Adaptive Mechanical Stage and Diagnostics Tool

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1 Executive Summary

This design pitch highlights the Adaptive Mechanical Stage and Diagnostics Tool (AMSaD) design concept that will aid eHA (eHealth Africa) with the battle against malaria. Currently, eHA is looking to improve the conditions in Nigeria by introducing a design concept into their laboratories. The urgency posed by the threat of malaria requires more efficient results and presents an opportunity for process optimization that aligns with the stakeholders' needs. The AMSaD design seeks to automate the diagnosis and testing procedure that lab technicians go through by introducing two main components. The AMS component consists of an adaptive stage which will be placed on the stage of the microscope used by lab technicians. The Diagnostics Tool consists of a CNN (convolutional neural network) that is trained on a dataset containing malaria blood samples and cells. The CNN uses this information to help identify if a cell is or is not infected and outputs the appropriate diagnosis. A few key design decisions were made in the process, including the integration of the physical component (now being the AMS) as well as what training data to use for the Diagnostics Tool. This design pitch goes over the requirements and value propositions of the design concept as well as how it is valid for the target stakeholders.

2 Introduction to Design

2.1 Context

Malaria, a life-threatening disease transmitted by infected female mosquitos, is one of the big health concerns in Nigeria. Nigeria has the highest malaria risk with them being responsible for the 32% of overall deathroll counts due to malaria [1]. Malaria is a preventable and curable disease. However, the slow diagnosis and delivery system are hindering the improvements in the number.

The primary stakeholders in this situation are eHA patients living in Nigeria and eHA itself. The patients will be directly impacted by the design proposed since their diagnosis or the way they will receive their test result will depend on it. eHA is responsible for the entire system of collecting blood samples, diagnosing, and delivering the results back to the patients.

2.2 Opportunity statement

From the problem statement understood by the team. The team is looking to create a method or solution to improve the testing in the eHA labs. eHA's clinical lab malarial microscopy processes need to be efficient to deliver results faster to their patients. The urgency posed by the threat of malaria requires more efficient results and presents an opportunity for process optimization that aligns with the stakeholders' needs.

2.3 Value Proposition & Requirements Introduction

The scope of the project heavily implies automation. The value propositions that automation brings forth include convenience, efficiency, and accuracy. A few of the key tasks to optimize identified by the team (and eHA directly) include moving slide inserts, image processing, and the diagnosis time. The given value propositions directly align with the tasks identified, allowing tangible benefits to be realized through the given design. In our case, convenience refers to the ability to use something with little to no intervention. This means a solution would minimize the manual labor any technician, patient, or anyone else involved will have to do. Efficiency is achieved by making a part of a process or many processes take less time for completion. This can be seen through completing a greater number of tasks in the same amount of time, completing the same task in less time, or ideally a combination of both: more tasks in less time. Accuracy is described by being more precise. As the nature of the task has great implications for patients and eHA alike, high accuracy is another particularly important metric and value to be held.

After understanding the stakeholder's needs there are requirements that must be fulfilled for this design to bring holistic value. A few of those requirements include cost, longevity, safety, accuracy, efficiency, and privacy. We understand these requirements are vital to the solution based on what they represent and will be further elaborated on in the background. In the general case, having a solution towards a malaria-based problem must meet some basic standards in terms of handling and distribution such as safety and privacy. Furthermore, for the solution to be considered better than the null solution described in the requirements must be fulfilled such as accuracy, cost, longevity, and efficiency. This is all being spoken in a relative context, as well as considering stakeholders' needs given that the requirements hold similar values to the stakeholders.

2.4 Design Overview

Our final design concept consists of two parts: First, an adaptive microscopy stage with an image classifier that identifies plasmodia and second, a convolutional neural network that determines whether each cell identified is infected or not. Our design exhibits 3 key values: accuracy, convenience, and efficiency.

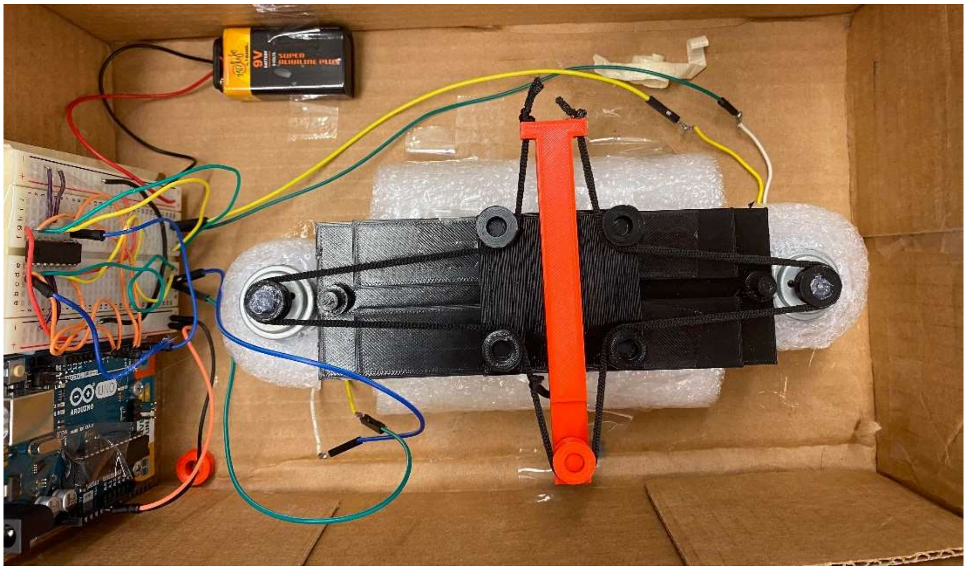

Figure 1: The physical prototype of the AMSaD, capable of fully controlled planar motion to center images

