# OTTER PRINT SHOOTER

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Final Report for ECE 445, Senior Design, Spring 2012

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2 May 2012

Project No. 9

## Abstract

The Otter Print Shooter is a footprint capturing device designed to facilitate research on the North American river otters by the Illinois Natural History Survey. It has a rectangular waterproof enclosure with a transparent window on the top and will be buried underground at a specific site so that its transparent window is at ground level. Inside its enclosure, the Otter Print Shooter uses an array of sensors to detect the presence of otters and a digital camera to capture images of otter footprints from below, through the transparent window. Although the Otter Print Shooter functions as desired, experiment on the actual site is required to optimize the device settings. The final cost of the device is also higher than expected. There is also room for improvements that can be made by using a more scratch-resistant material for the transparent window and implementing camera settings that adapt to all kinds of lighting conditions.

# Contents

# 1. Introduction

The Otter Print Shooter is a footprint capturing device intended to be used in a research on the North American river otter by the Illinois Natural History Survey. The device has a rectangular waterproof enclosure with a transparent window on the top and it will be buried underground so that its transparent window is at ground level. Inside its enclosure, the Otter Print Shooter uses an array of sensors to detect the presence of otters and a digital camera to capture images of otter footprints from below, through the transparent window. The images will later be collected from the memory card of the digital camera.

This final report focuses on the hardware modules of the Otter Print Shooter and addresses the design considerations made on all modules under heavy constrains on the cost, the size and the battery life of the device. The first half of the report is devoted to detail the design of each hardware module used in the Otter Print Shooter. The latter half of the report covers the testing and verification of these modules and the conclusion of this project.

## 1.1 Purpose

The purpose of this project is to create an automated footprint capturing device, called the Otter Print Shooter, for the study of wildlife. The device is designed for the Illinois Natural History Survey to facilitate its research on the North American river otters that inhibit in Illinois as the research requires identifying and counting individual otters through their footprints. For this purpose, the Otter Print Shooter explores the potential of digital imaging in the acquisition of wildlife footprints that is traditionally conducted using ink or clay printing. Using this approach, the device yields better quality footprints and reduces the maintenance required at the research site as it uses a reusable capturing surface and can take and store hundreds of images. Moreover, the digital format of the captured images allows these images to be sent directly to the Indiana Police Forensics Lab for identifying individual otters and maintaining a footprints database. John Vanderkolk, an expert on human fingerprints and the manager for the Indiana State Police Fort Wayne Forensic Science Laboratory who is working with us to identify otter prints. The Otter Print Shooter is also devised to be easy to operate and maintain by researchers with its modular design. It also enables the wildlife research to be performed in all seasons with its waterproof enclosure.

## 1.2 Specification

The Otter Print Shooter must be able to capture high-detail images of otter footprints for the identification of individual otters by the forensic lab, parallel with the primary purpose of the device. This specification requires the image taken must have high level of detail and the entire device must have low response time.

In the context of image quality, the level of detail of an image can be measured by taking an image of the ISO 12233 test chart (Figure F.1). Using this measuring method, the minimum level of detail required is set to the scale of 10 on the ISO 12233 test chart. The scale of 10 is chosen because it corresponds to 0.4 mm lines and spaces and it is a safe approximation for the level of detail of otter footprints.

On the other hand, the response time of the device is crucial to ensure that otter paw is always in contact with the transparent window when the camera takes an image of otter footprint. This response time is defined as the period of time from the moment an otter steps on the transparent window to the moment the camera begins to take an image.  Despite that otter frequently moves around, there is always a static point at its paw when the paw touches the ground. In order to capture high-detail images of otter footprints, the maximum response time of the device must be less than the static duration of the paw which is safe to approximate as 0.5 s.

## 1.3 Subprojects

The Otter Print Shooter comprises seven modules as shown in Figure 1.1. Each of them performs specific tasks and can be tested independently.

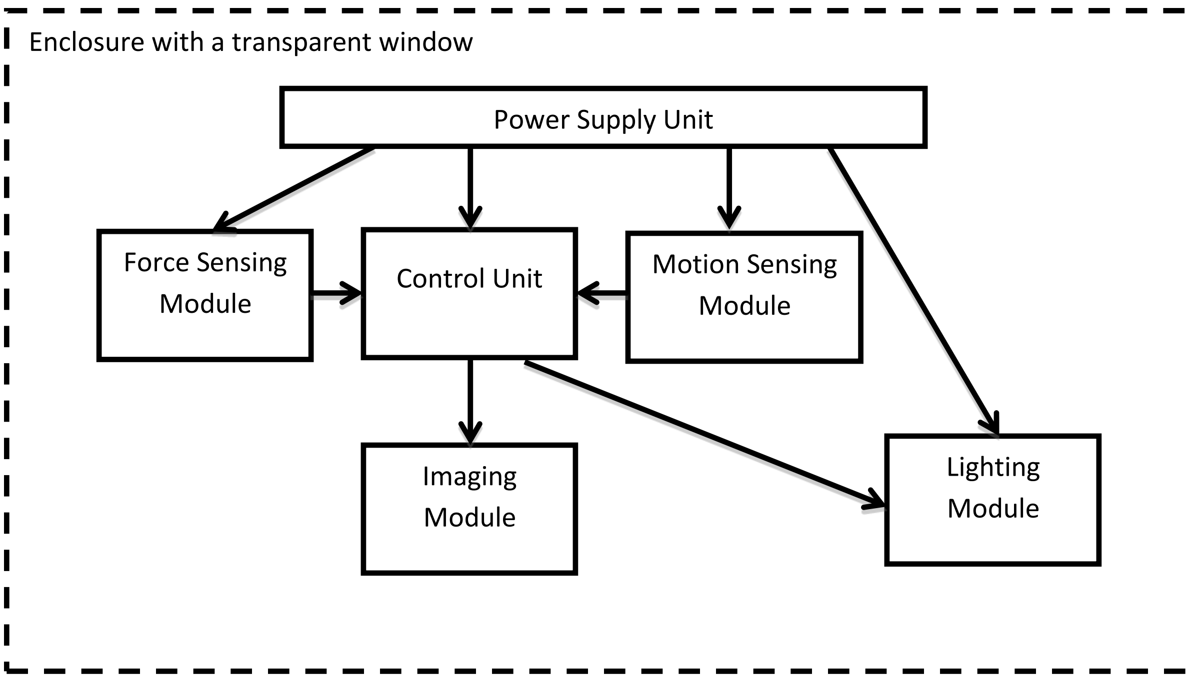


**Figure 1.1 Block diagram of the Otter Print Shooter.**

### 1.3.1 Power Supply Unit

The power supply unit needs to down-convert the unregulated DC voltage source (four AA NiMH batteries in series) that ranges between 4.6 V and 5.8 V to a stable 3.0V DC voltage source that can deliver current up to 250 mA. In addition, it must be able to provide power for device usage up to four days.

### 1.3.2 Control Unit

The control unit needs to determine the overall behavior of the device by interpreting digital signals from the motion sensing unit and the force sensing unit and generating digital signals to the imaging unit and the lighting unit. Depending on the input signals, it needs to be able to output 0 V digital low signal, 3.0 V digital high signal, 0.1 s 3.0 V digital pulses and 100 Hz 3.0 V peak-to-peak PWM signal that increases its duty cycle from 5% to 80% over 4 s with 5% increment every 0.25 s.

### 1.3.3 Imaging Module

The imaging unit needs to take a high-detail image and store it in a memory card after it receives a 3.0 V digital high signal from the control unit.

### 1.3.4 Force Sensing Module

The force sensing module is needed to determine if the weight transferred on the acrylic sheet is at least 3kg so that the output voltage would be at least 1.8 V as a high output signal to the microcontroller. This would enable the microcontroller to control when the camera should capture a picture.

### 1.3.5 Motion Sensing Module

The motion sensing module is needed to determine the presence of the otters even before they steps onto the device. This would enable the lighting module to light up gradually and not scares the otters away.

### 1.3.6 Lighting Module

The lighting module is needed to provide sufficient lighting when images of footprints are captured. Frustrated Total Internal Reflection (FTIR) is utilized to make footpad patterns stand out by shining the lights through the sides of the transparent window.

### 1.3.7 Container and Lid

The enclosure and lid are needed to provide a close and water-proof enclosure for the electronic components and devices of the Otter Print Shooter. This would also protect each component of the device from animals and harsh environments as it is placed outdoor at all times.

# 2. Design

The Otter Print Shooter comprises seven modules as listed in Section 1.3. All the modules were carefully designed and their parts were meticulously chosen to optimize the cost, the size and the battery life of the Otter Print Shooter in addition to meet the ultimate specifications of the device discussed in Section 1.2.

## 2.1 Power Supply Unit

The Otter Print Shooter will be buried at a specific site where lab researchers from Illinois Natural History Survey visit twice a week. Thus, the power supply unit is required to sustain the operation of the device up to four days. Besides that, the power supply unit should be easily rechargeable and replaceable for the convenience of users.

Taking all the above requirements into consideration, Sanyo Eneloop AA NiMH rechargeable batteries (2000 mAh) were chosen for the Otter Print Shooter. These batteries have a low self-discharge rate and can recharge up to 1500 times. Moreover, they can be easily swapped with their spares since they are small, light, and cheap. Four batteries connected in series give a VDD voltage of 4.8 V and 2000 mAh. This VDD voltage source is used directly by the lighting module.

The required input voltage for the control unit and the sensing modules is 3.0 V. Thus, VDD source inputs to a Microchip Technology MCP1700 LDO 3.0 V output voltage regulator to produce a 3 V output for VCC into those modules. Figure 2.1 below shows the schematic of MCP1700 LDO voltage regulator [1].

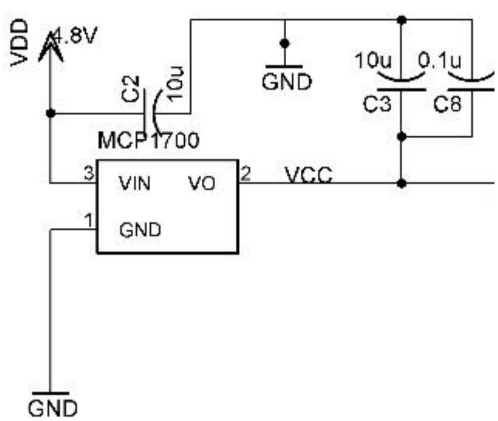


Figure 2.1 Schematic of voltage regulator.

## 2.2 Control Unit

The design of the control unit does not involve circuitry design as it is only consisted of a microprocessor. However, the selection of the microcontroller was a challenge due to heavy constraint on power consumption. After searching through various microcontrollers, the Texas Instrument MSP430G2553 mixed signal microprocessor was found to be the most suitable for the project. It has ultra low power consumption in standby mode (0.5 μA) [2]. This feature is essential because the device is expected to remain in standby for most of the time as otters are only active on land for a few hours a day. In addition, the microcontroller has fast wake-up time for minimizing response time, sufficient number of digital input/output (I/O) pins for interacting with all other modules, and controllable PWM output for tuning the luminous intensity of the lighting module.

