Arduino Based Sound Acquisition Device for Queen Bee Health Monitoring with Machine Learning

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Abstract—**Beekeeping is a huge industry that provides income to farmers and increase pollinations thus helps to stabilize ecosystem. Apis-mellifera commonly known as honeybees, known as the world's, most important pollinator, it is responsible for pollinating 80% of our cultivated crops it is estimated that every third of our food source depends on honeybee pollination. We, the proponents propose solution to create an Arduino-based Queen bee monitoring system through sound acquisition with a tiny machine learning model, A compact device than can be attached easily in a beehive box, powered by a Arduino Nano this will listen and collect specific bee sound data with a built-in algorithm to move sound wave from a time domain to frequency domain by performing a Fast Fourier Transform on data for feature extraction then feeds it into a Convolutional Neural Network to provide real-time and onboard analysis that would inform the keeper via SMS text to do the right beehive assessment practice for the given situation. Notification of SMS triggers once the "Possibility of Queen Bee Existence" reaches 85% above while the "Possibility of No Queen Bee" triggers if it drops to at least 15%. The consistency of Queen Bee movement inside the hive was tracked through real time recording. The accuracy of the gathered data is based on the sounds that is being recorded by the device itself. The program was improved to set the collection of data to real time data recording. Queen Bee sounds were monitored and programmed to prove the possibility of a queen bee existence.**

***Index Terms*—Pollination, Arduino Nano, Convolutional Neural Network, Fast Fourier Transform, Real Time Recording, SIM800L**

I. INTRODUCTION

Globally, Bees contribute the most when pollinating cultivated crops that feed humans daily. Beekeeping is a huge industry that provides income to farmers and increase pollinations thus helps to stabilize ecosystem. Beekeepers are professionals who cultivates bees for a source of income and promotes bee conservation. Study shows a positive correlation between beehive population increase to proper problem assessment on colony issues. The general problem is bee population declines to an alarming degree, resulting to lesser crop yields and disruption in a part of ecosystem which relies on these creatures. These declines represent an emerging concern since these pollinators contributes to a third of global food production and a loss of certain biodiversity. Hence, Honeybees has essential implications to our agricultural sector [1], [2].

In spite of being an ever-growing industry beekeeping is still considered a difficult field, making Beehive maintenance critical since these creatures need specific care when facing colony problems. Even experienced beekeepers tend to make colony killing mistakes due to lack of proper understanding on hive issues. The results of this mismanagement can greatly affect the beekeeper income and the colony itself. Potentially, starting a domino effect that can disrupt even different sectors of the agriculture industry.

Recent studies show a nearly 40% decline in the honeybee population. The overall loss rate is around the average of what researchers and beekeepers have been since 2006. Many factors contribute to these alarming phenomena, and one of them is Beekeepers making colony-killing malpractices when assessing a situation. One is failing to recognize bee swarming patterns that cause it to lose 50 percent of its beehive population and 50 percent of its honey reserves. And another scenario is failing to replace a new Queen bee when the death of the old queen is sudden and unexpected this causes the hive to be unproductive since the workforce is declining. Most of these problems can be solved easily if monitored properly but manually opening hive is tedious, and keepers tend to use smokes that can cause stress to bees [3], [4], [5]. Although prior works were made to analyze bee behavior through their sounds by collecting and converting the data to time and frequency domain to be analyzed properly in a laboratory but waiting for results to come can be time-consuming and tedious, these actions can be proven inefficient since quick and real-time decisions are necessary to address critical beehive issues. Failing to immediately act can cause a bigger hive issue [6], [7], [8].

The objective of this study is to develop a monitoring system that provides accurate and real time beehive analysis through a combination of Fast Fourier Transform algorithm and Convolutional Neural Network and provides a SMS notification to the Beekeeper to tend with the beehive issues that greatly increases hive efficiency. Specifically, this research work aims: (1) To develop an embedded waterproof Beemo device that contains the sensors necessary such as the Sound Acquisition System with Convolutional Neural Network. (2) To assign a real-time and on-board analysis that would inform the keeper via SMS text using SIM800L for Arduino Nano. (3) To utilize a preliminary mitigation that can help automate a primary response for a specific process/situation. (4) To test and evaluate the system using ISO Standard [9], [10], [11].

