Machine Learning for Human Biometrics

DESIGN DOCUMENT

SDDEC22-14

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Executive Summary

Development Standards & Practices Used

- Computer Technology standards
- Communications standards
- Cybersecurity standards

Summary of Requirements

- Analysis shall be performed in real-time in less than 1 second.
- An appropriate prompt shall be straightforward and clear and provided to the user to take a break.
- The camera shall capture images at a rate of 10 ms.
- The pupil detection algorithm shall consume 10-bit grayscale images, process images at a rate greater than 60 fps, analyze the frames under any lighting conditions and with various degrees of noise, and achieve an accuracy of 96%.
- Data shall be securely transferred to and from the device and the database.
- The database shall accept a stream of data from REMoDNaV, perform constant queries, provide data visualizations and have access to relevant parts of the system.
- A survey shall be used to analyze the accuracy of our model.
- Our project shall not violate any laws.

Applicable Courses from Iowa State University Curriculum

- COM S 363: Introduction to Database Management Systems
- CPR E 281: Digital Logic
- CPR E 288: Embedded Systems I: Introduction
- COM S 309: Software Development Practices
- SE 329: Software Project Management
- SE 339: Software Architecture and Design

New Skills/Knowledge Acquired that was not Taught in Courses

- Convolution Neural Network (CNN) machine learning model
- Robust Eye-Movement Detection for Natural Viewing (REMoDNaV) algorithm
- InfluxDB Database
- Jupyter Notebook

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- Convolution Neural Network (CNN): An eye or pupil-movement detection machine learning algorithm that detects the location of a pupil on an x-y plane at each frame using neural networks.
- Robust Eye Movement Detection for Natural Viewing (REMoDNaV): An eye-movement classification algorithm that takes in the output of the CNN model and identifies the type of eye-movement classification, i.e., saccades, fixation, error, frame by frame.
- Saccades: Quick, simultaneous movement of both eyes between two or more phases of fixation in the same direction.
- Fixations: When our eyes stop scanning a scene, holding the central visitation in place so the visual system can take in detailed information about what is being looked at.

1 Team

1.1 Team Members

- Nathanael Morris
- Ritvik Maripally
- Ron Mei Hang Teoh
- Yee Shen Teoh
- Zi-Jan Wong

1.2 Required Skill Sets for your Project

- C
- C++
- Python
- Machine Learning
- Image Processing
- HW Design
- FPGA Design
- Linux/Unix
- Database

1.3 Skill Sets Covered by the Team

- C: Nathanael Morris, Ritvik Maripally
- C++: Nathanael Morris
- Python: Zi-Jan Wong, Ritvik Maripally
- Machine Learning: Nathanael Morris, Zi-Jan Wong
- Image Processing: Nathanael Morris, Zi-Jan Wong
- HW Design: Yee Shen Teoh
- FPGA Design: Yee Shen Teoh
- Linux/Unix: Nathanael Morris, Zi-Jan Wong, Ritvik Maripally
- Database: Ron Teoh

1.4 Project Management Style Adopted by the Team

We all take turns to be team leader by adopting the Democratic style as well as using an agile project management methodology

1.5 Initial Project Management Roles

- Nathanael: Machine learning and image processing
- Ron: Database management
- Ritvik: Leader and coder
- Yee Shen: FPGA and HW design
- Zi-Jan: Machine learning and image processing

2 Introduction

2.1 Problem Statement

Our project is trying to solve the problem of surgeons continuing to perform surgery while under high amounts of stress that will negatively impact their performance. Through this project, we are aiming to reduce the chances that an error will occur during a surgery as a result of a surgeon's high stress levels or work fatigue.

2.2 Requirements & Constraints

2.2.1 Requirements

- The model shall perform analysis in less than 1 second (close to real-time).
- An appropriate prompt shall be provided for the surgeon to take a break or incorporate stress reduction behaviors.
- The Prompt provided shall be clear and straightforward to not serve as a distraction for the surgeon.
- The pupil detection algorithm shall analyze the eye movement data of a surgeon in any room condition and with various degrees of noise.
- The pupil detection algorithm shall consume 10-bit grayscale images.
- The pupil detection algorithm shall achieve an accuracy of 96%.
- The pupil detection algorithm shall process images at a rate of greater than 60 fps.
- The video camera shall capture images at a rate of 10 ms.
- The database shall accept a stream of data from REMoDNaV.
- The database shall perform constant queries.
- The database shall provide data visualizations.
- The database shall have access to relevant parts of the system.
- Data shall be securely transferred to and from the device to the database.
- A survey shall be provided after the surgery to verify the accuracy of our project.
- Our project shall not violate any laws.

2.2.2 Constraints

- Lighting condition of the surgery room
- Glares on the pupil from wearing glasses or lights
- Surgeons might ignore the prompt from the device

2.3 Engineering Standards

- Computer Technology standards: Our project required us to connect various external accessories to the Ultra96 board, and to program the FPGA of the board to meet our project requirements. For potential integration of our device with other technology, it is best to follow the computer technology standards.

- Communications standards: Our project involves communication between the Ultra96 board and a display to show the results or prompt. To make sure there is the ability of connecting to any type of display, it is important for us to follow the communication standards.

- Cybersecurity standards: Our project uses security measures and data isolation measures to incorporate safety measures against cyber threats. It is important for us to follow the cybersecurity standards to protect sensitive data collected from surgeons.

2.4 Intended Users and Uses

The users who benefit from the results of the project are:

- Hospitals
- Surgeons
- Patients
- Patient's family/friends
- Health insurance companies

The project will be used as such:

- Predicting the condition of surgeons
- Providing prompts for breaks
- Decreasing human error in surgery
- Providing data for analysis to continue improving the performance of the project
- Training new surgeons

3 Project Plan

3.1 Project Management/Tracking Procedures

Our team is adopting a waterfall+agile project management style because we have to iteratively develop our project. For instance, we need to have the database up and running in order to store the output of the machine learning algorithm. In addition to that, we need to get the Ultra96 board set up before we can connect a camera and get real-life input. However, those tasks can be overlapped to a certain degree, so we think that a waterfall+agile project management style best suits our project. We will be mainly using Discord to communicate with each other, and GitLab issues to track progress of our code repository.

