Detecting Explosive Material via Optical Systems Observing the Behavior of Bees

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1. / Executive Summary

The Bee Bomb Brigade (B3) is a bomb-detecting system making use of the proboscises of the common honeybee in conjunction with machine learning and imaging systems to observe consistent, double checked results via redundant systems. Bees have impressive scent-based capabilities highly similar to that of dogs - and much like dogs, they can be trained accordingly to detect various materials, including drugs and explosives. Unlike dogs, however, bees can be trained in hours; dogs take months in comparison. On the other hand, the usage of bees is limited to mere days before they are released back into the wild - in other words, using bees is the cheaper, temporary, and expedited option for detection of these substances.

Of course, lacking clearance for illicit substances, this system will be tested via (if permitted) a small dosage of Trinitrotoluene - also known as TNT. The bees will be carefully trained with pavlovian responses, with the taste of food being associated with the respective organic chemicals within the liquid explosive and teaching the bees that the representative scent equates to food, hence their tongues sticking out when presented with said scent. This particular portion of the project would not be possible without the assistance from Dr. Patrick Bohlen, the Arboretum faculty liaison.

Once their training is complete, the Bee Bomb Brigade will then be inserted into a bee-friendly cartridge and be primed to detect airflow brought in via controlled fans at the push of a button. From the moment the button is pressed, the fans will spin and the systems will begin detection, scanning for visual and infrared changes brought about by the bees extending their proboscises. For each of the two systems, independent checks will be made - one for each bee - effectively accounting for each bee being checked twice as to whether or not they put their proboscises out. Following this, the respective systems are capable of confirming each other’s detection via informing the operator through LED lights. With this, we can obtain reliable and consistent results of the bees detecting the chemicals used to make explosives - in this case, the TNT.

1.1. / Personnel

Dr. Patrick Bohlen - Arboretum Faculty Liaison, Department of Biology, Source of Bees

Cole Correa - Computer Engineering Undergraduate

Hussein A. Shelleh - Electrical Engineering Undergraduate, Photonic Science & Engineering Undergraduate

Nicholas R. Johnson - Photonic Science & Engineering Undergraduate

Trevor Van Baulen- Computer Engineering Undergraduate

2. / Project Description and Background

The earliest use of ‘sniffer’ animals in a police or military setting stems back to the late 1800s, where the London police made rigorous use of bloodhounds to hunt for Jack the Ripper. Bloodhounds were already well known for their tracking abilities, though it primarily saw use in hunting animals to shoot, not hunting human beings. Soon after, however, these sniffer dogs became widely used across Europe by the constabulary to assist in finding the perpetrator for certain crimes.

Their use in explosive detection was, in truth, sparse until the start of world war two, which is when mine-detecting dogs started to emerge. Due to the decreasing metal content in the planted mines, it made metal detectors wholly unreliable - as such, carefully trained dogs quickly stepped up to the plate, becoming the Royal Engineers Dog Platoons in time for Operation Overlord, also known as the Battle of Normandy. From here on, various sniffer animals prop up for bomb detection across both Europe and the United States in both military and police positions - though both tended to keep to dogs.

Following the second world war, there was another spike in the usage of sniffer dogs - namely, the war on drugs across the United States. The noses of these dogs were trained to identify the scent of various narcotics - such as cocaine, heroin, and weed - which were being funneled into the country. These K9s proved to be instrumental in finding hidden drugs in cars, planes, boats, buildings, airports, and more. At the same time, bomb sniffing dogs became further mainstream following the 1972 Munich Olympics Massacre, a serious bombing that occurred in Munich, Germany during the 1972 Olympic Games.

The usage of explosive and drug-detecting animals has continued since then, as technologies to replace the animals have still been slow or costly. This doesn’t mean that testing different animals for the same task hasn’t happened; various rodents have been trained to sniff for mines given their lightweight bodies don’t set them off. And in 2006, the Los Alamos National Laboratory conducted research on the topic of detecting bombs using bees. Researchers found great success in using bees to detect bombs because of their excellent sensors found at the end of their antennae. Using trained bees researchers and scientists were able to create a portable device that safely housed the bees, so they can be monitored.

