Automated Life Emergency Response Trigger System (ALERTS)

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How can we create a device that can be used to increase the chance of survival for a heart transplant recipient, who will experience eventual rejection?

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Abstract

Our study investigates how we can implement the ideas of ICDs (Implantable Cardioverter Defibrillator) and the Pacemaker into a simple technological device that contains a less invasive process and more safer surgery option. The Automated Life Emergency Response Trigger System (ALERTS) detects when a patient's heart has stopped or has irregular heartbeat. When this stimulus is detected, the ALERTS will send a safe electrical pulse that resembles that of an AED. The standard solution to heart attacks would require advanced CPR and the application of an AED. However, research shows that many areas do not have an AED available nearby to that of a heart attack patient. In addition, current heart attack survivor surgeries are invasive and even risky sometimes. Thus, the ALERTS creates an efficient way to solve the AED problem and a new surgical approach to stent surgeries or cardiac muscle repair surgeries. Generally, this system will be used for patients of heart transplant, considering they are almost always a recipient of rejection. To figure out when the rejection will occur, main symptoms include complete heart failure, or cardiac arrest. That is how the ALERTS system can distinguish possible recipients or near recipients of a heart rejection.

Background

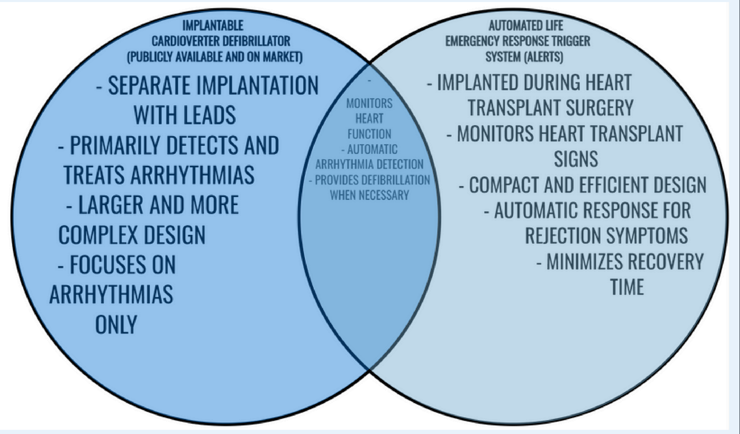
Heart transplantation is a critical procedure for patients with end-stage heart failure or severe heart conditions, involving the replacement of a diseased heart with a healthy donor organ. However, heart transplant recipients face ongoing challenges, primarily the risk of organ rejection. Common symptoms of heart rejection include cardiac arrest, heart attack, and heart failure. Cardiac arrest occurs when the heart stops due to electrical malfunctions, while heart attacks result from blockages in the coronary arteries, often leading to heart failure. Heart failure itself occurs when the heart cannot pump blood effectively, causing fluid buildup in the lungs and other organs. Despite advancements in medical techniques, monitoring and detecting signs of rejection remain a significant challenge, making it crucial to develop more effective, automated systems to improve patient outcomes and survival rates. Current methods for detecting heart rejection often require invasive procedures and close monitoring, which can be difficult to maintain over time. The development of an automated system like ALERTS could significantly improve the early detection of rejection symptoms, potentially saving lives by providing immediate responses during critical situations.

Implantation

The updated implantation method for the ALERTS system involves placing the device directly onto the heart during the heart transplant surgery. Instead of using catheters and small incisions around the aortic valve, the system will be surgically attached directly to the heart itself. This will involve a small incision near the chest, allowing the surgical team to carefully position the ALERTS system onto the outer surface of the heart. The sensor, responsible for detecting heart irregularities, will be directly affixed to the heart muscle, while the defibrillator and battery components will be secured nearby, connected through small incisions. This approach allows for real-time monitoring of heart function and immediate intervention in case of rejection symptoms, such as cardiac arrest or heart failure, providing a continuous and direct method for managing post-transplant complications.

Differences with an ICD?