2.5 Requirements

2.5.1 Convenience

We achieve convenience through the automation of the diagnosis process. From slide and stage manipulation through to the diagnostic result determining, the design requires minimal intervention except for possible verification. The Adaptive Microscopy Stage component of the design shifts the stage using an image classification model to enable consistently taken images to be used as suitable inputs for the Diagnostic Model. The Diagnostic Model is fed the images of each plasmodium and decides whether the sample is infected or not. The design also runs off a microprocessor, which with its small size and affordable pricing, introduces the possibility of scalable design.

2.5.2 Efficiency

Similar to convenience, efficiency is obtained through a union of each part of the design concept. Individually, savings on time are not as obvious as when the two work together. Having a diagnostic model still requires each cell to be imaged and the imaging itself requires constant adjustments from the technician. Automating both aspects allow for imaging that is well suited to the demands of the model and working with larger batches continuously will lead to efficient results over time.

2.5.3 Accuracy

The design concept requires the model accuracy be at least as high as the methods currently employed by eHA, and through our research of reference designs, we know test accuracies of greater than 97% are very possible. Pre-trained models such as AlexNet have shown great promise and can be used as reference (or as a whole) for the final design. The current prototype accuracy is approximately 95% and given that we do not know what eHA's current diagnostic accuracy is, we can only hope to be as accurate as possible.

2.5.4 Safety

Keeping in mind the safety standards surrounding machine learning models and other uses of artificial intelligence described in detail in the safety standards ISO/TR22100-5:2021, we realize that our design does not pose a risk to the patient's nor the technicians' safety beyond the risks already associated with eHA's methodology. As neither component of the design interacts directly with patients, their safety is unaffected by the design. The motors involved with the movement of glass slides has also shown minimal risk since the motors themselves do not appear to be strong enough to damage a slide and create a hazard.

2.5.5 Cost

The budget assigned to the prototype was CAD \$150 and we found that the final prototype fit within this budget quite well. The costliest components of the prototype were: Arduino Nano ~\$15, 3D printed stage ~\$12 assuming a high-quality PLA filament, and motors for about \$10. The diagnostic model and software components of the prototype (and design) will have no direct costs associated with the design. The final design, however, will include higher quality motors that are able to make finer movements. Higher quality components are naturally more expensive and could harm the scalability and affordability of the design concept.

2.5.6 Privacy

Another requirement we asked of the design is to uphold the privacy of the patients. Because the model is pretrained and exists locally on the microprocessor, their blood samples are not stored there. Furthermore, the data that is shared with the technicians will only be seen by them and approved for distribution however they choose. As a follow-up, the concept could include a UI aspect that allows patients and technicians to upload results to a database for viewing. Ultimately, data regarding an individuals' test results is kept secure and has does not interfere with eHA's current privacy practices.

2.6 Concept Design Decisions

Through an enormous amount of planning and discussion the team produced the final prototype by considering the values of the stakeholders. Ourselves being one of the stakeholders, we recognized our strengths in machine learning and programming. This allowed us to move forward with the idea of using a CNN and using it to identify malaria in patients. However, based on our success using AutoCAD, the team wished to create a physical solution to the problem as well. The microscope was the main instrument of use for the malaria diagnosis process, so creating a way to automate that was a goal. That is where the Adaptive Microscopy Stage (AMS) portion came into the design.

A major design decision that was included in the prototyping of the design was the use of a camera and centering software. The AMS utilizes a software component that detects dyed malaria cells and positions the picture in a way that can be read by CNN. This was key in creating an automated solution to the problem by introducing an extra step of automation.

3 Background Details

3.1 Stakeholders

As mentioned above, eHA patients living in Nigeria and eHA itself are the primary stakeholders in this situation. eHA patients living in Nigeria are primarily people from an urban setting who can access their lab reports in person, but also people from a rural area who can get their results delivered in paper format. An improved design could potentially be the difference between a diagnosis before the patient's health is in danger and a diagnosis when it is too late to fully recover so it is crucial that the overall system is fast and accurate for their health. As mentioned before, eHA is responsible and is the one that runs the whole malaria diagnosis and delivery system so making an improved design to any part of the system would greatly benefit the flow of the system in a way that it will be faster, more accurate, less costly, or have a longer life.

3.2 Scope

Using decision tree analysis, the preliminary scope of the project can be narrowed down to the automation of the diagnosing processes. The errors of traditional methods for diagnosing malaria in malaria testing centers of resource-poor settings are primarily attributed to a lack of well-trained technicians. Since eHA's mission is "to make microscopy processes such as moving slide insets and image processing efficient to deliver faster results." We can then scope it down further to the automation of the clinical lab microscopy processes. We decided to use a software approach to analyze the blood sample. And we used a Pugh chart to evaluate multiple machine learning methods. After scoping down the situation, we decided to use image recognition and convolutional neural network to detect malaria parasites. After working with the diagnostic model, we recognized the need for hardware support. Thus, we are focusing on automating the diagnosing process using convolutional neural network and centering images using a hardware approach.