3.2 Task Decomposition

We broke down the project into different tasks, and decomposed them into multiple subtasks and tie them with the specific requirements to be satisfied.

Task	Subtask	Requirements
Hardware	● Connect the microcontroller with a camera. ● Check the connection between the board and a monitor. ● Work on FPGA for visual processing.	● Camera shall capture images at a rate of 10 ms. ● Visual processing speed shall be at least 1.5 times.
Machine learning	● Set up the environment and install modules required. ● Optimize the model.	● Shall achieve at least 96% accuracy. ● Shall process images at a rate greater than 60 fps.
Database	● Set up database environment. ● Integrate database into the rest of the system, ● Perform testing on the database.	● Shall accept data from REMoDNaV and perform queries. ● Shall provide data visualization.
Security	● Research the legalities of working with human biometrics. ● Determine the authentication method and frequency to access the database.	● Shall grant database access to relevant parts of the system. ● Shall verify key and grant/reject permission. ● Shall not violate any laws.

Table 1: Task Decomposition

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

We broke down the tasks and defined the milestones of each task and their respective metrics, as well as the evaluation criteria on each milestone.

Task	Milestones	Metrics	Evaluation Criteria
Hardware	Display image from the camera on a monitor with less than 10 ms delay.	Delay	We can check that using timecode view.
	Visual processing speed increased 1.5 times or more.	Speed	Check by processing a set of visuals without the FPGA, then again with the FPGA.
Database	Set up the database environment.	Database	Database is up and able to perform simple queries
	Receive and store constant input data stream of more than 10 kB/s.	kB/s	Run the system and make sure there's no disruption of data flow
	Visualize the data generated by REMoDNaV in less than 5 seconds.	Seconds	Generate various graphs using a visualization tool and get accurate representation of the collected data
Machine learning	Achieve accuracy of 96% and above.	Accuracy	Can cross-check based on a fixed dataset
	Process frames at a rate greater than 60 fps	fps	Processing a 5 second video of 30 to 60 fps and check if the output generates 30 to 60 rows of data respectively for each frame
Security	Verify key and grant/reject permission	Key	Test by providing different keys and making sure the system grants permission to only the correct key and rejects the wrong key
	Project does not violate any laws	Law	Thorough checking the laws to ensure no violation

Table 2: Project Proposed Milestones, Metrics, and Evaluation Criteria

3.4 Project Timeline/Schedule

Our project will be carried out throughout two academic semesters, so we break down the different tasks and goals we hope to accomplish each month. However, the project schedule might change due to delays from previous tasks.

Figure 1: Project Timeline/Schedule Chart

Timeline	Tasks
January	Researching databases, security, and machine learning for the project, purchasing microcontroller for the project, develop problem statements, users, and proposed solutions (done)
February	Obtain and understand machine learning algorithm and datasets from the client, develop use cases and bounce diagram for databases (done)
March	Run machine learning algorithm fully through the datasets without errors, set up security for database
April	Train the machine learning algorithm with larger datasets, integrate the database with the microcontroller, has machine learning algorithm send data to database
May	Optimize machine learning algorithm and test security of database
August	Continuation of the project from May, catching up on any backlog work
September	Polish existing features, fix bugs
October	Marketing design, create advertisement
November	Additional features, optimize system
December	Final Documentation, Final Presentation

Table 3: Project Timeline/Schedule Chart

3.5 Risks and Risk Management/Mitigation

There are multiple risks associated with our project, so we analyzed and broke them down into how different risks are tied to each task, the probability of the risk happening, the significance of the risk, and mitigation strategies to each risk.

Task	Risk	Probability	Impact	Mitigation Strategies
Database	InfluxDB crashing	0.2	High	Have a backup database to create redundancy
Machine learning	CNN model crashing	0.1	High	
	CNN model inaccuracy	0.5	Moderate	Intensive training and testing with larger datasets
Hardware	Ultra96 overheating	0.1	High	Attach a cooling system
Security	Data leak	0.1	High	Use encryption for our data

Table 4: Risks and Risk Management/Mitigation

3.6 Personnel Effort Requirements

According to the different tasks and subtasks we broken down in Section 3.2: Task Decomposition, we came up with explanations on the tasks to perform, amount of people needed, and hours required to complete them.

Task	Explanation	Persons	Hours
Database	Research and select database for project	1	8
	Set up the database environment	1	2
	Integrate the database to the rest of the system	3	6
	Write code to perform required functionalities	2	6
	Testing the database	5	8
Ultra96 microcontroller	Select and purchase microcontroller	1	2
	Do smoke test on microcontroller	1	1
	Select and purchase video camera	1	0
	Integrate database	2	4
	Set up microcontroller for project	1	8
	Integrate machine learning algorithm	3	6
	Test and polish	5	8
Machine learning	Set up the environment, install modules, and import datasets to run the algorithm	2	4
	Understand machine learning algorithm	2	4
	Train the machine learning algorithm with larger dataset	2	8
	Optimize machine learning algorithm	5	8
Security	Research ways to secure information transfer	1	2
	Integrate security in database	2	4
	Test integrated security	5	6
	Fine tune security	5	4

Table 5: Personnel Effort Requirements

3.7 Other Resource Requirements

Based on our targeted user, we might need to conduct tests on real surgeons, then collect the data from hospitals to analyze and improve the machine learning algorithm. We will conduct a survey to aid in analyzing the accuracy of our project.

4 Design

4.1 Design Context

4.1.1 Broader Context

Area	Description	Examples
Public health, safety, and welfare	Increase the well-being of surgeons. Increasing the success rate of surgeries. Reduce mortality rate of patients from surgeries. Could also help in the quality of new surgeons' training.	● This device aims to identify signs of stress or fatigue in a surgeon during surgery and provide appropriate warning/advice to reduce the chance of human error.
Global, cultural, and social	It would increase a patient's faith in the surgeon, as the device aims to reduce human error during surgery.	● Since there will be something to monitor the surgeon performing the surgery, patients can rest assured that one more risk has been eliminated - human error.
Environ-mental	The acquisition of raw materials used to manufacture the circuit board like the Ultra96 could potentially harm the environment in several ways.	● For the purpose of this project, the Ultra96 would ideally be purchased once. Therefore, the negative effects on the environment would be minimal. ● In terms of selling this device as a product on the market, the environmental impact would be more of an issue, since manufacturing the product would require energy, as well as raw materials.
Economic	Our project requires an Ultra96 circuit board, and it costs around $250, which can be somewhat expensive. If we include the camera modules and the cost of purchasing software, the cost of the project could be more than $400. However, most of the purchases are just one-time purchases, therefore allowing for maintenance and testing without needing to purchase additional materials.	● Due to the cost of this project, it is safe to assume that it is not affordable to the general public. ● However, since our targeted users are surgeons working in a hospital, the cost of our device is very reasonably priced, and it is worth investing in since it is a life-saving device.