The ALERTS system offers several advantages over a traditional Implantable Cardioverter Defibrillator (ICD), particularly in the context of heart transplant recipients. First, ALERTS is implanted directly onto the heart during the transplant surgery, reducing the invasiveness of the procedure compared to an ICD, which requires separate implantation with leads attached to the heart. This approach minimizes incisions, cuts recovery time, and eliminates the need for additional surgical interventions. Additionally, while ICDs are designed primarily to detect and treat arrhythmias, ALERTS is specifically tailored to monitor for signs of heart transplant rejection, such as cardiac arrest and heart failure, providing more comprehensive protection for transplant patients. The ALERTS system is also more compact and efficient, with all its components — including the sensor, defibrillator, and battery — positioned in a way that reduces its size and the potential for discomfort, unlike the larger, more complex ICDs. Moreover, ALERTS provides an automatic response not only for arrhythmias but also for broader heart failure or rejection symptoms, offering a quicker and more tailored intervention for transplant recipients.



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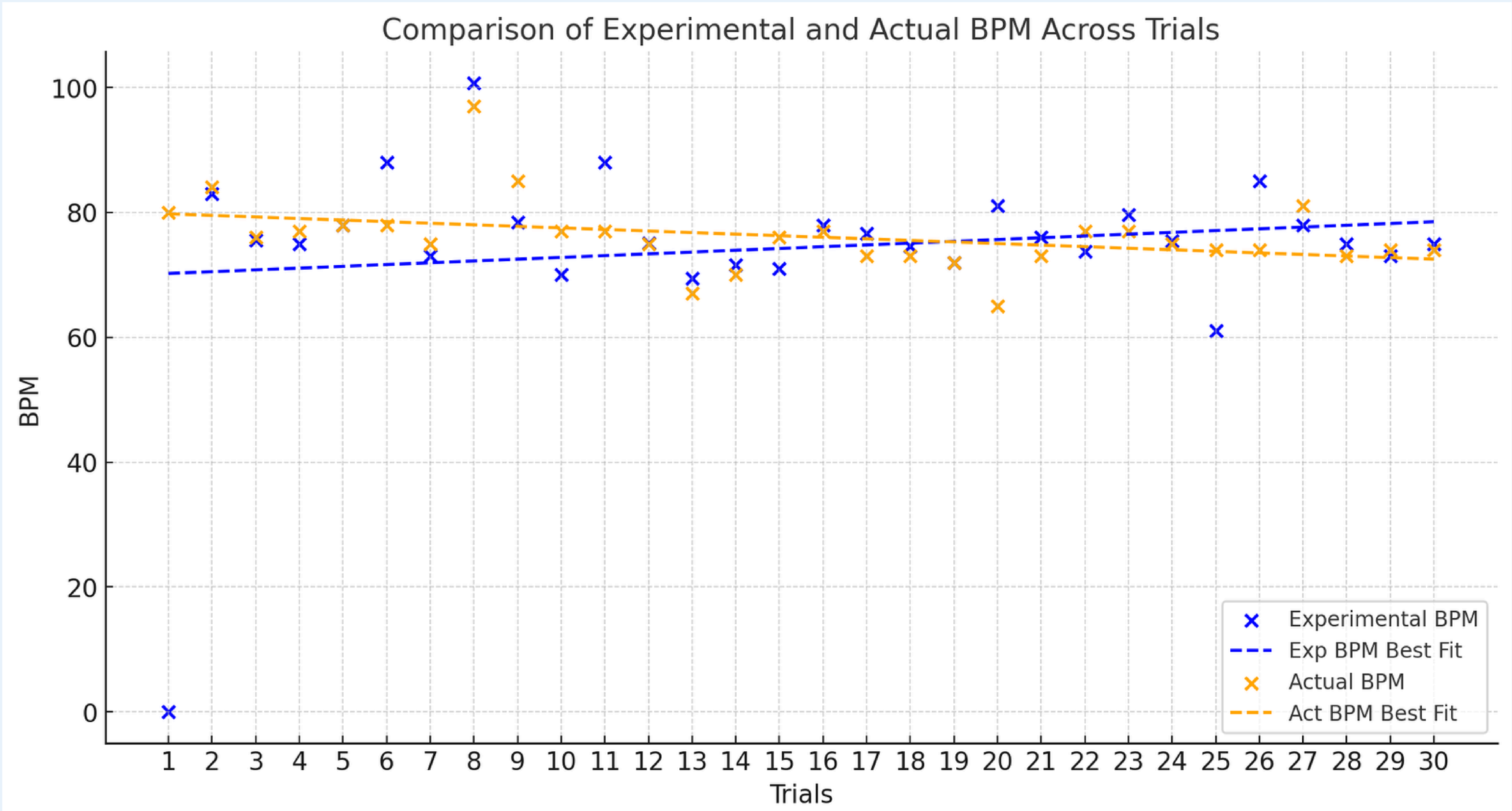
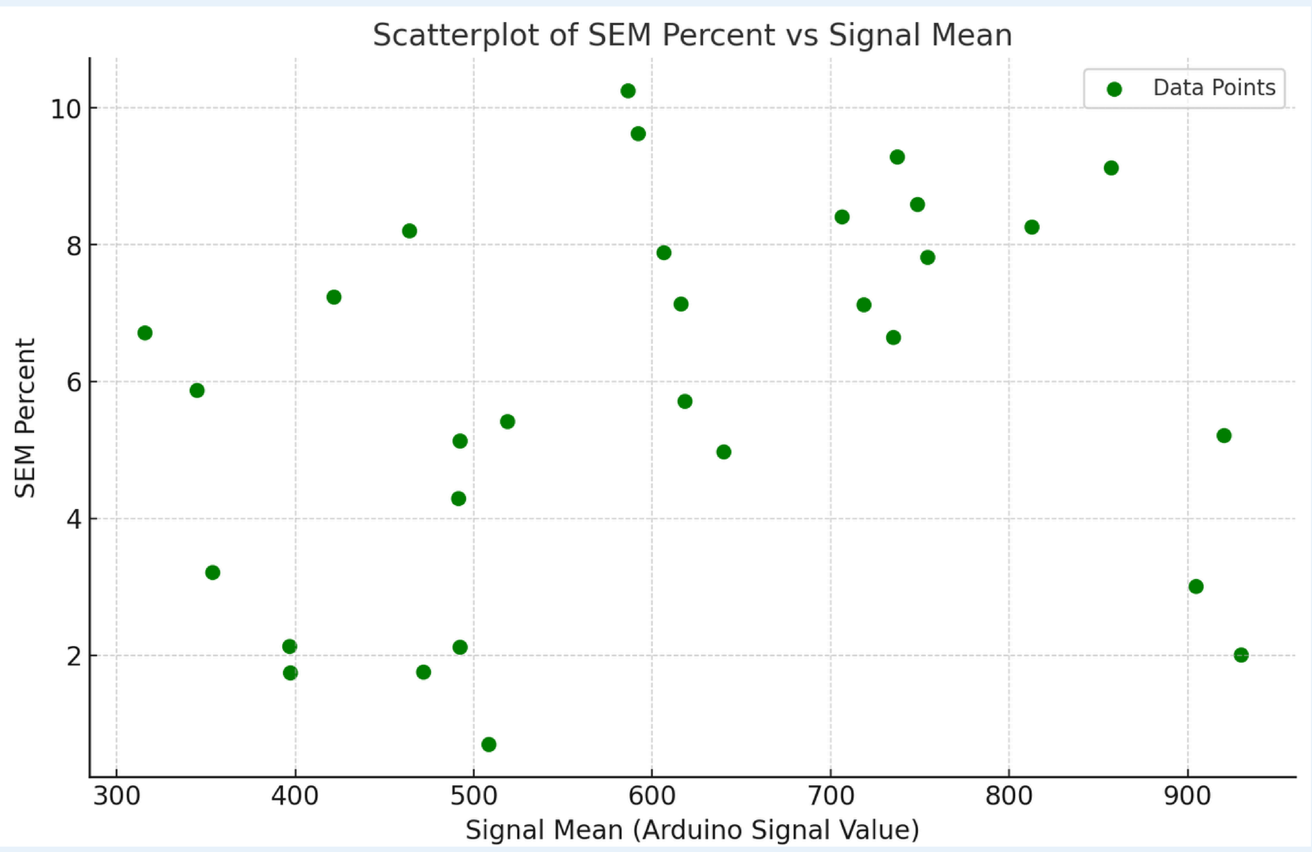
Data