This research aims to provide a low cost, user-friendly, non-invasive, and always-on device that helps and automate the process of monitoring the beehive by efficiently listening to the Queen bee, it also provides an output of a proper assessment practice through SMS directly to the beekeeper smartphone, notifying them when such a situation happens. And if the beehive issues are addressed and properly maintained this would increase the beehive population thus creating more benefits to farmers and the environment [12].

The goal of the study is to develop an embedded device equipped with a sound acquisition detector and Convolutional Neural Network classifier that will enable honeybee farmers to properly assess the situation inside the bee colony without manually checking the hive every now and then, the device notifies and track the data in real time when there are occurring queen bee problems inside [13]. The beneficiaries of the study are the honeybee industries, which will help them increase the profit of the business, detect the critical scenarios while at the same time increase its rate of production.

The study also focuses on the use of Arduino to automatically monitor the queen issues inside as well as notifying beekeepers when such situation occurs [14]. When it comes to the sound analyzation, the researchers use Convolutional Neural Network together with Fast Fourier Transform Algorithm to determine if a critical scenario involving queen bee occurs at the colony. The study also uses the IoT technology for monitoring and controlling the whole device. Automated intervention is not included in the research study, the only objective of which is to monitor and determine if a dangerous scenario to a queen happens to maintain hive efficiency.

II. REVIEW OF RELATED LITERATURES

A. Honeybees swarming detection approach by sound signal processing

In the recent years, few studies related swarming with sound, temperature and humidity inside the hive and weight. The analysis of sound emitted by honeybees showed that is one of the most used methods for detection swarming. In the studies for analyzing the sound in beehive, is shown correlation between narrow band of frequencies and swarming. By under- standing and analyzing the data collected in beehives, researchers can find solution how to predict swarming. This will result with less economic damages and less stress for the bee- keepers.

B. Audio-based Identification of Beehive States

Recent works in beehive sound analysis are carried out through a computational bioacoustics' scene analysis perspective. In this context, relevant representations for these audio signals are combined with machine learning methods in order to develop systems that can automatically distinguish between different states of a hive. The authors explore the use of Mel spectra and Mel-frequency cepstral coefficients (MFCCs) together with different machine leaning methods to detect hives with and without the queen bee. In the context of computational sound scene analysis research, state-of-the-art methods for sound scene recognition as shown, are mainly based in Convolutional Neural Networks (CNNs).

C. Frequency Analysis for Honeybee Buzz for Automatic Recognition of Health Status: A Preliminary Study

Pollinators are essential for diet diversity, biodiversity, and the maintenance of natural resources. The honeybee is the most important pollinator. Approximately 73% world cultivated crops depend on some variety of bees. The colony health is influenced by external fac- tors, such as, increase of pathologies, pollution, pesticides, among others. Monitoring honey- bee health is an important task for beekeepers. Early detection of health status can be crucial to ensure the survival of the colony.

D. Low-Cost Platform for Monitoring Honey Production and Bees Health

The construction of a low-cost platform for monitoring honey production and bee health in a small colony is described in this work. The suggested system keeps track of the beehive's weight, outside and internal temperatures, humidity, and CO_2 concentration. The system can estimate honey production, bee health, and possible pests based on the collected data, such as: Varroa destructor mite, Aethina tumida beetle, etc. Unlike other systems on the market that just monitor honey production or bee health, the suggested system examines both and alerts the beekeeper if there is an issue.

III. METHODOLOGY

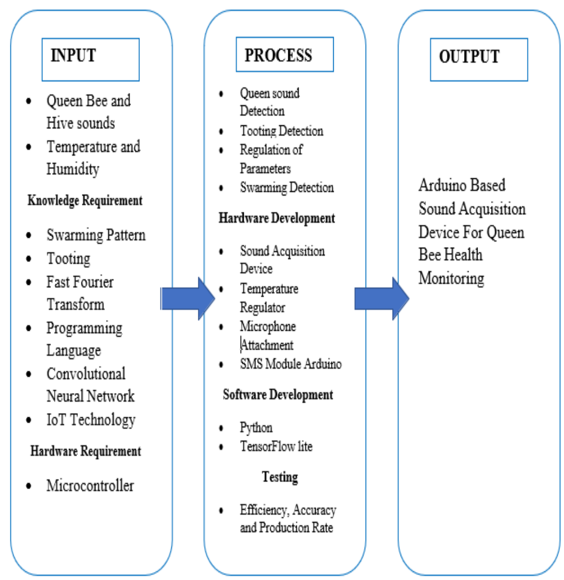


Figure 1 Block Diagram of the System

Figure 1 shows the Input Process Output Model of the study. Queen Bee and Hive Buzzing sound will be used as input for this analysis. At first it will undergo Sound Classifier which will detect the current situation inside the beehive and will send an automated SMS to notify the beekeeper if such situation occurs. The knowledge criteria for the project consists of the proper process of Feature Extraction, the process of Inference Analysis, the sound acquisition.

