ASEE 2022 ANNUAL CONFERENCE
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MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37349

# Low-Cost Raspberry Pi Compute Module 3+ Cluster for Mosquito Research via Capstone Project


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# Low-Cost Raspberry Pi Compute Module 3+ Cluster for Mosquito Research via Capstone Project


## Abstract

Mosquitos might have caused approximately seven hundred thousand deaths per year. Monitoring environmental factors for potential breeding sites of mosquitoes is an important and effective method in mosquito control. Several networks and systems for mosquito research have been developed in academic settings. For the research in this paper, the developmental progress of a low-cost data server and the network in the form of an IoT (Internet of Things) system with undergraduate engineering students is presented. A low-cost data server was proposed as one of the IoT system implementations for mosquito research. This low-cost cluster framework will be presented in this paper, which consists of multiple low-cost Raspberry Pi boards. A cluster was formed using four customized Raspberry Pi compute module 3+ (RPi CM3+) boards. In addition, the low-cost data server consists of a network switch, a custom interface PCB, and an enclosure. The network switch provides communication between the RPi CM3+ boards. The interface PCB was designed to provide power to the custom RPi CM3+ boards. An enclosure with a fan was designed and fabricated to secure all these boards and provide cooling to the system. Using this RPi cluster platform, a micro-Kubernetes cluster has been configured. One of the RPi CM3+ boards is configured as a master node, and the other CM3+ boards are configured as worker nodes. An Android application has been under development to access the data for the IoT cluster data server. The prototype cluster device was created by a capstone team at Texas A&M University. The capstone team was created in Fall 2020, and the capstone project was concluded in Spring 2021. Further research and development on this RPi cluster for mosquito research is in progress in the Dr. Hur's research group by one of the students who joined the graduate degree program.


## I. Introduction

Mosquitos can be deadly and might have caused approximately seven hundred thousand deaths per year due to the transmission of the diseases from people to animals [1][2]. Monitoring environmental factors for potential breeding sites of mosquitoes is an important and effective method in mosquito control. Several networks and systems for mosquito research were developed in academic settings [3][4]. For the research in this paper, the developmental progress of a low-cost data server and the network in the form of an IoT (Internet of Things) system with undergraduate engineering students at Texas A&M University is presented. For the IoT server for mosquito research, environmental sensor data from the sensor node devices may need to be periodically uploaded to a data server. The data from various locations can be analyzed as required by the scientists and researchers.

As one of the IoT system implementations for mosquito research, a low-cost data server was proposed and considered in this research [5]. This low-cost data server was developed as a cluster framework [6][7]. Using this low-cost server cluster, the formation of a large scale of a network could be more feasible. This low-cost cluster framework was proposed to use multiple low-cost Raspberry Pi boards. This research formed a cluster using four customized Raspberry Pi compute module 3+ (RPi CM3+) boards. In addition, the low-cost data server consists of a network switch, a custom interface PCB, and an enclosure. The network switch provides communication between the RPi CM3+ boards. The interface PCB is designed to provide power to the custom RPi CM3+ boards. An enclosure with a fan was designed and fabricated to secure all these boards and provide cooling to the system.

For the cluster configuration in this paper, one of the Raspberry Pi compute module 3+ boards works as a master node and the rest of the three RPi CM3+ boards work as worker nodes. They are connected using a network switch. Students have created a functional cluster system for the capstone project, and the cluster system has been verified to collect the sensor data properly. In the next phase, after the capstone project period, this research is still in progress with one of the students who stayed in this department as a graduate student. Using this RPi cluster platform, a micro-Kubernetes cluster has been configured. Kubernetes is also known as K8s, and it has strength in creating a reliable and highly scalable cluster [8-10]. Micro-Kubernetes (microK8s) is a lightweight version of Kubernetes, and it can be run on Raspberry Pi boards [11-13]. One of the RPi CM3+ boards is configured as a master node, and the other CM3+ boards are configured as worker nodes. An android application has been under development to access the data for the IoT cluster data server.