	Pulse (Y/N)	Buzzer Present (Y/N)	Standered Error of the Mean	Mean of BPM described (As per Arduino Signal Value)	Experimental BPM	Actual BPM	Percent Error (Actual v. Device)
Test 1:	N	N/A	0.70%	508.25	0bpm	80bpm	100%
Test 2:	Y	N/A	2.12%	492.32	83bpm	84bpm	1.19%
Test 3:	Y	N/A	4.98%	640.07	75.6bpm	76bpm	0.53%
Test 4:	Y	N/A	3.01%	904.47	75bpm	77bpm	2.60%
Test 5:	Y	N/A	7.89%	606.47	78bpm	78bpm	0.00%
Test 6:	Y	Y	6.72%	315.53	88bpm	78bpm	12.82%
Test 7:	Y	Y	1.76%	471.53	73bpm	75bpm	2.67%
Test 8:	Y	Y	8.20%	463.80	100.7bpm	97bpm	3.82%
Test 9:	Y	Y	2.01%	929.36	78.4bpm	85bpm	7.82%
Test 10:	Y	Y	7.14%	616.00	70bpm	73bpm	4.11%
Test 11:	Y	Y	7.24%	421.47	88bpm	77bpm	14.29%
Test 12:	Y	Y	5.21%	920.07	75.1bpm	76bpm	1.22%
Test 13:	Y	Y	8.26%	812.57	69.4bpm	67bpm	3.63%
Test 14:	Y	Y	6.65%	735	71.6bpm	70bpm	2.24%
Test 15:	Y	Y	5.71%	618.29	71bpm	76bpm	6.58%
Test 16:	Y	Y	9.28%	737.29	78bpm	77bpm	1.30%
Test 17:	Y	Y	7.12%	718.5	76.6bpm	73bpm	4.89%
Test 18:	Y	Y	8.41%	706.07	74.6bpm	73bpm	2.15%
Test 19:	Y	Y	2.14%	396.57	78bpm	72bpm	8.33%
Test 20:	Y	Y	7.82%	754.07	81bpm	65bpm	24.62%
Test 21:	Y	Y	1.75%	397.14	76bpm	73bpm	4.11%
Test 22:	Y	Y	8.59%	748.6	73.7bpm	77bpm	4.33%
Test 23:	Y	Y	9.63%	592.07	79.6bpm	77bpm	3.38%
Test 24:	Y	Y	9.13%	857.2	75.4bpm	75bpm	0.53%
Test 25:	Y	Y	4.29%	491.4	85bpm	74bpm	14.86%
Test 26:	Y	Y	5.42%	518.67	61bpm	74bpm	17.57%
Test 27:	Y	Y	3.21%	353.53	78bpm	73bpm	6.85%
Test 28:	Y	Y	5.14%	492	75bpm	81bpm	7.41%
Test 29:	Y	Y	10.25%	586.5	70bpm	73bpm	4.11%
Test 30:	Y	Y	5.87%	344.73	75bpm	74bpm	1.35%

The 5 values provided in our data table take allow for a comparison of the different values in the chart (e.g., relation between SEM Value and % Error) while also allowing for a comparison of the ALERT's accuracy



This graph shows the Experimental BPM and Actual BPM in a comparison. The two lines, towards the beginning, were very distant, due to lower quality test. However, as trials grew, so did the quality, leading to higher quality statistics and more accurate data



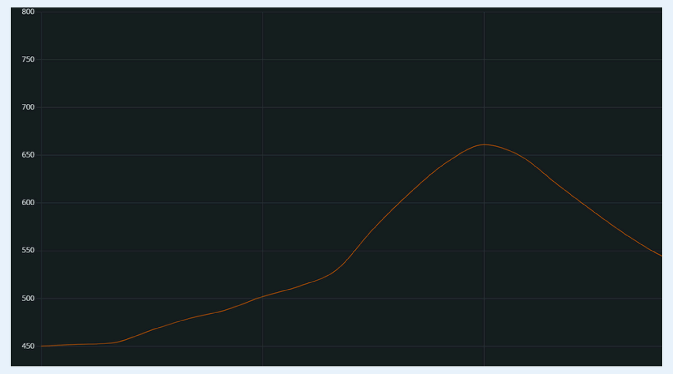
This Graph compares the Standard Error the mean for the signal mean, to the signal mean in and of itself. We use this data to help us learn how to create interferences within the signal mean, and properly enhance our project to the wanted parameters.