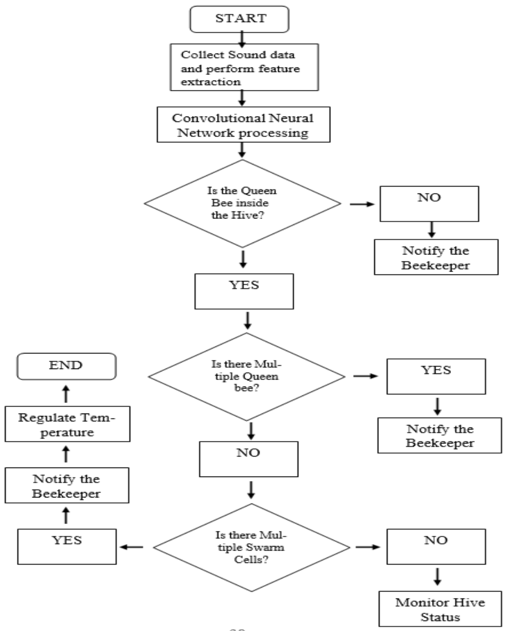


Figure 2. Queen Bee Status Monitoring Flow Chart

Figure 2 shows regarding how the program Queen Health Monitoring through sound acquisition will be run using the microphone and temperature and humidity sensors. At first, the sound data captured by the microphone attachment will be feature extracted and converted to spectrograms by Fast Fourier Transform then contrasted to the set of data. It will start by detecting if there still queen buzzing to ensure the queen is alive. Having no queen must be notified immediately to the keeper to introduce new queen and keep the colony efficient. Then it will proceed to detect if there are any Tooting Pattern, a major indicator for queen fighting among new queens. Newly emerged queens must be separated to ensure that a healthy queen must stay at the colony. Lastly it will proceed on detecting for swarm pattern and this is accompanied with collected temperature and humidity data ensuring accurate detection. Swarming must be address quickly as this situation can cause the hive to collapse, prior first-aid to these situations is to decrease hive temperature, doing so can calm the bees and will give enough time for the keepers to prevent potential swarm.

IV. RESULTS AND DISCUSSION

Table 1. Temperature and Humidity Data

Hour	Temperature	Humidity
1	32.8	36.6
2	33.3	37.1
3	33.5	37.4
4	33.8	38.5
5	33.8	38.8
6	33.3	38.7
7	32.9	39
8	32.5	38.6
9	32.2	39.1
10	32.7	40.6
11	32.7	40.4
12	34	44.2
13	33.8	42.8
14	33.3	42.9
15	32.8	42.7
16	32.5	42.1
17	32.3	41.2
18	32.3	40.4
19	31.8	39.9
20	32	40.1
21	32.9	42.8
22	32.4	43
23	32.2	43.1
24	32.2	43.5
Total Average	32.83%	40.56%

The table shows the data collected from the first day of Beemo deployment. An ideal average temperature ranges from 32% to 36% while the levels of humidity is at least 40%. was observed within the day to maintain a healthy hive. The total average of 32.83% for temperature and 40.56% for humidity ensures a healthy colony and normal brood development of honeybees inside the hive.

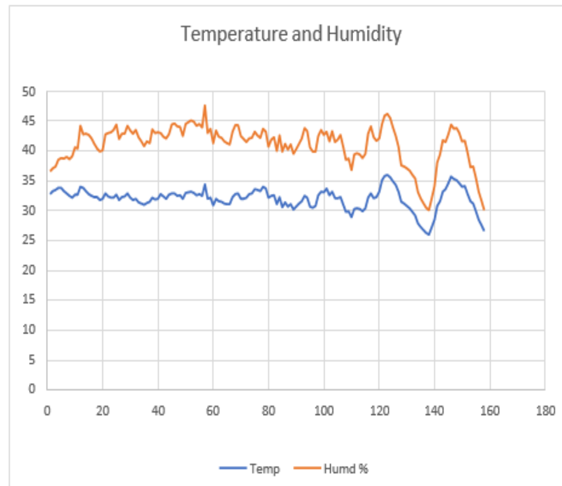


Figure 3. Temperature and Humidity Graph

Figure 3 illustrates the temperature and humidity readings from the first day of deployment. Records show that the beehive was able to keep the temperature between 29°C to 36°C and humidity between 28 to 47%, which indicates a suitable parameter for the bees inside the hive.