This capstone team was started in the Fall semester of 2020, and the capstone project was concluded in the Spring semester of 2021. The research and development have been continuing in the Dr. Hur's research group. One of the prior capstone students has joined the master's program in Fall 2021, and he has been making new and further progress on RPi clusters. This paper includes further progress on the RPi cluster development. This paper will introduce the educational effort related to a capstone project, and it will show the continued research and development effort in the low-cost RPi clusters for mosquito research.

## II. Capstone project management

Engineering Technology programs have effectively executed experiential learning practices via capstone or senior projects. Students could solidify their learning through rigorous two-semester capstone project courses in the Engineering Technology programs at Texas A&M University. One of the faculty in this paper, Dr. Hur, has been teaching a junior-level embedded system course [14][15]. Students could be given a reasonably challenging term project to help their education in this course. In Fall 2019, a robot challenge as the term project was given to the students [16]. For this robot challenge, students need to build their version of a two-wheeled robot using an MSP432 launchpad board and a custom educational board to tackle several given missions. The scores for each mission were determined, and there was the top group of students for the term project for the robot challenge mission portion. This student group has chosen to work on the Dr. Hur's capstone project. They joined a capstone team and this capstone project started in Fall 2020. During this capstone project period, the mode of operation was limited due to COVID-19. Weekly meetings were held over online Zoom meetings, and there were only a few in-person meetings. In the end, despite the challenging situation, students could complete the project to meet the capstone requirements and create the functional prototype device.

For this capstone, there were four undergraduate engineering students, and the name of the capstone team was Autonomous Integrated Monitoring Network (AIM-N). For this capstone project, one graduate student and one faculty member from the Computer Science Department came to help and mentor the students. This RPi cluster research and development is one of the ongoing research projects in the Dr. Hur's research group.

## III. Raspberry Pi Compute Module 3+ Cluster for Mosquito Research

Mosquito researchers can use a primary IoT server to collect the data from multiple remote server nodes. The remote server nodes are placed at the potential breeding spot to interface the environmental sensors and image data. The primary IoT server can be implemented as a cluster server.

### A. System block diagram of the RPi compute module 3+ cluster

A low-cost RPi compute module 3+ cluster was adopted for the primary IoT server component. Figure 1 shows the system block diagram of the RPi compute module 3 cluster. On the left side, it shows the primary IoT RPi cluster. It consisted of four custom RPi CM3+ boards and ethernet modules. In order to cool down and generate airflow, a decent size fan was used in this platform. This RPi cluster can be accessed via the internet. On the right side, it shows remote server nodes. The remote server nodes represent IoT devices at remote locations. Each remote server node has a Raspberry Pi 3 B/B+ board, camera, environmental sensors, and GPS module. For testing and data collection, four remote server nodes were built. These remote server nodes can access the RPi cluster. They are similar to IoT data servers., and they can upload the measured sensor data and location information.