3.3 Detailed Value Proposition

One of the primary objectives of our team's design is accuracy. Using a neural network and a dynamically moving stage, we minimize random errors in the diagnosis processes, helping provide consistent and reliable results. The stage complements the neural network by centering samples to be processed, which produce inputs similar to the training set to yield more accurate results. As the accuracy is enhanced, both Type 1 Errors (False positives) and Type 2 Errors (False negatives) can be significantly eliminated. [2] Risk to a patient of a false negative result includes: delayed or avoidance of therapy and lack of monitoring of the symptomatic individuals and their household members or other close contacts. On the other hand, false-positive diagnoses can lead to unnecessary quarantine and repeated testing of noninfected people and waste valuable resources. Therefore, ensuring the accuracy of the test result will mitigate the risk of the spread of malaria within the community or other unintended adverse events and save eHA's medical resources. Moreover, convenience is an essential value of our design. It requires less manual work than the current method, reducing the task to just the dying process. The whole design runs off a simple microprocessor with at minimum 2 pulse width modulation ports, 4 digital outputs at a very affordable price. Since less manual force is required, clinics can save money on hiring staff and on-the-job training, and it allows them to spend more on upgrading their medical equipment, purchasing medical supplies, and providing treatment. We also highly prioritize efficiency, assuming a batch dying process, our design can determine whether a sample is infected within seconds of receiving images of the sample. Paired with the moving stage's consistent imaging, the clinic can produce more results in less time. Therefore, more patients in Nigeria can get prompt diagnosis and treatment. One UN sustainable development goal is regarding "Good Health and Well-being" The United States aims to "Ensure healthy lives and promote well-being for all at all ages." By enabling accuracy, convenience, and efficiency, our design allows more patients to receive treatment so that the health and well-being of patients in Nigeria will get tremendous improvement. Therefore, our proposed design is in line with the UN sustainability goal indeed.

3.4 Service environment

The proposed design must work under the environment of the clinical lab in the eHA. Moreover, the Adaptive Microscopy Stage must be able to run on the object stage of the microscope under the assumption that the mechanism can be mounted on the microscope model being used in eHA's lab.

3.5 Previous Approaches

The team previously tried a concept that would increase the effectiveness of the delivery process. This solution was met with difficulty as the requirements were harder to judge using this approach to a solution. There was no tangible way to verify nor validate a delivery solution, and the strengths of the group were just not put at the forefront in that design concept.

When looking at similar solutions, there are two articles that highlight the automation process in malaria testing and diagnosis. The first speaks on the Sysmex-30 analyzer [3]. The analyzer uses an absolute approach to finding the total number of infected cells within a blood sample as well and the percentage of infected cells. The analyzer can determine such values by using the same fluorescence dye to stain parasitized blood cells as eHA uses. The second detection system put into place is called the automated microscopic malaria parasite detection system [4]. This system with its high accuracy of finding parasites (R^2 of 0.958) can detect parasites and evaluate the state of the given patients.

None of these solutions are feasible due to the overhead costs that they incur. The second system mentioned costs $18,000 USD to purchase, and while that may not seem much for the accuracy it provides, it is likely too costly for eHA. Furthermore, there is little to no machine-learning used in the solutions, rather a software-based analysis which can prove to be useful when dealing with diver datasets. However, since the data that the CNN will be exposed to is exclusive to malaria patients in Nigeria, the model will be more inclined to give positive e results based on data it has already seen (previous similar patients).

3.6 High Level Standards

High-level standards that the solution must meet can be interpreted as constraints that the solution must meet. Any solution must be accurate, time-efficient, cost-efficient, safe, private, and have a long life. Accuracy is a crucial requirement to have because the whole purpose of the diagnosis is to correctly predict whether the patient is infected with malaria or not and if the model is inaccurate that defeats the whole purpose. Time-efficiency is also very important because when checking if a patient has malaria, in the off-chance that they do, they need to know this information as soon as possible so that they can get the treatment they need to stay in good health, otherwise, things could get quite dangerous for them. Safety is also a primary objective because if the physicians are potentially put in harm's way from using the team's design, then the design should not be allowed in the workplace. Cost is another important objective because eHA has a limited budget, so the team must be able to make a design that requires a minimal cost to implement. Privacy is important because patients' information is something that should not be shared with anyone but themselves and maybe the physicians, so it must be kept somewhere private. Finally, longevity is important because eHA needs the design to last for the long term until malaria is eradicated or else the system could break down, for example if this design breaks down in the workplace.