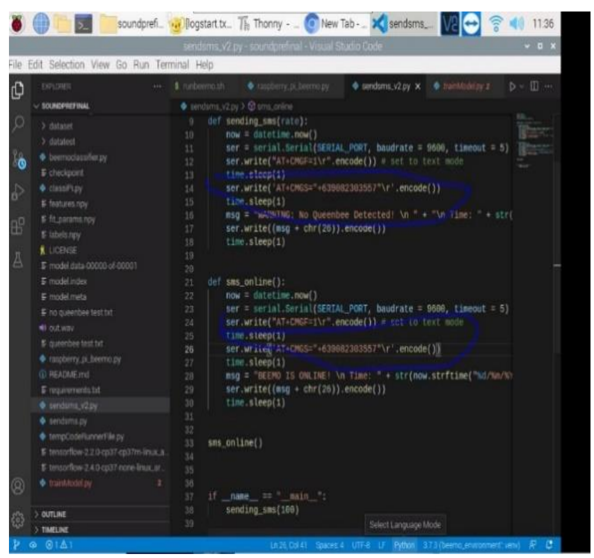


Figure 4. Short Message Service (SMS) Real Time Data

The diagram shows the program command that will identify if the queen bee is not detected inside the beehive. A “No Queen Bee Detected” will appear as text message to the cellphoneconnected to the device. The codes and records reveal that SIM800L module will immediately send text message once there is a possibility of no queenbee existence. A parameter of at least 85% indicates the detection of No Queenbee inside the beehive.

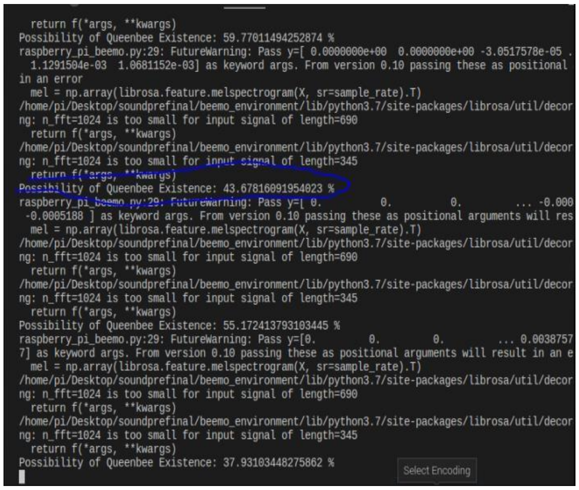
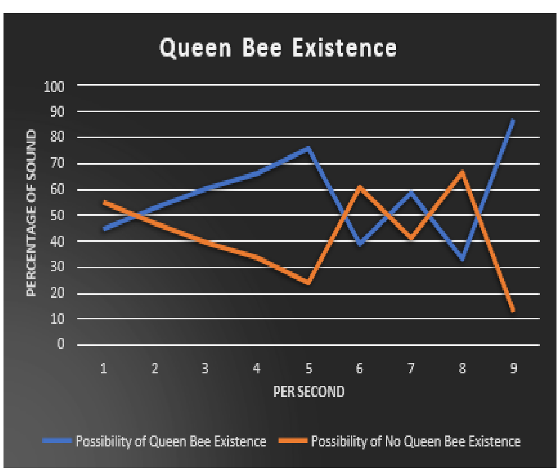


Figure 5. Real Time Running Code

The diagram shows the real time running code between the possibility of a Queen Bee existence and a no Queen Bee existence. When the percentage of the "Possibility of Queen Bee existence" drops to 15%, the farmer will be notified through a text message by SIM800L module, that there is no Queen bee. However, when the percentage increases to 85%. it meansthat there is an existing Queen bee inside the hive and a text message will be sent as well.

