Pilot Biometrics

ECG WAVEFORM CAPTURES

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Definitions

ECG - Electrocardiography - the process of recording the electrical activity of the heart over a period of time.

ADC - Analog to Digital Converter - device used to convert an analog signal to a digital signal

HIPAA - Health Insurance Portability and Accountability Act - regulates how medical information must be secured and stored

IEEE - Institute of Electrical and Electronics Engineers

1 Introduction

1.1 ACKNOWLEDGEMENT

Rockwell Collins is providing significant support in the form of resources, hardware components, and information.

Our point of contact at Rockwell Collins, JR Spidell, has been extremely beneficial with his guidance and background knowledge of the subject.

The Operator's Performance Lab (OPL) at the University of Iowa is allowing the use of their facilities for the purpose of testing.

1.2 PROBLEM AND PROJECT STATEMENT

When military pilots are in flight, they experience a range of forces and conditions. This environment can quickly affect the health of the pilot. Real-time health information is critical for trainers and health officers on the ground to make decisions about the safety of a pilot during training exercises. This information is critical in determining whether the pilot can safely continue a training mission, and whether the pilot will continue to be physically fit to fly.

Our project aims to provide this critical information using an ECG sensor harness and accompanying analysis device. The device will actively monitor the ECG waveform of a pilot in flight, analyze the waveform to detect when a pilot is in distress, and communicate this information to decision makers on the ground. The device will be capable of running continuously for 4-5 hours and store all of the operational data for later review.

1.3 OPERATIONAL ENVIROMENT

The ECG sensors will be attached to a pilot via harness in fighter jet test flights. It will experience rough shaking, inconsistent vibrations, movements from the pilot, and high-g maneuvers. We expect conditions inside the cockpit to be clean, the cabin partially pressurized, and within a reasonable range of temperatures. Our device will not come into contact with water or weather conditions and humidity in the cockpit will be minimal.

1.4 INTENDED USERS AND USES

Our product is intended to be used by US Navy fighter pilots in training. These pilots are already trained and certified to fly the aircraft, and will be practicing maneuvers and training missions involving multiple aircraft. The device is intended to gather and report ECG waveform data, as well as analyze the data in real time. Extracted data will be used by health officers and trainers on the ground to make decisions about the health of the pilot during and after the mission.

1.5 ASSUMPTIONS AND LIMITATIONS

Assumptions

- US Navy pilots have already gone through stringent health checks and are in solid physical condition
- Pilots will not have any previously known abnormal heart conditions
- Product will be used for training exercises
- Only one person will be using device at a time

Limitations

- 4-5 hours of battery life
- Conditions will be difficult to replicate for testing
- Testing product durability will not be performed
- Processed data may be delayed by 3-8 seconds
- Final product will not inhibit any other action performed by pilot

1.6 EXPECTED END PRODUCT AND DELIVERABLES

The end product is a wearable harness-mounted system capable of accurately reading the ECG of a fighter pilot for the duration of the flight. The product will also send readings to the ground where professionals can access the pilot's health and stress levels. The ECG sensor system has a continuous operational lifetime of 4-5 hours and can also store 4-5 hours of operational data. The system is capable of transmitting the ECG waveform data in real time, or only transmitting a distress signal. For communication, the device will interface with a Rockwell Collins device inside the cockpit.

- Delivery due on April 20th, 2018

2. Specifications and Analysis

To meet the functional and nonfunctional requirements outlined below, we explored several different aspects of the system design. In order to meet the required degree of accuracy, the ECG waveform needs to be heavily filtered for analysis. We discussed implementing the filter both in the hardware as a high-order bandpass filter, and in the algorithm as a software filter. A hardware filter works significantly faster and helps reduce the overall amount of data needed to be analyzed. However, this filter design will only work on a range of values and struggles to remove noise within the expected frequency range of our ECG waveform. A software filter would be more capable of removing noise in any frequency range, but will take longer to operate on a large volume of data.

Ultimately, we decided to implement both filters in a two-stage design. First, a hardware filter will remove values outside of the expected frequency range, to reduce the total volume of data. Then, a software filter will remove noise and anomalies.

