ENSC 305W/440W Grading Rubric for Design Specification

Criteria	Details	Marks
Introduction/Background	Introduces basic purpose of the project.	**/05%**
Content	Document explains the design specifications with proper justification for the design approach chosen. Includes descriptions of the physics (or chemistry, biology, geology, meteorology, etc.) underlying the choices.	**/20%**
Technical Correctness	Ideas presented represent valid design specifications that will be met. Specifications are presented using tables, graphs, and figures where possible (rather than over-reliance upon text). Equations and graphs are used to back up/illustrate the science.	**/20%**
Process Details	Specification distinguishes between design details for present project version and later stages of project (i.e., proof-of-concept, prototype, and production versions). Numbering of design specs matches up with numbering for functional specs.	**/15%**
Test Plan	Provides a functional test plan for the present project version. (Note that project success will be measured against this test plan.)	**/10%**
Conclusion/References	Summarizes functionality. Includes references for information from other sources.	**/05%**
Presentation/Organization	Document looks like a professional specification. Ideas follow in a logical manner.	**/05%**
Format Issues	Includes letter of transmittal, title page, abstract, table of contents, list of figures and tables, glossary, and references. Pages are numbered, figures and tables are introduced, headings are numbered, etc. References and citations are properly formatted.	**/10%**
Correctness/Style	Correct spelling, grammar, and punctuation. Style is clear concise, and coherent. Uses passive voice judiciously.	**/10%**
Comments		

MOTUS

Simon Fraser University
School of Engineering Science
8888 University Drive
Burnaby, B.C.
V5A 1S6

November 13, 2013
Mr. Sjoerdsma
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Design Specifications – Digital Auto-Focus with Shifting Sensor

Dear Mr. Sjoerdsma,

This package contains Motus' design specifications for our Image Sensor Shifting System (ISSS) for cameras. Our group is currently in the process of building a camera prototype that makes use of a mobile image sensor that can achieve auto-focusing without having to shift any glass lenses.

The attached document outlines the design choices that we have made during the development of our project in a variety of systems ranging from software, to hardware, to the optical system. In addition, we also cover a test plan that we have created, which will be used at a later time to test the various functions of our product.

If you wish to discuss our project in further detail, or have any questions or concerns, please feel free to contact me via email at jpa30@sfu.ca.

Sincerely,

Jeff Priest
Chief Executive Officer
Motus

Image Sensor Shifting System for Cameras

Design Specifications

Project Members

Jeff Priest
jpa30@sfu.ca

Roy Choi
rychoi@sfu.ca

Bill Xu
yunhanx@sfu.ca

Vincent Chen
qca10@sfu.ca

Submitted To

Mr. Sjoerdsma – ENSC 305
Dr. One – ENSC 440
Simon Fraser University – School of Engineering Science

Date Issued

November 13, 2013

Revision

1.0

Acknowledgment

We would like to thank the engineers at GrabCAD.com who shared their Solidworks design models with us. Some Solidworks parts used in this document and our project are modified based on models posted on GrabCAD.com. All of the reference Solidworks models will be placed at the end of this document.

Executive Summary

Motus’ Image Sensor Shifting System is being designed to provide photographers with an alternative means of achieving auto-focus, even if their preferred lens doesn’t natively support it. After doing an exhaustive market search for a camera that has this feature, and discovering that none currently exist, we decided to develop a prototype that would be able to demonstrate this.

The design for our product can be broken down into several sub-systems, each can be broken down further into its constituent components. At the highest level, our system can be viewed as four major systems working together. The optical system, mechanical system, software and image processing system, and the control hardware all work together to create a working product. The design of these sub-systems and their components will be outlined in this document.

Glossary

Aperture – a hole or an opening through which light travels. Aperture’s size can be converted to the F stop number. The bigger aperture, the smaller F-stop number and vice versa.

Circle of confusion – an optical spot caused by a cone of light rays from a lens not coming to a perfect focus when imaging a point source.

Depth of Focus – the range of the tolerance of placement of the image plane in relation to the lens.

Flange Focal Distance – the distance from the metal ring on the camera (rear end of the lens) to the image plane.

ISO – Measurement of sensitivity of light

ISSS – Image Sensor Shifting System

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1. Introduction

Motus' Image Sensor Shifting System (ISSS) introduces an alternative method of achieving auto-focus for cameras. The primary objective of the device is to let camera users use manual-focus lenses to perform auto focus. The ISSS is designed to move an image sensor inside the camera instead of moving the focal glasses inside a camera's lens attachment. The advantages of the shifting the image sensor instead of the lens are numerous. Lenses manufactured in the future will be smaller without sacrificing image quality. The lens will not require a motor and focal glass, and it will be cheaper to manufacturer. This document outlines the design decisions made up until this point in the project's development lifecycle. It covers the image sensor, image processing subsystem, and motor control systems.

1.1 Scope

Based on the functional specification document, the design specification highlights and details the implementation of functions related to the ISSS. The information provided will justify the design techniques implemented and will further provide detailed information regarding hardware parts and software interface. It should be noted that the design specification will not fulfill all functions highlighted in the functional specification document.

1.2 Intended Audience

The design specification document is created to guide and provide detailed information to Motus engineers. This document will detail all subsystems and their components and describe how each is implemented.

2. System Specifications

The ISSS will allow users to capture a focused image by using any 35mm full frame lens. The image sensor will be moved to the corresponding focal plane, which is based on the flange distance of the camera lens. Once the image sensor reaches this position, it will slightly shift within the depth of focus and record all the images, at which point the image processing algorithm can take over and notify the microcontroller how much to move the sensor.

2.1 System Design Overview

The ISSS (Ball Screw) is shown in Figure 1. The image sensor is mounted on a linear motion mechanism which is widely used in CNC machines. The camera lens is mounted in front of the enclosure, and aligned with the image sensor. The microcontroller and stepper motor driver are safely secured inside the enclosure without interference from any mechanical moving parts. None of the cable connections or fasteners are shown in the CAD model.