Next, the pins of the microcontroller were mapped as in Figure 2.2. The microcontroller was initially powered by 3.6 V VCC but the voltage of VCC has changed been changed to 3.0 V to accommodate the voltage requirement of the motion sensing unit. This decrease in the supply voltage does not affect the performance of the microcontroller and, in fact, it helps to reduce power consumption. It is also important to note that the I/O pins of the microcontroller are divided into two ports and each port has eight pins. Based on this architecture, the four FSR_SIGs from the force sensing module are connected to Port 1 whereas the two PIR_SIGs from the motion sensing module are connected to Port 2. Similarly, the output signals are also split among the two ports where the CAM_SIG is controlled by Port 1 while the LED_SIG is controlled by Port 2. This allocation of I/O pins is important because it allows the implementation of two independent input interrupt service routines.

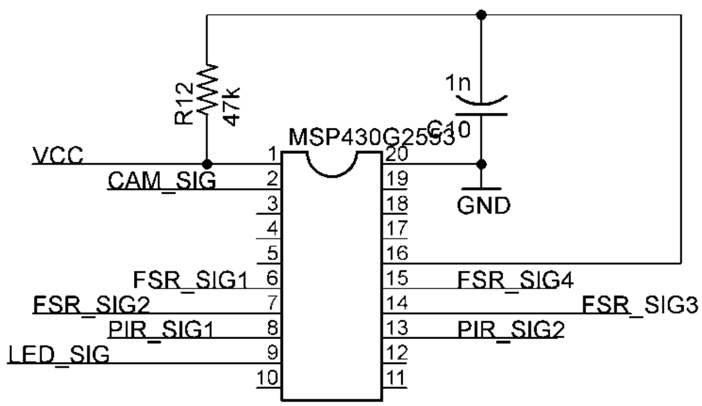


Figure 2.2 Schematic of the control unit.

The design of the control unit mainly fell on programming the microcontroller. The primary concern when programming was to minimize power consumption while retaining the functionality and responsiveness of the device. Firstly, the master clock of the microcontroller was set to 1 MHz and the auxiliary clock is set to 12 kHz. The master clock is used for processing command lines and generating PWN signal while the auxiliary clock is used for counting 0.25 s period. Both these clocks were programmed to turn on only when the microcontroller is active to save power.

Programming the PWM output demanded special consideration on its frequency. The frequency cannot be too low to prevent the LEDs in the lighting module from flickering accurate duty cycle and the frequency must at least 100 times smaller than the clock driving it to allow fine tuning of its duty cycle. Using the 60 Hz refresh rate of a standard monitor as a guideline, the frequency of the PWM output was set to 100 Hz.

In the context of operation, as shown in Figure C.1, the microcontroller will remain in standby mode until the motion sensing module detects motion (one or both of the PIR_SIGs high) or the force sensing module detects force (at least one of the FSR_SIGs high). If it wakes up through motion interrupt, the microcontroller will generate a PWM signal that increases its duty cycle over 4 s to the LED_SIG so that the lighting module gradually brightens up the LEDs. After 4 s, the microcontroller will turn off LED_SIG and rests for 5 s before next motion detection. On the other hand, if it wakes up through force interrupt, the microcontroller will prompt the imaging module to take an image by turning the CAM_SIG high for 0.1 s while keeping the LEDs at maximum brightness by turning the LED_SIG high. It will repeat this process for a maximum of three times with 1 s intervals if at least one of the FSR_SIGs remains high. Then, if all of the FSR_SIGs become low, microprocessor will return to standby mode for next cycle.

## 2.3 Imaging Module

The imaging unit of the Otter Print Shoot includes a camera that takes and stores images and a shutter controller that serves as an interface between the microcontroller and the camera.

### 2.3.1 Camera

Similar to the microcontroller, the camera is a standalone device. Hence, the design decision fell solely onto the selection of camera. First and foremost, the camera must be able can take images with the level of detail specified in Section 1.2. Moreover, the camera must have long battery life and low cost. Given these requirements, an imaging test was conducted on a wide range of imaging devices listed in Table 2.1 in order to determine the most suitable camera for the Otter Print Shooter.

Table 2.1 Imaging Devices Tested and Their Specifications

| Imaging Device | Type | Pixels (M) | Focus | SRP ($) |
|---|---|---|---|---|
| Logitech Webcam Pro 9000 | High-end webcam | 2 | Auto/Manual | 64.99 |
| Iphone 4S rear camera | Best phone camera | 8 | Auto | 30.99 |
| Sony DSC-W310 | Budget compact camera | 12 | Auto | 44.95 |
| Panasonic DMC-LX5 | High-end compact camera | 10 | Auto/Manual | 499.99 |
| Nikon D3000 w/ lens kit | Entry-level DSLR camera | 10 | Auto/Manual | 499.95 |
| Nikon D5100 w/ lens kit | Mid-level DSLR camera | 16 | Auto/Manual | 849.95 |

In this experiment, the images of fingerprints were taken at different distances (5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 30 cm, 35 cm, 40 cm and 45 cm) with each device. Using this method, the maximum distance for capturing clear images of fingerprints was determined for each device. This maximum distance is crucial because a larger capturing area on the Otter Print Shooter can be obtained with a longer maximum distance.

According to Table B.1, the result of the experiment shows that only the DSLR cameras were capable of taking high-detail images up to 45 cm. The experiment also proved that the camera optics is the limiting factor of image sharpness since both the Nikon D3000 and the Nikon D5100 produced very identical images when using the same lens. In addition to their poor image quality, webcams, phone cameras, compact cameras were found to be unsuitable for this application because they use electronic shutters that lead to slow operation and high power consumption. This experiment concludes that a DSLR camera with a sensor greater than 10 megapixels and a decent lens is suitable for the Otter Print Shooter. Consequently, a list of compatible DSLR cameras was compiled as in Table G.1.

Among the compatible cameras, the Canon EOS REBEL T3 was chosen as the reference camera due to its low cost. It features a 3:2 aspect ratio CMOS sensor with effective resolution of 12.2 megapixels [3]. Since there is no device-specific camera for the Otter Print Shooter, the Canon T3 can be easily replaced or upgraded by user to other compatible camera without making any change to the rest of the device.

In the aspect of the optics, the lens for the camera must have large angle of view so that the capturing area of the device is large and the depth of the enclosure is small as shown in Equation 2.1. The angle of view is

$$angle\ of\ view = 2\tan^{-1}\left(\frac{h}{2 \times d}\right) \tag{2.1}$$

where h is the diagonal length of the capturing area and d is the distance between the transparent window and the lens. After searching for suitable wide-angle lens, the Nikon AF-S DX Nikkor 18-55 mm f/3.5-5.6G VR lens with its maximum angle of view of 76° was selected for the compatible Nikon cameras whereas the Canon EF-S 18-55 mm 1:3.5-5.6 IS II lens with its maximum angle of view of 74°20’ was selected for the compatible Canon cameras [4],[5]. These 18-55 mm lenses were found to be the best options as they are sharp, wide angle and cost efficient. Additionally, the DSLR cameras have interchangeable lens system and are ready for any future optical upgrade.

Regarding the image storage, the camera uses an 8GB SDHC (Secure Digital High Capacity) memory card as its data storage. This 8 GB memory card can store up to 1600 images and can be easily swapped with a new memory card because it is inexpensive and physically small.

The camera used in the imaging module is powered by a battery dedicated to the camera itself. The battery lives of the compatible cameras range from 550 shots to 1050 shots and these cameras can last for several weeks in idle. For the reference camera, the Canon T3 is capable of taking 800 pictures with a fully-charged battery [3].

The imaging unit will be positioned at the bottom center of the enclosure with its lens facing upward. This allows it to capture the otter footprints whenever the otters step on the transparent window. Finally, the imaging unit will operate using the settings in Table 2.2 to acquire fine-detail images.

Table 2.2 Camera Settings Used in the Otter Print Shooter

| Parameter | Value | Description |
|---|---|---|
| Focal Length | 18mm | The shortest focal length maximizes the angle of view and minimizes the depth of enclosure |
| Focus | Manual | The focus point is fixed on the transparent window |
| Shutter Speed | 1/100 sec | Fast shutter speed helps to reduce motion blur |
| Aperture | F 3.5 | The smallest F-number (largest aperture) allows more light to enter the camera for better low light performance |
| ISO Sensitivity | ISO-800 | The camera will have the sensitivity to capture image in low light without being too noisy. |
| Release Mode | Continuous | This enables continuous rapid shooting |
| Image Format | JPEG | This format is widely supported and retains high image quality after compression. |

### 2.3.2 Shutter Controller

The purpose of the shutter controller is to electronically control the shutter of the camera using the control signal generated by the microcontroller. This can be accomplished by using one of the four interfaces for triggering the shutter of a DSLR camera – mechanical button on the camera, IR remote control, wired remote shutter release and USB Picture Transfer Protocol (PTP). After testing with the IR remote control and the USB PTP interfaces, they were found to be unsuitable for this application because they keep the camera in active mode and greatly deplete the battery life of the camera. On the other hand, triggering the shutter using the wired remote shutter release was proven to be the best approach because it does not drain the battery life of the camera and its delay is much smaller than pressing the mechanical button on the camera.

The wired remote shutter release accesses three I/O signals – SHUTTER, FOCUS and GROUND – via manufacturer specified ports. Regarding these ports, the Nikon cameras use its own 8-pins connector whereas the Canon cameras use a 2.5 mm stereo plug. Despite of having different connectors, the operation principle for the remote shutter release is the same for the cameras by both manufacturers. More to the point, these cameras will autofocus when the FOCUS is connected to the GROUND and will release their shutters when both the FOCUS and the SHUTTER are connected to the GROUND.

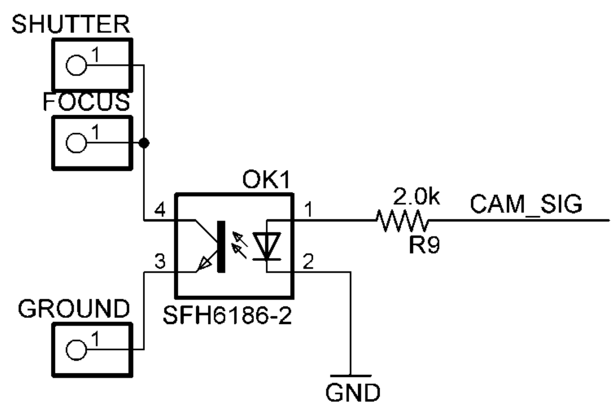


Figure 2.3 Schematic of the shutter controller.