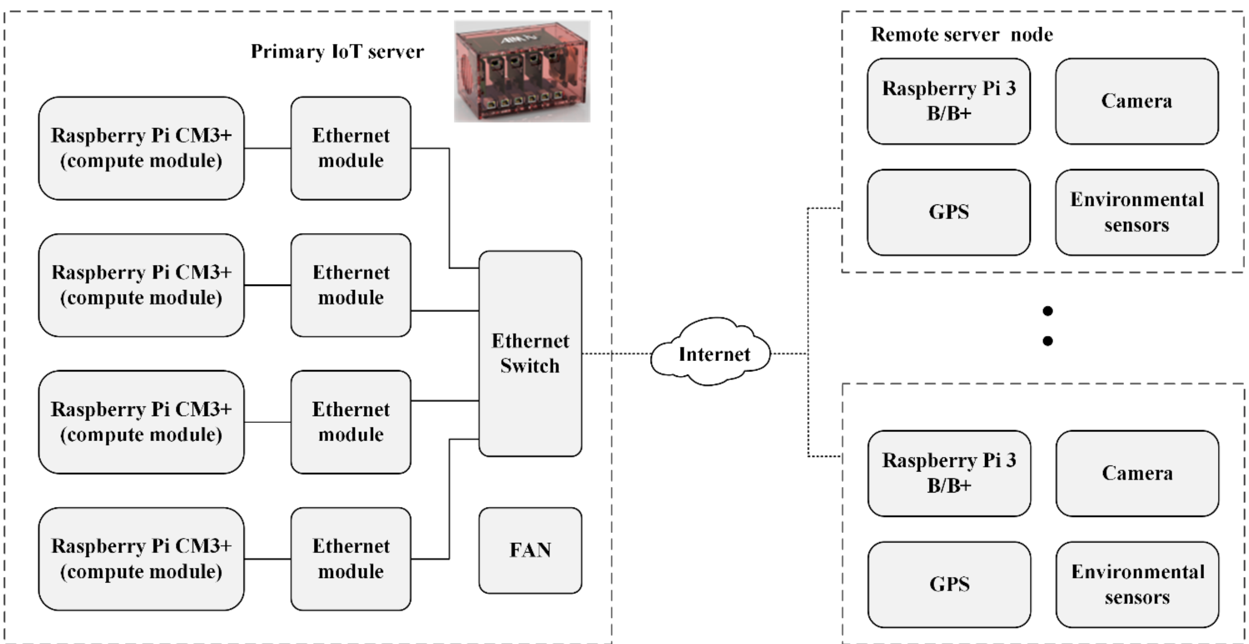


**Figure 1. System Block Diagram of an RPi compute module 3 cluster.**

### B. Custom RPi CM3+ board

On the primary server, the custom RPi CM3+ boards were used. Figure 2 shows the simplified block diagram of a custom RPi CM3+ board. This custom RPi CM3+ board has a Raspberry Pi

CM3+ module with USB and HDMI connectors. This board has buttons, LEDs, and an onboard temperature sensor. Moreover, a 40-pin connector provides connectivity to the custom interface board. A custom interface board was designed to hold these four RPi CM3 boards and handle power distribution and fan control.

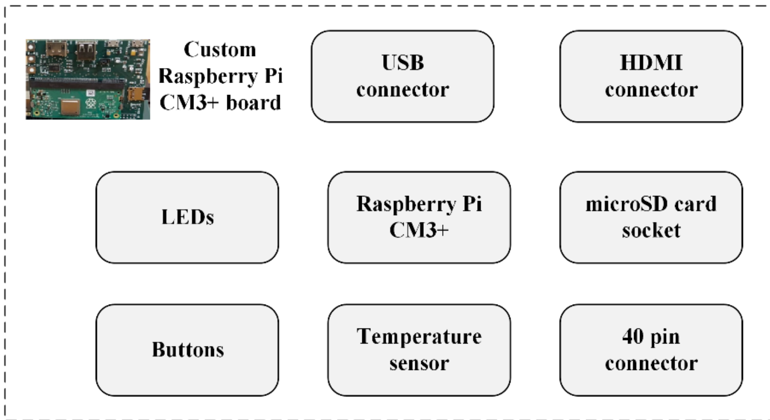


**Figure 2. Simplified block diagram of a custom RPi CM3+ board.**

### C. System Integration

Figure 3 shows the integration of the RPi cluster system. On the right side, it shows four custom RPi CM3+ boards installed on the interface board. Each RPi CM3+ board has a RPi compute module 3+. On the left side, it shows the ethernet switch for internet access and the communication between modules. Moreover, a fan is delivered and installed on an acrylic enclosure.