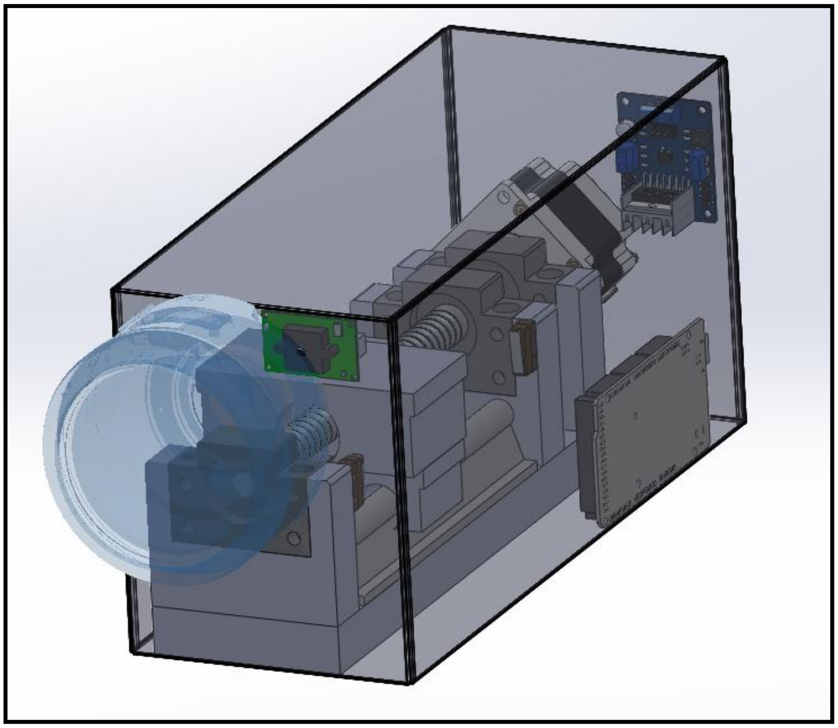

Figure 1 – ISSS (Ball Screw) 3D Model

The ISSS (Gear Train) is shown in Figure 2. The only difference between concept 1 and 2 is the mechanical shifting system. The ISSS (Gear Train) can significantly reduce the physical size of the ISSS, but the trade-off for physical size reduction is the control precision of shifting steps.

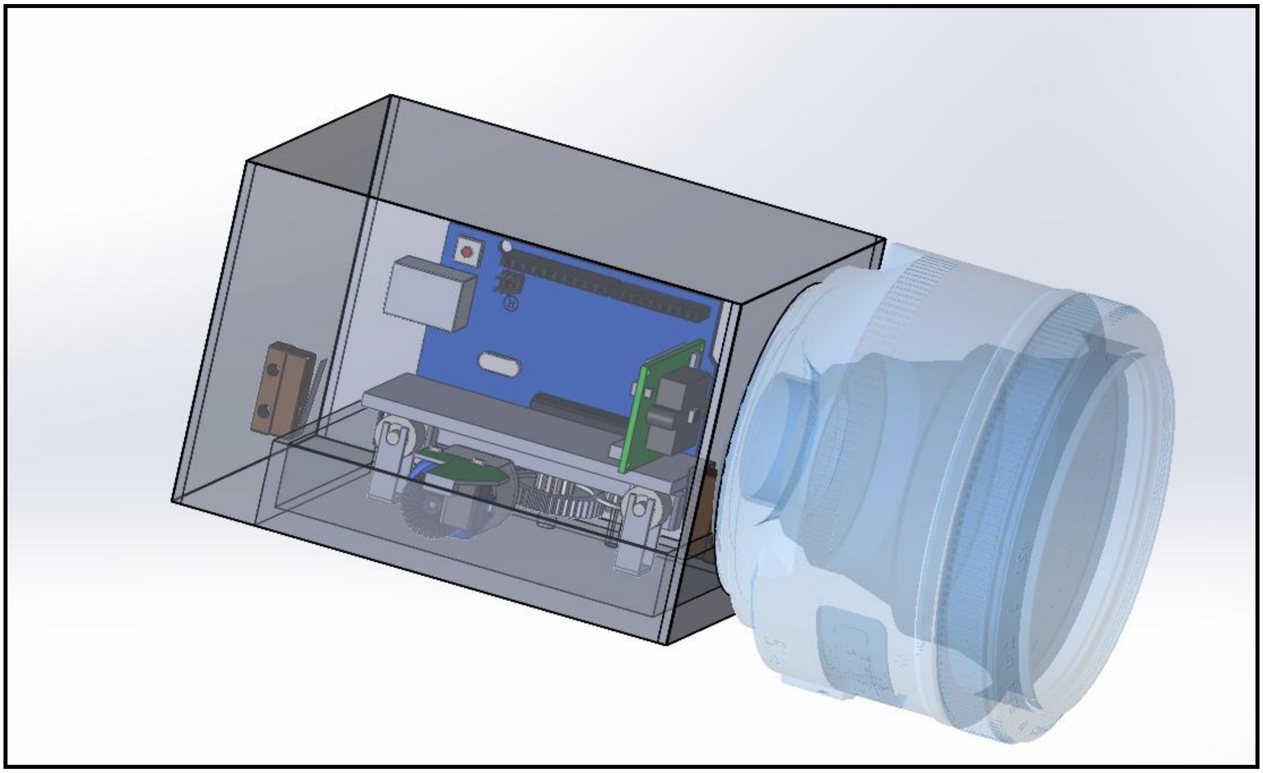

Figure 2 – ISSS (Concept 2) 3D Model

2.2 High Level Design

A high level diagram of the ISSS is shown in Figure 2. There are two input signals which can be received by the image sensor and limit switches. When the image sensor captures the image, the image sensor will transfer data to the local workstation for real time image processing. The picture will be displayed to the user via the local workstation's monitor. If the current picture is not in focus, a shifting command signal will be sent to the microcontroller. After the shifting command has been received by the microcontroller, the microcontroller will generate a shifting signal, which will shift the image sensor forwards and backwards. The shifting command signal will be amplified by a stepper motor driver and will be transmitted to the linear motion actuator. The stepper motor driver will be only used for ISSS (Ball Screw).