The shutter controller in the Otter Print Shooter uses the Vishay SFH618A optocoupler as a digital switch. This optocoupler was chosen because it uses low input voltage and current and it provides good isolation for the camera from the rest of the device. The connections of the shutter controller are shown in Figure 2.3. It is important to note that the FOCUS and the SHUTTER (2.7V) are allowed to connect together to the Pin 4 because the camera does not require auto-focus. The value of the current limiting resistor, $R_9$ is

$$R_9 = \frac{V_{cc} - V_F}{I_F} \tag{2.2}$$

Where $V_{cc}$ is the voltage of the CAM_SIG generated by the microcontroller, $V_F$ is the forward voltage of the LED inside the optocoupler and $I_F$ is the forward current of the LED inside the optocoupler. Since $V_{cc} = 3.0\ V$ and $V_F = 1.1\ V$, $R_9$ was found to be around 2 kΩ using Equation 2.2 when $I_F$ was set to a small value of 1 mA to conserve power [6].

Using the setup in Figure 2.3, both the FOCUS and the SHUTTER will only connect to the GROUND when the CAM_SIG is high. Thus, the shutter control unit will act as a switch that triggers the imaging unit whenever it receives a high signal from the microcontroller.

## 2.4 Force Sensing Module

The purpose of the force sensing module is to determine when the camera should take a picture. The force sensing unit consists of four force sensitive resistors (FSR) and eight normal resistors to form four voltage dividers as shown in Figure 2.4. The output of each voltage divider was connected to a shunt capacitor to maintain the stability of the output signal.

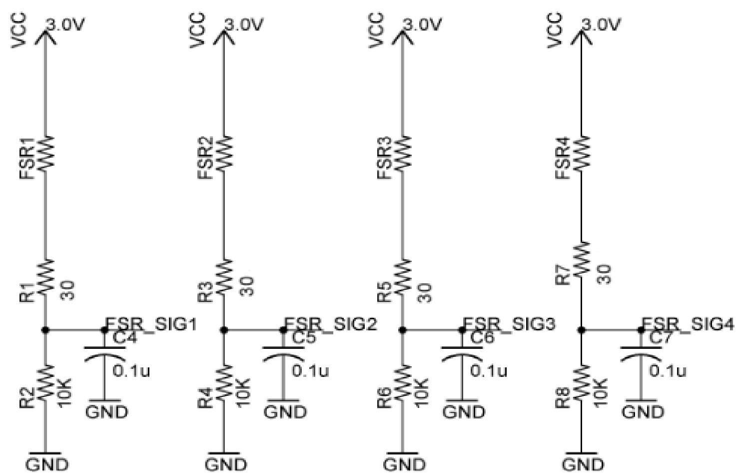


Figure 2.4 Schematic of the force sensing module.

The FSRs are the Interlink Electronic FSR402FRSs which have the force sensitivity range between 0.1 N and 10 N [7]. As the force increases, the resistances of the FSRs go down until they reach the minimum resistance of 0.25 kΩ. For better force transfer, a washer was placed on top of each FSR to provide a more concentrated contact.

For the voltage dividers to work as digital switches, the values of normal resistors must be chosen carefully. With an applied mass of 3 kg, the resistances of the FSRs are approximately 6 kΩ. On the other hand, the microcontroller will register an input as HIGH when the input voltage is 0.65 VCC and above.

$$V_{ON} = 0.6 \times 3.0\ V = 1.8\ V \tag{2.3}$$

Given the above conditions, a 10 kΩ resistor was connected in series to each FSR so that the output voltage of each voltage divider is higher than 1.8 V when 3 kg is applied on the FSR. The 10 kΩ resistor also serves as current limiter to prevent a current greater than 1 mA that will permanently damage the FSR. There is also a 30 Ω resistor in series with each FSR for fine tuning the output voltage.

Using the above parameters, the output voltage can be calculated using the voltage divider rule in Equation 2.4,

$$Vo = Vcc \times \left(\frac{10k}{FSR + 30 + 10k}\right) \tag{2.4}$$

## 2.5 Motion Sensing Module

The purpose of the motion sensing module is to detect the presence of the otter even before the otter steps on the device. This would enable the LEDs to be lighted up gradually so that the lighting from the device would not scare the otters away. The motion sensing unit is the Panasonic NaPiOn Slight Motion Sensor (AMN42122). This sensor has horizontal and vertical detection angles of 90°. It also can detect motion up to 78.74 inches (equivalent to 2 m) and only consumes 46 µA current [8].

Originally, the motion sensors were positioned at the bottom of the enclosure. However, the sensors were unable to detect motion using the placement because the acrylic window impeded the transmission of infrared [9]. Thus, in the new design, the motion sensors were moved to the surface of the acrylic window as shown in Figure E.2.

Since the motion sensor has both horizontal and vertical detection range of 90°. Equation 2.5 shows that it can detect up to 55.669” away from the device at an angle of 45° from the ground.

$$\sin 45° = \frac{x}{78.74"} \qquad (2.5)$$
$$x = 55.669"$$

Each motion sensor has three pins – VCC, DATA and GND. The VCC pin is connected to the 3.0 V output of the power supply unit, the DATA pin is connected to the input of microcontroller and the GND pin is connected to common ground. The circuit of the motion sensing unit is connected as shown in Figure 2.5.

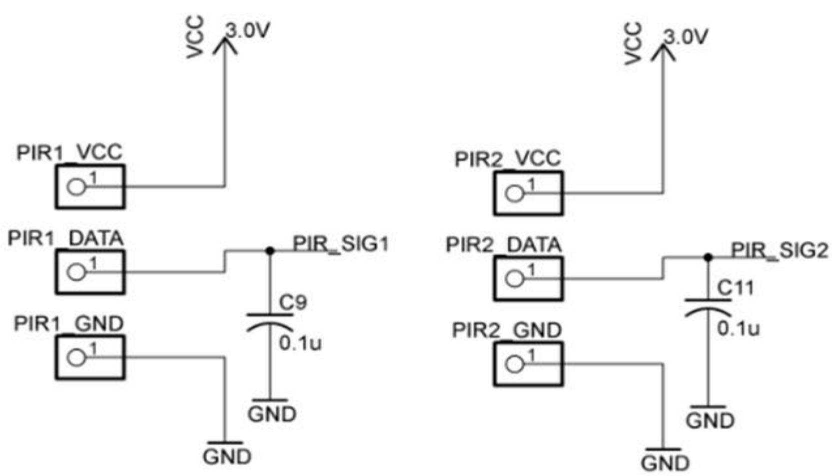


Figure 2.5 Schematic of the motion sensing module.

## 2.6 Lighting Module

The lighting unit consists of 14 surface mounted LEDs (part number: 61-238/QK2C-B28322FAGB2/ET from Everlight Electronics) which will be mounted on the sides of the acrylic sheet which is the material for the capturing surface. These LEDs will be responsible for providing adequate lighting when the camera is capturing images. This LED model actually has 3 LED dies within to produce a more concentrated light [10].

Table 2.3 Attributes of the LEDs

| | |
|---|---|
| **Illumination Color** | White |
| **Forward Voltage** | 3.2 V (when three LED dies are operated simultaneously) |
| **Forward Current** | 20 mA (for each LED die) |
| **Viewing angle** | 120° |
| **Luminous Intensity** | 5900 mcd |

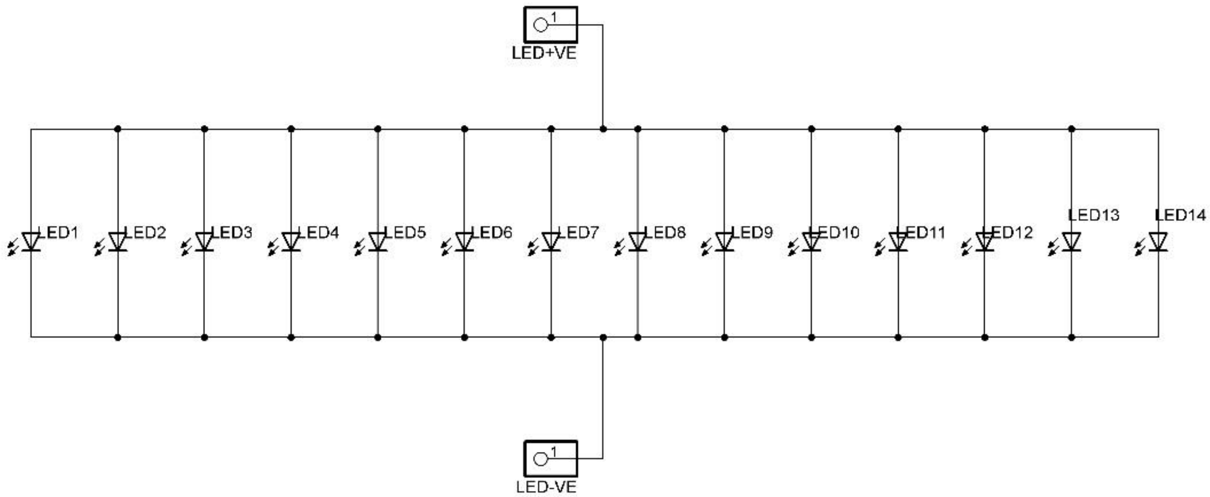


Figure 2.6. Schematic of lighting module.

Figure 2.6 shows the schematic of the lighting module. Maximum forward current for each LED runs through each LED branch.

$$Forward\ current\ in\ each\ LED\ branch = 60\ mA$$
$$Current\ in\ whole\ LED\ circuit = 60\ mA\ x\ 14 = 0.84\ A \qquad (2.6)$$

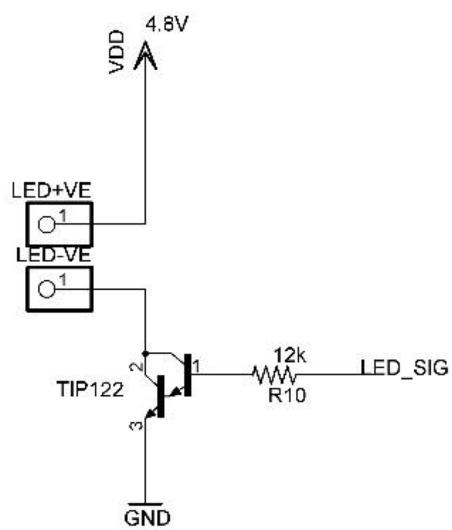


Figure 2.7. Schematic of the switch of lighting module.

Figure 2.7 shows the schematic of the switch and how it is connected to the lighting module. A NPN transistor (part number: TIP122 from Fairchild Semiconductor) acts as the switch [11]. The switch operates in modes as shown in Table 2.4.

Table 2.4 Modes of switch and LED lights under different situations

| Situations | LED_SIG | Modes of switch | LED lights |
|---|---|---|---|
| When in standby | LOW | OFF | OFF |
| When activated by FSR | HIGH | ON | ON |
| When activated by PIR | Square waveform with increasing duty cycles from 0-80% within 4 seconds | ON at top of waveform and OFF at base of waveform | ON gradually |

From measurements with a multimeter, the voltage at the base of the transistor is found to be 1.2 V and the current at base is found to be 0.15 mA.

$$V_B = 1.2\,V$$
$$V_{LED\_SIG} = 3.0\,V$$
$$I_B = 0.15\,mA$$
$$R = \frac{V_{LED\_SIG} - V_B}{I_B} \tag{2.7}$$
$$R = 12\,k\Omega \tag{2.8}$$

Thus, a 12 kΩ resistor is added to lower the input signal voltage of LED_SIG to the transistor base voltage.