2.2. / Motivation

Our group decided on this project for a myriad of reasons. First, we recognized the need for an improved drug detection system. The training of drug detection dogs is expensive, time consuming, and often impractical. When states began to legalize marijuana, many dogs who were trained to detect it had to be retired. Since it takes at least six weeks to train a dog, along with a time-consuming practice of narrowing down candidates in puppyhood, this posed a significant issue. Scientists decided to turn to the advanced scent capabilities bees possessed and were able to train them in approximately four hours. As different substances are decriminalized, such as psychedelics in Colorado, our group recognized that current dogs may once again become obsolete and aim to improve the efficacy of detection bees.

The second reason is cost. While a dog needs extended training and premium foods, thousands of bees can be fed with just a pound of sugar water. Bees also do not require the cost of a dog handler. Our group saw this as an opportunity to lower the overall cost of security operations. We also saw an opportunity to increase the portability of security systems. A handheld detector is inconspicuous, easy to reload, and can be easily transported. The bees are harnessed into cartridges, meaning they can be moved without risk of the operator being stung.

The last reason we chose this project is its overall potential. Insects are highly specialized creatures with incredible sensitivity to their environment. We saw a chance to integrate what evolution has already provided with the rapidly developing technology of the optics world. We hope to demonstrate the ability of bees as useful tools, and inspire the creation of similar projects.

2.3. / Goals and Objectives

The overall objective of this project is to create a handheld portable device used to monitor trained bees for bomb detection. The device will be user-friendly and easily accessible given the user has access to trained bees. The prototype device should help decrease overall cost and time in bomb detection.

As for basic goals along that line of logic, the B3 should be capable of detecting the bees putting their tongues out with an at minimum accuracy of 75% for both systems, and spend under a minute reading and collating the data from the observed bees. Furthermore, the cost for the device itself should at the very least fall under five hundred dollars - while expensive for a basic goal, most trace explosive component detection devices cost several thousand dollars, not to mention the cost of training animals - such as mice or dogs - to do something similar if not the same task.

Advanced goals would be simple improvements upon the existing ones. A higher accuracy - say, 80% per bee - and a data collation time of under forty-five seconds. The cost could be capped at three hundred dollars instead of five hundred; when it comes to cost-profit ratios, the cheaper it actually is to develop the B3, the better it is for our wallets in both cost and ‘profit’. As for possible high-end goals, there are a few additional considerations. An accuracy of 85% per bee or higher, a data collation time of thirty seconds or less, a development cost of under two hundred dollars, and an addition of the option to connect the B3 device to a smart device - such as a computer - and display the images which were ‘hits’ for the neural network. Perhaps, albeit unlikely, there could be a final goal of spending under one hundred and fifty dollars given use of a lower quality camera. All of these are hypothetically feasible goals.

2.4. / Requirements and Specifications

The peculiarities and specifications of the project are numerous for both the hardware and the software constraints. Given the unique nature of each of those hemispheres of creation, however, they've been split into two different excerpts. The hardware portion will cover each of the critical physical components, their respective compositions, their necessary performance capabilities, and any critical design constraints. The software portion will cover much of the same, but with a focus on digital components instead of physical ones.

For B3, the device frame which will house the switch, the power supply, the fan system, the sensors, the microcontroller, the LEDs, the bees, and the lens system will be designed through a 3d modeling program, most likely Solidworks due to its accessibility for student use, as will the cartridges to transport and insert the bees safely. The microcontroller will be modified to operate as the internal controller for the device - majority of the changes will be software related. The lenses themselves are currently a work in progress, but a decision will have to be determined for whether or not they will be carefully fashioned or if the necessary five-in-one lens system will be built from existing commercial components (i.e. using commercially available lenses as design limitations) to lower build cost. Additionally, a pair of high-resolution cameras - one for the visible spectrum, one for infrared - will be fitted into the frame, which will likely be the most costly part of the device. It is, however, an unfortunate necessity due to the needs of the detection software.