3.7 Primary Level Standards

Objective	**Metrics**	**Criteria**	**Constraints**
Accuracy	Numerical measurements of how well it identifies malaria in blood sample. Unit: [Precision] and [Accuracy]	The more accurate the model is the better ▪ Less false positive the better. ▪ Less false negative the better.	Must have similar, same, or better accuracy than the null solution.
Time Efficiency	Percentage difference in time taken to determine results from when samples are collected between Null Solution and proposed solution	Higher time efficiency is preferred (higher percentage difference faster).	Must take as much time or less time than the null solution.
Safety	Boolean measurement of whether the solution meets all applicable safety regulations. Measured as indicated by standards.	Safer design will be more preferred.	Must meet safety standards highlighted by ISO/TR22100-5:2021; (yes)

3.8 Secondary Level Standards

Objective	**Metrics**	**Criteria**	**Constraints**

Cost	The cost of the design for it to be prototyped. The cost of the design to be manufactured or implemented in the long term. Unit: [CAD]	Lower cost is preferred.	The prototype must be less than $150 CAD. Must be within eHA's budget when the implementation is scaled.
Privacy	Boolean: yes/no	N/A (yes)	Must keep the results of the testing procedure completely private. In no situation may the condition of the patients be known to anyone else other than the patients. (yes)
Longevity	Time (years)	Higher longevity is preferred.	Maintenance can be done without specialists/technicians or special parts or needs to last long enough such that it does not disrupt the maintenance schedule of a technician under regular use. (>30 years – predicted lifetime of malaria)

3.9 Design Concept Validation & Verification

To verify and validate the design to meet the team's criteria, we went through a checklist procedure as a group and deduced how well each aspect of the design contributes to each criterion. This allowed us to judge the design in an objective yet democratic fashion and converge in the same sense. This is how the combination of using software and hardware components to increase the efficiency and accuracy of the design came to be. Using a voting system and attributing points to each requirement per each design, as a team we were able to verify and validate our choice of final design.

4 Methods & Key Design Decisions

4.1 Project Management Plan

The Project Management Plan played a key role in the distribution and management of work among team members, the decisions that the team made, and how the team would move forward on certain topics and discussions. For the team, the PM plan allowed us to use various models such as the decision matrix, pros and cons list, and debate format to come to sound decisions. On top of that, the roles that each member was responsible for (such as notetaker, issues-coordinator, etc.) allowed for work to be tracked, recorded, used, and completed on time.

4.2 Key Design Decisions

One primary design decision that we made was to switch from AlexNet to our current CNN model. AlexNet[5], being a CNN architecture with 8 layers in-depth, requires heavy computation to conduct and would be very practical if the microprocessor being used had the ability to run such a robust architecture. However, given the microprocessor we use, we needed to use a much simpler but still effective CNN that can detect malaria in an easier manner. Therefore, we built a CNN model which has only four layers in total. This was done through a series of meetings, long debates, and pros and cons lists which are all tools highlighted on the Project Management Plan.

Another key design decision that used the Project Management Plan is the recognition of needing a hardware approach after working with the CNN model. When working on the design, we were informed by the Praxis team about the need for a physical component using the knowledge from the Widget Studios that we had acquired. This was taken to the issues coordinator, who logged in to the issue and decided to have a meeting on it. She realized that the images fed to the model had to be consistently taken. However, the camera is mounted on the eyepiece of the microscope, if we want to move the slide around until the sample is in the center of the field, we have to track the position of the sample through the viewfinder of the camera. Due to the nature of the lens being used and eye motion, the images in the viewfinder may appear distorted. [7] If we choose to remove the camera and manually center the sample in each round of test, the microscopy of multiple slides will be very time-consuming and inconvenient. To obtain high-quality images in an efficient and convenient manner and ensure accuracy, our team used a decision matrix to choose which approach to create a physical prototype with (as in which Widget Studio to focus on). With one of the members being well equipped with AutoCAD, the team moved forward with a solution that used AutoCAD which came to be the AMS.

4.3 Prototype Validation & Verification

The validation and verification process for the prototype was a technical task and required many iterations for each component. For the diagnostic model, the dataset was split into mutually exclusive training, validation, and testing subsets that were used to evaluate the model. Furthermore, the hyperparameters were tuned frequently and thoroughly to provide more accurate results in a (computationally) smaller package. One of the important features tuned included the switch from 256 by 256 sized input images (with 0-padding) to compressed 128 by 128 images. This change reduced the load on the Arduino and made training and testing much faster. As for the Adaptive Microscopy Stage, we were able to verify the design through testing proxy features.

Using a colored cube as a proxy for the stained cell (dyeing process), the motors were able to rotate the arms of the stage to orient the middle of the stage to the center of the frame.

Since the prototype consists of two separate parts, the team verified and validated that each individual part of the prototype met the proposed requirements instead of looking at it as a single design. With regards to the adaptive microscopy stage with the image classifier, in order to verify that it meets the requirements stated above, since the team does not have access to actual blood samples that are dyed, the team tested that it functioned as expected for several different other objects of different colours. This was done by holding them at each corner of the camera, which would be the microscope, and checking if the motors would activate which signifies that the prototype recognizes that the "blood sample" is not centered and is attempting to bring it to the center by activating the motors and spinning the base in the correct direction. Through this testing method, it can be concluded that our prototype meets the accuracy requirement. Although it cannot be confirmed through testing that our method is more efficient than the null solution, since we are limited by our equipment and budget, with the right equipment our design theoretically will be faster in insertion and centering of the blood sample in comparison to how fast a physician would do it. Ideally, if the physician places the blood sample anywhere on the stage of the microscope, both the longevity and safety requirements are met if the prototype is used properly. Finally, the design is a single-purchase cost just for the equipment which should be under the budget that eHA has, meeting the cost requirement. With regards to the convolutional neural network, we verified that our prototype meets accuracy requirements by running it with the test set from TensorFlow. The neural network currently has an accuracy of 95% with 6 epochs which can be slightly improved upon, and the team can verify that this accuracy would be unchanging from actual samples with our Adaptive Microscopy Stage which ensures that the inputs into the convolutional neural network will be of similar form to that of the data from TensorFlow that our model trained on. It can be shown that this part of our prototype is efficient as it takes only a few seconds to run through a single sample whereas for the null solution that is currently implemented in can take around a few minutes due to the test strip device taking a while to analyze the strip or due to the physician carefully examining the dyed blood sample through the microscope [6]. Cost, safety, and longevity do not apply to this part of the prototype as it is simply stored in the microprocessor so its cost is negligible, and it can't get modified or malfunction unless the chip gets damaged.

