand haptic device is significantly complex since the diversity of the tasks performed from the human hand is great. This complexity ought to be challenged by any haptic system that aims to succeed in a generic virtual reality application. The diversity of the tasks performed by the human hand can lead to a complex mechanical design if many aspects of the human touch are to be simulated. Therefore the most important part of the development of such a system is the mechanical design approach.

2 INTRODUCTION

The hand is an organ of grasp as well as fine movements. It is an organ of sensation, fine discrimination and exquisite dexterity. In medical sectors the hands are very important for a doctor to get a good overview about the physical situation for his or her patients. In these area there still a lack of medical specialists. Everyday we have a lot of different health problems where we need the correct specialist to help the patient. Now, the vision is that specialist can treat patients through a simulation on his desk or current space with Virtual Reality or other VR[1] simulations. Within a VR environment the ability to translate the sensations associated with the hand into realistic user data forms. A vital component that moves any interaction from the purely observational to the physically intractable. Issues of particular importance within any hand level haptic interface relate to: (1) the sensory quality that can be provided to the operator, in terms of the kinaesthetic data, and (2) the portability of the system that must not hamper user movement or dexterity. The characteristics of the human hand motion and particularly the features of dexterity and flexibility have led to the development of a number of whole-hand input devices for the control of tasks in virtual environments. For the tracking of hand motions a number of different sensor technologies have been developed including fibre optics, magnetic, or electrical resistance based sensors. In most of the cases the data gloves sense motions of 4 or 5 fingers (the little finger sometimes is excluded). In this work the hand interfaces uses two different sensor systems, resistance based sensors and the digital magnetic resonance encoder signal from the motors. To simulate the surface from skin, muscles, bones or other part of the human body, Motors are used to restrict of the fingers on the simulated surface.

[1] Abbreviation for Vitual Reality

3 MECHANICAL PARTS

3.1 Hand Exoskeleton

The structure resides on the dorsal side of the hand and the forces are applied from that direction. The feedback forces are generated by dc motors and are transmitted to the joints by two pulleys with a transmission ratio of 3:1. The glove provides force feedback to the proximal and distal joints of the index, middle and ring fingers and to proximal joint of the thumb. The Motors are having a diameter of 13mm and a power rating of 2.5 Watt. If one finger in movement then this movement is registered by a resistance based sensor and additionally the positions data are registered by encoders in the motor and analyst by the microcontroller. If one finger on his simulated and calculated position, the motor will stop the movement and the person feels and thinks that it is a genuine surface.

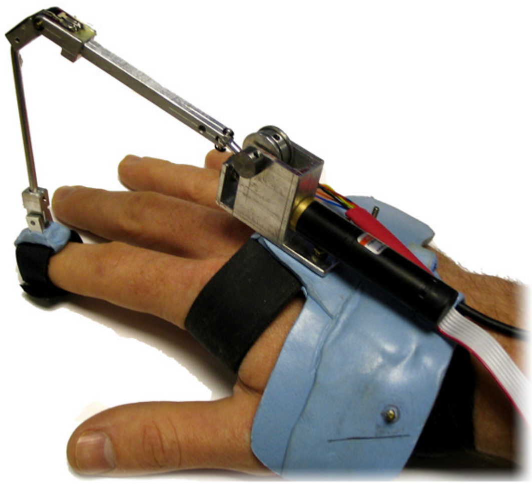

Figure 3.1: Photograph of the hand with one basic finger module

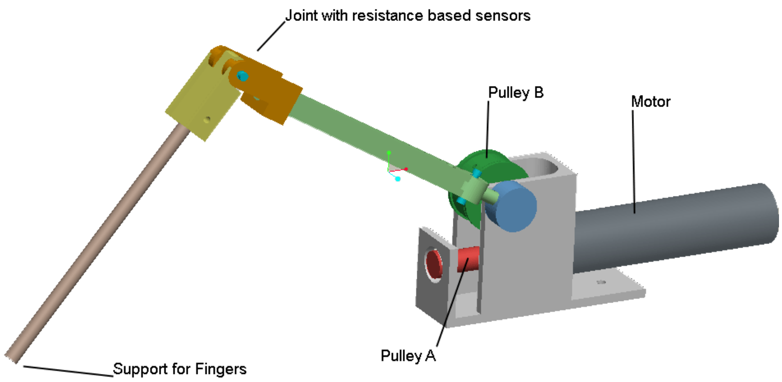

Figure 3.2: Mechanical part for one finger

3.2 Force Transmission

Force feedback of glove is provided by using four dc motors. Forces are generated by the motors which are transmitting to the fingers segments with using a cable transmission system. Figure 3.3 shows the tying cable which guarantees the transference of the force from the motors to fingers and from the fingers to the motors with conjointly directions. The cable is fasten on the motor side (1) on pulley A with a screw. And the cable is wound around the pulley B and threaded through a hole where the cable inside with a screw fasten it. On the other end of the pulley A (2) is the cable fasten with a screw where it is possible to tight.