Table 6: Broader Context

4.1.2 User Needs

Surgeons: Surgeons need a way to warn them of signs of stress/fatigue because performing surgery while feeling stressed/fatigued greatly increases the risk of human error.

Trainers/Instructors: Instructors need a way to visualize the biometrics or emotions of a surgeon to use it as an example to train new surgeons.

Hospital Management: Hospital Management needs a way to evaluate a surgeon's capability in performing high-risk or long-hour surgeries because some surgeons tend to break under pressure and that is not ideal.

4.1.3 Prior Work/Solutions

Machine learning algorithms for pupil detection and tracking exist in the market, and models such as Convolution Neural Network (CNN), Support Vector Machine (SVM), and Starburst are used widely. Our project is similar in terms of detecting the location of the pupil and provide classification of the eye-movement.

According to a research article titled "Using machine learning to detect events in eye-tracking data" by Zemblys et al., the shortcomings of most machine learning algorithms for eye detection is that hyperparameters, a number of settings, must be manually set and tweaked until the model is performing optimally. It is possible for the model to suffer from overfitting, where a model describes random error or noise instead of the underlying relationship due to having too few samples to train on, resulting in a model with poor generalization performance. (Feb 23, 2017)

The CNN model is significantly faster than other models such as SVM because we can run the model on multiple threads, and it is easily accessible on any device. A research by Yardimci and Ayyildiz on "Comparison of SVM and CNN classification methods for infrared target recognition" stated that the CNN model is about 7.7% faster compared to the SVM model. (Apr 30, 2018)

According to an article by Dertat titled "Applied Deep Learning - Part 4: Convolutional Neural Networks," CNN model would start to memorize the training data, and would fail to generalize new instances, causing overfitting and the validation performance becomes worse. (Nov 8, 2017)

According to the same article by Zemblys et al., the solution to overcome overfitting is data augmentation. Data augmentation is a method where we generate more data for training based on our current available data sets. It augments the original data sets by generating new and different examples by random transformation on existing data sets and increasing the amount of data we can train on the model, therefore reducing overfitting. Some common augmentation

include readjusting the size, rotation, brightness, exposure, contrast, and so on to the original data to generate new and realistic images so that the augmented data are learnable for the model.

As we develop our model further, we would be making a lot of tweaks to the hyperparameters so that our model has increased accuracy and would have reduced overfitting using data augmentation. Besides the training model, we would also be incorporating a database to store data collected from the output of REModNav for analysis and evaluation.

4.1.4 Technical Complexity

Our design consists of four major components which each use different engineering principles. The first component is a video input from a camera which goes into an Ultra96 board using FPGA. The next one is CNN model which is implemented as a machine learning algorithm that computes the location of the pupil in each frame of the video stream for pupil detection. Then, REMoDNaV determines if a certain frame from the output of the pupil detection algorithm is a saccade, fixation, smooth pursuit, or unknown. The final component is a database which stores the eye movement classifications at each frame. The stored data is then used to determine the user's condition.

There are many challenging requirements for each of the components of the system and the interfaces between components which are specific and attainable. We can assume that these requirements match current industry standards because our client has made recommendations for most of the requirements and approved them. Some examples of these requirements are:

- The pupil detection algorithm shall consume 10-bit grayscale images.
- The pupil detection algorithm shall achieve an accuracy of 96%.
- The pupil detection algorithm shall process images at a rate of greater than 60 fps.

4.2 Design Exploration

4.2.1 Design Decisions

- We decided to use an Ultra96 board because it is targeted for machine learning and connectivity for add-on sensors.
- We are using the CNN model as our pupil detection algorithm because it will be faster since we can run in on multiple threads to perform matrix calculations with tensorflow.
- We are using the REMoDNaV algorithm for eye-movement classification because it is one of the efficient algorithms for this classification and it effectively classifies eye-movements even in environments with lots of noise (e.g. a surgery room).
- We are going to use influxDB for our database, since it is perfect for custom monitoring, real-time analytics, and it is optimized for time-series data.

4.2.2 Ideation

For the fourth design decision above, where we chose to use InfluxDB, we also considered using two other databases. The other options we considered were MongoDB and PostgreSQL. We identified the possible options by searching for databases that would be appropriate for our project, and then compared all of them. By searching for a broad list of options and then narrowing it down to which one we wanted, allowed us to choose the best option for our project.

4.2.3 Decision-Making and Trade-Off

The process we used to identify the pros and cons between our options was to prepare a presentation which would be used to inform the rest of the team about the potential technologies we could use. Then at the end of the presentation, a list of pros were written out to summarize each of the options, which made it easier to visualize the differences between technologies. When deciding what database to use, our database manager, Ron Mei Hang Teoh, prepared and delivered a presentation reviewing each of these databases and what they are good for, and then collectively as a team we decided which one would be best for our project.

4.3 Proposed Design

- From a machine learning perspective, we have tried some basic training and understand how the CNN model identifies and guesses the image.
- From an embedded/hardware perspective, we have received the Ultra96 board from our client and began experimenting with some simple functionalities.
- From a database perspective, we've compared several different databases and decided to use InfluxDB.

4.3.1 Design Visual and Description

In this first visual, it gives an overview of each of our main components that were talked about in *Section 3.2: Task Decomposition*. The video input is stored in DDR memory, and then the pupil detection algorithm calculates the x and y axis of the pupil from the video at each frame, the REMoDNaV movement classification component determines what type of eye movement occurred at each frame, and then the results are stored in the InfluxDB.