4.4 Previous Approaches

Some previous approaches that were mentioned above are the Sysmex-30 analyzer and the automated microscopic malaria parasite detection system. The team's solution is an appropriate choice in relation to these reference designs because the team's solution is hardware and software combination design, it is more experienced with detecting malaria cases from Nigeria, and it is cheaper. By being a hardware and software combination design, the team's solution excels in convenience as it can both adjust the blood sample and detect whether it is infected with malaria whereas the two reference designs only do the detection part. The team's convolutional neural network is trained on blood samples like the ones that eHA will insert into our design which gives our solution an advantage over the reference designs which are not trained on previous blood samples but simply just software solutions. Finally, the last reason the team's solution is appropriate for eHA in comparison to the reference designs is because the team's solution costs much less, with a total cost of under $150 CAD whereas one of the reference designs costs $18,000 USD.

4.5 Global Virtual Collaboration Reflection

Through global virtual collaboration with Georgia State University, we gain much useful feedback to help us improve our design and reach our final design in the end. We collaborate with our GSU counterparts through regular meetings and a Q&A document. We also receive feedback from her regarding our design proposal. She pointed out both strengths and weaknesses of our proposal so that we could make corresponding adjustments to optimize our design. For instance, she suggested we include more sustainable production practices into our design, providing an affordable design to help combat inequalities and promoting health and well-being at all ages within the communities.

5 Final Outcome (Design & Prototype)

5.1 Validity of Design

Initial communication with the stakeholders, eHA, helped us identify the primary need to have a more efficient diagnosis and results delivery. Along with this, it was made known that parts of the eHA's malarial microscopy processes such as adjusting slide inserts and processing images taken via the microscope were key bottlenecks to address in pursuit of a more efficient system. Our design addresses the inefficiencies in both the image processing and slide insert adjustment halves of the diagnostic procedure through automation. The technicians insert the dyed samples into the microscope the same way as before, except now the microscope is fitted with the Adaptive Microscopy Stage. From here, consistent, and clear (not distorted & in-focus) images of the sample are taken and fed to the Diagnostic Model (CNN) which can then determine a reliable diagnosis result within seconds. The only interaction necessary with the process is the technician's input of the slide and possible verification of results at the end. Lab staff can therefore use the time saved however they like, for example: collecting more samples, tending to more patients, and preparing samples for testing. The minimal interaction with the process, the saved time, and the high accuracy of the model all showcases the three primary value propositions of the design: efficiency, convenience, and accuracy. Beyond addressing the needs of the stakeholders, the design is a valid and feasible choice based on the additional criteria & requirements determined earlier, such as cost, privacy, efficiency, and accuracy. The design being run off an inexpensive Arduino Nano and software allows the design to be scalable as well as adaptable to the setup eHA chooses.

5.2 Limitations and Assumptions

Some limitations that the team has with respect to the Adaptive Microscopy Stage are a lack of information about the stakeholders and a lack of resources. A lack of information about the stakeholders results in possible incompatibilities between the equipment that the team currently uses to build the prototype and the equipment that the people at eHA use. This forces the team to assume that their prototype can be mounted on eHA's microscope without any incompatibilities. A lack of resources, for example, funds, results in the team having limited access to equipment that can fully carry out its function without any problems. This was a problem that occurred when testing movement of the Adaptive Microscopy Stage where the motors were not strong enough to pull the stage simply because they were not powerful enough. This forces us to assume that for actual implementation the motors are good enough to move the stage and make fine adjustments at the microscopic level so that the blood sample can be perfectly centered.

One limitation that the team has with respect to the convolutional neural network is that the model does not have a 100% accuracy, so it fails to classify 5% of the images. This means that, although the whole diagnosis system is practically automated, it would still be required to have a physician there to confirm that what the neural network classifies is correct. One final assumption that the team needs to make is that the Adaptive Microscopy Stage system and the diagnostics model can be integrated seamlessly. This is a necessary assumption because there may be issues capturing images with a camera through the microscope & the colors determined by OpenCV may not be correctly identified, so the two parts of the prototype could potentially not be perfectly synchronized.