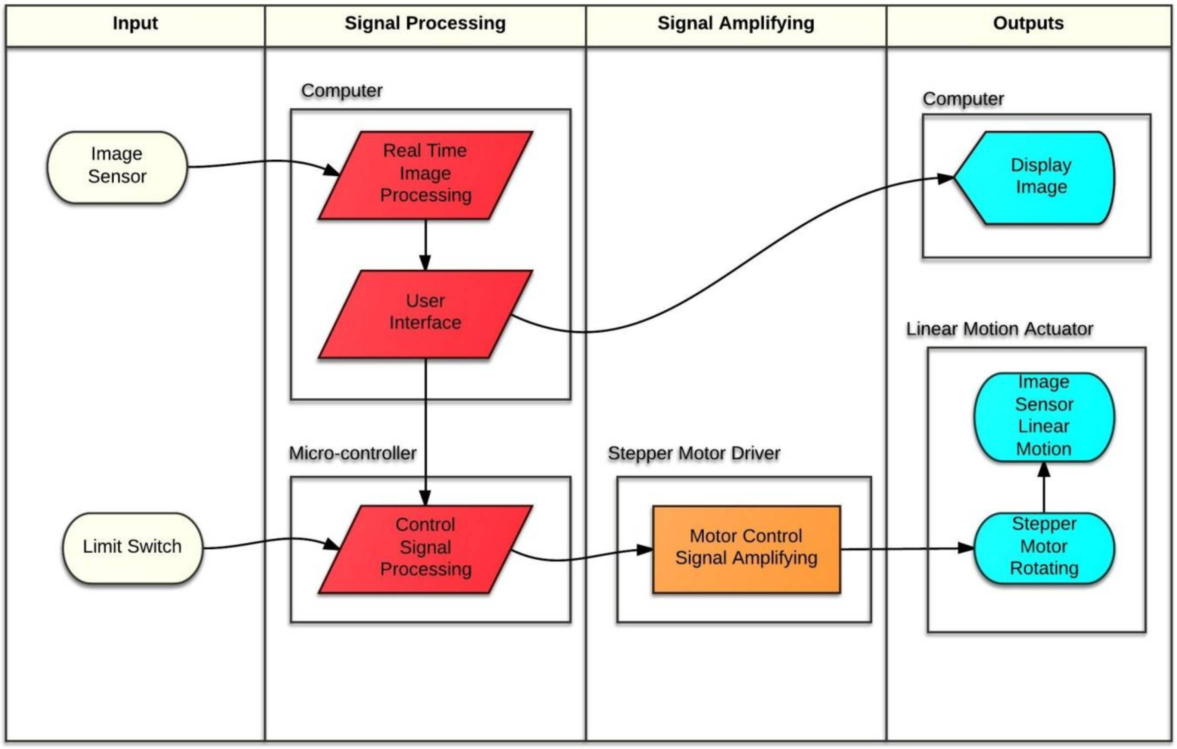

Figure 3 – ISSS High Level Diagram

Another input of the ISSS is the safety switch signal. This switch signal is used to determine if the image sensor carriage is reaching either of the two extreme positions along the rail. If the carriage is reaching one of extreme positions, the motor will be shut down immediately to avoid damaging the hardware.

3. Optics Specification

In the prototype development stage, the Helios 44-2 58mm F2 manual focus lens is used to project images onto the image sensor. It is a 35mm full frame manual focus lens with a 58mm focal length, F2 maximum aperture value, and F16 minimum aperture value. Theoretically, it is capable of producing 36mm x 24mm images. Its mount type is a M42 screw mount with a 45.46mm flange focal distance.[1] In other words, for the ISSS, the image sensor should be at least 45.46mm of separation from the rear end of this lens in order to capture focused images.

Figure 4 - Helios 44-2 58mm F2 Lens, excerpted from [1]

In this stage, the aperture value of the lens is set to be in between F8 and F16 due to two reasons: First, the image sensor that is used is not able to control the ISO. If the aperture's F-stop number is smaller than F8, the image tends to be over exposed. Second, in order to let the shifting image sensor easily capture sharp and clear images, the depth of focus should be maximized. Apertures between F8 and F16 are capable of providing wide enough depth of focus. The position of the depth of focus is demonstrated in Figure 2.

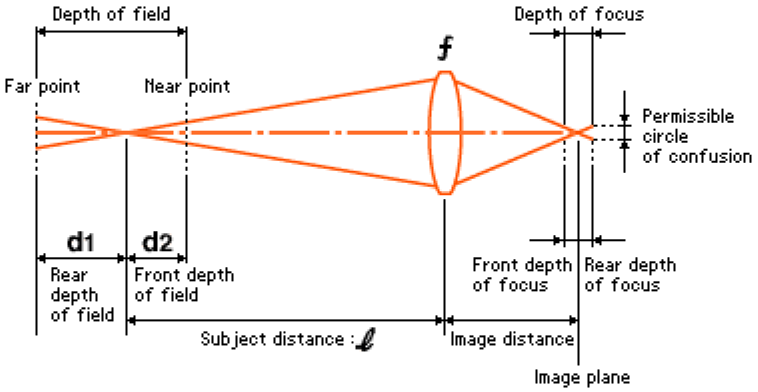

Figure 5 – Depth of Focus [2]

The formula used to calculate the depth of focus is given below.[3]

$$t \approx 2Nc$$

Equation 1

Where t is the depth of focus, N is the lens aperture F-stop number, and c is the circle of confusion. The circle of confusion of the 35mm full frame lens is 0.029mm.[4]

If we individually substitute F8 and F16 into Equation 1, t should be 0.464 and 1.276. That means at F8 aperture, the depth of focus is 0.464mm; at F16 aperture, the depth of focus is 0.928mm. The values of depth of focus determine the accuracy of the image sensor’s positioning. For example, at F16 aperture, the image sensor should be placed within 0.928mm of the lens. As the aperture F-stop number decreases, the placement of the image sensor should become more precise.