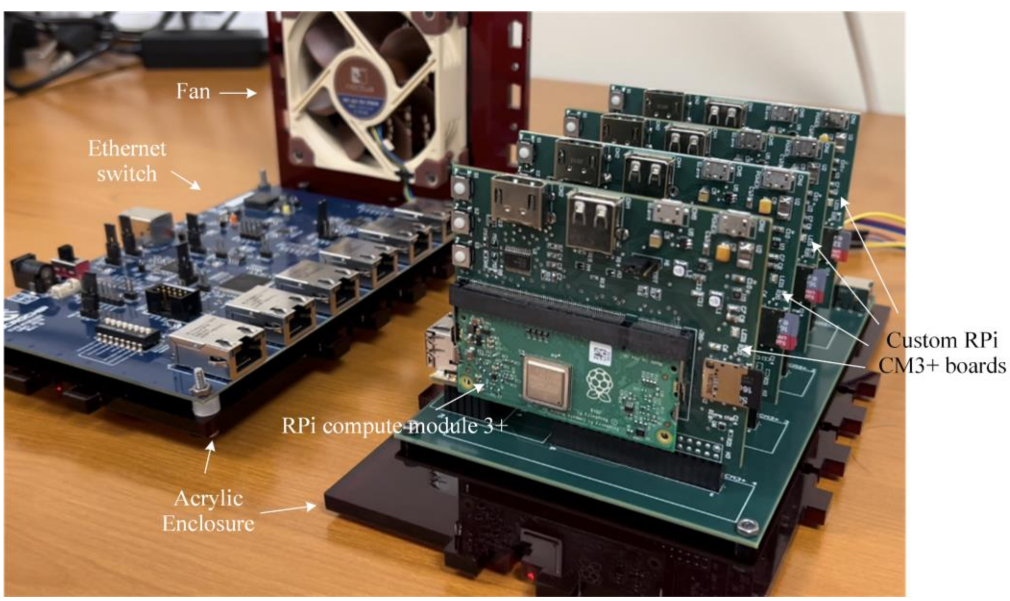


**Figure 3. System integration of the RPi compute module 3 cluster.**

The enclosure and the assembled RPi compute module 3+ cluster are shown in Figure 4. On the left side, it shows the acrylic section. The enclosure was designed using Fusion 360 [17]. The acrylic materials were cut by a laser cutting machine. The top plate holds an interface board, and the bottom plate holds a network switchboard. As shown in the figure, the openings for the ethernet cables and power cables were properly designed. The image on the right side shows the fan location and the opening for the airflow.