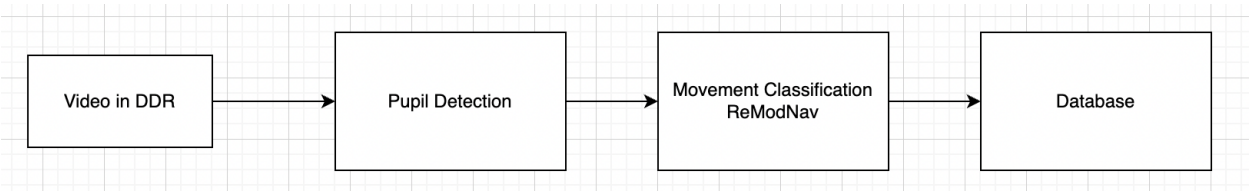


Figure 2: Main Components

The second visual shows what the Ultra96 board will look like. The camera sends a video stream into the FPGA on the Ultra96, which is then stored in DDR Memory. The Ultra96 board contains four Application Processing Unit (APU) processors and two Real-time Processing Unit (RPU) processors. The APU processors send reset signals as well as communicate with the camera using an I2C serial communication bus.

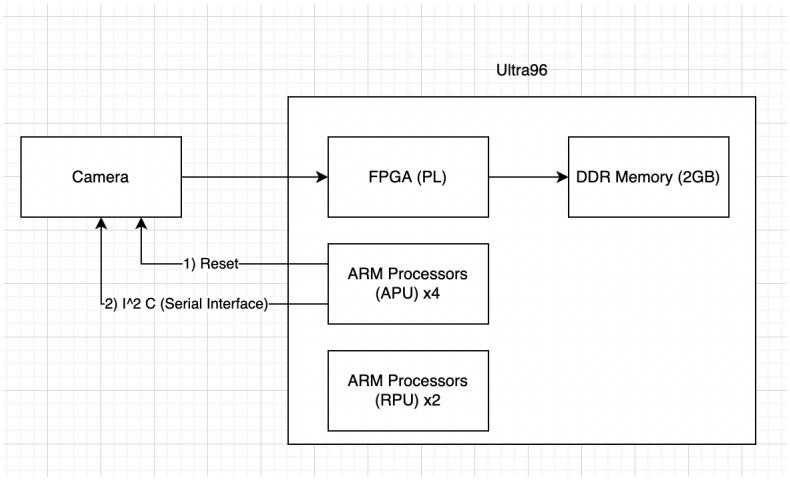


Figure 3: Ultra96 Board

The third visual representation shows how different components interface with the Ultra96 board. The camera uses the Mipi display serial interface to send video streams to the board. We are using the Mipi Display Serial Interface (DSI), a high-speed interface for displays, which is important for a real-time system. The PC uses a USB interface and programming interface to interact with the camera's datastream.

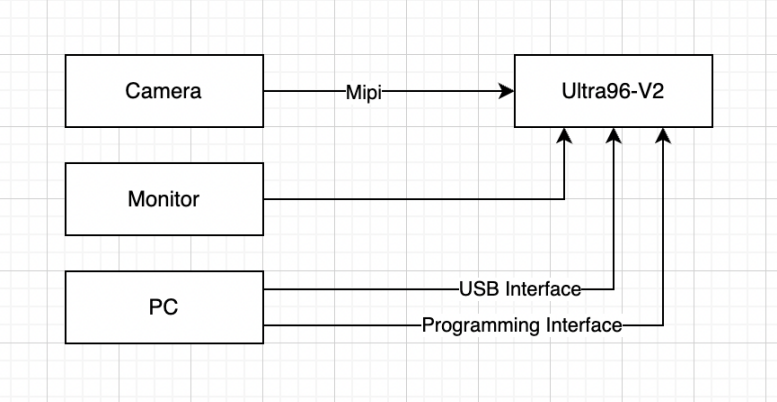


Figure 4: Various Components Interface with Ultra96

4.3.2 Functionality

This design is intended to operate in a surgery room while a surgeon is performing procedures on a patient. The design will take input from some camera, either a mounted camera in the room or one that is on the surgeon's glasses. The camera will then send its data stream to the Ultra96 board through a wire, WiFi, or Bluetooth.

Next, the computations will be performed on the Ultra96 and the output will display if the surgeon is stressed or under work-overload in as close to real-time as possible, and then give recommendations on how to lower stress levels. The current design satisfies functional and non-functional requirements because it will determine if the surgeon is stressed within an environment which could have lots of noise or inadequate lighting in real-time.

4.3.3 Areas of Concern and Development

Given our current design, some concerns are: what camera will be used to collect the data in the surgery room? How are we going to make the system run in real-time? How do we ensure that the predictions about the surgeon being stressed are accurate?

Our immediate solution to addressing the concern about which camera will be used is that we will use a camera that can have a wired input into the Ultra96 board. This camera will be used for testing our product and ensuring that it operates properly. Then, when the project is used in the surgery room, a different camera can be used based on what the surgeon or the hospital wants.

The system must run in real time to meet the requirement of receiving 60 fps from the camera. This would mean that each frame must be processed in < 16.7ms. We can address this problem by ensuring that we choose the quickest algorithms and interfaces to make sure data is

processed quickly. Over time we will continue to optimize the machine learning classifications to increase accuracy and reduce runtime.

The last concern is how do we ensure that the surgeon is actually stressed or not? Our immediate solution to this problem is to talk to the surgeon after the surgery and review times where our system determined that they were stressed. We can ask the surgeon if they were actually stressed or not, and then use this data to help the machine learning algorithm learn.

4.4 Technology

For our hardware, we have considered two different kinds of boards. They are Arduino and Ultra96. Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino are flexible enough to be used in any kind of projects, and are widely used for fast prototyping. On the other hand, Ultra96 is targeted at a few specific applications, which includes machine learning. It is also widely used for the purpose of image processing. With Ultra96, we could also run our machine learning algorithm though the board itself. But with Arduino, we would need to connect it to an external PC or computing device since Arduino itself does not have enough processing power. Ultimately, we have decided to use Ultra96 since it is targeted for machine learning and can easily be used for image processing. Most importantly, they have enough processing power to run a machine learning algorithm on its own, making it easier to use and more compact for our project.