Since the image sensor is able to shift variable distances, it means flange focal distance changes as well. As per the shifting system overview section in this document, the furthest end of the rails will be 10cm away from the rear end of the lens. Based on the object image and focal distance relationship, the longer distance between the rear nodal point of the lens and the image sensor will allow the lens to focus on closer objects. This relationship is given in the following formula:

$$\frac{1}{S_1}+\frac{1}{S_2}=\frac{1}{f}$$ **Equation 2**

Where S_1 is the distance from the front nodal point of the lens to the object, S_2 is the distance from the rear nodal point of the lens to the image sensor, f is the focal length. This formula is only applied to 35mm full frame normal lenses. Focal lengths between approximately 40mm and 58mm are considered normal.[6]

In our case, S_2 is 100mm and f is 58mm. By substituting these two values into Equation 2, we are able to know the theoretical closest focus distance of this lens on the ISSS is approximately 138mm.

On the other hand, when the lens focuses on infinity ($S_1 = \infty$), S_2 becomes 58mm, meaning theoretically the image sensor should be shifted to the position which is 58mm away from the rear nodal point of the lens.

4. Imaging Sensor Specification

The purpose of the image sensor is to capture the image and send it to the local workstation for processing. Ideally, the best candidate for the image sensor is the 35mm full frame image sensor with 36mm x 24mm physical dimensions, in order to capture the whole image projected by the lens. However, due to shortages of project funding, sensor complexity and limited time, we acknowledge that a full frame image may be unattainable, and instead decide to use webcam’s image sensor as a much simpler and more economic solution that will still be capable of demonstrating the product.

Figure 6 – ¼ Inch CMOS image sensor[7]

The webcam is powered by the USB cable. The image sensor inside the webcam is ¼ inch VGA CMOS digital image sensor. It produces a 1.3 megapixel still image. Its size is 3.6mm x 2.7mm. It is only capable of capturing a 3.6mm x 2.7mm rectangular area on 36mm x 24mm image plane produced by the lens. However, this tiny image sensor is still sufficient to obtain a clear image of the object once it is placed at the correct flange focal distance.

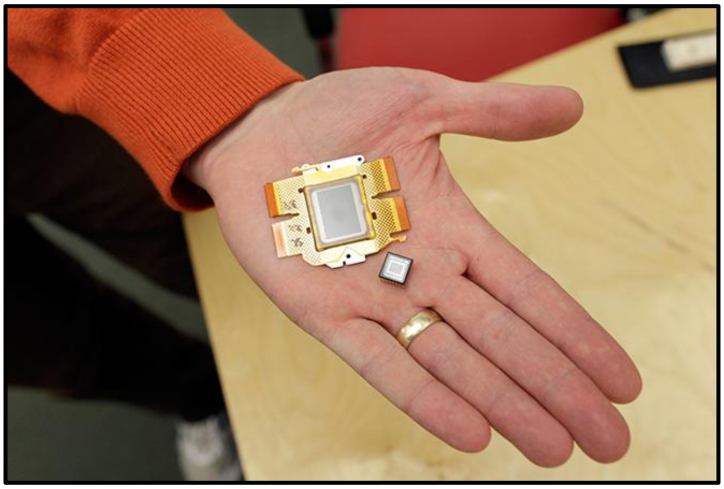

Figure 7 – 35mm full frame and ¼ inch image sensors [8]

During testing, we found that this image sensor is unable to auto adjust the ISO in different lighting situations. In a well-lit indoor environment, the pictures captured by this image sensor tend to be overexposed. This is because the image sensor has a very high ISO value, meaning it has superior low light performance. As discussed in the optics overview section in this document, the lens's aperture should be relatively small in order to prevent over-exposure. One point of note is that the image sensor may introduce some noise to the image quality, due to having a high ISO. However, the relatively noisy image should not adversely affect the ability to be processed by our software algorithm.

5. Shifting System and Enclosure Specification

Motus' ISSS prototype offers two types of image sensor shifting mechanisms. One is a ball screw shifting system and another one is gear train shifting system. Both of these mechanisms are composed of mechanical linear actuators and motors. The control process of the two mechanisms is the same: control how many degrees the motor rotates in order to set how far the linear actuator can shift.

