Low-cost microcontroller platform for real-time control of an isolated lymphatic vessel perfusion device

J. A. Kornuta[1], E. Salazar[1], Z. Danielak[1], and J. B. Dixon[1]
[1]Georgia Institute of Technology, Atlanta, GA

Introduction: Most tissues in the body are supported by the lymphatic system for a variety of functions, including the regulation of fluid balance, the removal of particulate matter from the interstitium, as well as the transport of fat from the intestine to the blood, among others. Lymphedema, a chronic disease characterized by an inability of the lymphatics to maintain tissue homeostasis and estimated to affect over 130 million people worldwide, can result in serious clinical problems for which there are very few beneficial cures or therapies. Despite the importance of lymphatics and the prevalence of lymphatic disease, very little is known about the particular mechanisms through which the lymphatics fulfill its primary functions.

Lymphatic vessels contract much like the heart to promote flow, demonstrating functional changes in pumping in response to alteration in the mechanical loads experienced by the vessel, such as fluid shear stress and pressure-induced hoop stress. While it is known that the shear-induced inhibition of lymphatic contraction is important in regulating function, whether the magnitude or the rate of fluid shear stress is more important remains unknown. Additionally, little is certain regarding the coupled effects of fluid shear stress and hoop stress due to transmural pressure. Thus, there exists a great need for a flexible, low-cost platform to study the relationships between these mechanics and lymphatic pump function.

Materials and Methods: The authors have previously designed a lymphatic isolated vessel perfusion system in order to independently control fluid shear stress and hoop stress. The isolated vessel perfustion system utilizes two opposing syringes with precision linear stages to vary these parameters of interest within the vessel. The control these parameters, a servo control loop employing full-state feedback was implemented using gains chosen via linear quadratic regulation (LQR). The hardware for this controller is a Digilent chipKIT Uno32 development board ($26) [Fig. 1a], which utilizes an 80 MHz, 32-bit PIC32 microcontroller for computation. In order to interface this development board with the isolated vessel perfusion system, the authors designed and fabricated a custom daughter board that plugs directly into the Uno32. In addition, the authors have developed a simple LabVIEW GUI to serially program the development board at the beginning of each experiment.

Results and Discussion: Figure 1b shows a top-view of the daughter board used to interface to both the sensors (two quadrature encoders, two pressure transducers) and the actuators (two linear stages). Since the pressure transducers are digital (I^2C) and the quadrature signals are decoded in hardware on the daughter board, the Uno32 development board expends little computational effort for I/O. This additional headroom is advantageous because it allows the flexibility to implement complex control algorithms that may use many sequential matrix computations. In testing, the development board could execute sampling times in excess of 1 kHz using its timer interrupts, which far exceeds the requirements for this particular real-time control application.

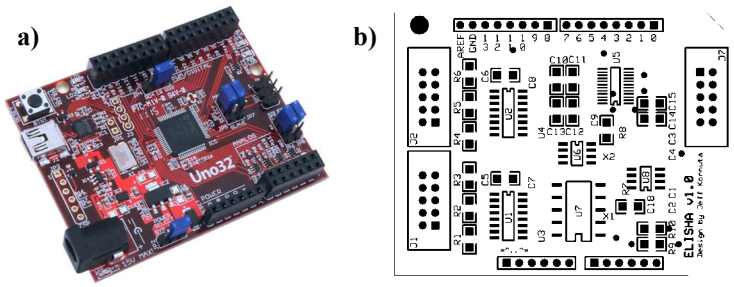

Figure 1. The real-time control platform utilizes a Digilent chipKIT Uno32 (a) development board to perform all necessary computations. The 80 MHz, 32-bit PIC32 microcontroller provides ample computational headroom for this particular application. In order to interface with the necessary transducers and actuators, the authors designed and built a custom daughter board (b) to connect directly into the development board.

Conclusions: The authors have developed a simple, low-cost platform to control an isolated vessel perfusion system in real time. Due to its flexibility and price point, the authors believe this platform is a useful tool for implementing real-time control and could allow for novel experiments to be designed and performed.

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