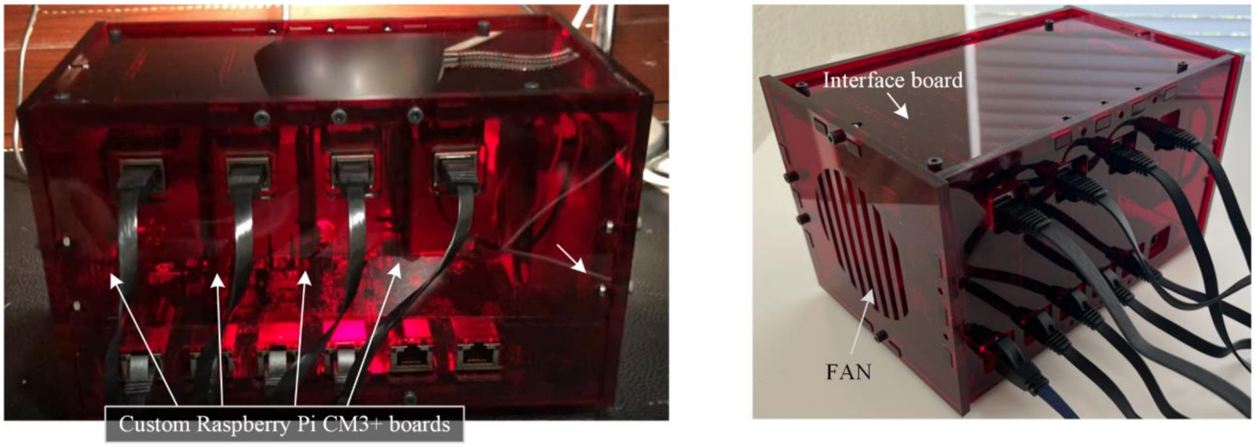


**Figure 4. Enclosure and assembled RPi compute module 3 cluster.**

### D. Tests and Measurements

The functionality for the capstone project was tested and verified. Figure 5 shows the tests and measurements that were accessed via an internet browser. On the top left side, it shows the temperature, humidity, and pressure data as well as the timestamps. On the bottom left side, it shows the recorded location of the sensor node. On the right side, it shows the image data via the camera connected to the remote sensor node. Using machine learning, it can detect the object. In this case, the analysis results indicated that there is the 78.65% chance of being a bottle for the captured image.

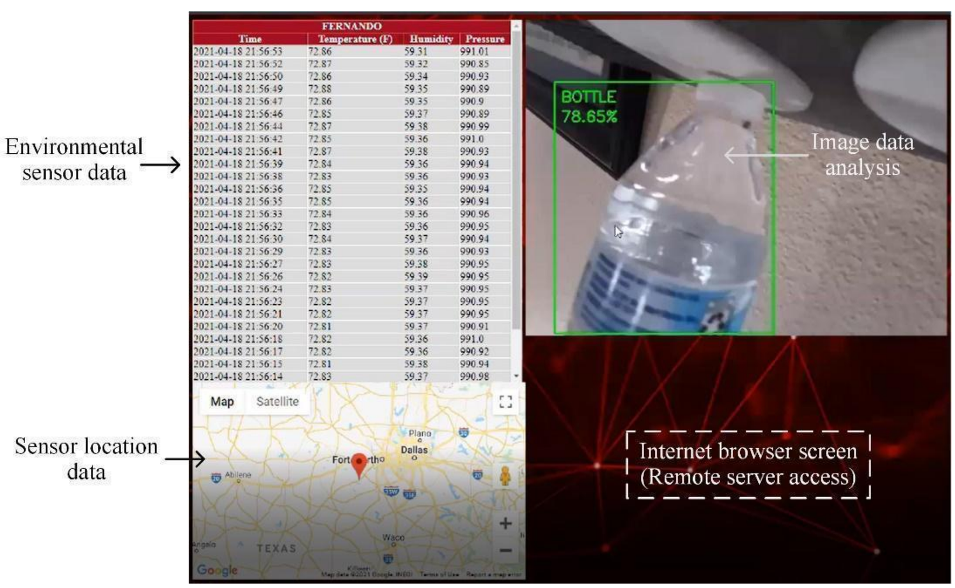


**Figure 5. Tests and measurements are accessed via an internet browser.**

The data and analysis results in Figure 5 were transmitted from one of the remote server nodes. There is a total of four remote server nodes, and they were able to transmit data to the primary cluster server. The recorded data from the four remote servers include sensor data, location, and image data. The transmitted data can be accessed via an internet browser

## E. Kubernetes

The Mircosk8s (Micro-K8s) is the lightweight version of Kubernetes [11-13]. Micro-K8s is installed and configured on each RPi board in the cluster. One of the RPi boards is the master node, and the rest of the three RPi boards are the worker nodes. This micro-Kubernetes cluster can process parallel computations. One of the simple parallel computation examples is splitting up tasks of a program and using the worker nodes to complete tasks.

Remote server nodes are configured. The remote server node consists of Raspberry Pi, sensors, and GPS module. The measured data can be uploaded to the RPi cluster server over the Internet. The micro-Kubernetes Dashboard is shown in Figure 6. This Dashboard shows the status of the cluster, including the CPU usage and memory usage.