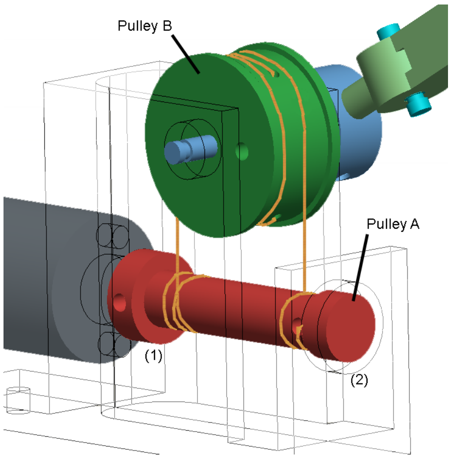

Figure 3.3: Tying cable

4 ELECTRONIC

4.1 System Hardware Diagram

The Core of the System, Figure 4.1 is formed as three modules: the glove based modules with four Motors, the main control unit with an ATMEL Microcontroller ATmega128L and the Bluetooth Dongle which is connected with the computer. The Computer sends the surface position data through the Blue Base to the controller unit. The ATMEL Controller rules the Motor torque controll which computes the signals and send the to the digital-analogue converter. These analog data form the input of the power drivers for the motors. The resistance sensors are connected with the microcontroller over a 16-Channel Multiplexer and the motor position rectangle signals over a voltage divider. Additionally it is possible to connect the controller board with the PC over a serial cable which is connected through a MAX232 level converter.