## 2.7 Container and Lid

The dimension of the enclosure for the Otter Print Shooter is 23” (length) × 15.5” (width) × 21.5” (depth). There is a removable lid that can be lifted off using a pair of handles. In between the lid and the enclosure, there are rubber foam and plastic tube that would form a water-proof seal when the lid is latched down. There are also drain holes around the top of the enclosure to remove the stagnant water around the lid.

Moreover, the acrylic window is secured to the lid using the rubber gasket. This enables the force to be transferred to the FSR. A total of 11 wires were used for the FSR, PIR and LEDs with a shared VCC for all the components. These wiring was done under the lid and these wires were soldered to a 15 pin D-subminiature connectors to connect to the PCB. These would allow the lid to be completely taken off from the enclosure.

The drawing in Figure E.1 was used to give a better illustration to the ECE Machine Shop to understand about the design. The container that has been built is shown in Figure E.2, E.3 and E.4. The container has to be precise because the lighting module, force sensing module and motion sensing module were placed on the container’s lid that have major influence on the success of the device.

# 3. Design Verifications

Design verification involves testing of individual modules to uncover any potential design flaw. The modular testing method employed in the process of design verification allows quick detection of problem and its source. Concisely, design verification is a crucial step for satisfying the specifications of the device outlined in Section 1.2.

Testing was conducted on each module based on the procedures in Table A.1. Table A.1 also shows the requirements for each module that have to be met in the process of design verification.

## 3.1 Power Supply Unit

The power supply unit passed the verification as it satisfied Requirement 1 in Table A.1. The batteries maintained its voltage above 4.7 V under load and the voltage regulator provided a stable voltage for input voltage ranged from 4.6 V to 5.8 V. The measurements of the tests on batteries are shown in Table 3.1 and 3.2. The power supply unit was also able to last up to four days for device usage.

Table 3.1 Tests on batteries using 4.7 Ω and 4.7 kΩ resistors

| Trials | Voltage across 4.7 Ω resistor (V) | Voltage across 4.7 kΩ resistor (V) | Current across 4.7 Ω resistor (A) | Current across 4.7 kΩ resistor (mA) |
|---|---|---|---|---|
| Trial 1 (Fully-charged) | 5.6 | 5.7 | 1.191 | 1.213 |
| Trial 2 (After 10 uses) | 5.3 | 5.3 | 1.128 | 1.128 |
| Trial 3 (After 50 uses) | 4.8 | 4.9 | 1.021 | 1.043 |

Table 3.2 Tests and measurements of voltage from voltage regulator with different input voltages

| Input Voltage (V) | Voltage across 3 kΩ resistor (V) | Current across 3 kΩ resistor (A) |
|---|---|---|
| 4.6 | 3.0 | 1.133 |
| 4.8 | 3.0 | 1.071 |
| 5.0 | 3.0 | 1.083 |
| 5.2 | 3.0 | 1.104 |
| 5.4 | 3.0 | 1.075 |
| 5.6 | 3.0 | 1.138 |
| 5.8 | 3.0 | 1.116 |

Table 3.3 Current Usage of device under different situations

| Situations | Device Current Usage (mA) |
|---|---|
| When in standby | 3.08 |
| When activated | 500.00 |

Standby Current for four days:

$$3.08\, mA\ x\ 4\ days\ x\ \frac{24\ hours}{day} = 296\, mAh \tag{2.9}$$

Active current for PIR activation case is taken since it takes up more power than the FSR activation case.

Active current for 800 shots with PIR activation prior to each shot:

$$0.5\ A\ x\ 5\ seconds\ x\ 800\ shots\ x\ \frac{1\ hour}{3600\ seconds} = 556\ mAh \tag{2.10}$$

$$Total\ power\ consumed = 296\ mAh + 556\ mAh = 852\ mAh \tag{2.11}$$

The total power consumed in four days is much lesser than the 2000 mAh provided by the power supply unit.

## 3.2 Control Unit

The control unit passed the design verification as it satisfied Requirement 2 in Table A.1. Although the initial requirements for the control unit were based on 3.6 V VCC in the design review, changing the VCC to 3.0 V only scaled down both of the input and output voltages to 3.0 V and the all other criteria were preserved.

As in Figure 3.1, the microcontroller managed to output three 0.1 s 3.0 V square pulses with 1 s intervals for triggering the camera. The microcontroller also managed to output a 100 Hz 3.0 V PWM signal with increasing duty cycle as shown in Figure 3.2.

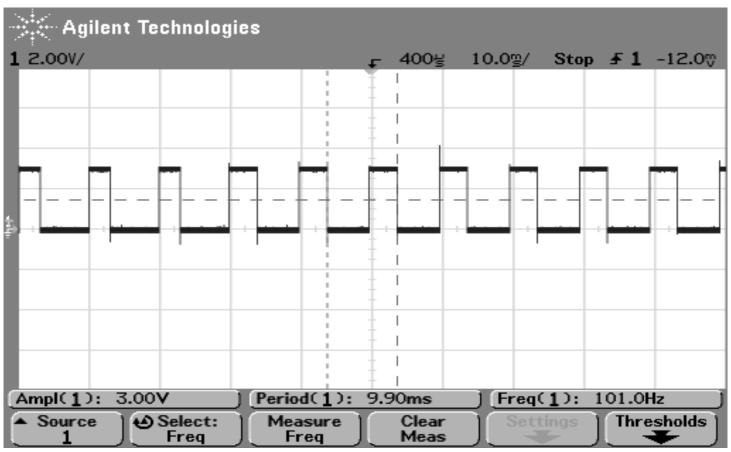


Figure 3.1. 101Hz 3.0V PWM signal with increasing duty cycle from the microcontroller

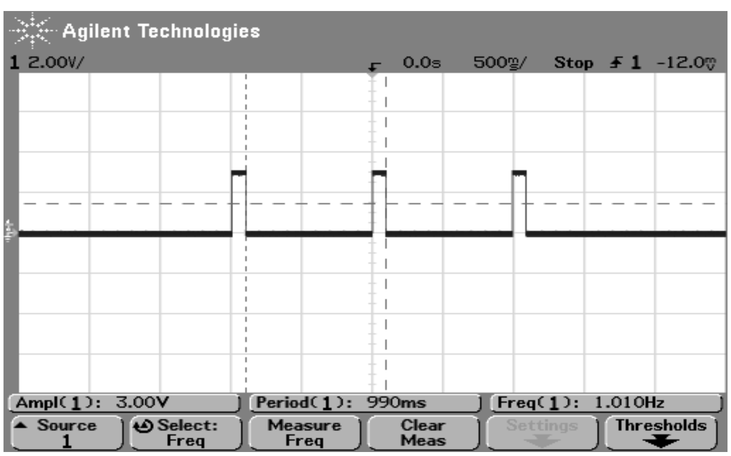


Figure 3.2. Three consecutive 0.1 s 3.0 V square pulses from the microcontroller

## 3.3 Imaging Module

The imaging module also passed the test as it satisfied Requirement 3 and 4 in Table A.1. As in Figure B.2, the camera managed capture an image with the level of detail at least the scale of 10 in the ISO 12233 test chart at 18 inches away. The shutter controller also managed to trigger the camera without any noticeable delay.

## 3.4 Force Sensing Module

The force sensing module passed the test as it satisfied Requirement 5 in Table A.1. The measurements obtained in testing are shown in Table 3.4. Although the initial requirements for the force sensing module stated that when no weight is applied it should have a resistance of at least 1 MΩ, the weight of the acrylic sheet on the FSR needed to be taken account. Thus, when no weight is applied the resistance of the FSR would be at least 100 kΩ. On the other hand, when 3 kg weight is applied on the FSR, the FSR has a range of 3.1 kΩ to 5.3 kΩ resistance value. Thus, when 3 kg weight is applied, the resistance of the FSR must be at least 6 kΩ.

Table 3.4 Tests and Measurements of the Force Sensitive Resistors

| FSR | Resistance (kΩ) | | Output Voltage (V) | | Microcontroller Logic | |
|---|---|---|---|---|---|---|
| | 0 kg | 3 kg | 0 kg | 3 kg | 0 kg | 3 kg |
| 1 | 2600.0 | 5.3 | 0.000 | 1.957 | LOW | HIGH |
| 2 | 235.0 | 3.3 | 0.122 | 2.251 | LOW | HIGH |
| 3 | 3800.0 | 4.8 | 0.000 | 2.023 | LOW | HIGH |
| 4 | 118.0 | 3.1 | 0.234 | 2.285 | LOW | HIGH |

## 3.5 Motion Sensing Module

The motion sensing module passed the test as it satisfied Requirement 6 in Table A.1. The testing measurements and results are shown in Table 3.5 and 3.6. When the motion detects motion, it has an output voltage of 2.81 V measured using an oscilloscope shown in Figure 3.3.

Table 3.5 Output voltage of motion sensor from different testing angles

| Angle from the center point of the motion sensor (°) | Angle from the surface of the acrylic sheet (°) | Output Voltage of Motion Sensor (V) |
|---|---|---|
| 0 | 90 | 2.81 |
| 20 | 70 | 2.81 |
| 45 | 45 | 2.81 |

Table 3.6 Output voltage of motion sensor from different testing distances

| Distance from the Motion Sensor (m) | Output Voltage of Motion Sensor (V) |
|---|---|
| 0.5 | 2.81 |
| 1.0 | 2.81 |
| 1.5 | 2.81 |

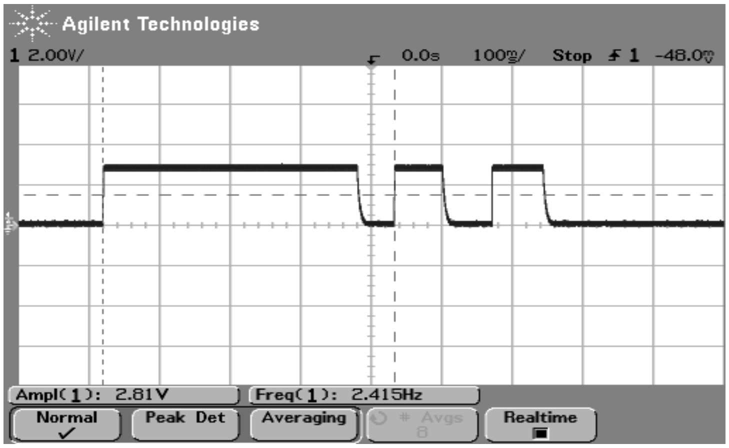

Figure 3.3. Measurement of output voltage when motion sensor detects motion from oscilloscope

## 3.6 Lighting Module

The lighting module passed the test as it satisfied Requirement 7 in Table A.1. The images from the testing for Requirement 7(a) are shown in Figure B.3 and B.4 in Appendix B. The lines and spaces for the ISO 12233 test chart are distinguishable. Meanwhile, for Requirement 7(b), the brightness of the LED lights increases with the duty cycle. This is observed during testing and demos.

