World Academy of Science, Engineering and Technology
International Journal of Biomedical and Biological Engineering
Vol:12, No:06, 2018

Development of an Automatic Control System for ex vivo Heart Perfusion

Authors : Pengzhou Lu, Liming Xin, Payam Tavakoli, Zhonghua Lin, Roberto V. P. Ribeiro, Mitesh V. Badiwala

Abstract : Ex vivo Heart Perfusion (EVHP) has been developed as an alternative strategy to expand cardiac donation by enabling resuscitation and functional assessment of hearts donated from marginal donors, which were previously not accepted. EVHP parameters, such as perfusion flow (PF) and perfusion pressure (PP) are crucial for optimal organ preservation. However, with the heart's constant physiological changes during EVHP, such as coronary vascular resistance, manual control of these parameters is rendered imprecise and cumbersome for the operator. Additionally, low control precision and the long adjusting time may lead to irreversible damage to the myocardial tissue. To solve this problem, an automatic heart perfusion system was developed by applying a Human-Machine Interface (HMI) and a Programmable-Logic-Controller (PLC)-based circuit to control PF and PP. The PLC-based control system collects the data of PF and PP through flow probes and pressure transducers. It has two control modes: the RPM-flow mode and the pressure mode. The RPM-flow control mode is an open-loop system. It influences PF through providing and maintaining the desired speed inputted through the HMI to the centrifugal pump with a maximum error of 20 rpm. The pressure control mode is a closed-loop system where the operator selects a target Mean Arterial Pressure (MAP) to control PP. The inputs of the pressure control mode are the target MAP, received through the HMI, and the real MAP, received from the pressure transducer. A PID algorithm is applied to maintain the real MAP at the target value with a maximum error of 1mmHg. The precision and control speed of the RPM-flow control mode were examined by comparing the PLC-based system to an experienced operator (EO) across seven RPM adjustment ranges (500, 1000, 2000 and random RPM changes; 8 trials per range) tested in a random order. System's PID algorithm performance in pressure control was assessed during 10 EVHP experiments using porcine hearts. Precision was examined through monitoring the steady-state pressure error throughout perfusion period, and stabilizing speed was tested by performing two MAP adjustment changes (4 trials per change) of 15 and 20mmHg. A total of 56 trials were performed to validate the RPM-flow control mode. Overall, the PLC-based system demonstrated the significantly faster speed than the EO in all trials (PLC 1.21±0.03, EO 3.69±0.23 seconds; $p < 0.001$) and greater precision to reach the desired RPM (PLC 10±0.7, EO 33±2.7 mean RPM error; $p < 0.001$). Regarding pressure control, the PLC-based system has the median precision of ±1mmHg error and the median stabilizing times in changing 15 and 20mmHg of MAP are 15 and 19.5 seconds respectively. The novel PLC-based control system was 3 times faster with 60% less error than the EO for RPM-flow control. In pressure control mode, it demonstrates a high precision and fast stabilizing speed. In summary, this novel system successfully controlled perfusion flow and pressure with high precision, stability and a fast response time through a user-friendly interface. This design may provide a viable technique for future development of novel heart preservation and assessment strategies during EVHP.

Keywords : automatic control system, biomedical engineering, ex-vivo heart perfusion, human-machine interface, programmable logic controller
Conference Title : ICMBE 2018 : International Conference on Medical and Biomedical Engineering
Conference Location : Toronto, Canada
Conference Dates : June 21-22, 2018