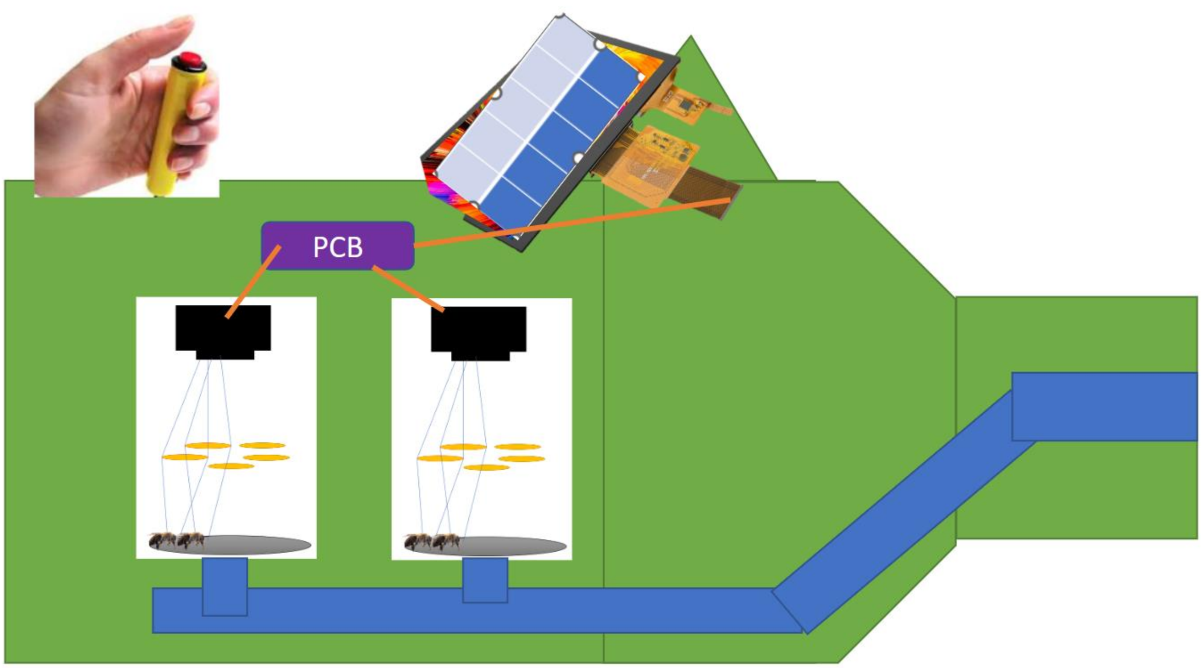

Figure 2.4.1: Rough diagram of the B3 device.

The imaging software itself will be operating either via the Region-Based Convolutional Neural Network (R-CNN) - which is an accuracy focused object detection machine learning algorithm - or via the You Only Look Once (YOLO) algorithm - which is a speed focused alternative for the same. Regardless of the selection, the end option should automate the recording process, taking around 30 or so images in the span of a second, which are then processed over the course of a few dozen seconds. From this, the algorithm selected should manage a reasonably consistent accuracy of checking for proboscis extension per bee and send the appropriate results over to the microcontroller, which will then light the appropriate LEDs on the device. They will utilize computer vision, region proposal, feature extractor, and classifier features of the algorithm selected in order to help accelerate the process. A possible additional specification is checking for all five proboscises simultaneously, as a means to notably increase processing speed.

