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Development Of Totally Implantable Total Artificial Heart Controller

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Abstract

Using one chip microcontroller 87C196 (On chip EPROM type) and EPLD (Erasable & Programable Logic Device), an implantable control system to drive pendulum type electromechanical total artificial heart was developed. This control system consists of 4 parts, main management system, motor driver with power regulator, state monitoring system and communication part. The main system has the functions for speed detection, PI (proportional and integration) control, PWM generation, communication and analog data processor. Two kinds of power system were used and seprated by 8 photo coupler arrays to improve the system stability. The performances of each compartments were compared with our previous z80 microprocessor based control system and good correspondences was shown. Logic power consumption was reduced to a one third of our previous cotroller. Using mock circulation tests, the overall performances of control system are evaluated.

1. Introduction

To realize totally implantable control system for electromechanical total artificial heart, the minimization of size, improvement of stability and optimization of power consumption are essentially required. Using one chip microcontroller 87C196 (On Chip Type : Intel, Santa Clara) and EPLD (Erasable and Programable Logic Device), implantable control system to drive pendulum type total artificial heart(1), in which 4 pole and 3 phase brushless DC motor produces back and forth motion of actuator, is developed satisfying the above mentioned conditions. Block diagram of overall system is shown in Fig. 1) and its main functions are as follows ; 1) system management, 2) motor driver, 3) state monitoring and 4) serial communication with outer system.

2. Method

Management system

The management system consists of 1 chip microcontroller and peripheral logic and its function diagram is shown in Fig. (2). Optimal velocity profiles are calculated and stored in the EPROM of microcontroller. This velocity profiles was shown to be relatively optimal through the simulation and mock circulation test(2). The difference between optimal velocity profile and the measured velocity produced by the discrete speed detector is fed to discrete PI control system with sampling interval of 1 msec. Fig 3) shows the block diagram of PI controller and its relation is written in eq (2). To implement this continuous time equation with microcontroller, it is approximated to discrete time equation in recursive form and discrete equation is writnen in eq (3).

$$\varepsilon(t) = \omega - \omega(t) \quad (1)$$

$$U(t) = Kp*\varepsilon(t) + Ki*\int\varepsilon(\tau)d\tau \quad (2)$$

$$U[(k+1)T] = U[(kT)] + Kp[\omega - \omega(kT)] + Ki[X(k+1)T] \quad (3)$$

$$X[(k+1)T] = X[(kT)] + (T/2)*\{\omega - \omega(kT)\} + (T/2)*\{\omega-\omega(k-1)T\} + X[(kT)] \quad (4)$$

The output signal of PI controller is fed to the PWM generator imbedded in microcontroller and it regulates motor speed by adjusting the duration of FET switching time. The motor speed can be detected from hall sensor signal. But since the maximal speed of motor is 4000 rpm and its normal operating range is 0 rpm to 2000 rpm, the resolution of measured speed should be improved. For this this purpose, falling and rising edge of 3 phase's hall sensor output signal are detected and employed in measuring motor speed. Once this edge is detected, the output value of speed detector is increased by constant amounts and then the output values are decreased every 0.2 msec with its decreasing rate depending on the motor speed.

By computer simulation, relatively optimal constant increasing amounts and decreasing rate are determined and the function of speed detector is evaluated by the comparision with the commercial F/V converter.Fig 4) shows the result of computer simulation for speed detection.

Timer system, which uses 6 MHz processor clock as a source, supplies various kinds of clock and they are 0.2 msec for speed detector, 1 msec for main samplig timer, 5 msec for data communication and various control clock such as the actuator's pausing time at the end of left ana right side.

Alarming system continuously monitors current state and hall sensor signal and notifies the emergent state to operator at the time when the motor current increases abruptly over the limit or motor does not work more than any preset time interval or when abnomal hall sensor states are detected. The center sensor signal used as information to control the stroke length is detected. Thus the regulation of left and right cardiac output is possible by adjusting the left and right length of actuator's movement from this center positin to avoid imbalance problem in TAH(3).

Communication system

To make this management system communicate with human interface system, an information bank which manages all the information about controller and physiological state is used and two kinds of communication mode are employed. The first one is cross communication mode in which the controller states, such as occurrence of emergency condition and left or right stroke time, are transmitted and the commands from human interface system are received. The second one is parameter transmission mode in which control parameter, such as velocity or PI controller output signal, or physiologic parameters like AoP are transmitted and they can be displayed respectively or simultaneously. This simultaneous display mode is very useful in diagnosis of controller or inspection of physiological state.

Power and state monitoring system

Logic power is completely isolated from the motor power with a photo coulper to prevent switching noise from exerting influences on the overall system. Twelve volts power for FET driving is supplied by the regulation of 24 volts motor power. The state monitoring system inspects motor currents by low pass filtering of voltages across current detection resistance 0.1 ohm and serially connected to motor power. It also detects current when its amplitude is over the preset limit. To detect center position, a magnet is attached on the center of actuator and a hall sensor is fixed on the center of the outer case which supports pendulus motion of actuator. When the actuator passes the center position, the hall sensor is activated and this activated pulse is sent to management system.