## 3.7 Container and Lid

The enclosure and lid passed the test as it satisfied Requirement 8 in Table A.1. The enclosure is proved to be water-proof as no water droplet is found in the enclosure after water is sprayed at the enclosure at various angles.

# 4. Costs

## 4.1 Parts

Table 4.1 Cost of Parts

| Parts Name | Total Price ($) |
|---|---|
| Power Unit | 20.36 |
| Control Unit | 7.60 |
| Imaging Module | 524.01 |
| Force Sensing Module | 34.60 |
| Motion Sensing Module | 31.68 |
| Lighting Module | 35.47 |
| Container and Lid | 554.11 |
| **Parts Total** | **1207.83** |

The breakdowns of the costs for each module are shown in Table D.1, D.2, D.3, D.4, D.5, D.6 and D.7 in Appendix D.

## 4.2 Labor

Table 4.2 Cost of Labor

| Name | (Rate/hour)×(2.5)×(Total hours) | Total Price ($) |
|---|---|---|
| Hoong Chin Ng | ($40/hour)×(2.5)×(150 hours) | 15,000 |
| Sabrina Cheng | ($40/hour)×(2.5)×(150 hours) | 15,000 |
| Sze Yin Foo | ($40/hour)×(2.5)×(150 hours) | 15,000 |
| **Labor Total :** | | **45,000** |

## 4.3 Total Costs

Grand total = Parts + Labor = $1199.03 + $45,000

= **$46199.03**

# 5. Conclusion

The device is successfully constructed. However, there are still a lot of work and uncertainties as the device has not been tested on site.

## 5.1 Accomplishments

The Otter Print Shooter was able to capture high-resolution images of the ISO 12233 test chart and human fingerprints. By modifying camera settings, this device works equally well under lighted or dark conditions. When handprints are in contact with the transparent window surface, the phenomenon of Frustrated Total Internal Reflection (FTIR) works well and makes the print patterns distinctive.

Furthermore, the force sensing module which uses Force Sensitive Resistors (FSR) and relies solely on physical movement of the gasket on the container lid was able to detect pressure upon the transparent window. Since the surfaces around the enclosure (where FSRs were placed upon) are rough, tapes and foams were added around the enclosure gaps to level the unevenness of the surfaces. Washers were also put on the top of FSRs to have a smaller point of weight and thus higher contact pressure.

## 5.2 Uncertainties

As the operation of the Otter Print Shooter is stepping on unknown grounds, the unpredictable behavior of otters posts an uncertainty on the ability of the device to capture high-detail images of otter footprints. Various device settings such as the camera shutter speed and the brightness of LEDs may have to be tweaked to adapt to real-world situations. Revisions on the source code of the microcontroller might also be needed in order to adapt the device to the behavior of otters.

Besides these, the location of the actual site is still unknown. If the device is placed nearby a river where it may be fully submerged in water when the tide rises, the container and lid will have to be fortified with more waterproof measures.

## 5.3 Ethical considerations

In the process of obtaining background information and assembling the Otter Print Shooter for this project, ethical guidelines based on the IEEE Code of Ethics should be adhered to at all times.

The device for this project will be placed at certain sites susceptible to humans and endangered animals. Thus, pertaining to first code of ethics which states that "t*o accept responsibility in making decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment*", the device is designed to fit public safety standards. An inch-thick acrylic sheet capable of supporting the weight of an adult human is used for the transparent window.

As the device is a new technology never used in the field of animal-tracking before, the project is stepping on unknown grounds. Thus, pertaining to fifth code of ethics which states that "*to improve the understanding of technology, its appropriate application, and potential consequences*", research on otter behavior is done thoroughly regarding their weight, biometrics (footprints data), and active hours (night time) before designing the device that fits all the requirements exactly. Lighting module is added as otters on active on land at night. Moreover, the lighting of the device is programmed to brighten up gradually for the fear of alarming the otters.

## 5.4 Future work/Recommendations

Although the device is expected to work, the reaction of the otters towards the device remains unknown until the device is tested on the research site. Thus, the workings of the device and the footprint images obtained should always be kept track of in order to optimize the device operation.

There are a number of improvements that can be implemented for the device in the future. To decrease the cost of the device, cheaper cameras can be used but probably with some tradeoff for image quality. Apart from that, it is preferable to have adaptive camera settings to handle all kinds of lighting conditions and thus increasing the tolerance of the device towards external parameters. The transparent window can also be replaced with a more scratch-resistant material than the acrylic sheet currently used.

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# Appendix A Requirement and Verification Table

Table A.1 System Requirements and Verifications

| Requirement | Verification | Verification Status |
|---|---|---|
| 1. The power unit must provide stable 4.8 V VDD from the batteries and stable 3.0 V VCC from voltage regulator.<br>a. The batteries must provide at least 4.8 V when 1 mA current is drawn and at least 4.6 V when 1 A current is drawn.<br>b. The voltage regulator must provide 3.0 V when 1 mA current is drawn.<br>c. The voltage regulator must provide 3.0 V when its input voltage is between 4.6 V and 5.8 V. | 1. The voltages across the batteries and the voltage regulator are measured using a DMM.<br>a. Test the batteries using different resistors.<br>i. Connect a 4.7 kΩ resistor to the batteries simulate 1mA current drain and measure its voltage.<br>ii. Repeat the above test with 4.7 Ω resistor to simulate 1 A current drain.<br>b. Connect a 3 kΩ resistor to the voltage regulator to simulate 1mA current drain and measure its voltage.<br>c. Supply the voltage regulator with 4.6 V, 5.0 V, 5.2 V, 5.4 V, 5.6 V and 5.8 V using tunable power supply and measure its output voltage. | Yes |
| 2. The control unit must be able to receive signals from the motion sensing module and the force sensing module, output signals to the imaging module and the lighting module and operate according to the Section 2.2.<br>a. The microcontroller must be able to interpret a signal with 0.6 VCC (1.8 V) or higher as high.<br>b. The high signal generated by the microcontroller must have 0.9 VCC (2.7 V) or higher when 2 mA current is drawn.<br>c. The microcontroller must be able to generate a 0.1 s 3.0 V square pulse.<br>d. The microcontroller must be able to generate a 100 Hz 3.0 V PWM signal that increases its duty cycle from 0% to 80% over 4 s with 5% increment every 0.25 s. | 2. Connect the inputs of microcontroller 3.0 V switches and connect the outputs to LEDs. Turn on and off the switches to simulate input signals from the sensing modules and monitor the LEDs to verify whether its operation is similar to Section 2.2.<br>a. Connect a 10 Hz square wave signal from a function generator to the input of the microcontroller and gradually increase its peak voltage. Record the first voltage that the microcontroller interprets as a high signal.<br>b. Connect a 1.8 kΩ resistor to the output of the microcontroller to simulate the 2 mA drain to the lighting unit. Program the microcontroller to output high signal and verify the output voltage on a DMM.<br>c. Program the microcontroller to | Yes |

| | | |
|---|---|---|
| | output a 0.1 s 3.0 V square pulse and verify the output waveform on an oscilloscope.<br>d. Program the microcontroller to output a 100 Hz 3.0 V PWM signal that increases its duty cycle from 0% to 80% over 4 s with 5% increment every 0.25 s and verify the output waveform on an oscilloscope. | |
| 3. The camera must be able to capture images with the level of detail at least the scale of 10 on the ISO 12233 test chart at 18 inches away. | 3. Take an image of the ISO 12233 test chart at 18 inches away in a well-lit room using the camera settings listed in Table 2.2. Zoom in the image to inspect whether the lines and spaces for the scale of 10 on the ISO 12233 test chart are distinguishable. | Yes |
| 4. The shutter controller must be able to trigger the camera to take an image when it reaches a high signal. | 4. Connect the input of the imaging module to a 3.0 V switch and use the switch to trigger the camera. Turn on the switch and verify whether an image was taken by the camera. | Yes |
| 5. The force sensing unit must generate high signal to the control unit when 3kg or more is applied.<br>a. The output voltage of the force sensing unit must be 1.8 V or higher when 3 kg weight is applied.<br>b. Resistance of the force sensor must have 6 kΩ or less when 3 kg weight is applied and have at least 100 kΩ when no weight is applied. | 5.<br>a. The force sensing unit will be tested using no weight, 1 kg and 3 kg weights and its output voltage will be measured using a DMM.<br>i. Connect 30 Ω and 10 kΩ resistors in series with a FSR.<br>ii. Place the FSR on a flat surface.<br>iii. Place a large acrylic sheet on top of the sensor.<br>iv. Measure the voltage across the 10 kΩ resistor using a DMM.<br>v. Place different weights of 1 kg and 3 kg on top of the sheet at various spots while measuring the voltage across the 10 kΩ resistor using a DMM.<br>vi. Determined if the microcontroller interprets the signal as HIGH or LOW based on the programmed configuration.<br>b. The force sensor will be tested using no weight, 1 kg and 3 kg weights and its resistance will be | Yes |

| | | |
|---|---|---|
| | measured using a DMM.<br>i. Place the FSR on a flat surface.<br>ii. Place a large acrylic sheet on top of the sensor.<br>iii. Measure the voltage across the 10 kΩ resistor using a DMM.<br>iv. Place different weights of 1 kg and 3 kg on top of the sheet at various spots while measuring the resistance of the sensor using a DMM. | |
| 6. The motion sensor must detect motion generate a 3.0V HIGH output.<br>a. It must detect motion within 45° from its center point.<br>b. It must detect motion within 1m away. | 6. The output of the motion sensor will be examined using an oscilloscope.<br>a.<br>i. Wave hand at the center point of the sensor (90° from the surface of the acrylic sheet) while observing the output on the oscilloscope.<br>ii. Then, move to the side 20° (70° from the surface of the acrylic sheet) and 45° away from the center point while observing the output on the oscilloscope.<br>b.<br>i. Wave hand right in front of the sensor while observing the output on the oscilloscope.<br>ii. Then, move 0.5 m, 1 m and 1.5 m away from the sensor while observing the output on the oscilloscope. | Yes |
| 7. The lighting unit must have adequate and controllable brightness.<br>a. The lighting unit must generate sufficient lights for the camera to take high-detail images at the ISO 800.<br>b. The brightness of the lighting unit must change according to the duty cycles of its input, LED_SIG. | 7.<br>a. The lighting unit will be tested at maximum brightness with its lights shone into the sides of an acrylic sheet.<br>iii. Place the ISO 12233 (Figure F.1) test chart under the acrylic sheet.<br>iv. Turn off other light sources and take an image of the test chart using the camera settings listed in Table 2.2.<br>v. Zoom in to inspect whether the | Yes |

| | | |
|---|---|---|
| | lines and spaces for the scale of 10 on the ISO 12233 test chart are distinguishable.<br>b. The brightness of the lighting unit will be observed in a dark room with its input (LED_SIG) connected to a function generator.<br>i. Generate a 100 Hz 3.0 V square wave with duty cycle of 20% to the input of the lighting unit.<br>ii. Observe the brightness of the lighting unit.<br>iii. Repeat the observation using square waves with duty cycles of 40%, 60%, 80% and 100%. | |
| 8. The enclosure must be water-proof. | 8.<br>i. Spray water on the sealed enclosure at various angles and sides.<br>ii. Open the enclosure and look for water droplet. | Yes |