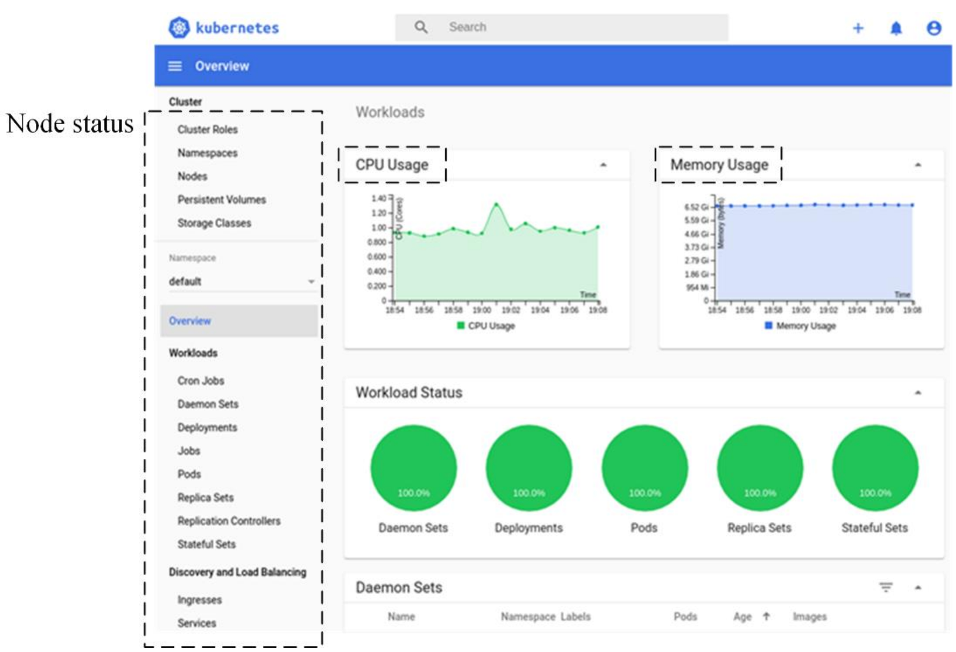


**Figure 6. Kubernetes dashboard access for the RPi compute module 3 cluster.**

The main server collects data from remote servers located at multiple locations. In order to provide an easy access for the measured data to users. An android application is in development for this RPi cluster [18]. The screenshots of this Android application are shown in Figure 7. The first screenshot on the left is a login screen. Next, the locations of the remote servers are displayed on a map, and the remote server can be selected. Once the remote server is selected, the list of the available data can be displayed. A user can click the item of interests, and the relevant data can be viewed. As an example, the temperature data graph is shown on the right side. Moreover, as described, instead, a user can use an internet web browser to access the data from the cluster server.