5.3 Feasibility of Design

The prototype fulfills many of the key aspects of the design concept. Looking at the Diagnostics Tool, our current neural network being used to for the diagnosis of malaria performs at approximately 95% accuracy as mentioned above. Although the accuracy of eHA's current methods is unknown, we hope to improve on this metric as much as possible. In order to feasibly and cost-effectively implement the design concept, the realized product needs to be computationally light enough for a small inexpensive computer to run it. The prototype model is demonstrably light enough to run off the Arduino Nano and leaves enough room computationally for the OpenCV model to run the Adaptive Microscopy Stage prototype as well. This is a realized and functional part of the design concept. However, rather than outputting a binary result, 1 or 0, the final design must include a user-friendly interface to aid in the interpretability of results by non-technical staff and patients. This implementation will take less time to do than CNN itself and adds to the feasibility of the final design.

Looking at the Adaptive Microscopy Stage, the feasibility of this design hinges on the hardware accessibly to design with. The limitations of the AMS prototype are a result of poor hardware such as faulty actuators and motors too weak to move the main arms of the stage. The bands along the arms and motors in theory should work with better belts and surface friction. The k-means algorithm has not yet been implemented but given that the algorithm is known, it should be easier to implement. Under our assumptions from above, it is likely that the design concept is feasible. However, this does not take away from the fact that when these are implemented and used in unison with the Diagnostic Tool the final design seems to be feasible.

5.4 Teamwork

The Diagnostics Tool was completed by using a GitHub repository to assign tasks to every member of the group. Using the tasks assigned parts of the Diagnostics Tool had started to develop, parts of the neural network. Examples of a few tasks are included below in Figure 2

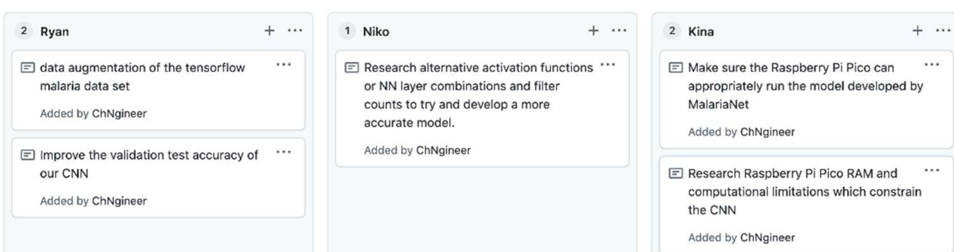

Figure 2: Screenshot of GitHub tasks

The AMS was completed via AutoCAD and visits to the Myhal LFF. The initial physical component of the AMS was completed via AutoCAD and 3D-printed, which was done mainly by Kina who has a vast amount of experience in that field. Next, using the breadboard and motors to allow the stage to move the physical component of the stage was complete. Lastly, creating and using an algorithm to detect and center to the stage to the correct position finished the AMS portion of the prototype. All these parts were done by the team, having each member use their strengths in hardware and software to finish the prototype. Ryan helped with the hardware components of the motor while the rest of the group worked with the software side of things.

6 Conclusion and Next steps

The final design provides a valid solution to the intended environment by allowing all requirements established by the team and eHA to be fulfilled. As mentioned above, the cost, longevity, accuracy, efficiency and privacy of the new design are all improved upon or upheld. With that being said the desired value is provided to the primary stakeholders and proves to be a valid solution.

As mentioned before, the prototype shows how the different value propositions of the design are met via the prototype. The AMS and Diagnostics Tool allows both convenience and efficiency in the entire process by reducing the workload on the technicians. Furthermore, the accuracy of the Diagnostic Tool is based on a CNN which is overall more accurate than the current identification measures. These elements of the prototype verify the design concept as a whole.

Looking at ways to further develop the design, there are a few approaches that can be used. One of them is to reduce the number of assumptions made in the prototype to increase the feasibility of the design. For example, assuming the AMS can be mounted on the microscope while not knowing the microscope model is not ideal. Furthermore, using the right camera to capture images through the microscope lens, again on a microscope model that we do not know. These assumptions can easily be avoided by finding the appropriate information needed to make sure the design is feasible, such as the microscope model.

In terms of testing the prototype, the two need to be done in unison to ensure the design is feasible. Right now, when testing the team has made sure the prototype is functional as two separate components. However, a key assumption is that they work in unison, but this may not be the case when trying to integrate the two components. To further develop both the design concept and prototype concrete components must be used and stated for the design and prototype. The AMS prototype uses polylactic acid, an open breadboard and an underpowered motor. All these factors can be improved by specifying more solid components like using a specific type of plastic for the AMS instead.

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8 Appendix

8.1 Team Values

As a team, we strongly value communication, equity, punctuality, safety, and work-life balance. Our individual values form a basis for effective communication and being able to build off of each other's strengths. As a team of both Machine Intelligence and Engineering Mathematics, Statistics, & Finance students, we carry a broad skillset among us to address the design opportunity, with possible designs ranging from delivery optimization algorithms to machine learning diagnosis models and hardware automation designs. Collectively we play the roles of researcher, system and design engineers while individually we have roles that play to each of our unique strengths. We believe that cohesion among our values and shared vision have allowed us to develop an effective solution for our stakeholders.