# Appendix B Test Data and Measurements

Table B.1 Result of the Imaging Test on Various Imaging Devices

| Imaging Device | Result Description |
|---|---|
| Logitech Webcam Pro 9000 | Clear images of fingerprints were obtained for distance less than 10cm using manual software focus. |
| Iphone 4S rear camera | Clear images of fingerprints were obtained for distance up to 15cm. The autofocus was hard to lock on the fingerprints. |
| Sony DSC-W310 | The autofocus was impossible to lock on the fingerprints. No clear image was obtained. |
| Panasonic DMC-LX5 | Clear images of fingerprints were obtained for distance up to 30cm using autofocus. |
| Nikon D3000 w/ lens kit | Clear images of fingerprints were obtained for the maximum test distance of 45cm. |
| Nikon D5100 w/ lens kit | Clear images of fingerprints were obtained for the maximum test distance of 45cm. |

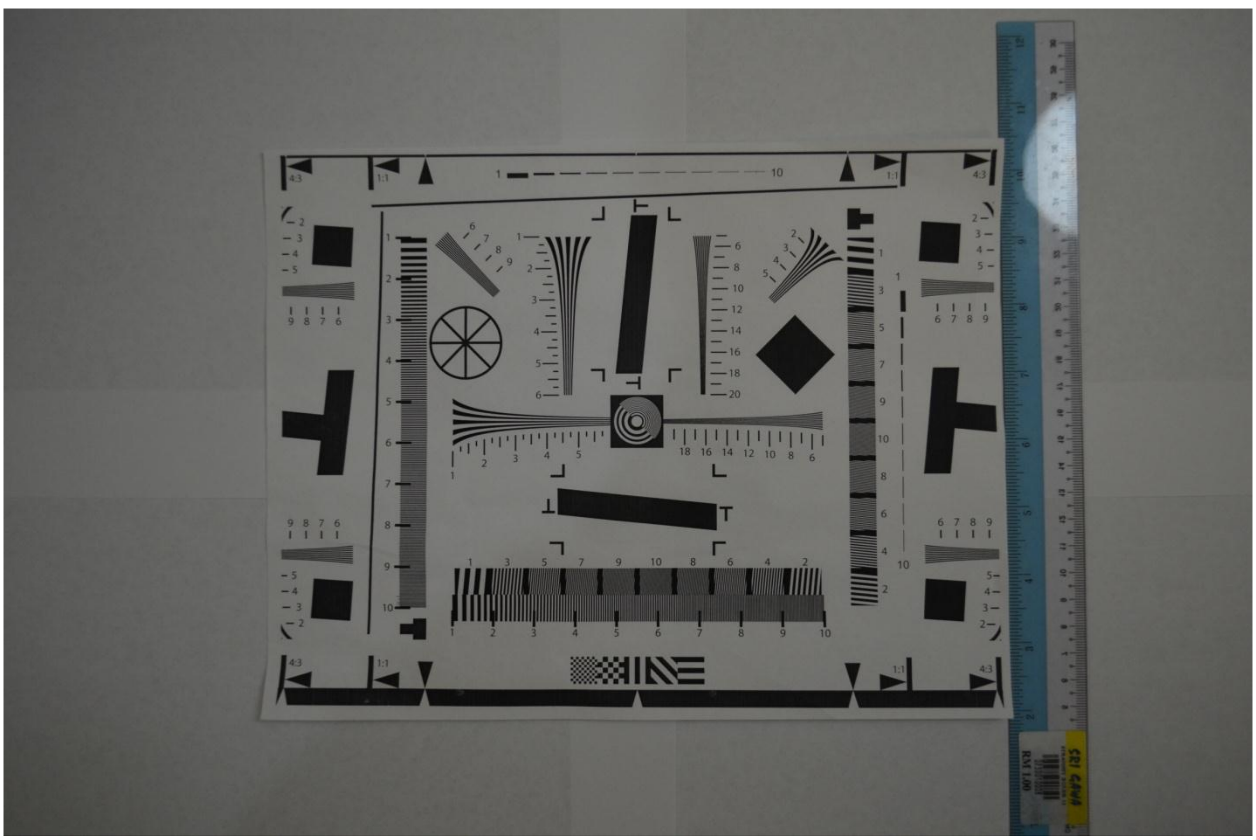

Figure B.1. Image of the ISO 12233 test chart taken 18 inches away

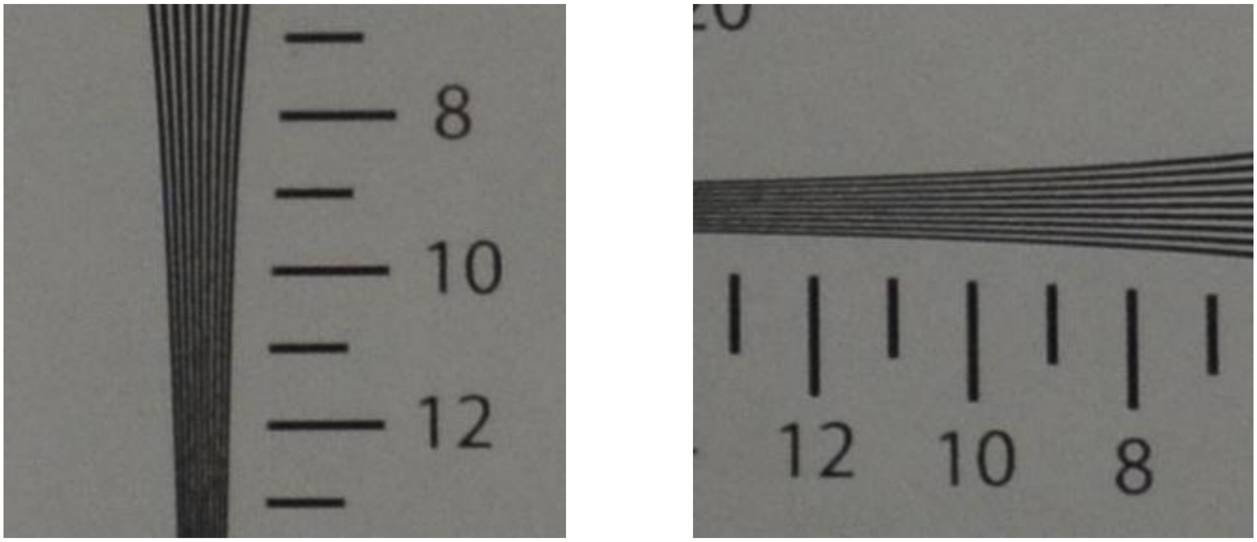


**Figure B.2. Enlarged images of Figure C3 to show the lines and spaces at the scale of 10 on the ISO 12233 test chart**

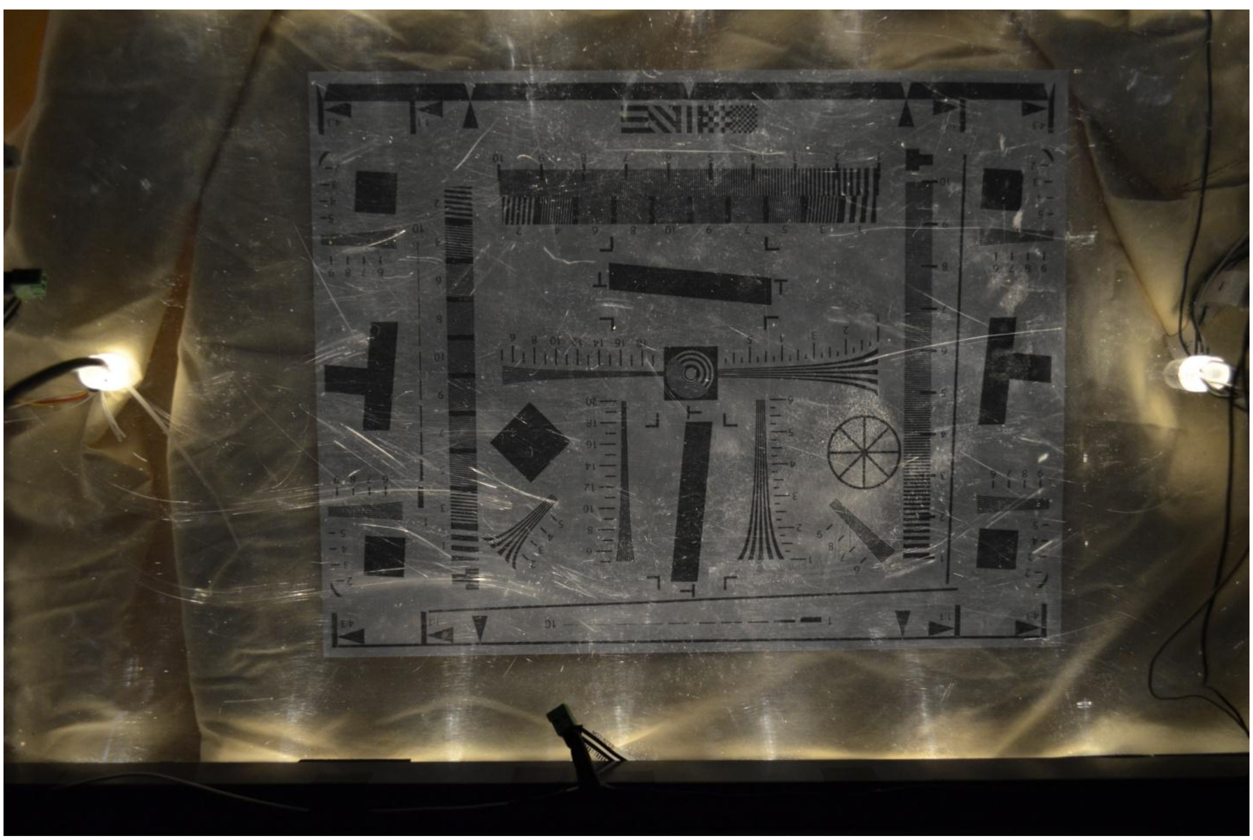

**Figure B.3. Image of ISO 12233 test chart taken with only LED lights as lighting source**

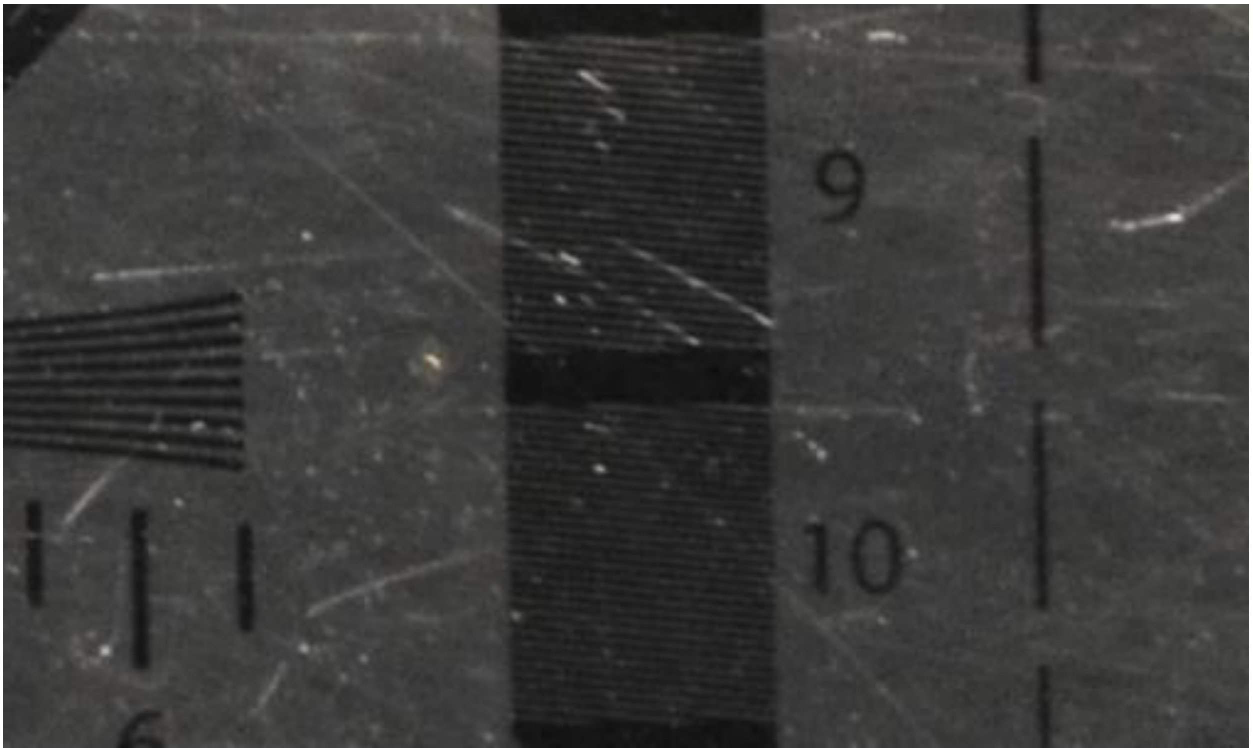


**Figure B.4. Enlarged view of Figure K1 with lines and spaces of scale 9 and 10**

# Appendix C Flow Chart

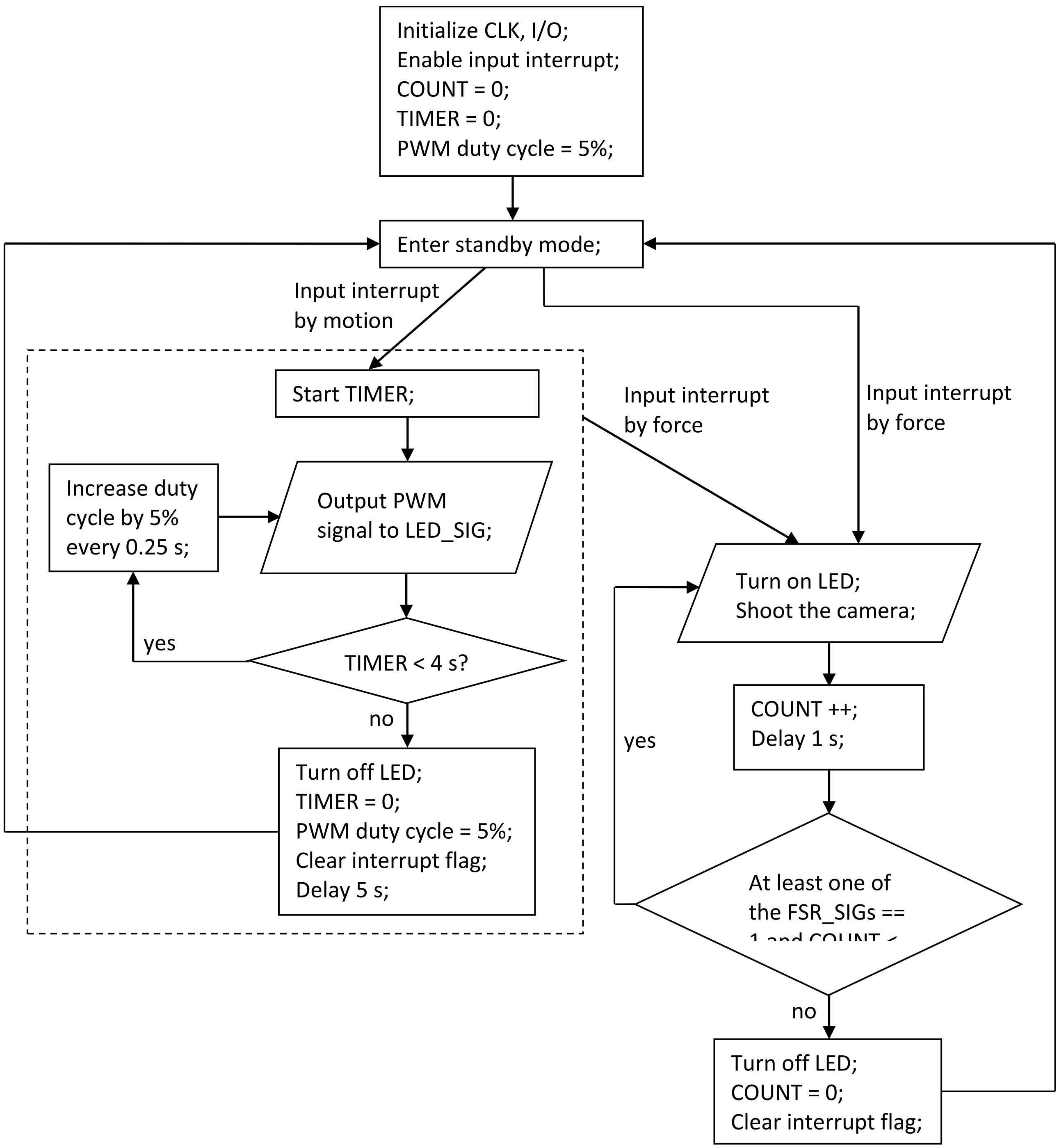


Figure C.1. Flow chart of the operation of the microcontroller

# Appendix D Parts Cost

Table D.1 Parts Cost for Control Unit

| Part Name | Quantity | Price/Unit ($) | Total Price ($) |
|---|---|---|---|
| 4 Sanyo Eneloop AA NiMH Rechargeable Batteries and Charger | 1 | 16.00 | 16.00 |
| Battery Holder 4AA-Cells | 1 | 1.33 | 1.33 |
| Voltage Regulator 250mA 3V (MCP1700) | 1 | 0.39 | 0.39 |
| Switch Slide DPDT 6A (S202131MS02Q) | 1 | 2.64 | 2.64 |
| **Parts Total** | | | **20.36** |

Table D.2 Parts Cost for Control Unit

| Part Name | Quantity | Price/Unit ($) | Total Price ($) |
|---|---|---|---|
| Texas Instrument Launchpad MSP430G2553 | 1 | 4.30 | 4.30 |
| Ceramic 1nF 100V Capicator (MCRR25102COGJ0100) | 1 | 0.18 | 0.18 |
| IC Socket 20 Pos Dip Tin | 1 | 0.83 | 0.83 |