In terms of databases, we were considering two options: InfluxDB and MongoDB. One of the strengths of InfluxDB is that it is a time-series database, meaning that each value in the database is associated with a timestamp. MongoDB on the other hand is suited to store arrays and objects. Both databases have free versions, however, we decided to proceed with InfluxDB as it would be very useful if all data in our database has a timestamp associated with it.

We are using CNN for our pupil detection algorithm as it is widely used in the market as described in *Section 4.1.3: Prior Work/Solutions*. We can run CNN on multiple threads to perform fast matrix calculations to increase the processing speed. However, some weakness of the CNN model are training the model so much that it starts overfitting and negatively impacts the performance and accuracy on the new data; or not enough training that it underfits and does not capture the input and output of the variables used on the new data accurately.

For the classification of eye movements, we decided to use REMoDNaV, because it is very effective when coming to evaluating dynamic stimuli. Current algorithms are lackluster when it comes to viewing dynamic stimuli, and REMoDNaV was created with a velocity-based algorithm, so it is suitable for both dynamic and static stimuli. The algorithm also yields eye-movement event data even in suboptimal conditions, which is extremely important in a surgery room setting, since there can be a lot of noise and various light levels. The

eye-movement classifications also include the timestamps in which they take place, which is needed to figure out when a user is stressed or overloaded.

For the cybersecurity aspect of our project we used multiple safety measures for our project. Our first major security consideration was adding encryption, mainly the PGP encryption which allows the data that's being sent from machine to database to be harder to decrypt and read in the wrong hands. Another major security measure that our team considered was how to add isolation methods onto the database so when it's not being used so cybercriminals don't have a way to access the machine at all virtually or off site. Last but not least is authentication measures, when an employee needs to check into the database to access a patient's record, the database that is authenticating the employee should have the necessary steps to prove that the employee is who they say they are.

4.5 Design Analysis

The initial proposed design mentioned in *Section 3.3: Project Milestones, Metrics, and Evaluation Criteria* is currently working and everything is working according to plan. However, we will most likely make some minor changes as we might face some unexpected issues later on. We observed that even though we know which hardware and software to use, it takes time and effort to integrate them together, as some of them require specific libraries and permission to work harmoniously. When we reflected on our overall progress so far, we were glad that we gave ourselves enough time to complete each subtask, because we did encounter some issues during the development process, and having more time to work on the issue is definitely helpful.

4.6 Design Plan

Our design plan is to consider the many different use cases for the surgeon using this device and incorporate it into our hardware device and our software. We have four main components within our project, and each use case will be more prevalent in certain modules. The four components are video in DDR, pupil detection, eye movement classification in REMoDNaV, and the InfluxDB database.

The surgeon will be using this device in a high-pressure environment, so they must receive a response within 0.1 second after the classification has been made that they are experiencing a negative response, e.g., stressed, overloaded, or fatigued. Surgeons in training could also use this device to be aware of when they are experiencing negative responses so that they can know what events are causing distress, and how to reduce the distress. Surgeons in training could also use this device to reflect on their emotions or behavior during surgery so that they can identify areas of improvement, and how to react during certain situations.This will ensure that a surgeon takes action to reduce these side effects sooner rather than later. We will

ensure that this requirement is met by streamlining the interfaces and modules so that they run efficiently and accurately.

In addition, our team brainstormed various scenarios where our finished device is compromised, and our mitigation strategies for the different scenarios. For example, the device was stolen from the hospital, WiFi connection of the device was intercepted, The database that is stored on USB drive is stolen, a hacker gains WiFi access, a hacker gains access to the PC where the database is stored, a hacker installs data monitoring software onto the machine. The threats are never ending and it's our job to remedy and prevent these threats when they come intact with our machine.

5 Testing

Testing is an extremely important component of our project, so we came up with testing plans to make sure that our project is working as intended and satisfy the requirements provided. Our test plans are divided into unit, interface, integration, system, regression, acceptance, and security testing, as well as the results of our test plans.

5.1 Unit Testing

We will mainly be focusing on machine learning, InfluxDB, Ultra96, database storage, and security. Machine learning will be testing the Convolution Neural Network (CNN) eye detection, which is to determine the average error after running training sets. Our initial requirement of error is less than 5%. Next, We will perform unit testing on InfluxDB and test the boundary values of the code.

As for Ultra96, We will run a smoke test to check if the hardware is good enough for the simplest software. After we have got most of the software working, run a stress test to make sure the hardware is able to handle heavier loads. The tools needed are a working software program and the Ultra96 hardware. Once we have those, we can start the Ultra96 testing.

For the database storage on the physical system, we will perform a penetration test to figure out bugs and safety measures of the system. Lastly, we will be doing a penetration test on the security unit as well as a risk assessment to determine the parts to be secured are protected.

5.2 Interface Testing

We have three interfaces in our design: the pupil detection interface, the eye movement classifier interface, and the database interface. The database interface can be tested by using unit tests, so we can ensure that the data being sent to the database is received in the correct format and order and to make sure that none of the data got corrupted.

The eye movement classifier interface can be tested by comparing it to data we already have. After we get the pupil locations from the pupil detection component, when we send it to the REMoDNaV movement classification component, we can ensure that the locations are accurate by comparing it to correct data that was manually gathered. After testing these interfaces, we can make adjustments to the algorithms to lower the error percentage.

5.3 Integration Testing

The few integration paths we have in our design are the machine learning algorithm, the Ultra96 board, and the database. The integration of the machine learning algorithm can be tested by seeing if the algorithm has no problems taking in the provided input, and generates a correct output format. In terms of the integration of the Ultra96 board, we need to test if the board is able to communicate with the camera to generate input and store it in the database. For database integration, we need to test if the database is able to receive input from the camera and is able to perform read/write operations.

5.4 System Testing

We will be manually providing video footage of eye movements and confirming that the system acts appropriately. All the interface and integration tests will be applicable to the system test as well.

5.5 Regression Testing

We would first create a duplicate and make sure we can roll back to our previous working model, then add new functionalities and make sure old ones do not break, and last we combine them. Besides, more testing will be required when new additions are added in to ensure that old functionalities do not break after the addition. The main implemented critical features that we need to ensure do not break are the CNN model, ReModNaV classification algorithm, tables in InfluxDB, Ultra96, as well as the security of our model.