Table 2. Queen Bee Existence Data

Per Second	Possibility of Queen Bee Existence	Possibility of No Queen Bee Existence
1	44.82	55.18
2	52.87	47.13
3	60.34	39.66
4	66.25	33.75
5	75.86	24.14
6	39.08	60.92
7	58.76	41.24
8	33.33	66.67
9	87.03	12.97
Total Average	57.59333333	42.40666667



The line graph illustrates the percentage of either Possibility of Queen bee existence or Possibility of No Queen Bee existence. It shows here that the percentage of Queen bee existenceis increasing per second that meets the specific parameter for the detection of Queen Bee. Asseen in the graph, it started at 44.82% in the first reading and gradually went up to 87.03% as its highest. This confirms the presence of the Queen Bee inside the hive and a total average of 57.59% was recorded that leads to a good result over a period of time. Notification of SMStriggers once the "Possibility of Queen Bee Existence" reaches 85% above while the "Possibility of No Queen Bee" triggers if it drops to at least 15%. The consistency of Queen Bee movement inside the hive was tracked through real time recording. The accuracy of the gathered data is based on the sounds that is being recorded by the device itself. The program was improved to set the collection of data to real time data recording. Queen Bee sounds were monitored and programmed to prove the possibility of a queen bee existence.

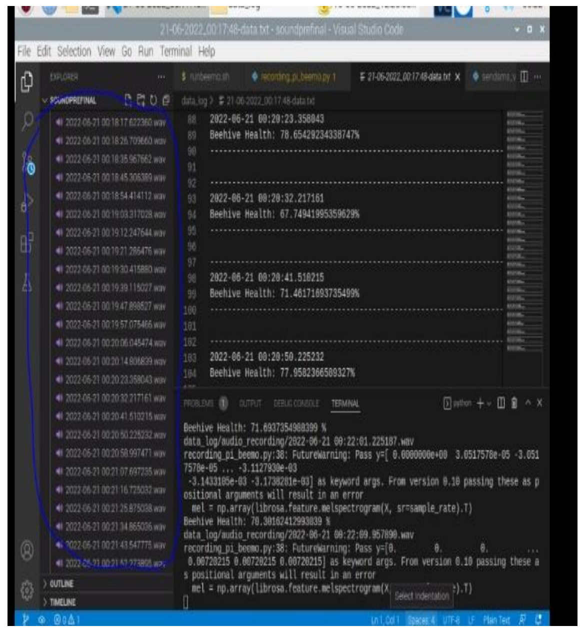


Figure 7. Audio Records of Beehive Health Status

The diagram on the left illustrates the audio sound data gathered that identifies the beehivehealth status shown on the right. The device records sound every nine seconds to monitor the hive's health status. This facilitates the beekeeper for easy tracking rather than the manual method which brings about stress to the bees that is crucial in beekeeping. The device notifies the beekeeper when the beehive's health status drops to 20%. Right preventive measures can be done immediately.

Table 3. Beehive Health Status Data

Per Second	Beehive Health Status
1	75.86
2	68.96
3	63.21
4	43.68
5	64.36
6	48.28
7	75.86
8	55.17
9	34.38
10	52.87
11	66.66
12	44.82
13	64.36
14	39.08
15	60.92
16	50.57
17	41.38
18	55.17
19	62.07
20	51.72
21	50.57
22	58.62
23	58.62
24	37.93
25	67.82
26	56.32
27	36.78
28	45.98
29	62.07
30	34.38
Total Average	54.28233333

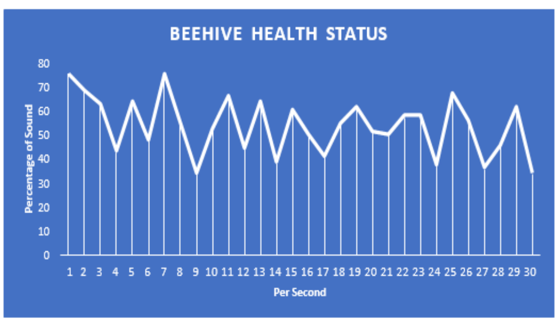


Figure 8. Beehive Health Status Data Percentage

The above given data collection was interpreted by a line graph. Said line graph shows the collected data of the beehive health status as per real time recording. Based on the dataabove, the highest rate of beehive status is 75.86% and the lowest rate is 34.38%. A total average of 54.28% ensures a moderate condition of bees inside the hive. The record provesthat in a short period of time, changes in bees' behavior can occur especially that the queen bee mainly controls the population and health of the hive. It is assumed that if the health status inside the beehive bears a high percentage, the Queen bee is at work.