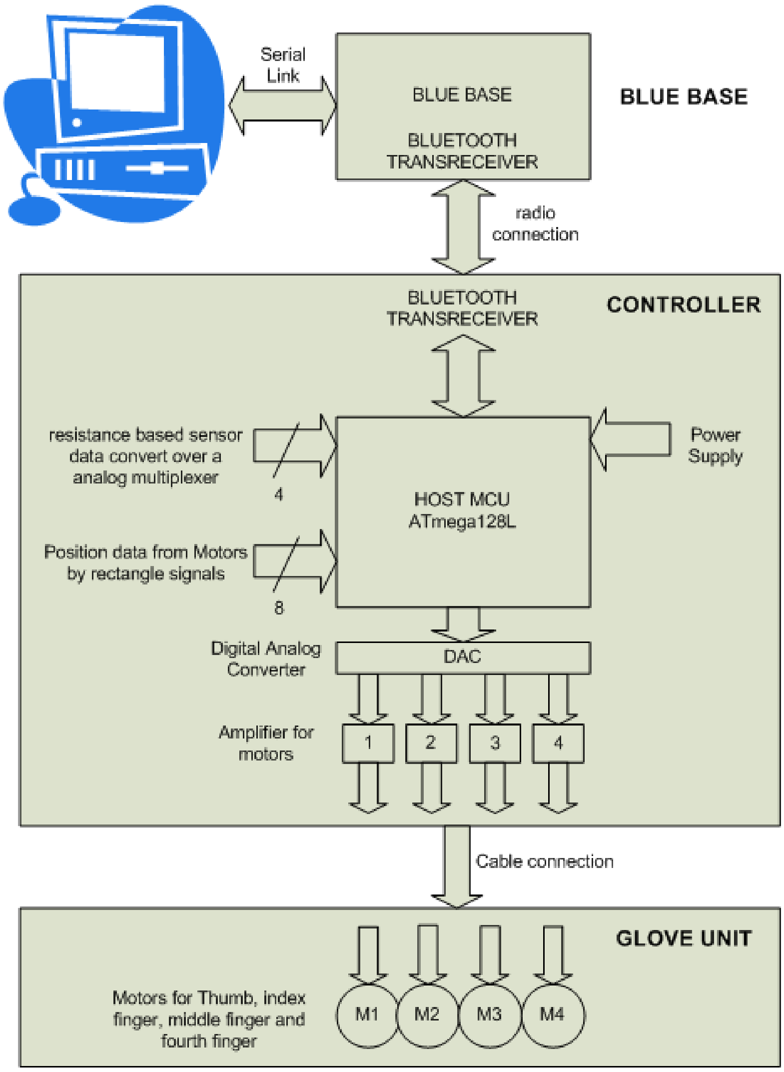

Figure 4.1: System Hardware Diagram

4.2 Electronic Device

The electronic unit exist on a double-side SMD-Board. A red LED shows the programming mode for the ATMEL Controller. If a connection between the PC and the controller unit is established then it will show a blue LED. The 5V power supply is transformed by a Voltage Regulator to 3.3V for the microcontroller and the Bluetooth unit. The motors require for forward and backward movement a power supply of +5V and -5V. Figure 4.2 shows the finished SMD-Board unit with all components.

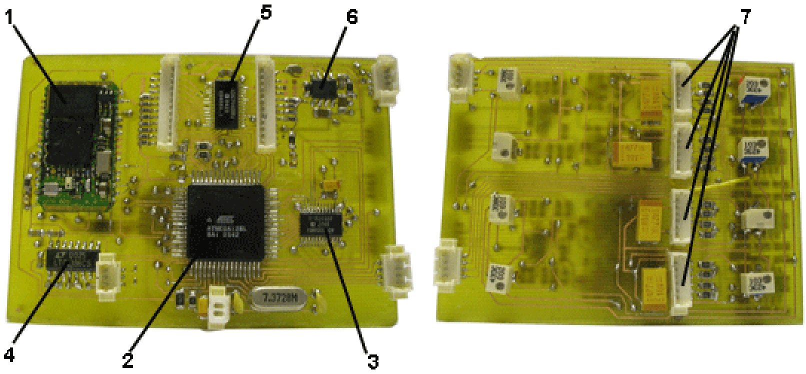

Figure 4.2: Two Double-side SMD-Boards

1 . . . *Bluetooth Module*
2 . . . *ATMEL Microcontroller ATmega*128*L*
3 . . . *Digital – Analog Converter*
4 . . . *MAX*232 *lever converter*
5 . . . 16 – *Channel Multiplexer*
6 . . . 3.3 *Voltage Regulator*
7 . . . *Connectorsfor motors with amplifiers on bottom side*

5 SOFTWARE PARTS

5.1 Software Module

Figure 5.1 shows the general state diagram software running of the Atmel Microcontroller unit.