5.1 Ball Screw Shifting System

5.1.1 Ball Screw System

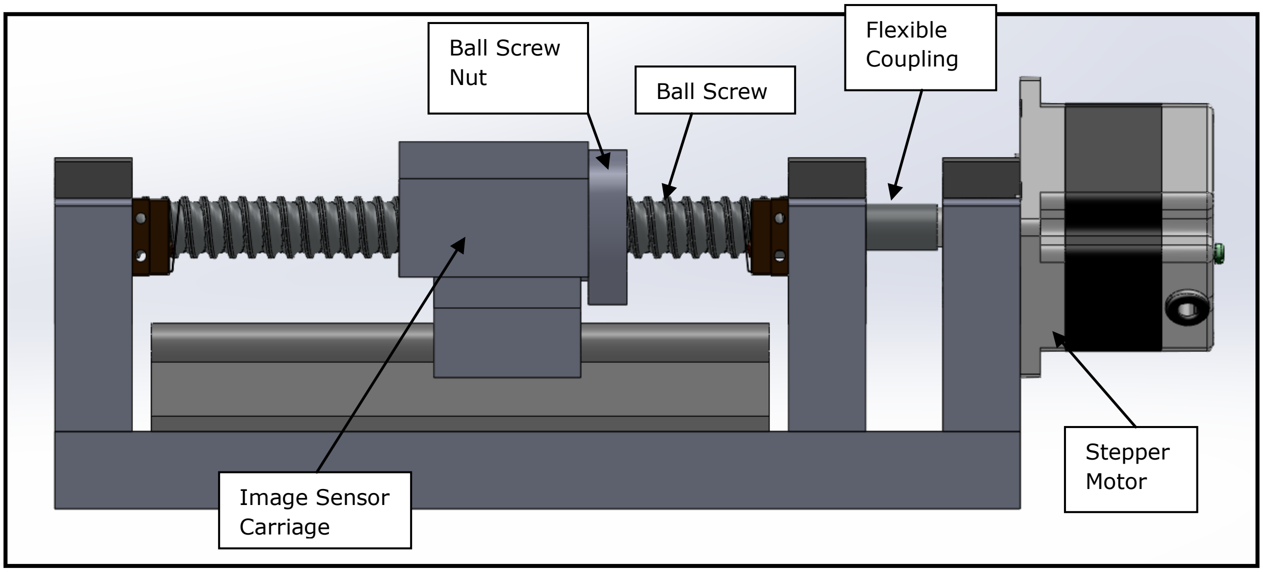

Figure 8 – Ball Screw Shifting System

Figure 8 shows the ball screw shifting system. The main components consist of rails, the stepper motor, ball screw and nut. The ball screw is secured to the stepper motor by the flexible coupling, and the ball screw can rotate the same angle that the motor can. The rotational motion of the ball screw will be translated to linear motion of the image sensor carriage via the ball screw nut. While the ball screw mechanism was designed for heavy loads, the image sensor is very light (15 grams). This particular mechanism was chosen for its precision, and not its load-bearing capability.

One full rotation of the ball screw will shift the image sensor carriage by 5mm. The minimum step of stepper motor is 1.8^{o}, as per the datasheet. For one full rotation, the full rotation steps can be calculated as follows:

$$Full\ rotation\ steps = \frac{360°}{1.8°} = 200\ steps \qquad \textbf{Equation 3}$$

The shifting distance of the image sensor carriage with only one step is as follows:

$$Shifting\ distance = \frac{5mm}{200\ steps} = 25\mu m/step \qquad \textbf{Equation 4}$$

Details for the stepper motor control will be proposed in the stepper motor driver section in this document.

5.2 Gear Train Shifting System

5.2.1 Gear System

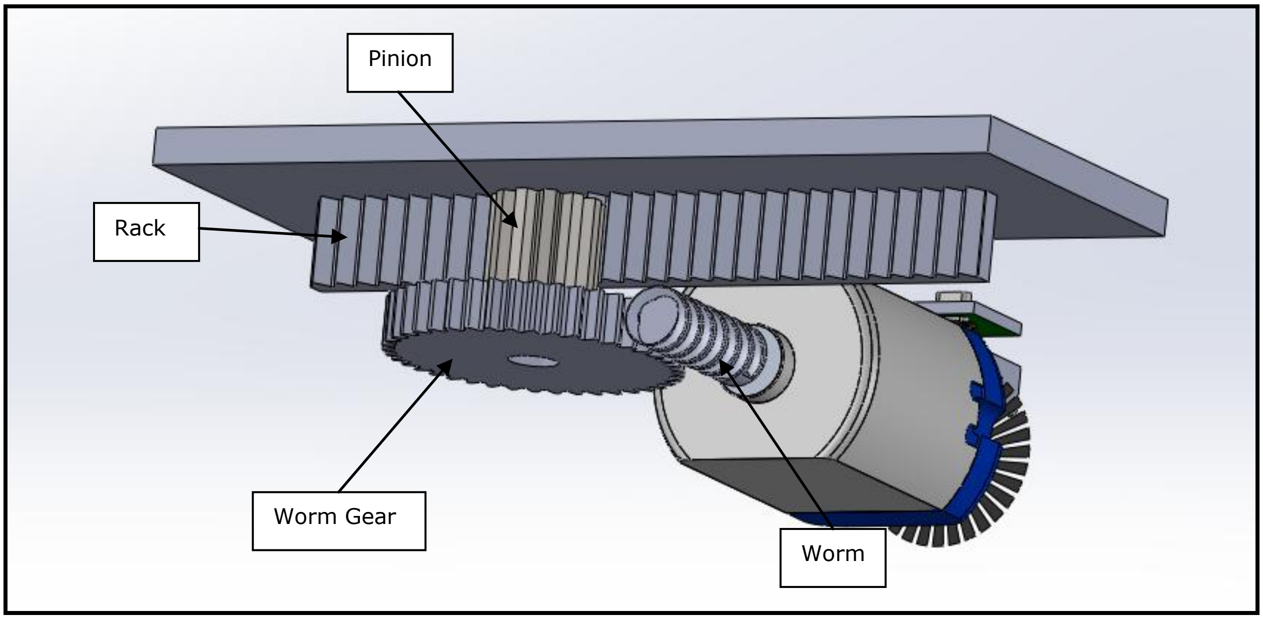

Figure 9 – Gear Train Shifting System

The figure above shows the shifting system for concept 2. The main components of this mechanism consist of a DC motor with encoder, photo sensor, and a gear system. The DC motor encoder has 32 transparent slots, which can cause the sensor be triggered 32 time for each 360° turn of DC motor. The sensor will be triggered once per 11.25 degrees of motor rotation.

$$\frac{360^\circ}{32} = 11.25^\circ$$

Equation 5

The encoder and photo electrical sensor is shown in Figure 10.

