Autonomous Control System for Left-Ventricular Assist Devices

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***Abstract*— The Cardiloop feedback control system uses a combination of sensor and negative feedback loop technology to control the parameters of a left ventricular assist device (LVAD). The active control of these parameters prevents further damage to the heart caused by current LVAD designs, in which these parameters stay constant. The Cardiloop feedback control system is a separate system that is designed to be implemented into current LVADs. Controlling parameters will prevent pulmonary congestion and left ventricular suction (major causes of heart damage) in LVAD patients which will increase the post-implantation survival rates and quality of life. The Cardiloop feedback control system will be tested on a mock circulatory system loop with an adjustable continuous flow pump acting as an LVAD. This testing will ensure the accuracy of the mock loop to physiological parameters and assess the effectiveness of the control system by monitoring the pressure changes in the system. It is expected that the Cardiloop feedback system will adjust the LVAD's output to compensate for the patient's needs, therefore reducing pulmonary congestion and ventricular suction events in patients upwards of 50%.**

Keywords—LVAD; suction event; pulmonary congestion; control system; mock loop

I. INTRODUCTION

Heart failure is a major cause of morbidity and mortality in the United States with approximately 7 million patients living with this diagnosis [1]. In 2013, 18% of the approximately 4,000 recipients of left-ventricular assist devices (LVADs) died within one year of receiving the treatment, chiefly from device-related causes [2]. The high fatality rate is primarily due to the fact that current devices, while able to monitor real-time patient data, are unable to respond actively to the differing stresses put on the heart through everyday activities. The effective implementation of the Cardiloop feedback system will improve long-term patient survival rates and quality of life for patients who receive an LVAD system, which will result in fewer doctor visits, lower post-operative costs, and a higher potential level of physical activity.

The LVAD control system uses a negative feedback system to decrease the stresses on the heart caused by improper LVAD flow rate. An increased heart rate, due to an elevated activity level, can cause a buildup of pressure within the left heart and pulmonary system, which may result in pulmonary edema (congestion). A decreased heart rate, due to a relaxed physical state, can cause negative pressure at the LVAD inlet, creating a state known as ventricular suction. This state can cause cardiac arrhythmia and damage to the heart tissues [3].

The 2015 INTERMACS annual report found that approximately 1,000 patients died within the first year of LVAD implantation, with 20% of these patients suffering from either right heart failure or multiple organ failure, both of which may be caused by either pulmonary congestion or ventricular suction [4]. With the market for LVAD devices growing rapidly, a control system for LVAD devices could potentially save hundreds or thousands of lives and up to $144,000,000 annually in the United States alone [2].

II. MATERIALS & METHODS

A. Control System

The Cardiloop feedback system will be implemented through a programmable Arduino controller. The software logic is shown in Fig. 1 below.

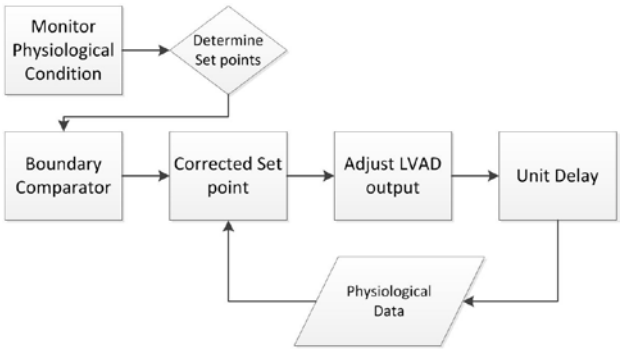

Fig. 1. Control system logic flow

The software controller will monitor physiological conditions that describe the patient's current state. The controller will govern the parameters of the continuous flow pump in response to changes in sensor readings.

B. Mock Circulatory System Loop

The mock circulatory system loop simulates the circulatory system and is the testing apparatus for the Cardiloop feedback system. The ventricles in this system will mimic pulsatility within the heart, while cylindrical tubes serve as atria. Backflow is prevented through the use of check valves. The

peripheral cardiovascular system can be modeled using four compliance chambers to assure physiological conditions are maintained. Blood vessels are modeled by plastic tubing with appropriate physiological resistances. The assembly drawing of the mock loop is shown in Fig. 2 below.