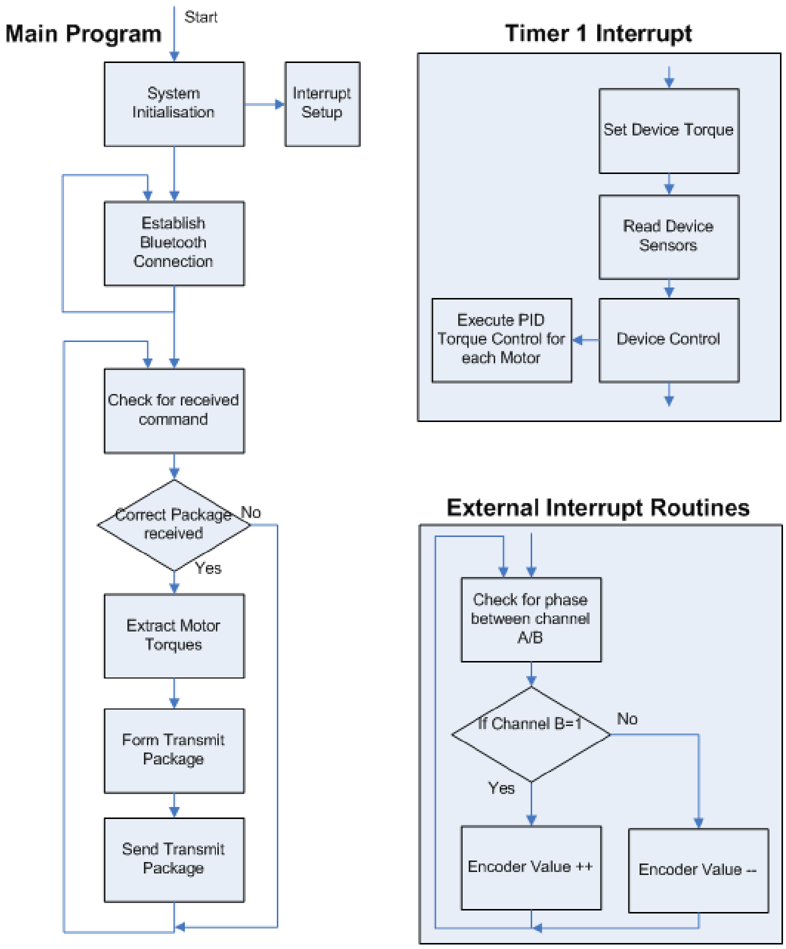

Figure 5.1: Flow chart for ATMEL microcontroller software

First the system initialisation starts with setting timer interrupts, setting direction register, setting analogue-digital converter interrupt and external sensor interrupts. After that the device is trying to establish a connection with the host PC. Having established a connection with the host PC commands can be sent to the device using the following format:

$$[FF][7F\ 7F\ 7F\ 7F][00][00][FE]$$

In the above format FF is the start byte, the next four entry's are torque data for the motors. 7F means zero torque and the range is from 00 to FF. The next two zero bytes are additionally zero for future work and they are currently not used. FE is the end byte. Subsequently the program checks if the data package is correct. If this is no true the program will check until a correct package is detected. The data then is extracted and converted into appropriate torque reference signals for the Motor torque controller.

The reply of the device to the detection of a correct data packet is to send the sensor data packet to the host PC. This packet has the following format:

$$[FF][s_1s_2s_3s_4][m_{11}m_{12}m_{21}m_{22}m_{31}m_{32}m_{41}m_{42}][00][00][00][00][00][00][FE]$$

FF which is again the start byte, followed by four byte (s_{1-4}). These are the resistor based sensor data for every finger. After that there are eight bytes which included the position data from the motors (m_{11-42}). Two variables build one 16 bit data for one motor encoder value. The following two triple zeros byte are unoccupied. And again the end byte FE. These data of sensors are then sent to the PC while the PC program will compute a new package for the motor torque data.

The main program includes five interrupt routines. The first one is Timer1 interrupt routine, which set the control bandwidth of the device to 500Hz read the device sensors and execute the PID torque control for each motor. The other four interrupts are to check the phases between Channel A and B of the four Motor encoders.

With the test program Doglight™ it is possible to send the transmitted data (TX) over the Bluetooth connection to the Board and it is possible to see the received data (RX) on the screen. The following codes demonstrate this test.

```
...
[TX] - FF 7F 7F 7F 7F 00 00 FE
[RX] - FF 65 07 0A 07 BD 3E BE 2C AC D0 51 27 00 00 00 00 00 00 FE
[TX] - FF CF CF CF CF 00 00 FE
[RX] - FF 65 07 0A 07 51 27 53 9E 4C DF A4 96 00 00 00 00 00 00 FE
[TX] - FF 7F 7F 7F 7F 00 00 FE
[RX] - FF 64 07 0A 07 CD 55 D2 D2 D8 9F 64 07 00 00 00 00 00 00 FE
[TX] - FF 7F 7F 7F 7F 00 00 FE
[RX] - FF 65 07 0A 07 A4 96 A0 00 98 03 BD 3E 00 00 00 00 00 00 FE
...
```

5.2 System Control

The control processor is responsible for the data acquisition of the input sensor signals and the computation of the output motor data of the hand exoskeleton unit and for the execution of the control scheme that enables accurate rendering of the simulated grasping forces generated during the virtual object manipulation. The main software running on the dedicated PC can be divided into two main modules (Figure 5.2).

The first ”Grasping Force regulator” module is responsible for the control of the torque for each of the four motor transmission systems and uses a classic PID[2] controller. The reference to the Grasping force regulator module comes from the ”Force Analysis” module. This module is responsible for two tasks. The first task is to generate the required reference torque from the simulated grasping force, coming form the virtual environment simulation. The second task is the signal processing and calibration of the finger joint angles. Joint angle data are exchanged with the virtual simulation through this module.