In order to analyze and store the ECG waveform, we did significant research into how similar waveform data has been handled by other projects. We decided to convert the analog signal into ECG points, which will be stored as a continuous list of voltage readings. Based on the sampling rate of our sensors and the ADC, we decided to store the data in a micro SD card attached to the main board. This will also allow for easy retrieval.

Our project is following the IEEE standards and Rockwell Collins specifications for quality and handling of personal medical data. Our final design will not take credit for work that we did not do ourselves and we will deliver all deliverables upon the completion of our project in accordance with the agreement made with Rockwell Collins.

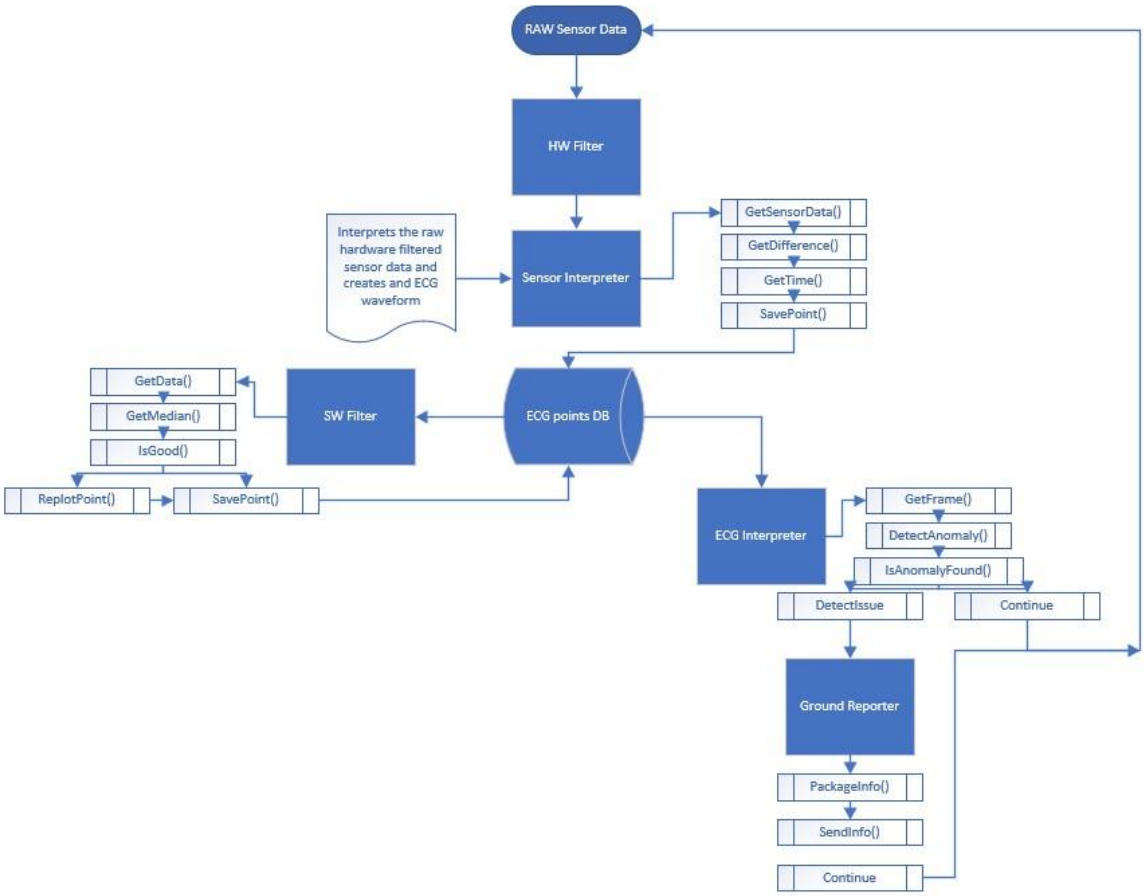
2.1 PROPOSED DESIGN

Our proposed design consists of several hardware and software components. For hardware, our design utilizes four ECG sensors, a bandpass filter, an Analog to Digital Converter, a microcontroller board, and a battery with power distribution system. For software, we will be using a device driver, software filter, and main algorithm for analysis, all running on the microcontroller board. The ECG sensors and remaining hardware will be integrated into a physical harness to be worn by the user. The harness will keep the four sensors in contact with the user while the battery and board are kept out of the way of the pilot as not to interfere with flight operations. The microcontroller will also interface with hardware inside the cockpit to allow communication with the ground.