Kina Kim	
Responsibilities:	Project Planning, Facilitating, System and Design Engineering, and Researching
Experiences & Values:	From Praxis widget studio learned how to handle hardware components. I utilized the widget skills with personal software knowledge to build the prototype. While working, communication and safety - one of the team's shared values - came across. Clear communication was essential for everyone's input to be implemented in the prototype and safe handling of the tools ensured no potential dangers. Also, learning from experience outside of the classroom, I tried to make effective use of the shared platform. This allowed thorough communication among the team which allowed us to achieve work-life balance, timeliness, and fairness.
Experiences & Management Plan	From Praxis I and II experience, I understood the importance of clear communication. Also keeping tracks of those communications. So, I always tried to double confirm all the information or decision made within the team. Once decided, I added into our main platform of communication to reassure all and to make sure no one misses the information.
Contribution to Team's Success	I have tried to initiate the conversation in the team, make sure all the team members feel included. Throughout the project, I actively made inputs and for the final presentation

	contributed in making the physical prototype to demonstrate our final design.
Ryan Chen	
Responsibilities:	Project Planning, Systems, Design, Data, and Electronics Engineer, Machine Learning Researcher, Issues Coordinator and Note Taker
Experiences & Values:	Experience with robotics and microprocessors for physical prototyping, critical decision-making for agile deadline management and product delivery. Experiences were acquired throughout high-school, extra-curricular robotics, and widget studios as part of Praxis III. Values effort and dedication within the team, and safety, usability, and efficiency in design. Values were discovered and refined through Praxis and engineering ethics course work.
Experiences & Management Plan	Management plan experiences center around delivering a minimum viable product which is presentable, acceptable to stakeholders, and accurately reflects the original vision. These ideals stem from previous Praxis experiences, where presenting a feasible and promising prototype significantly improved stakeholder interest. Primary contributions to the plan include agility in pivoting the design plan when new stakeholder information rendered previous solution infeasible, execution of the plan in constructing the actual prototypes, and general overhead for design insight.
Contribution to Team's Success	Extensive hardware and software prototyping, project direction under tight deadlines. Responsible for the final iteration of the CNN prototype and the intermediate process of data pre-processing, training, validating, and testing the model. Contributor to the moving stage prototype through design of the electronics circuit used to manipulate the interlocking components of the 3D printed prototype. Responsible for technical explanation of CNN and response to

	questions regarding prototype specs in presentation.
Rupin Khadwal	
Responsibilities:	Project Coordinator, Editor, Researcher, Risk Coordinator, Presenter, Design and Systems Engineer.
Experiences & Values:	Experience working with software and hardware projects. Value working in a group environment in a respectful manner. Working in parallel creates efficiency and well-done work.
Experiences & Management Plan	The management plan is to deliver a working product under the practices designed by the group. Using decision matrices and debates to come to sound decisions and outcomes.
Contribution to Team's Success	Extensive work on the deliverables such as the brochure and document. I was ill for the presentation but was able to still show. Helped formulate the ideas for the prototype and design concept as well as distribute the needed work to each team member.
Arjun Sharma	
Responsibilities:	Project Coordinator, Issue Coordinator, Presenter, & Editor. Shared responsibility of researcher & design engineer
Experiences & Values:	Research experience and communication skills will lend themselves to the teamworking and technical demands of the team. As a researcher I've learned to uphold the value of objectivity through identifying biases in my work and minimizing them where possible. In making design decisions, I hope to reduce my designer's bias and look for solution designs beyond my skillset.
Experiences & Management Plan	My work on the project management plan was helping with discussion and encouraging everyone to share their opinions. Working in many team environments and leadership roles I find it very important to maintain psychological safety and develop healthy relationships with teammates. Specifically, my time in Praxis I and II helped me develop the team building skills and a better

	appreciation for ground rules and shared understandings during group formation. I made sure to share these insights and create a more open and communicative environment within the group.
Contribution to Team's Success	I contributed greatly to the brochure, presentation, and document by leveraging my past research, writing, and presentation experiences to help develop a greater final product. Being aware of many different parts involved in each stage helped with answering most non-technical questions and helping deliver the cohesive product. Earlier in the semester I helped identify areas for our design to pivot to, the machine learning model direction in particular. I helped look for datasets and reference designs to verify the idea as a plausible solution.
Nikolas Marinkovich	
Responsibilities:	Note Taker, Time Keeper, Systems Engineer, Design Engineer, Researcher, Cost Coordinator, Global Team Peer Liaison, Global Client Liaison, Machine Learning Researcher
Experiences & Values:	Research experience, engineering document experience, and communication skills result in values of communication and teamwork. Additional values of punctuality, safety and equity come from experiences working and being part of sports teams and school teams.
Experiences & Management Plan	My past experiences from praxis I and II align with the project management plan as many of the approaches of coming into agreement as a team and resolving conflict come from past successes that I have had from those two courses. Apart from that, from past mistakes that I have made in praxis, some parts of the project management plan, such as in the section for feedback, are purely built for the purpose of not making said mistakes again so that I become a better team member.
Contribution to Team's Success	Contributions to early research for the development of the machine learning model

	with regards to data collection for training, decisions revolving around scope and values, and extensive work on the brochure, presentation, and final document.
Yanni Lu	
Responsibilities:	Systems Engineer, Design Engineer, Cost coordinator, Component Purchase Coordinator, Researcher
Experiences & Values:	Research experience and experience in designing an investment banking solution from a summer internship. I developed skills in thorough analysis and empathetic thinking to help reduce bias when framing a potential solution from my past experience.
Experiences & Management Plan	In Praxis I and Praxis II, I learned how to manage project operations, keep track of the design process, and facilitate group meetings. These experiences in engineering design projects allowed me to help manage the design process to create a successful final design. Moreover, my personal values for equity, punctuality, and work-life balance directly align with our team values, which contributed to team collaboration and successful production of our final design.
Contribution to Team's Success	I contributed to the design brochure, final presentation, and report. My strong mathematical background helps with all our team's quantitative analysis, including areas of cost management, risk assessment, cost management and optimization.