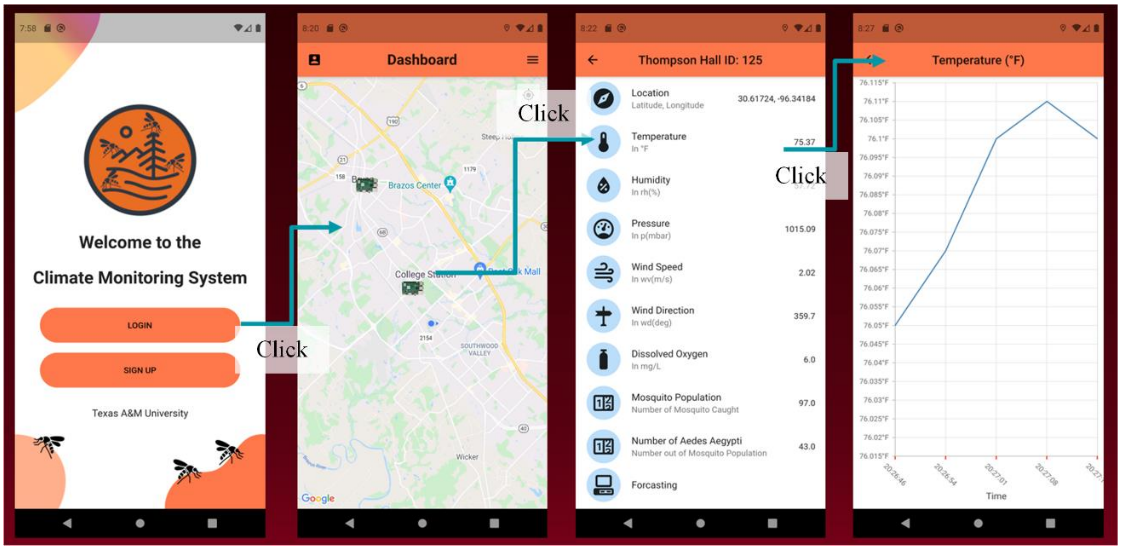


**Figure 7. Data access via Android application**

## F. Project schedule and progress

This capstone project was launched in Spring 2021. The capstone project schedule and milestones for Fall 2021 are shown in Figure 8. In Spring 2021, there were several milestones, such as project demonstrations and Critical Design Review (CDR). The final demonstration was carried out on April 19, 2021. In Spring 2021, the mode of operation was still limited to COVID-19. Three students and one faculty member participated in this in-person final demonstration, and the rest of the members joined the demonstration session remotely over the Zoom meeting. After the final demonstration, the prototype cluster device was delivered to the Dr. Hur's research group.

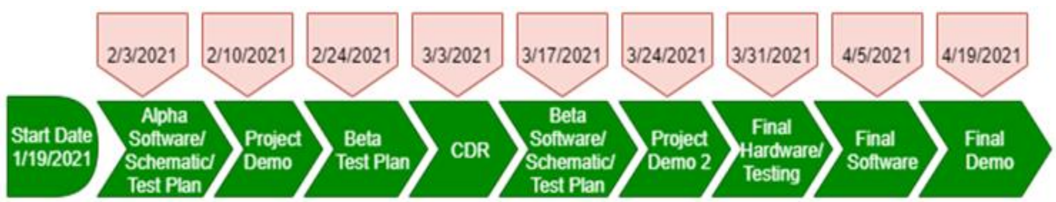


**Figure 8. Capstone project schedule (Fall 2021, 2nd semester)**

As described, one of these capstone team members has continued further development as a part of his graduate study and research. There has been further research and development effort to advance this cluster development for mosquito research.

## G. Educational value and evaluation

This capstone project built a functional low-cost IoT data server for mosquito research. This capstone project was carried out under the restricted mode of operation due to COVID-19. The capstone project was concluded in Spring 2021. An initial post-capstone survey was collected for the analysis of a bigger scope of multiple capstone projects. To gain understanding of the educational impacts on this project only, another post capstone survey was carried out in May 2022. The questions in the online survey are shown as follows:

*1. Do you think this capstone has been beneficial to your current or future career?*

| **Strongly agree** | **Agree** | **Neutral** | **Disagree** | **Strongly disagree** | **N/A** |
|---|---|---|---|---|---|
| 5 | 4 | 3 | 2 | 1 | 0 |

*2. Briefly state the impact and/or influence of this capstone project related to your current or future career.*

*3. In your experience and opinion, did COVID-19 affect your capstone project?*

| **Strongly agree** | **Agree** | **Neutral** | **Disagree** | **Strongly disagree** | **N/A** |
|---|---|---|---|---|---|
| 5 | 4 | 3 | 2 | 1 | 0 |

*4. Briefly state the impact on your capstone experience due to COVID-19.*

*5. Did this capstone project enhance your learning about relevant technical skill sets?*

| **Strongly agree** | **Agree** | **Neutral** | **Disagree** | **Strongly disagree** | **N/A** |
|---|---|---|---|---|---|
| 5 | 4 | 3 | 2 | 1 | 0 |

*6. Briefly state the technical skills that you learned during this capstone project.*