Table 4. Queen Bee Detection Data for False Positive

Per Second	Possibility of Queen Bee (+)	Posibility of No Queen Bee (-)	Total
1	59.77	40.23	100
2	43.68	56.32	100
3	55.17	44.83	100
4	37.93	62.07	100
5	42.53	57.47	100
6	41.37	58.63	100
7	55.17	44.83	100
8	51.72	48.28	100
9	11.49	88.51	100
10	21.22	78.78	100

		Condition		
		With Queen Bee Detection (+)	Without Queen Bee Detection (-)	
Test	+	True Positive	False Positive	A+B
	-	False Negative	True Negative	C+D
		A+C	B+D	Total

1 = False Positive 4 = True Negative

False Positive Rate = 1 / (1+4) x 100% 20%

Figure 9. False Positive Rate

In the Table 4 shown above, when it comes to false positive rate, it shows that the Queen Bee isinside the hive, however a "No Queen Bee Detected" was received through SMS resulting that the Beemo incorrectly predicts the positive class. In a span of 10 seconds, there is one data prediction for false positive which is 21.22% and four assumptions of true negative. To compute the false positive rate, the truth is negative but the test is positive. Taking in to ac- count the possible scenarios, a true negative is that the device did detect that there is no QueenBee in a queen-less beehive. The false positive is that the system mistook a worker bee or a soldier bee as the Queen Bee. A false negative is that the system did not detect a Queen Bee in a hive with a Queen Bee. Lastly, a true positive is that the system did detect a Queen Bee in a hive with a Queen Bee existent.

V. CONCLUSION

After conducting the intensive and research about "Arduino Based Sound Acquisition Device for Queen Bee Health Monitoring with Machine Learning", the researchers confirmed that the parameter control and the temperature and humidity sensors produced results with high accuracy, thus proving the system can be used to measure the beehive parameters accurately. The Raspberry Pi was configured to collect and process all the data during deployment. Monitoring and Controlling of these parameters are attainable. The Queen Bee presence or Absence is detected every time the sound acquisition system detects a spike of sounds produce by the bee, it also captured queen cell and swarming patterns. The system also backtracks the output to provide accurate analysis. The Beemo device displays the temperature and humidity using LCD and can be accessed remotely using cloud storage. The collected parameters and device output can be accessed by the proponents to further analyze the results. The SMS notification system is for the generation of accurate detection and can be used by the beekeeper to provide the right action for the colony, thus ensuring that swarming behaviors can be prevented by the beekeeper. The system is efficient by ensuring an accuracy of 85% in detecting the status of the beehive and the system greatly reduces the monitoring compared to manual inspection of the beehive. Future works will further improve the methods of Queen Bee sound acquisition. Not only for Queen Bee, but also for the entire colony.

VI. ACKNOWLEDGEMENT

Our group would like to thank our parents and family members who continuously supported us financially and mentally, we will not be able to conduct this research without their guidance, love, and assistance. Thank you for giving us a chance to study and making us feel that we are loved.

To our caring thesis adviser, Engr. Cherry G. Pascion, for being with us in times of difficulties and lack of knowledge. Your experience and wisdom truly helped us accomplish our desired outcome. We would like to express our gratitude for your prolonged consultation hours, we are very lucky to have an adviser who is willing to help us anytime.

To Libay's Bee farm who accommodated us for our deployment, we would like to express our gratitude for letting us deploy our device and conduct our study on your private farm. For accommodating us wholeheartedly and treating us like your important guest. Our research will not be possible without your kindness.

To Mr. and Mrs. Verecio who's been very accommodating to our group by providing us our needs every time we need help. For serving as our service from Manila to Batangas and mak-ing sure that we are safe every time we go to our deployment area. We would also like to thank them for tirelessly reminding us to work hard and focus on our studies.

To our Advisory Committee, Chair member Engr. John Peter Ramos, Panel Member Engr. Romeo L. Jorda Jr., Panel Member Engr. Gilfred, Allen Madrigal, and Panel Member Engr. Lejan Alfred Enriquez, for their valuable and precious comments and suggestions for our study. We would like to thank them for continuously giving us recommendations to improve our device and for making sure that our study will have its best possible outcome. Our success for our study will not be possible without them.

To our Alma Mater, Technological University of the Philippines Manila. For giving us the knowledge and experience to finish this study. We are grateful for your wisdom and knowledge. We'll keep it in the rest of our lives.

To our Almighty God, who's given us the wisdom, mental and physical strength, spiritual needs, and encouragement to continue. We will not be here if not because of him.

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