The four sensors will collect initial ECG readings from the pilot. This raw data will run through a hardware bandpass filter to quickly remove interference outside of the expected range of our ECG waveform. The hardware filter is used early on to eliminate unneeded data and reduce the total volume of data to be analyzed. This filtered data will then be sent to the ADC to be converted it into ECG points. These points are then filtered by the slower software filter as needed and then the ECG graph is finalized and recorded. The highly filtered graph is then stored in a database on the device. Next, the ECG graph is analyzed for conditions that might indicate health risks and distress. Finally, data is organized into packets and sent to a communication device in the cockpit to be transferred to personnel on the ground.

The diagram below shows the details of the software components of the pilot biometrics device. This diagram also illustrates how data moves through the two stage filter and main algorithm.

Figure A.
This figure shows details of the software and data components of the system.



A complete list of functional and non-functional requirements is included below:

Functional
Accurately detect a pilot in distress
Capture ECG waveform of pilot in operation
Accurately identify distress based on waveform
4-5 hours of continuous operation
Consistent and reliable power supply
Notify ground station
Store 4-5 hours of operational data
Operate in real time on an ARM microcontroller

Non-functional
Don't interfere with pilot's primary tasks, flight operations, or emergency ejection
Don't interfere with pilot's safety harness
Don't interfere with pilot's normal communications

2.2 DESIGN ANALYSIS

We have considered a number of design options in our current implementation. Both a hardware and software filter were considered, and we have also considered using a combination of both. A hardware filter is quick and could be used early on to reduce data, the reduced data could then be sent to a more complex software filter with a lower risk of slowing down operation. For power distribution, we considered a dedicated power supply from the cockpit, as well as an integrated battery. The dedicated power supply could further clutter the cockpit with wires, but the integrated battery has the potential to make the harness more cumbersome. Furthermore, the integrated battery would allow greater portability, but may be less reliable. Finally, for data storage, we are currently exploring a number of options for saving 4-5 hours of operational data.

3 Testing and Implementation

Check circuit and ECG filter algorithm on pre-extracted ECG readings to check if the circuit and software are set up correctly.

Test ECG sensors with the validated software to make sure they are working correctly, induce stress on wearer to check if a difference in stress levels can be measured as expected.

Once system is set up on a harness, test the comfort, stability, and accuracy of entire system under extreme conditions.

3.1 HARDWARE AND SOFTWARE

STM32F767 Microcontroller from ST micro is used to interface with the ADC and interpret the data.

ADS1298RECGFE-PDK is an ADC used to convert the data received from our ECG sensors into data that our microcontroller can use.

ECG sensor ADS129R will read ECG waveforms from our user and then send it into our ADC.

3.2 INTERFACE SPECIFICATIONS

To test the main algorithm in a controlled environment we will have to have consistent and accurate ECG readings. To do this we will need to have the sensors working and viable test subjects. We were just approved for the latter, but the former is still in transit. It will be fairly difficult to imitate the conditions of the cockpit while in flight, but we will do our best to imitate similar stressful situation. Once we adequately test in this stage we can move on to a real test provided by Rockwell Collins. This will be a real pilot that will be flying a real plane.

3.3 FUNCTIONAL TESTING

Check circuit and ECG filter algorithm on pre-extracted ECG readings to check if the circuit and software are set up correctly.

Test ECG sensors with the validated software to make sure they are working correctly, induce stress on wearer to check if a difference in stress levels can be measured as expected.

3.4 NON-FUNCTIONAL TESTING

Once system is set up on a harness, test the comfort, stability, and accuracy of entire system under extreme conditions.

3.5 MODELING AND SIMULATION

A member of our team will wear the harness and be asked to perform mentally stressful tasks in a turbulent environment (vibration table, vehicle, etc). Testing blackout may not be plausible. ECG readings can be checked for sensibility with online data from references [2, 3].