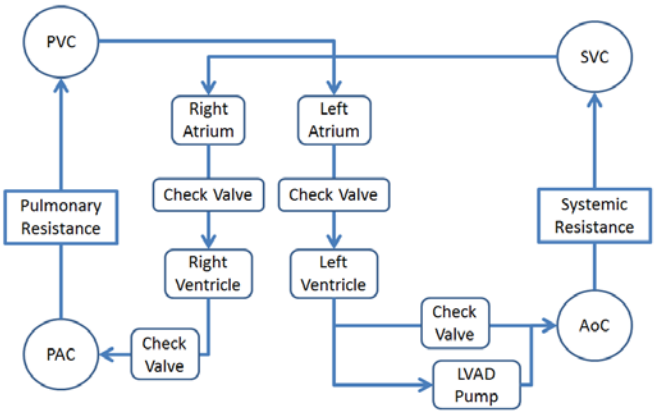

Fig. 2. Diagram of mock circulatory loop assembly

C. *Description of Test Protocols*

Following construction of the mock loop, the assembly will be tested with and without the implementation of an LVAD analogue, to ensure that the physiologically parameters of the disease state are appropriately imitated and there is noticeable improvement of parameters with an LVAD installed. Additionally, the ventricular suction and pulmonary congestion events will be created by increasing or decreasing the heart rate (ventricular pulsatility) within the loop. Appropriate heart ramp rates will be determined by gathering EKG data from group members during light exercise. Finally, the Cardiloop control system will be implemented into the mock loop and LVAD to verify that the system reduces instances of ventricular suction and pulmonary congestion.

III. ANTICIPATED RESULTS

A. *Suction and Congestion Event Prevention*

Ventricular suction and pulmonary congestion events will be created using a mock circulatory system and LVAD analogue by varying the mock loop heart rate with constant LVAD speed. The success criterion for proper performance of the Cardlioop feedback system is a 50% reduction in the number of suction and congestion events when the heart rate within the mock loop is varied in the same way alongside Cardiloop implementation. Fig. 3 shows the anticipated pressure readings over time with the top, black oval indicating the pressure condition of pulmonary congestion and the bottom, blue oval indicating the pressure condition of a suction event.

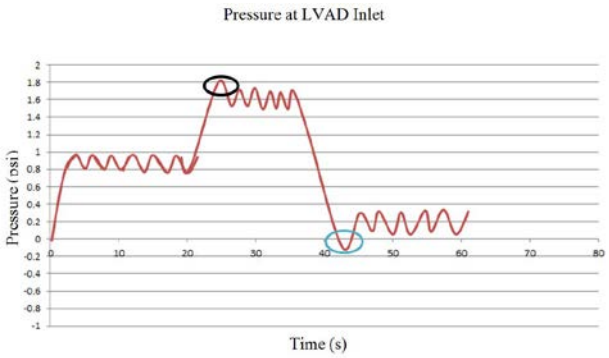

Fig. 3. Pressure at the inlet of LVAD pump

IV. DISCUSSION

It is anticipated that proper implementation of the Cardlioop control system will reduce the number of suction events and instances of pulmonary congestion. This is due to the real-time feedback from the "patient" allowing the LVAD to match the demand and needs of the "body". The limited reduction in the number of suction events is a result of the limitations of the algorithm. With the incorporation of a more complex array of sensors and more efficient algorithm, the system can more effectively anticipate and therefore reduce suction events.

V. CONCLUSION

The Cardiloop control system will be designed to reduce the instances of ventricular suction and pulmonary congestion by monitoring the patient's physiological condition and adjusting the output of the LVAD accordingly. By ensuring that the testing apparatus models the circulatory system effectively, further tests on the LVAD control system can be confirmed to be applicable to the human body and LVAD patients.

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