3. Results

To evaluate developed control system, the functions of each compartment are tested. As a firststep, the performance of digital speed dector is compared with commercial F/V converter and showed good correspondence. And the waveform of reference which is selected from the optimal velocity profile, speed detector's output, and PI control system are recorded with a simultaneous displaying function and they are shown in fig. (5). From these waves, we can see a larger difference between reference and measured velosity than that of our previous Z-80 based control system, especially in case of decreasing phase. Power consumption of logic circuit is about 1 watt while our previous controller consumed about 3.5watt, which shows the possibility of reduction in the size of internal logic battery when TAH is totally implanted. Mock circulation tests are performed under the various AoP, heart rate and stroke length and showed stable operation. Fig. (6) shows aortic pressure.

4. Discussion

Our control system achieved minimization of size by using microcontroller and EPLD. Also the stability improved by power isolation and reduction of wire connection. Logic power has decreased by more than one third compared with our previous control system. In the mock circulation tests, a stable operation could be observed. To perform animal experiments with this control system, the following issues should be considered.

1) Precise detection of motor speed from hall sensor signals.
2) Determination of optimal PI gains.
3) Development of filters which improves transient response of PI controller will ensures more afterload insensitive operarion
4) For the balance of left and right cardiac output, the preload should be estimated first of all. After estimation, the parameters to control left and right cardic output should be determined. Through the simulation and mock circulation test, we concluded that adjustment of left and right stroke length from center position can be a control parameter to balance left and right cardiac output. On the basis of these results, an effective control algorithm will be developed.
5) Full automatic control system should be realized for the implantable total artificial heart.
6) This control system should be easily combined with transcutaneous energy transmission system and signal transmission system
7) Communication time is one of the limit in increasing the heart rate. So reduction of this serial communication time should be done by compressing the communication data.
8) Small and verstile human interface system should be developed.

Reference

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2. B.G. Min, S.H. Lee, H.C. Kim ;"A Tether Free, Moving Actuator Total Artificial Heart", Trans Am Soc Artif Internal Organs 36: M249 - M251, 1990

3. S.H. Lee. W.W Choi, B.G.Min ;"Development of Totally Implantable Total Artificial Heart", Am Soc Artif Internal Organs, will be published at the end of this year

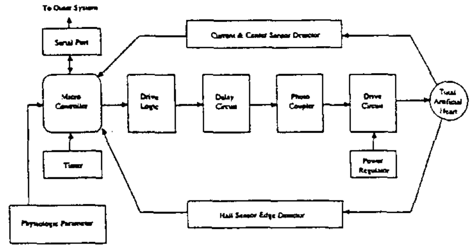

Figure 1. Block diagram of the overall control system.

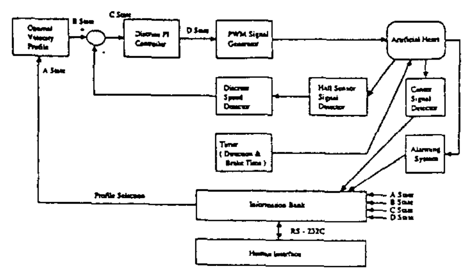

Figure 2. Function diagram of the management system.

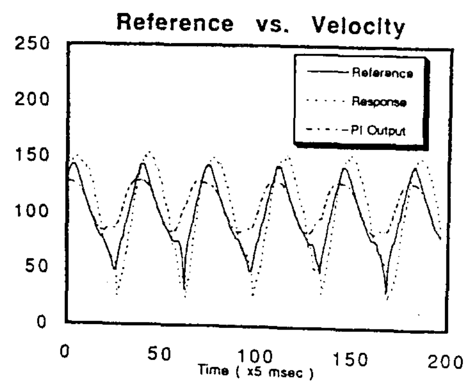

Figure 5 Waveforms of velocity profile, measured speed, and PI control system.

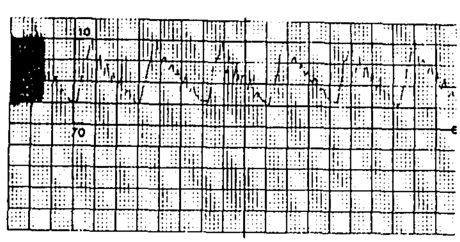

Figure 6 Waveform of AoP obtained from mock circulation tests.

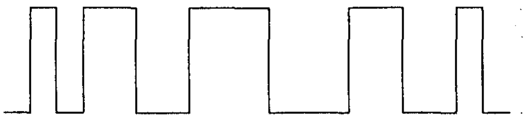

Figure. (4-1) Hall Sensor Signal

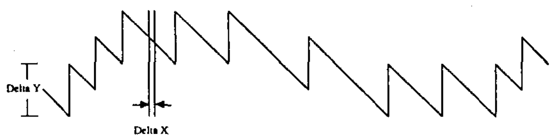

Figure (4-2) F/V Conversion

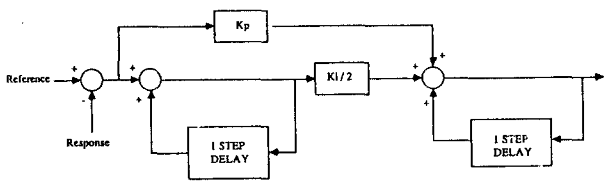

Figure.(3) Block Diagram of PI Controller