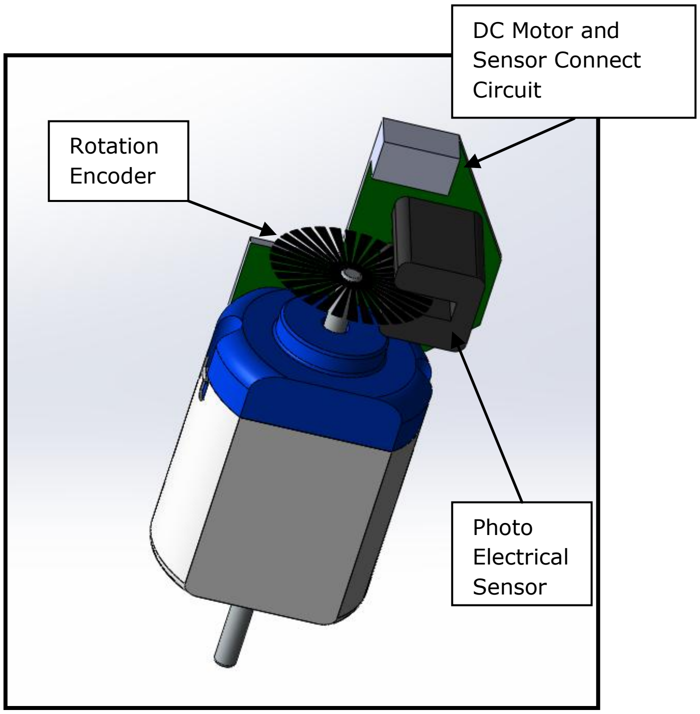

Figure 10 – DC motor and sensor

The gear system is a combination of two smaller gear systems. The first system includes the worm and worm gear. The worm is locked to the motor shaft. This system can convert vertical rotational motion into horizontal rotational motion. With a single start worm, for each 360° turn of the worm, the worm gear advances only one tooth of the gear. The worm gear has 42 teeth in total, so for each 360° turn of the worm, the worm gear will rotate 8.57°.

$$\frac{360°}{42} = 8.57° \qquad \textbf{Equation 6}$$

The second small gear system is a rack and pinion system. This system will translate horizontal rotational motion into linear motion. The pinion gear and worm gear are secured together, which means that for each 360° turn of the motor, the pinion gear will rotate 8.57° (Equation 5). There are 12 teeth on the pinion gear (30° per tooth), so for each 8.57°, the pinion gear rotation is equivalent to the pinion gear rotation of 0.287 teeth, which can be calculated as follows:

$$\frac{8.57°}{30°/tooth} = 0.287\ teeth \qquad \textbf{Equation 7}$$

Since the distance between two teeth on the rack gear is 2mm, for 360° turn of the DC motor, the rack can shift

$$2\frac{mm}{tooth} \times 0.287\ teeth = 0.574mm \qquad \textbf{Equation 8}$$

Based on the information given by Equation 4, every time the photo sensor has been triggered, the rack will be shifted

$$\frac{0.574\ mm}{32} = 18\mu m \qquad \textbf{Equation 9}$$

5.2.2 DC Motor and Photo Sensor Connection

The DC motor can not be controlled to move in steps like a stepper motor can. Two variables affect how far the DC motor can rotate: supplied voltage and running time. In the ISSS, the supply voltage for the DC motor will be set to 5V DC. The photo electrical sensor will be work as a feedback sensor to control the running time of the motor.

The circuit board used to control the DC motor and photo sensor is shown in Figure 11.

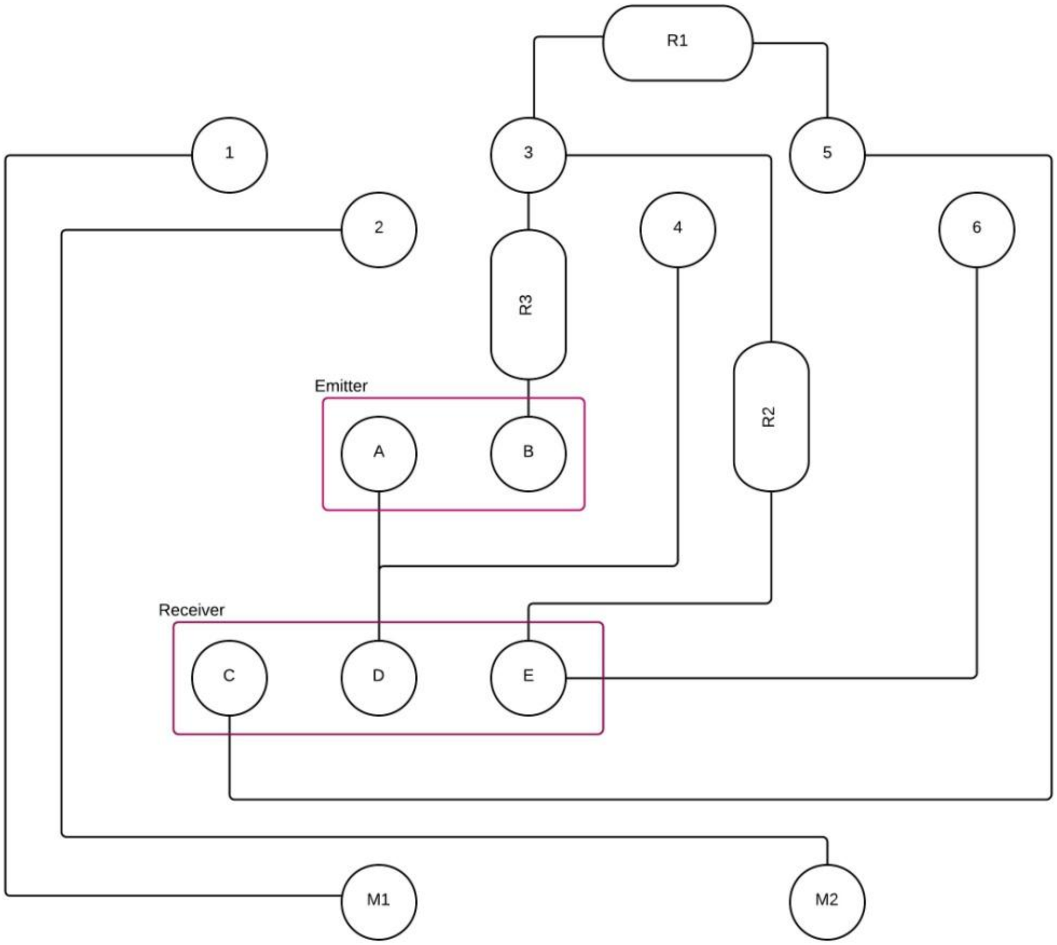

Figure 11 – Schematic Diagram of Motor and Sensor Circuit

Pins 1 and 2 are used to control the DC motor. Pin 1 can be +5V or -5V depending on the direction of motor rotation. Pin 2 is connected to ground.

