DEVELOPMENT OF AN UPPER LIMB ORTHOTIC EXERCISE SYSTEM

Alan Yardley[1] Gianluca Parrini[2] David Carus[1] and John Thorpe[1]

[1] University of Abertay Dundee, UK
[2] Scienzia Machinale s.r.l., Pisa, Italy

Abstract

A motorised upper limb orthotic system has been developed which can provide a facility for joint exercise. The control system has four modes; two for user exercise (percentage resist and percentage assist) and two for profile acquisition (resistive torque and assistive torque tests). The system is described with reference to the elbow joint.

Introduction

The development of a Motorised Upper Limb Orthotic System (MULOS) is a project funded by the Technology Initiative for Disabled and Elderly (TIDE) programme of the Commission of European Communities. The final system will be used in any one of three roles; assistive (to compensate for loss of muscle action), exercise (for active movement to improve muscle tone) and continuous passive motion (for prevention of joint contractures and reduction of oedema).

Current exercise systems are generally of the large gymnasium type for strong, able-bodied people. It was felt that there is a need for a lightweight, low-torque device for disabled and elderly people. Such devices have been suggested for stroke patient rehabilitation [1, 2] though they have not progressed beyond the research project stage. The MULOS system has been designed to provide single joint limb exercise and this paper describes the development of the control system for the exercise mode, with particular reference to the elbow joint.

Description of the Elbow Joint Mechanism

The elbow joint mechanism has been designed as a one degree of freedom joint; pronation & supination are provided by a separate powered unit positioned at the wrist. The specification requires a maximum output torque of 7 Nm, maximum speed of 9.5 rpm and an integral slip clutch between the motor and the elbow drive for safety reasons. The joint consists of a gearbox which contains spiral bevel gears, as they offer smoother, less noisy operation and can transmit slightly higher torques than straight-sided bevel gears. A potentiometer for position control is located in line with the lower arm section of the orthosis. The arrangement is illustrated in figure 1.

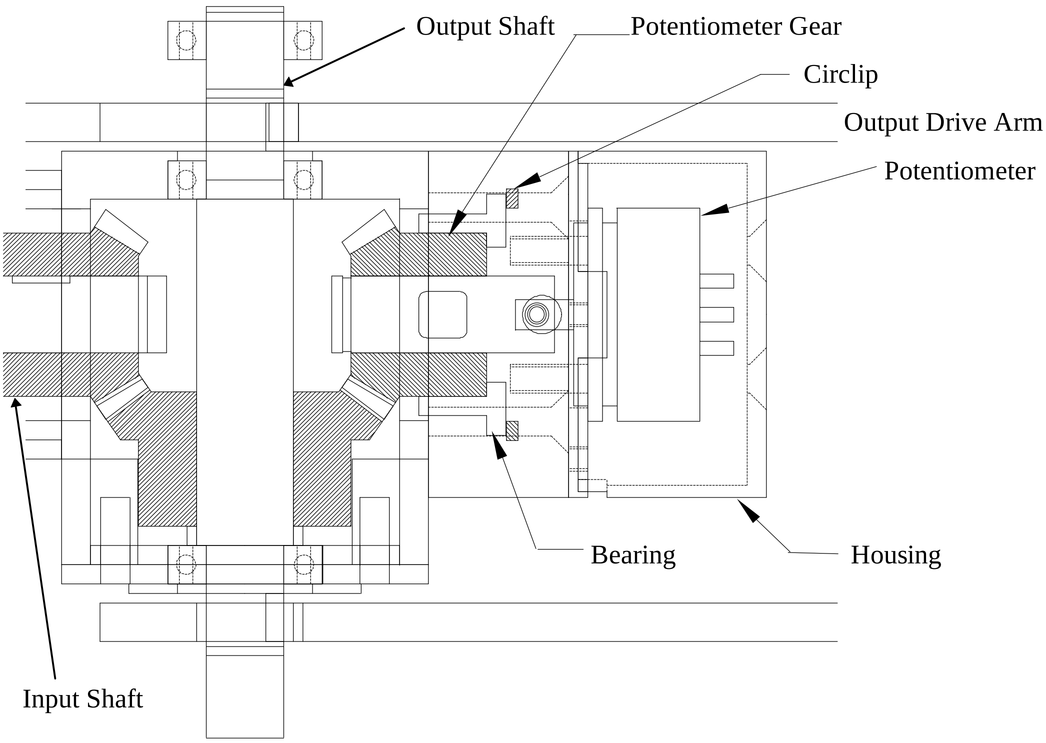

figure 1

The elbow orthosis comprises an upper arm and a lower drive arm fixed to a thermoplastic hinged interface. The lower, or output, drive arm is driven by the output shaft from the gearbox; the upper arm of the orthosis which carries the motor and gearbox assembly is, in turn, connected to a shoulder drive unit.

Overstroke microswitches are located on either side of the output drive arm and they are operated by adjustable mechanical stops which are provided for safety reasons.

Control System

The control system is based on that developed by Scienzia Machinale s.r.l., Pisa, and is outlined in figure 2. The joint is moved by a dc servomotor which has a linear torque/current relationship so the joint torque can be controlled by the motor current. The amplifier is an Elmo Small Servo Amplifier (SSA 12155) and this is used in current mode, ie the motor current is proportional to the amplifier input. The control system is completed by an MEI DSP/PC Axis Control board and a pentium PC. These will be replaced by PC-104 boards in the final MULOS system.