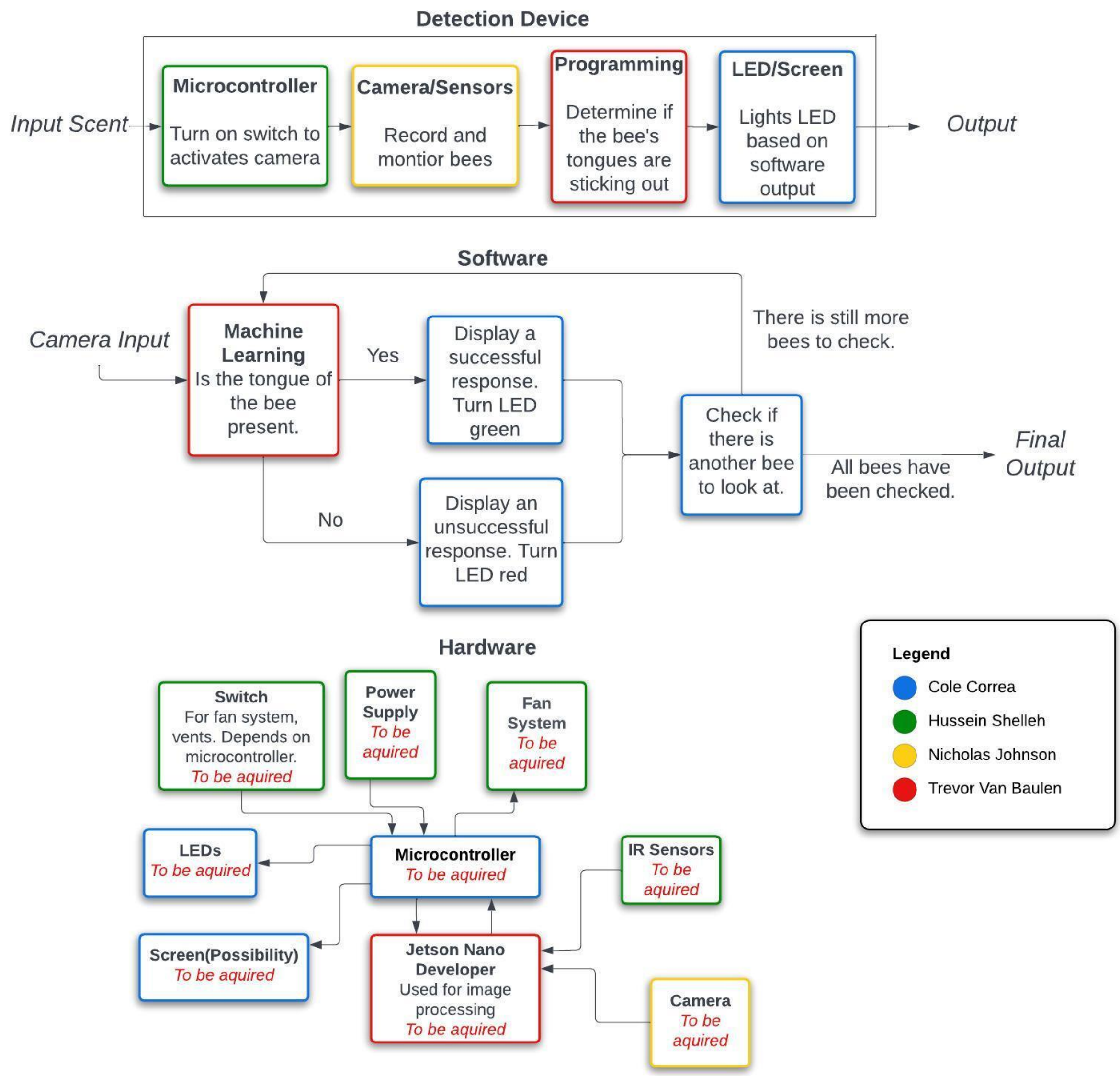

Figure 2.4.2: A pathway representing the group's individual roles and device 'action path', alongside both a Software and Hardware block diagram.