Analysis

The graph compares heart rate data collected by our custom-built heart rate sensor (Experimental BPM) with data from a reliable external heart rate sensor (Actual BPM) across 30 trials. Our sensor demonstrates a clear trend in detecting heart rate, as shown by the blue data points and trendline. While there is some variability in the experimental readings, the general upward trend reflects the sensor's sensitivity to physiological changes over repeated trials. In contrast, the actual BPM, represented by the orange points, remains more consistent, highlighting the stability of the external sensor's data. Despite slight deviations between the two datasets, our heart rate sensor shows promising accuracy, closely mirroring the external sensor's results in many trials. The positive trajectory of the experimental data also suggests that our sensor has the potential for improvement and calibration to achieve greater precision. Overall, this comparison highlights the impressive capability of our sensor to measure heart rate while emphasizing opportunities for further refinement.

The scatterplot titled "Scatterplot of SEM Percent vs Signal Mean" shows the relationship between the signal mean (Arduino signal value) and the corresponding SEM percent (standard error of the mean as a percentage). Each green dot represents a single data point, showing variability in SEM percent across a range of signal mean values from approximately 300 to 900. The plot suggests that there is no strong correlation between SEM percent and the signal mean, as the data points appear scattered without a clear trend. However, SEM percent values tend to cluster between 2% and 10%, with some outliers below 2%. Notably, the majority of higher SEM percent values occur around signal means between 500 and 700, indicating that variability in measurements may be more pronounced in this range. This scatterplot highlights the precision of our heart rate sensor measurements across different signal intensities. While some variability exists, the majority of data points remain within an acceptable range, demonstrating the robustness of our sensor design. Further optimization and calibration could help reduce the variability observed in SEM percent, especially at mid-range signal mean values.

The image depicts an EKG that was taken during the beginning trials of the project. Currently, we used a different system for graphing the EKG (on right) to show the signal values instead of an EKG



Scalability

To scale the ALERTS system for implantation within the heart, the device will be miniaturized to ensure it can be seamlessly integrated into the heart's anatomy without interfering with its natural function. This involves redesigning the components — including the sensor, defibrillator, and battery — to be significantly smaller while maintaining functionality and reliability. Advanced microfabrication techniques and biocompatible materials will be utilized to create a lightweight and compact system capable of enduring the heart's constant movement and exposure to bodily fluids. The system's electronics will be integrated into a single chip to reduce size further, while the battery will be replaced with an energy-harvesting mechanism to harness the heart's kinetic energy for power. By embedding the sensor directly within the heart muscle and attaching the defibrillator to a strategic internal location, the ALERTS system will operate discreetly and efficiently, continuously monitoring for irregularities and delivering precise electrical pulses when needed. This scaled-down version ensures the device is both minimally invasive and highly effective for long-term use in heart transplant recipients.

Conclusion

Our project focused on developing a implantable defibrillator an AED that goes presently within the heart and comparing its performance against a reliable external heart rate sensor. Through extensive testing across 30 trials, we gathered and analyzed both experimental and actual BPM data, alongside additional metrics such as the signal mean and SEM percent. The comparison between our sensor's data and the external sensor revealed that while there were some deviations, our custom sensor consistently tracked heart rate trends and showed promising accuracy. The scatterplot of SEM percent vs. signal mean further highlighted areas where measurement variability occurred, providing key insights into how signal strength impacts precision. Despite minor inconsistencies, the overall performance of our sensor demonstrates its potential as a functional and cost-effective solution for heart rate monitoring. This project not only showcased our ability to design and implement a functional heart rate sensor but also emphasized the importance of calibration and optimization to reduce variability and improve accuracy. Moving forward, we aim to refine the sensor's design by enhancing its sensitivity and stability, ensuring it performs reliably across a broader range of conditions. Ultimately, this project represents a significant step toward creating accessible and reliable biomedical technology.