Control Strategies

The control strategies of the system are based on the principle of recording a torque & position profile for the joint, then outputting a torque value corresponding to the current joint position. The four modes are described below;

1 Percentage Resist Exercise Mode

In this, current is output in such a direction as to oppose movement of the joint. The resistive level is selected by the user/therapist and represents a percentage of the level recorded in the profile. This is intended to be the main operational mode, because exercising at less than maximum power is considered to be of greatest benefit to elderly and disabled users.

2 Percentage Assist Exercise Mode

Current is output in such a direction as to aid movement of the joint. Again, the assistive level is selected by the user/therapist and it represents a percentage of the level needed to move the joint.

3 Resistive Torque - Profile Acquisition

The joint is moved automatically to the first range of motion point. The user then tries to move the joint to the second range of motion point. The resistive torque is increased until the joint stops and the torque & position are recorded. The torque is reduced until the joint moves, then it is kept at a constant level until the joint has moved by a pre-set increment. This cycle is repeated until the end of the range of motion is reached.

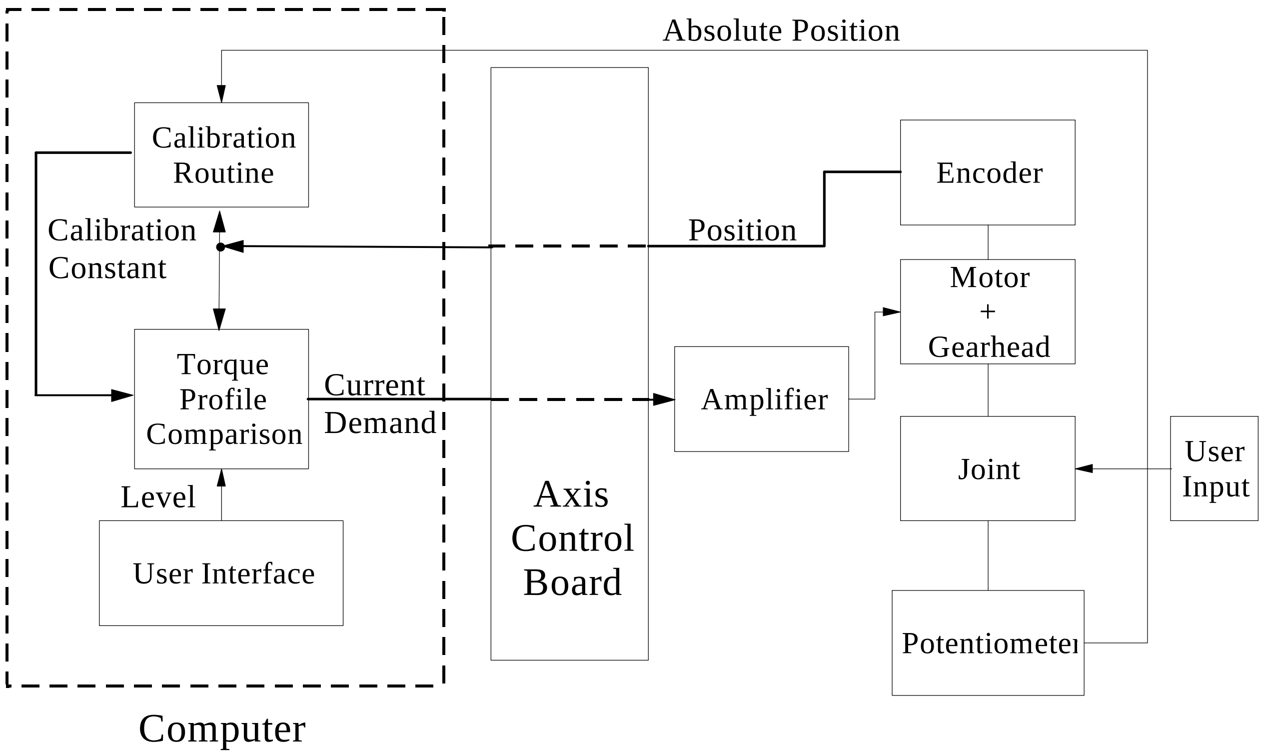

Figure 2

4 Assistive Torque - Profile Acquisition

The joint is moved to one end of the range of motion with the user making no attempt to move the joint. The torque is increased until the joint moves; it is then kept constant until the joint moves by a required increment. The position and current are recorded and the current is decreased until the joint stops. The cycle is then repeated until the other end of the range of motion is reached.

Control Software

Software has been written in C++. The torque profiles obtained are stored as files. At the start of the program, a calibration routine finds the equivalent encoder position for zero degrees joint angle and this is the position's calibration constant. For operation, the torque profile is read into a linked list in memory and the calibration constant is added to the positions. For torque tests, the calibration constant is subtracted from linked list values before they are stored as a file. At the time of writing, the four modes have been implemented and tested. Currently however the torque profiles are calculated in one direction only. This means that the joint is assumed to operate identically in both directions but due to gravitational effects and differing muscle strength, this will not be the case. Bi-directional profiles are now being implemented therefore. Possible future developments include making the control system adaptable to changing user strength. One way of doing this could be to monitor the cycle speed and adjust the level to compensate for changes in it. A further development to the control software could be an attempt to exercise more than one joint at a time.

References

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Address

Mr Alan Yardley,
School of Engineering,
University of Abertay Dundee,
Bell Street, Dundee DD1 1HG, UK

tel: (0)1382 - 308201
fax: (0)1382 - 308261
e-mail: A.YARDLEY@TAY.AC.UK