3.6 IMPLEMENTATION ISSUES AND CHALLENGES

Our team has identified several main challenges in the development of our product. The first challenge will be researching and implementing an accurate filter design to eliminate noise. Pilots operate in an environment with a significant amount of vibrations and signal interference, which will make it a challenge to collect an accurate ECG waveform. Our team is also concerned about the possible execution speed limitations of a software filter operating in real time on the microcontroller. If we develop the design and the microcontroller is unable to filter the waveform quickly enough, it will hurt the performance of the device. One possible solution is to use a combination of hardware and software filters to meet performance and accuracy needs.

The second challenge our team identified is in designing the device driver. We want to ensure the final product is highly portable and capable of running on systems with different hardware, which may require a specific driver design. One possible solution will be to research many driver designs, find one that best fits our needs, and base our design on this.

A third challenge we are facing is in meeting rigorous real-time performance needs on the microcontroller. In addition to the software filter, our algorithm will need to analyze the ECG waveform for signs of distress, encrypt and store a full copy of the waveform, and package the data for communication with the ground through a component in the cockpit. To tackle this challenge, we will need to carefully consider performance needs of each part of the algorithm.

One final challenge we identified is how to best test our product once we have a prototype developed. Because our product is meant to be used in flight by a trained pilot, it is very difficult to

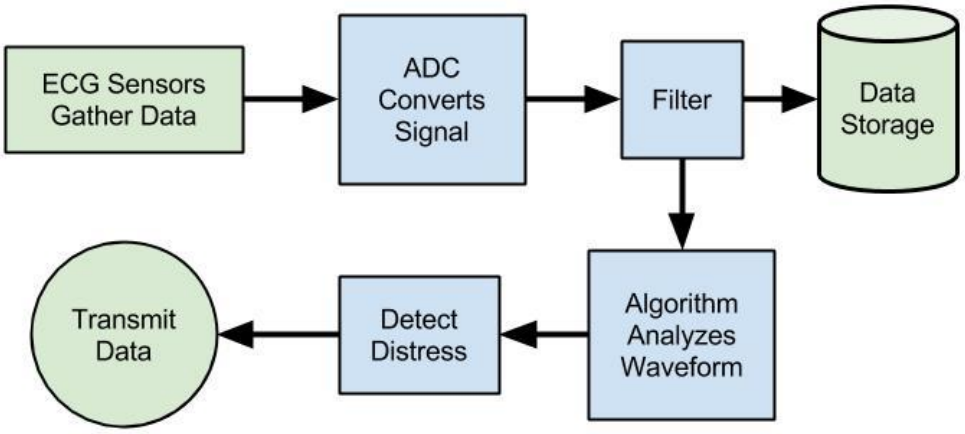
replicate the necessary conditions on the ground. To tackle this problem, we intend to test the product in a variety of ways and closely simulate the conditions as best as possible.

3.7 PROCESS

Our design begins with four ECG sensors creating an analog signal. The signal goes into an ADC to create a digital form of the waveform. The waveform data is then filtered to reduce noise. The filtered data is then stored for later use, and also analyzed to detect distress. Finally, the data is transmitted to observers on the ground.

Figure B.

This figure shows the system process from ECG measuring to transmission.



4 Closing Material

4.1 CONCLUSION

Our goal is to create a device capable of monitoring the health of a pilot during training operations and communicating critical data with ground teams. The device must be capable of running continuously for 4-5 hours and securely store 4-5 hours of operational data. The ECG harness system must not interfere with a pilot's primary tasks or ability to safely eject.

Our research suggests the best plan of action to achieve these goals is a system of four ECG sensors, connected to a harness. ECG sensor data is fed into an ADC, and then to a microcontroller for processing, data storage, and transmission. The system will use a dedicated battery pack and be designed to function under standards conditions inside an aircraft.

4.2 REFERENCES

Client: JR Spidell at Rockwell Collins

Faculty Advisor: Dr. Akhilesh Tyagi

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4.3 APPENDICES

Figure B.