[2]PID-Regulator are PD-Regulator and I-Regulator which connected in parallel

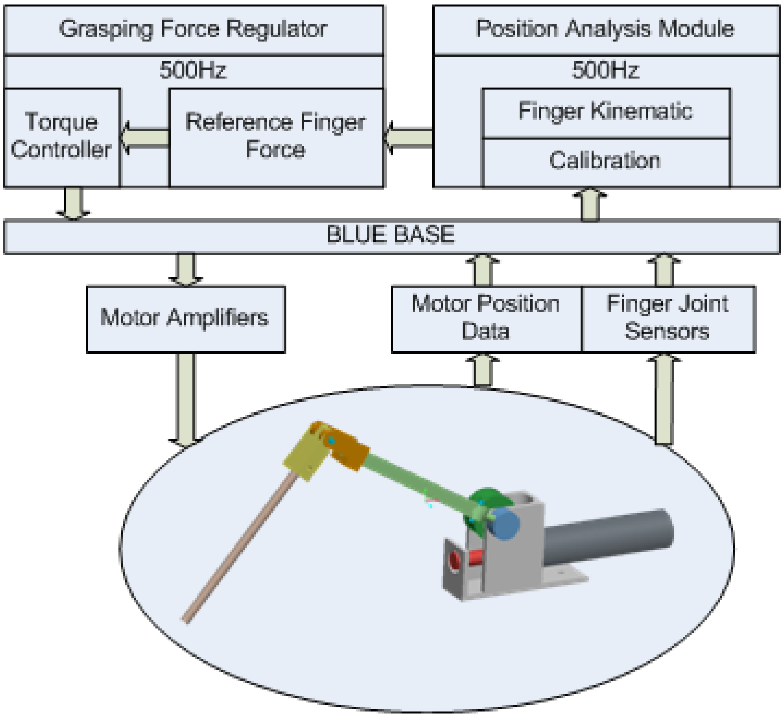

Figure 5.2: PC Program Hand Control

5.3 Finger Feedback Analysis

Figure 5.4 shows the Simulink model from one of four amplifiers from Figure 4.1 on page 7. The closed-loop system get his command variable from the reshaping of the input force from the fingers mechanical system. In Figure 5.3 on page 12 are shown the forces F_{1x}, F_{1y} and the resulted force F_1 for the finger movement. The command variable for the Simulink model are build as the following equation.

$$T_{ref} = J^T \cdot F_1 \Leftrightarrow \begin{bmatrix} T_{M1} \\ T_{M2} \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{12} & J_{22} \end{bmatrix} \cdot \begin{bmatrix} F_{1x} \\ F_{1y} \end{bmatrix} \quad (5.1)$$

$$J \ldots exert\ work\ transpose$$
$$J^T \ldots Jacobian\ of\ the\ finger$$
$$F_1 \ldots Force\ on\ the\ Finger\ tip$$

Figure 5.3 shows the derivation of these forces. A PID-Regulator forms the $G_R(s)$ of this system. $G_S(s)$is formed by the amplifier and the motor. The refeeding of the system (E) result as the position data from the motors. The dependent variable (Y) from the system are the torque of the motors and there'from the current position from the mechanical parts.

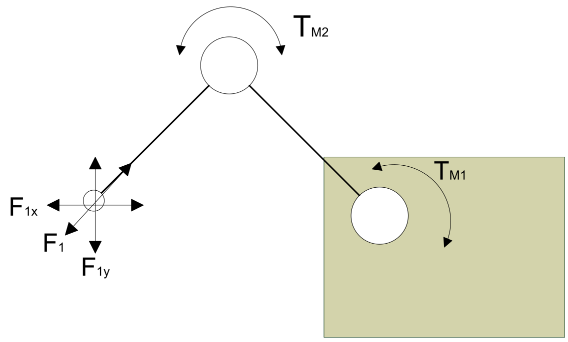

Figure 5.3: Model of the finger system for the kinematics

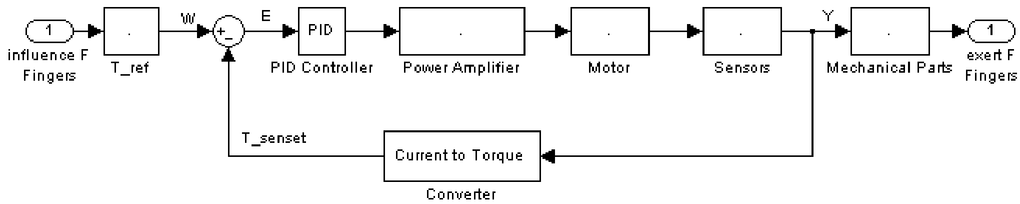

Figure 5.4: Simulink Model of Motor Control