5.6 Acceptance Testing

We will be running a few of the tests using some sample video footage that is provided by the client. After that, the output data, run time, process time, and any other observation will be recorded. Then, we will verify with the client that the design requirements are satisfied.

5.7 Security Testing

For security purposes in this project, we will be doing a risk assessment on exactly what needs to be protected and potential risks that can be used against us or future clients that may use our service/product. When the risk assessment is done, the initial phase of tweaking to increase safety measures will be implemented then will proceed with penetration testing acting as the perpetrator in order to breach our system. This process will repeat till the majority or if not all safety measures are implemented.

5.8 Result

We have not done much testing yet as we are still in the process of developing our project. However, we are testing each component before they are integrated into the main components to ensure compliance with the requirements by observing and obtaining data from each test. From those data, we would be able to determine if the requirements are satisfied. Furthermore, we can start building up more testing for our devices once all components are finalized, since we will be more familiar with our design and understand what kinds of testing are important for our implementation.

6 Implementation

Our implementation plan for the next semester currently is to increase the accuracy and increase the frames processed by the pupil detection algorithm. Next, we also plan to ensure that our database is able to ingest and output data as fast as the rate of frames processed by the pupil detection algorithm so that nothing gets bottlenecked. Besides, we will come up with a survey that contains a list of questions that can help us determine the accuracy of our model after the surgery. Questions such as “Are you feeling stressed at [timestamp] time?” or “Do you think the prompt given “[prompt]” is helpful?” are useful for us so that we can improve our model.

We will also work on streaming data through all the components. We will have to take live data as an input into a camera, and then run it through the classification algorithms and then into the database.

7 Professionalism

This discussion is with respect to the paper titled “Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment”, International Journal of Engineering Education Vol. 28, No. 2, pp. 416–424, 2012

7.1 Areas of Responsibility

We decided to look into the comparisons between the area of responsibility of NPSE and IEEE code of ethics as well as how they differ from each other.

Area of responsibility	Definition	NSPE Canon	IEEE Canon	Comparison between NPSE and IEEE
Work Competence	Perform work of high quality, integrity, timeliness, and professional competence	Perform services only in areas of their competence; Avoid deceptive acts.	To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations.	NSPE has a similar definition to IEE Canon. NSPE defines work competence as only working in areas that you’re competent in, while IEEE Canon defines it as only working in areas that you are qualified or have experience in.
Financial Responsibility	Deliver products and services of realizable value and reasonable cost	Act for each employer or client as faithful agents or trustees.	to reject bribery in all its forms	NSPE defines financial responsibility as being faithful and delivering products at a reasonable cost while IEEE defines it as rejecting all forms of bribery.

Table 6: Comparing NPSE and IEEE Code of Ethics

Area of responsibility	Definition	NSPE Canon	IEEE Canon	Comparison between NPSE and IEEE
Communication Honesty	Report work truthfully, without deception, and understandable to stakeholders	Issue public statements only in an objective and truthful manner; Avoid deceptive acts.	To be honest and realistic in stating claims or estimates based on available data.	NPSE and IEEE differ a bit, where NPSE requires public statements to be truthful while IEEE must be honest and realistic in stating claims and should be backed up by data to prove.
Health, Safety, Well-being	Minimize risks to safety, health and, well-being of stakeholders	Hold paramount the safety, health, and welfare of the public.	To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to promptly disclose factors that might endanger the public or the environment.	The NSPE and IEEE have similar triads for this area. But the IEEE has additional clauses that specify disclosing factors that might endanger the public.
Property Ownership	Respect property, ideas, and information of clients and others	Act for each employer or client as faithful against or trustees.	To seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to properly credit the contributions of others.	NSPE defines property ownership as respecting the owners of any properties, ideas, or information, while IEEE defines this as to credit anything that doesn't belong to yourself.
Sustainability	Protect environment and natural resources locally and globally	N/A	N/A	There is no code of ethics that corresponds to the area of sustainability for both NSPE and IEEE.
Social Responsibility	Produce products and services that benefit society and communities	Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honey, reputation, and usefulness of the profession.	To be honest and realistic in stating claims or estimates based on available data.	The NSPE version is more about public images, but the IEEE version focuses more on being honest and informative.

Table 7: Continuation of Comparing NPSE and IEEE Code of Ethics

7.2 Project Specific Professional Responsibility Areas

We rank (High, Medium, Low, and N/A) each of the professional responsibility areas in *Table 6: Comparing NPSE and IEEE Code of Ethics* according to how relevant they are towards our project:

- Work Competence: This responsibility area does apply to our project's professional context because our project will need to be of high quality, or the device may not be as accurate as needed, leading to incorrect predictions. Timeliness is also important with our project because our whole team is relying on other team members to get work done. If some members don't work competently, it could delay the project. [High]

- Financial Responsibility: Our team is responsible for sticking to the budget given to us by our client. We will be delivering our product at a reasonable cost since we will only be using a few hardware components that are provided to us by our client. [High]

- Communication Honesty: This responsibility area is VERY important to our group as this project requires a lot of time and communication. If information is not being communicated properly, it could lead to problems and distrust by the client which could end very badly for this project and class. If information is also not truthfully said, it could lead to imbalances and misunderstandings in the group which also could be a major problem. That's why we need to keep honest and consistent communication throughout the project. [High]

- Health, Safety, Well-Being: This responsibility area is not super applicable to our project, since there are not many health and safety risks present. For the well-being portion of this area, we can ensure that members are being helped when working on a challenging part of the project. [N/A]

- Property Ownership: This responsibility is somewhat important for our project since we are being loaned hardware equipment from our advisor and it is our responsibility to take good care of it. We also must be respectful of the ideas and information that our team members and clients share with one another by having healthy conversations. [High]

- Sustainability: As a team, our project really doesn't affect the environment as much as other things but the one thing we could do is not waste or reuse resources within our project. [N/A]

- Social Responsibility: This is similar to communication honesty, the team has a responsibility to produce a quality product from the resources given by the client. We also have moral standards/responsibilities for this class so we must be honest and thoughtful for what we do. Furthermore, we are working on a project that would help the general public determine their health with eyeball movements, which would greatly benefit society now since most people are overworked and have jumbled-up sleep schedules. [High]

7.3 Most Applicable Professional Responsibility Area

One area of professional responsibility that is important to our project, and for which our team has demonstrated a high level of proficiency in the context of our project is the social responsibility where we produce products and services that benefit our society and communities.