Pin 3 is the ground pin for the photo sensor and it connects to both the ground of the emitter and receiver.

Pin 4 is the supply voltage for the photo sensor. It also connects to both the ground of the emitter and receiver.

Pin 5 and 6 are the output pins for the receiver of the photo sensor.

R1 is a 1.8 KΩ resistor. It is in parallel with the receiver circuitry as a current divider to avoid excessive current loads through the receiver.

R2 is a 100Ω resistor and R3 is a 1.8 KΩ resistor. R2 and R3 are load bearing resistors to reduce the applied voltage across the emitter and receiver circuitry.

When setting the supply voltage of the DC motor and photo sensor to 5V and limiting the current to 150 mA, the output signal of the receiver (Pin 6) can be captured with an oscilloscope as shown in Figure 12.

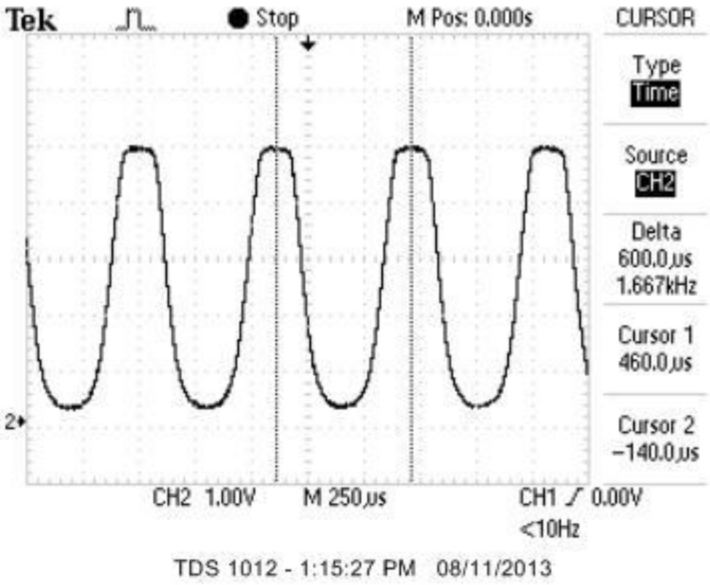

Figure 12 – Output signal of the photo sensor receiver

Each peak of the output signal means that the sensor has been triggered. The time delta between two continuous trigger events is 600 µs. Since each 360° turn of the motor results in the sensor being triggered 32 times, one full rotation of the motor will cost

$$600\ \mu s\ \times 32 = 19.2\ ms$$

Equation 10

The motor can rotate 3125 RPM when the supply voltage is 5V.

5.2.3 DC Motor Control

Unlike the stepper motor from the ball screw system, the DC motor does not require a motor driver. The motor and sensor can be directly connected to the microcontroller and driven by digital output pins. Pins 1 and 4 will be connected to the 5V power output port. Pins 2 and 3 will be connected to the ground pin. Pins 5 and 6 connect to analog input pins A0 and A1 on the microcontroller.

As an example, suppose the image sensor is at the home position and the lens attachment is a Helios 44-2 58mm. The distance from the image sensor's home position to the lens is 20mm, which means the image sensor needs to be shifted 38mm to the rearward side of the ISSS. From Equation 9, to move the image sensor 38mm, the photo sensor must be triggered 2111 times before stopping. If motor overshot occurs, the motor can rotate in the opposite direction until the target location has been reached. With a 5V supply voltage, the DC motor requires 1.26 seconds to move the image sensor to the target location (not accounting for potential overshoot).

5.3 Safety Switch

There are two safety switches in the ISSS, which will be triggered only when the image sensor carriage has reached the end of the ball screw. When the switches are triggered, the microcontroller will turn off the motor immediately. The switches will be connected to 3.3V power output from the microcontroller. The switch signal output will be connected to pin A2 in parallel. Under standard operating conditions, the switches will not be triggered and the switch output signals should be 0V. In the event that the switches are triggered, the output signal will be raised to 3.3V. Figures 13 and 14 show the location of switches in each mechanism.