This work will be split according to the respective majors of our team, of course. Cole Correa and Trevor Van Baulen are both computer engineers, who will primarily focus on determining and teaching the machine learning algorithm alongside the coding that will be put into the microcontroller for the fan and LED control. As both Nicholas Johnson and Hussein Shelleh are photonic scientists and engineers, they will be responsible for the development of both of the optical systems that will be emplaced into the B3 device. Finally, Hussein Shelleh - the sole electrical engineer of the team -will be responsible for wiring and fitting the microcontroller, power supply, switch, and fan system into the framework.

2.4A. / Overall Functionality Requirements

For the explosive material detecting device, we're looking for a reasonable list of requirements to obtain consistent and reliable functionality, as seen in Table 2.4A.1. Of course, putting aside these individual objectives, we're also looking to build the explosive material detecting device with a fairly high degree of accuracy - in this case, accuracy of measuring the response of the bees, not accuracy of the bees themselves. We're also looking to accommodate with a relatively quick response time - which also means a high quality camera. Unfortunately, this means a high likelihood of a high power requirement and a fairly high cost in order to achieve such a desired outcome. The house of quality, Figure 2.4A.1, shows this clearly.

Overall Device Objectives
1. The device must not bring **any** harm to the bees inside.
2. The device's battery life should be reasonably high - long enough for a half hour or so.
3. The device must not be overly clunky or obstructive.
4. The device should weigh no more than two to four kilograms.
5. The device should be able to communicate with a computer via cable connection.

Table 2.4A.1: Overall Device Objectives.

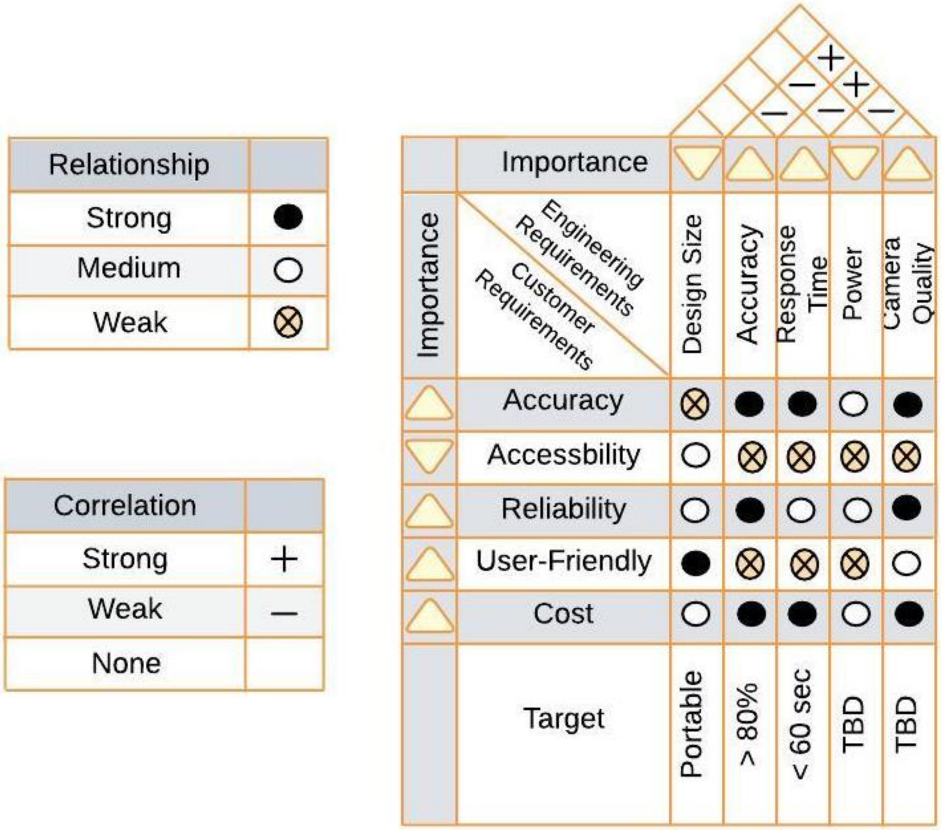

Figure 2.4A.1: House of Quality diagram portraying relationship and correlation between engineering requirements and customer requirements.