8.2 Bill of Materials

Material	**Cost ($)**	**Justification**
Arduino Nano	34.99	Needed to control the motor and various parts of the AMS.
Polylactic acid	25.99	Material needed to construct the AMS.
Breadboard	18.99 (per 3)	Needed to link the various parts of AMS together such as the battery, motor driver and Arduino Nano.
Motors	15.98 (per 10)	Needed to move the AMS along the y-axis and x-axis.

Wires	16.99 (per 120)	Needed to connect pins between different components via the breadboard.
9V Battery	10.25 (per 10)	Needed to supply power to different parts of the AMS, mainly the motor.
USB, A to B Cable	8.67	Needed to connect the Arduino Nano to the computer.
Motor Driver	15.36	Needed to control the motor.

The other components that are not mentioned include a computer and 3D printer. Even though these are required to construct the prototype, they are not necessarily part of the prototype itself. The Diagnostics tool runs via a .ipynb file which can be run on programs like Google Collab and Jupyter Notebooks which do not necessarily have a cost. They must use a computer to run on, however do not use the computer itself in a sense, so adding it to the bill of materials did not make much sense. Also, the 3D printer has the same argument, where the printer is not part of the prototype, rather a way to create it.

All the components listed in the Bill of Materials are justifiable, none are listed that are used for aesthetic or compactness purposes (such as the box and Styrofoam in the box). Each component is necessary for the design, and none would work without the other portions which rationalize the choice of components.

Arduino Nano - https://www.amazon.ca/KeeYees-Module-ATmega328P-CH340G-Arduino/dp/B0816SGKHH/ref=asc_df_B0816SGKHH/?tag=googleshopc0c-20&linkCode=df0&hvadid=335201232415&hvpos=&hvnetw=g&hvrand=4919307603335694020&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000839&hvtargid=pla-877589932303&psc=1

PLA - https://www.amazon.ca/Filament-Metallic-Printing-Materials-Composite/dp/B07PF94VHC/ref=asc_df_B07PF94VHC/?tag=googleshopc0c-20&linkCode=df0&hvadid=459658227836&hvpos=&hvnetw=g&hvrand=9221919049899202776&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000839&hvtargid=pla-897422411479&psc=1

Breadboard - https://www.amazon.ca/Breadboard-Solderless-Prototype-Distribution-Connecting/dp/B01EV6LJ7G/ref=asc_df_B01EV6LJ7G/?tag=googleshopc0c-20&linkCode=df0&hvadid=292901727348&hvpos=&hvnetw=g&hvrand=7949679365914525859&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000839&hvtargid=pla-368202573973&psc=1

Motors - https://www.amazon.ca/Gikfun-Motor-Electric-Arduino-EK1291x10C/dp/B06WLL6QM5/ref=asc_df_B06WLL6QM5/?tag=googleshopc0c-20&linkCode=df0&hvadid=292968375828&hvpos=&hvnetw=g&hvrand=7919378567334922947&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000839&hvtargid=pla-493374726681&psc=1

Wires - https://www.amazon.ca/Elegoo-120pcs-Multicolored-Breadboard-arduino/dp/B01EV70C78/ref=asc_df_B01EV70C78/?tag=googleshopc0c-

20&linkCode=df0&hvadid=292982668700&hvpos=&hvnetw=g&hvrand=13030025212830283420&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000839&hvtargid=pla-362913641420&psc=1

USB, A to B Cable - https://www.amazon.ca/AmazonBasics-USB-2-0-Cable-Male/dp/B00NH11KIK/ref=asc_df_B00NH11KIK/?tag=googleshopc0c-20&linkCode=df0&hvadid=293004044609&hvpos=&hvnetw=g&hvrand=4859241181387478819&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9061009&hvtargid=pla-331160418120&psc=1

9V – Battery - https://www.amazon.ca/AmazonBasics-Everyday-Alkaline-Batteries-8-Pack/dp/B00MH4QM1S/ref=asc_df_B00MH4QM1S/?tag=googleshopc0c-20&linkCode=df0&hvadid=292954640612&hvpos=&hvnetw=g&hvrand=2426280540224374897&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000839&hvtargid=pla-332122495433&psc=1

Motor Driver - https://www.mouser.ca/ProductDetail/Texas-Instruments/UC3770ANG4?qs=qQ1QRlPY81blhXhicDccIg%3D%3D&mgh=1&gclid=Cj0KCQiAzMGNBhCyARIsANpUkzMAlvST2oW7MEvZnoh9dwii7mgsl6M463P5gfsKg5KePyo2WH-IFqkaAkM0EALw_wcB