*7. Did this capstone project enhance your learning about working in a team environment?*

| **Strongly agree** | **Agree** | **Neutral** | **Disagree** | **Strongly disagree** | **N/A** |
|---|---|---|---|---|---|
| 5 | 4 | 3 | 2 | 1 | 0 |

This survey was created and conducted using Qualtrics. This voluntary survey was designed to ask a few questions related to the educational impact and their feedback related to their capstone experience. "Anonymize responses" option in Qualtrics was used. The summary of this post capstone survey results is shown in Table 1. All the students have participated in this post capstone survey. Participants have shown positive responses toward their capstone project related to the impact on their career (Q1, Average: 4.75), and technical skill sets (Q5, Average: 5.00), and the teamwork (Q7, Average: 5.00).

**Table 1. The post capstone survey results for the AIM-N team**

| | |
|---|---|
| Survey participation rate | 100% (4/4) |
| *1. Do you think this capstone has been beneficial to your current or future career?* | 4.75 (Mean)<br>(Std. deviation: 0.43) |
| *2. Briefly state the impact and/or influence of this capstone project related to your current or future career.*<br>Summary of the selected answers:<br>* Project planning and management * Working in a team for a goal * Helped with a job interview | |

| | |
|---|---|
| *3. In your experience and opinion, did COVID-19 affect your capstone project?* | 4.25 (Mean)<br>(Std. deviation: 0.43) |
| *4. Briefly state the impact on your capstone experience due to COVID-19.*<br>Summary of the selected answers:<br>* Difficulty in meeting together to work * Limited access to the facility to work | |
| *5. Did this capstone project enhance your learning about relevant technical skill sets?* | 5.00 (Mean)<br>(Std. deviation: 0.0) |
| 6. Briefly state the technical skills that you learned during this capstone project.<br>Summary of the selected answers:<br>* Web development, Networking, Linux, Python and Software development * PCB layout and Circuit parts * Parallel computation in a cluster | |
| *7. Did this capstone project enhance your learning about working in a team environment?* | 5.00 (Mean)<br>(Std. deviation: 0.0) |

The technical skills that students learned include web development, networking, Linux, Python, and software development. Moreover, they learned about PCB layout and circuit parts as well as parallel computation in a cluster server. For the impacts on their career, students gained knowledge and understanding of project planning, management, and teamwork. It seems this project helped a student's job interview.

For the COVID-19 impact, students had difficulty meeting together to work on this project. This may be related to the COVID-19 restriction and the mixed mode of the course delivery options offered by the University during this capstone period. This means some of the students could choose to be remote. Moreover, the facility was not readily accessible due to the COVID-19 restrictions. Given the difficult situation, students were able to deliver the requested functional capstone project.

The capstone project was successfully completed in Spring 2021. The three undergraduate students graduated and joined the industry. As mentioned, one of the students from the capstone team decided to stay for his master's degree in this department. Thus, this project has been vertically integrated. The student has been continuing this research and development as a part of his graduate study and research.

## V. Discussion & Concluding remarks

The low-cost cluster using custom Raspberry Pi compute module 3+ boards was successfully created, and functional requirements were tested via a capstone project. This low-cost IoT data server for mosquito research may have the potential to be applied to a wide range of locations. It can assist in data integration and analysis for mosquito control and potential breeding spots. For more reliability and stability, micro-Kubernetes have been applied using this Raspberry Pi cluster. There have been further research and development efforts related to the cluster server development for mosque research in the Dr. Hur's research group. Moreover, an android application is also in further development. An Android application can provide an easy access to the data that are stored in the cluster server. The authors plan to continue to advance the development of low-cost cluster servers for mosquito research applications.

## Acknowledgments

This work was partially supported through Cooperative Agreement Number 1U01CK000512 between the Centers for Disease Control and Prevention (CDC) and University of Texas Medical Branch/ Western Gulf Center for Excellence in Vector-Borne Diseases. Moreover, this work was supported by Dr. B. Hur’s Texas A&M research fund and resources.

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