| 47K Ohm 1/2w 5% Carbon Film Resistor (Pk/5 2160242) | 1 | 1.00 | 1.00 |
| Aluminum 10UF 10V 20% RADIAL Capacitor (SN100m010ST) | 2 | 0.14 | 0.28 |
| Tantinum 0.1uF 50V 26Ohm Radial Capacitor (TAP104K050SCS) | 1 | 0.40 | 0.40 |
| MOSFET N-Channel (FDV301N) | 1 | 0.61 | 0.61 |
| **Parts Total** | | | **7.60** |

Table D.3 Parts Cost for Imaging Module

| Part Name | Quantity | Price/Unit ($) | Total Price ($) |
|---|---|---|---|
| Canon EOS REBEL T3 with 18-55mm lens | 1 | 494.00 | 494.00 |
| Optocoupler Phottrans 200% 4SMD (SFH6186-2) | 1 | 1.01 | 1.01 |
| Nikon MC-DC2 Shutter Release Interface Cable | 1 | 16.00 | 16.00 |
| Canon SMDV Shutter Release Interface Cable | 1 | 12.00 | 12.00 |
| Metal Film 2.1k Ohm 1/4W 1% Resistors (42R2101) | 1 | 1.00 | 1.00 |
| **Parts Total** | | | **524.01** |

Table D.4 Parts Cost for Force Sensing Module

| Part Name | Quantity | Price/Unit ($) | Total Price ($) |
|---|---|---|---|
| Interlink Electronics Force Resistor Sensor (402) | 4 | 7.48 | 29.92 |
| Flat Metal Washer | 4 | 0.10 | 0.40 |
| RES Metal Film 10K Ohm ¼W 1% Resistors (MFR-25FBF-10K0) | 4 | 0.13 | 0.52 |
| RES Metal Film 30 Ohm 2W 5% Resistor (PR02000203009JR500) | 4 | 0.54 | 2.16 |
| Tantinum 0.1uF 50V 26Ohm Radial Capacitor (TAP104K050SCS) | 4 | 0.40 | 1.60 |
| **Parts Total** | | | **34.60** |

Table D.5 Parts Cost for Motion Sensing Module

| Part Name | Quantity | Price/Unit ($) | Total Price ($) |
|---|---|---|---|
| Panasonic NaPiOn Motion Sensor (AMN42122) | 2 | 15.44 | 30.88 |
| Tantinum 0.1uF 50V 26Ohm Radial Capacitor (TAP104K050SCS) | 2 | 0.40 | 0.80 |
| **Parts Total** | | | **31.68** |

Table D.6 Parts Cost for Lighting Module

| Part Name | Quantity | Price/Unit ($) | Total Price ($) |
|---|---|---|---|
| Everlight SMD Low Power LED (61-238/Qk2C-B28322FaGB2/ET) | 14 | 0.92 | 11.04 |
| 3M Copper Strips | 1 | 16.43 | 16.43 |
| 100 feet Wire 22 Gauge | 1 | 8.00 | 8.00 |
| **Parts Total** | | | **35.47** |

Table D.7 Parts Cost for Container and Lid

| Part Name | Quantity | Price/Unit ($) | Total Price ($) |
|---|---|---|---|
| Gasket and screws | 1 | 40.43 | 40.43 |
| ¾” Acrylic sheet (22”×15”) | 1 | 102.69 | 102.69 |
| Silicon sealant | 1 | 4.99 | 4.99 |
| 2” Foam Tape 30 ft | 1 | 6.00 | 6.00 |
| Custom made enclosure | 1 | 400.00 | 400.00 |
| **Parts Total** | | | **554.11** |