Our project is to develop a human biometric system that tracks the eye movement of users and determine if they are stressed, fatigued, lack oxygen, and so on and will determine if the user needs to rest or any action is required. Because the human eye is very vulnerable and valuable, we should do everything we can to protect it.

Our team constantly thinks of ways to have more data to produce an accurate result, ensuring that our product is consistent and accurate so that it can reliably give advice to anyone who uses our product. Our project started out as something that would be focused on helping society, so it was already the main focus since the start of our project. In conclusion, our high social responsibilities would benefit society and communities.

8 Closing Material

8.1 Discussion

We have not implemented our product yet. So far, we are working on different parts of the project before putting it all together. Those parts consist of hardware, a machine learning algorithm, a database, and security. While we are working towards completing different parts of the project, we have been meeting the requirements in each area. We will continue to check if the requirements are met when working towards our final product to make sure that our overall product is as specified.

8.2 Conclusion

In terms of the database side of things, we have researched and compared several different databases and decided to go with InfluxDB. We have also identified the several scenarios and use cases of the database as well as if some scenarios are happening in real-time or not. For instance, as the database is getting input from the device, everything is happening in real-time, so we have to take the processing time into consideration. On the other hand, when we are just querying from the database, the processing time is not much of a concern.

Given the scope of our project, we have done well adhering to the goals and working within the constraints and requirements. However, it is important to keep in mind that we do not have a working prototype yet, so even though we are on schedule, it is too early to assume that we're getting everything right. In the future, we could have potentially allocated more time for us to get familiar with the software/hardware environment, since most of us do not have experience with the environment we are working on. For instance, most of us do not have experience with the Ultra96 Board, CNN, REMoDNaV, or InfluxDB.

8.3 References

A. H. Dar, A. S. Wagner, and M. Hanke, “REMoDNaV: Robust Eye-movement classification for dynamic stimulation,” *Behavior Research Methods*, vol. 53, no. 1, pp. 399–414, 2020. Available: https://link.springer.com/article/10.3758/s13428-020-01428-x

Dertat, A. (8 Nov, 2017). “Applied Deep Learning - Part 4: Convolutional Neural Networks.” *Towards Data Science*. Available: https://towardsdatascience.com/applied-deep-learning-part-4-convolutional-neural-networks-584bc134c1e2#:~:text=The%20main%20advantage%20of%20CNN,CNN%20is%20also%20computationally%20efficient

J. Chandran and A. Joseph, “2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI),” in *Eye Gaze as an Indicator for Stress Level Analysis in Students*, 2018.

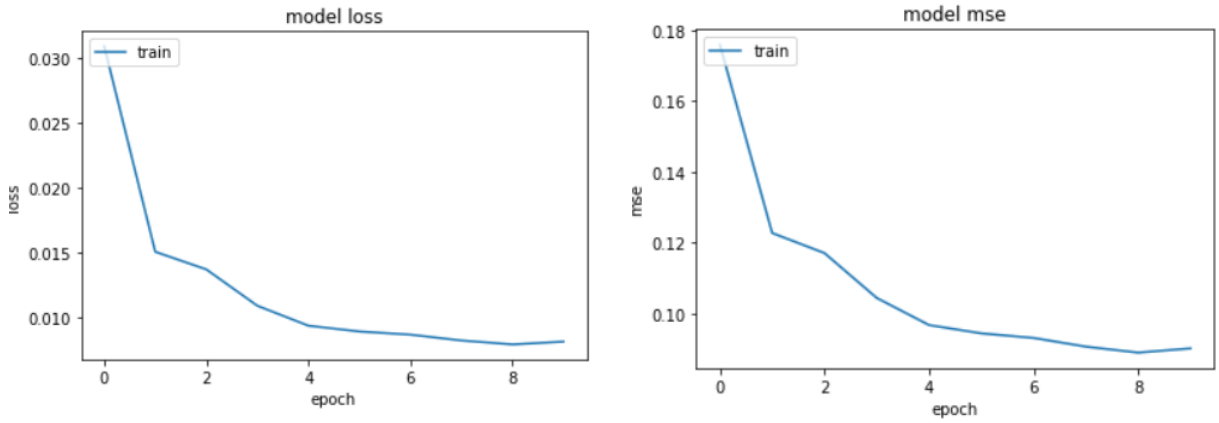
Mccormack, J., Beyerlein, S., Davis, D., et al. “Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment.” *International Journal of Engineering Education*, vol. 28, no. 2, pp. 416 - 424, 2012.

“Ultra96-V2,” *Avnet*. [Online]. Available: https://www.avnet.com/wps/portal/us/products/avnet-boards/avnet-board-families/ultra96-v2/ultra96-board-family/?CMP=AVNET-AMER-PPC-GG-USA-English-AVE14-DSA-1658060323-62203480245-122018&gclid=Cj0KCQjw6pOTBhCTARIsAHF23fLWYiI0vHfm8BuELrqo1gk494Z5A09KFl2vmPrdUV7Uo_pLC72iue0aAruIEALw_wcB. [Accessed: 24-Apr-2022].

Yardimci, O., & Ayyıldız, B. C. “Comparison of SVM and CNN classification methods for infrared target recognition.” *SPIE Proceedings*, vol. 10648, no. 4, 30 Apr, 2018. Available: https://doi.org/10.1117/12.2303504

Zemblys, R., Niehorster, D. C., Komogortsev, O., et al. “Using machine learning to detect events in eye-tracking data.” *Behavior Research Methods*, vol. 50, pp. 160 - 181, 2018. Available: https://doi.org/10.3758/s13428-017-0860-3

8.4 Appendices



Graph of loss and mean squared error (mse) when training the pupil detection algorithm

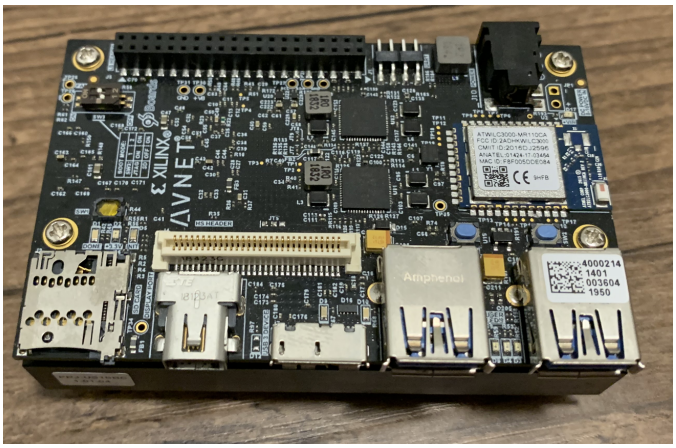


Image of the Ultra96-V2 Board

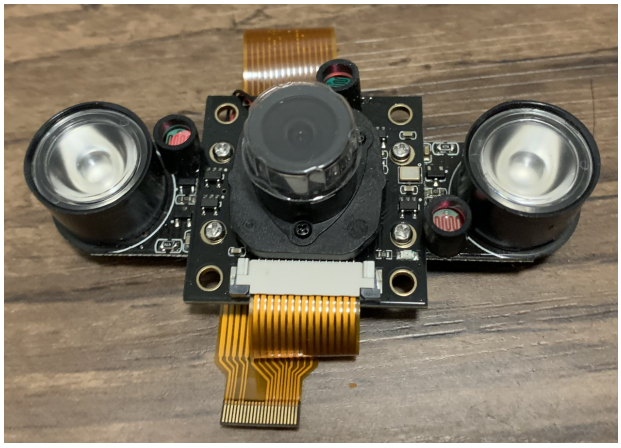


Image of OV5647 Camera Module by ArduCam

8.4.1 Team Contract

8.4.1.1 Team Members

- Nathanael Morris
- Ritvik Maripally
- Ron Mei Hang Teoh
- Yee Shen Teoh
- Zi-Jan Wong

8.4.1.2 Team Procedures

- Day, time, and location for regular team meetings:
    - Virtually on Mondays at 8:00am with the advisor.
    - Virtually on Mondays at 4:30pm with the client.
    - Virtually on Sundays at 10:00am with team members.

- Preferred method of communication updates, reminders, issues, and scheduling:
  Email, Telegram and Discord.

- Decision-making policy:
  Consensus

- Procedures for record keeping:
  We will take turns to write the meeting minutes, and the minutes will be shared via Discord.

8.4.1.3 Participation Expectations

- Expected individual attendance, punctuality, and participation at all team meetings:
    - Full attendance and participation, and punctual to all meetings: team members need to be informed at least 2 days in advance if members are expected to be absent.

- Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
    - High level of responsibility: completing assignments in a timely manner and in good quality.

- Expected level of communication with other team members:
    - High level of communication: important information must be announced in the appropriate Discord channel.

- Expected level of commitment to team decisions and tasks:
    - High level of commitment: must have sufficient input during meetings and committed to completing tasks given.

8.4.1.4 Leadership

- Leadership roles for each team member:
    - Nathanael: Machine learning manager
    - Ron: Database management
    - Ritvik: Team organization/communication
    - Yee Shen: Testing manager
    - Zi-Jan: Client and advisor interaction

- Strategies for supporting and guiding the work of all team members:
    - Each team member will present their work for the past week during the meeting so that everyone knows what is going on.
    - It is also essential that everyone can pick up where they left off.

- Strategies for recognizing the contributions of all team members:
    - A simple meeting minutes will be written by different members each meeting to record contributions and ideas given by each member.
    - The contributions of each member will be written in the weekly report that will be submitted and sent to the advisor and the client.

8.4.1.5 Collaboration and Inclusion

- Skills, expertise, and unique perspectives each team member brings to the team:
    - Nathanael: I love to learn new things from other people and I have good teamwork and conflict management skills. I also have good programming skills.
    - Ron: Willing to learn new things, have experience working long term with a group of people.
    - Ritvik: Programming skills related to cybersecurity and leadership qualities from previous clubs.
    - Yee Shen: Moderated programming skills. Embedded system knowledge. HW, FPGA, and VLSI knowledge and design skills.Bringing in the perspectives of an EE student.
    - Zi-Jan: Good programming skills, capable of working in a team, willing to learn new things and take on challenges.

- Strategies for encouraging and support contributions and ideas from all team members:
    - Listen to ideas from everyone and be respectful to each other's ideas.
    - Our team's brainstorming motto is: "*No idea is a dumb idea!*"

- Wait for members to finish speaking before chiming in with opposing ideas or thoughts.

- Procedures for identifying and resolving collaboration or inclusion issues:
    - Bring up the issue privately with the particular team member. If there is no improvement, we will bring it up during team weekly meetings and we will discuss as a team and compromise to reach a common ground.

8.4.1.6 Goal-Setting, Planning, and Execution

- Team goals for this semester:
  Plan and research our project so that all team members have an excellent understanding of how the project will work and how we will build it/execute our planning next semester.

- Strategies for planning and assigning individual and team work:
  Each week we will be having a meeting with our client and with our group, and during these meetings we will discuss what each team member will be working on for the following week.

- Strategies for keeping on task:
  We will have weekly meetings to make sure everyone is on the same page, and that all team members are putting in an adequate amount of work.

8.4.1.7 Consequences for Not Adhering to Team Contract

- If there are infractions of any of the obligations of this team contract, we will bring up the infractions with all team members and figure out a way to fix it.

- If the infractions continue, we will have an internal discussion to fix the issue. If the issue persists, bring up the issue to the professor/advisor.

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*
b) *I understand that I am obligated to abide by these terms and conditions.*
c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*

1) RON MEI HANG TEOH	DATE 2/11/2022
2) ZI-JAN WONG	DATE 2/11/2022
3) NATHANAEL MORRIS	DATE 2/13/2022
4) YEE SHEN TEOH	DATE 2/13/2022
5) RITVIK MARIPALLY	DATE 2/13/2022