# Appendix E Container and Lid

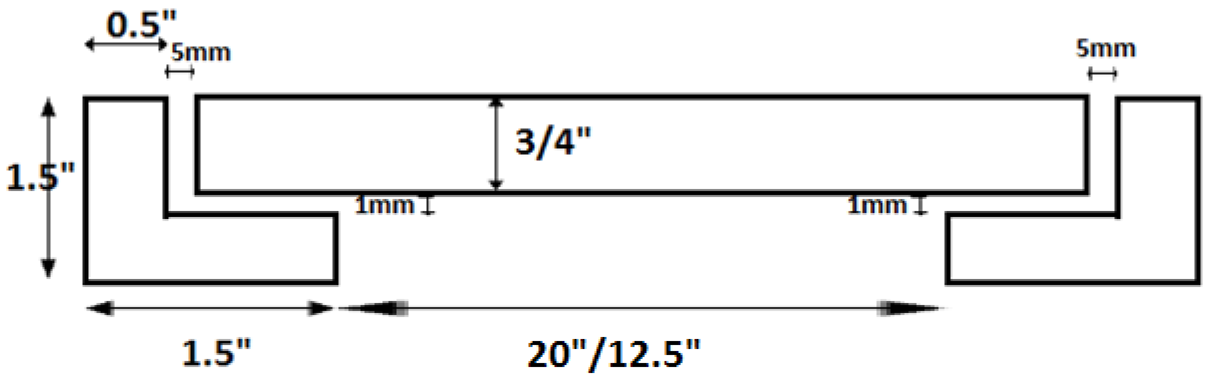


Figure E.1. Side views of the lid

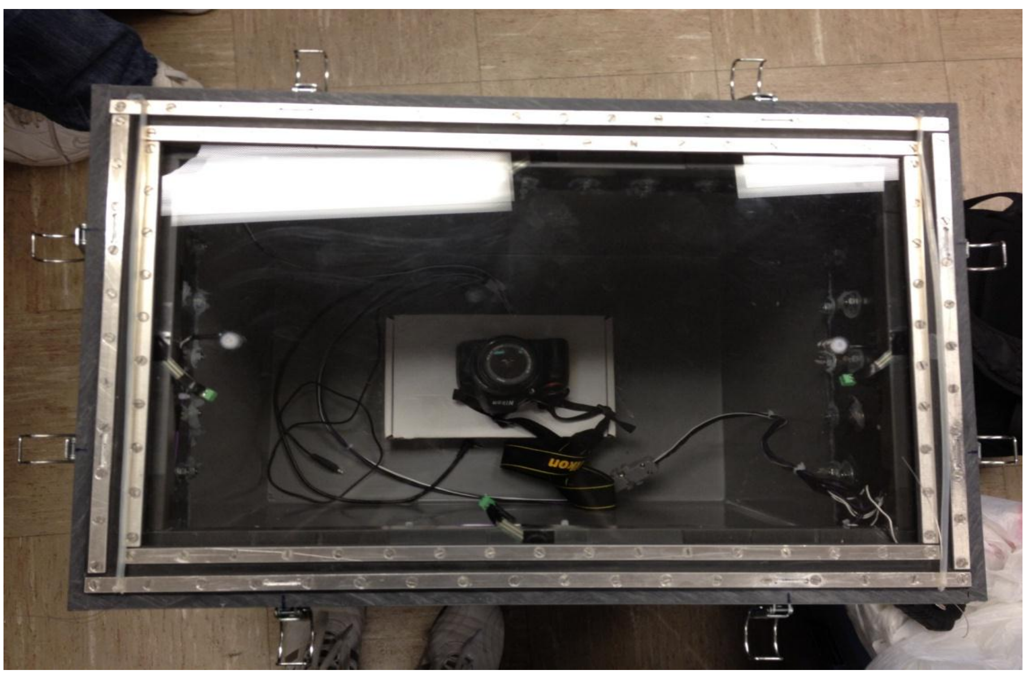

Figure E.2. Top view of the lid

Figure E.3. Wiring of FSR, PIR and LED under the lid

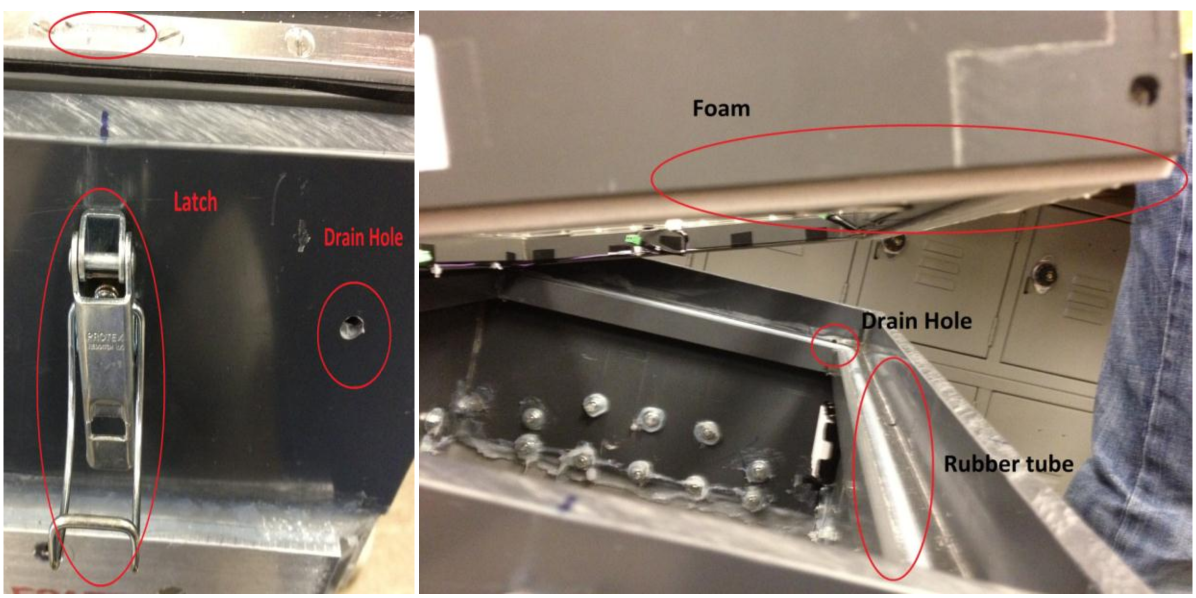


Figure E.4. Latch, rubber tube, drain hole and extra foam under the lid to enable the container to be water proof.

# Appendix F ISO 12233 Test Chart

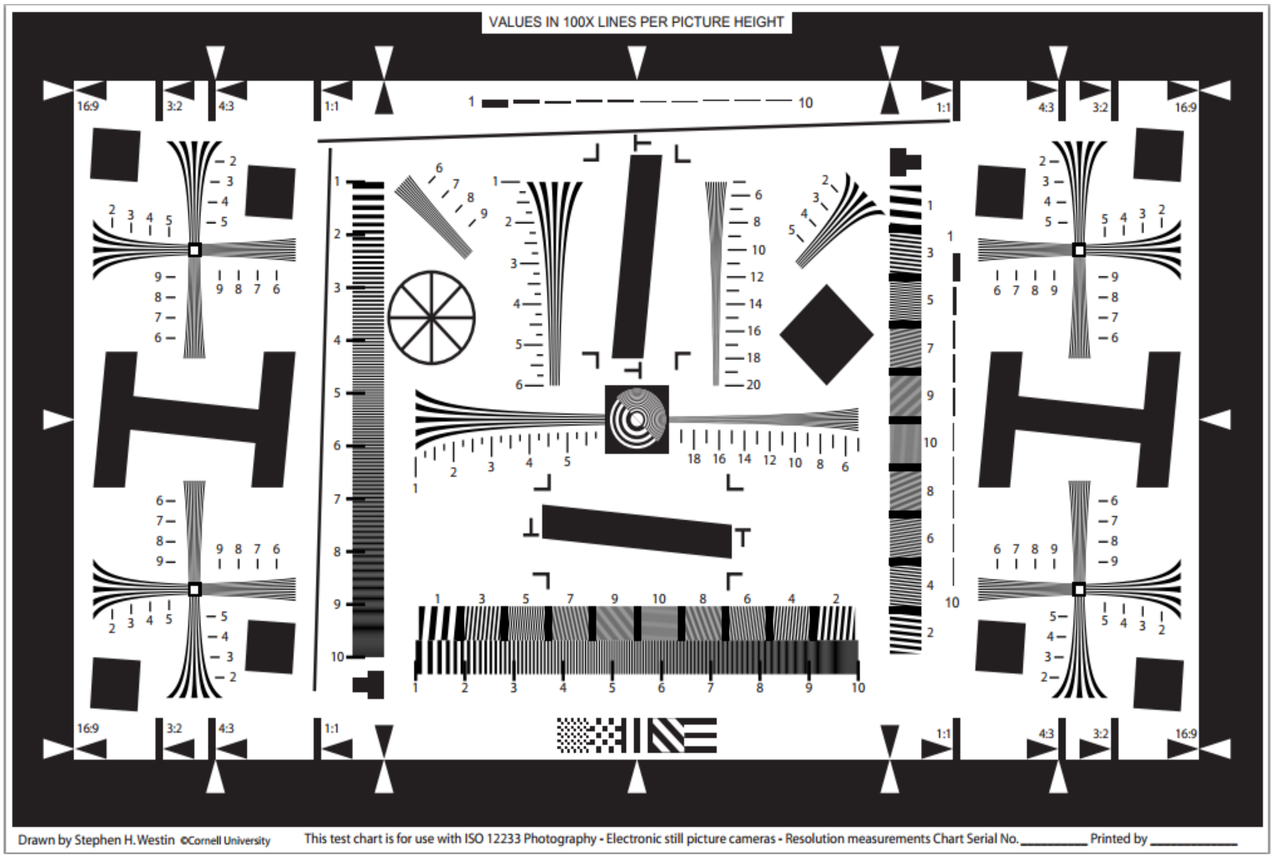


Figure F.1. ISO 12233 test chart [12]

# Appendix G Table of Compatible Cameras

Table G.1 Compatible Cameras for the Otter Print Shooter

| Brand | Model | Effective Resolution (M) | Suggested Retail Price ($) |
|---|---|---|---|
| Canon | EOS Rebel T2i w/ lens kit | 18.0 | 699.99 |
| Canon | EOS Rebel T3 w/ lens kit | 12.2 | 549.99 |
| Canon | EOS Rebel T3i w/ lens kit | 18.0 | 849.99 |
| Canon | EOS 60D | 18.0 | 999.99 |
| Nikon | D3100 w/ lens kit | 14.2 | 649.95 |
| Nikon | D5000 w/ lens kit | 12.3 | 629.95 |
| Nikon | D5100 w/ lens kit | 16.2 | 849.95 |
| Nikon | D7000 | 12.3 | 1199.95 |
| Nikon | D90 | 16.2 | 899.95 |
| Nikon | D800 | 36.3 | 2999.95 |
| Nikon | D4 | 16.2 | 5999.95 |