Safety
Switches

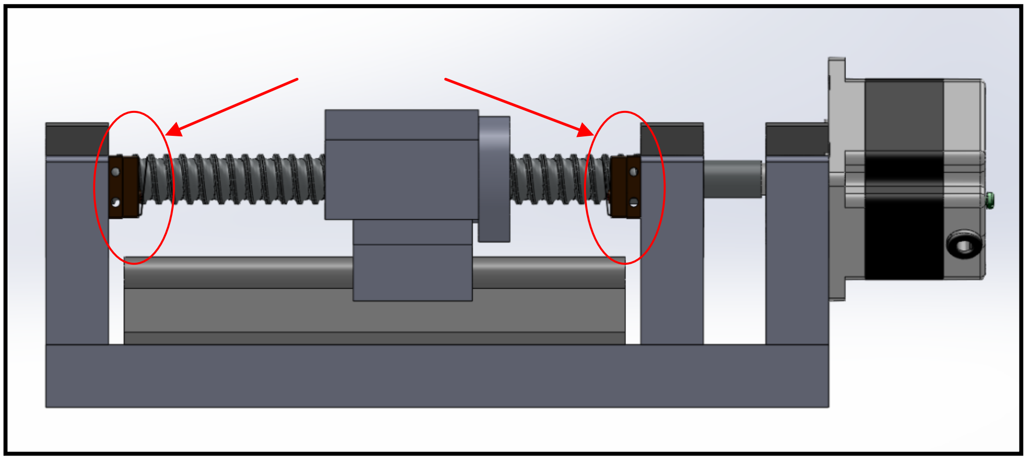

Figure 13 – Safety switches in the ball screw mechanism

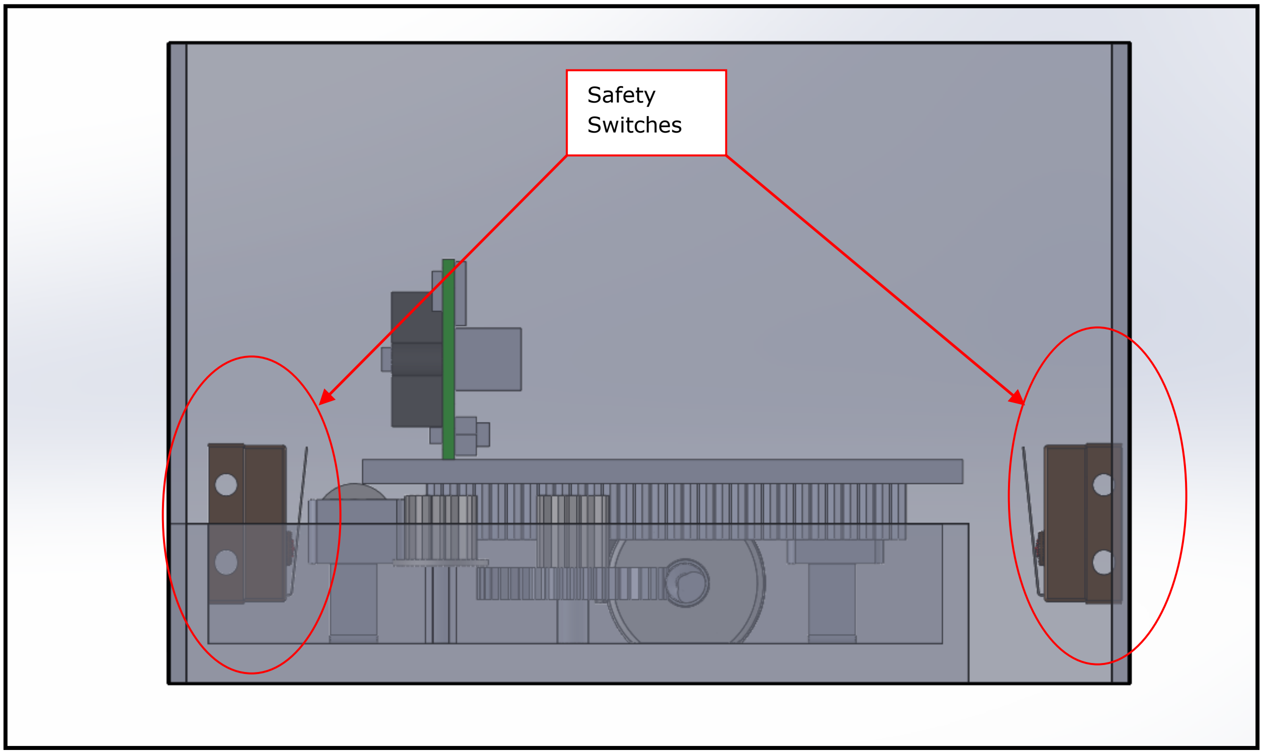

Figure 14 – Safety switches in the gear train mechanism

5.4 Enclosure

The enclosure should provide a darkened environment in which to capture imagery. Sheet metal has been chosen to create the enclosure, because it is easier to be custom tailored to fit our enclosure than some other choices such as plastics.

6. Micro-controller Specification

To control the motor system for Motus' ISSS, an Arduino Uno R3 microcontroller has been selected. The Arduino Uno R3 contains an ATmega328 microcontroller at its core.

Figure 15 – Arduino Uno R3 controller board

The Arduino Uno R3 controller board operates at 5V, and needs an input voltage in the range of 7V – 12V. It is powered via a USB connection from a local workstation, and is able to output 5V and 3.3V from the power pins.

6.1 Stepper Motor Driver for ISSS (Ball Screw)

The stepper motor is driven by the microcontroller, but since the microcontroller can not output more than 40mA, an external motor driver is used to provide additional power. Figure 16 shows our selected motor driver.

Figure 16 – Microstep driver

The microstep driver requires four inputs from the microcontroller: PUL, DIR, VCC and EN. The PUL signal is generated by microcontroller by setting the digital out signals to ‘HIGH’ and ‘LOW’, which generates a pulse waveform, similar to that of a clock signal. This input will specify the movement speed of the rail. In addition, there are three switches which use this pulse signal: switch 5, 6, and 7. The DIR input specifies the direction of movement of rail. The rail will move either forward or backward, depending on the value of this DIR signal. The VCC input is used for powering the driver itself, and requires 5V DC (which is supplied by the microcontroller). The EN pin is used to enable the driver, and can be thought of as an on/off switch for our purpose. If the driver has been disabled, it also disables the stepper motor.

To control the motor, four wires from the stepper motor[1] are connected to the driver. By generating the correct sequence of pulses, the motor will turn in a desired direction. For example, if stepper was supposed to rotate clockwise, then the correct sequence would be A+, B+, A-, and B-. Likewise, the correct sequence for counter-clockwise rotation would be A+, B-, A-, and B+. The motor driver also needs two further inputs: AC1 and AC2. These two pins are used to provide power to the stepper motor. A 12V / 3A power supply is being used to power the driver.

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[1] Four wires are used for two phases: A+, A-, B+, and B-.

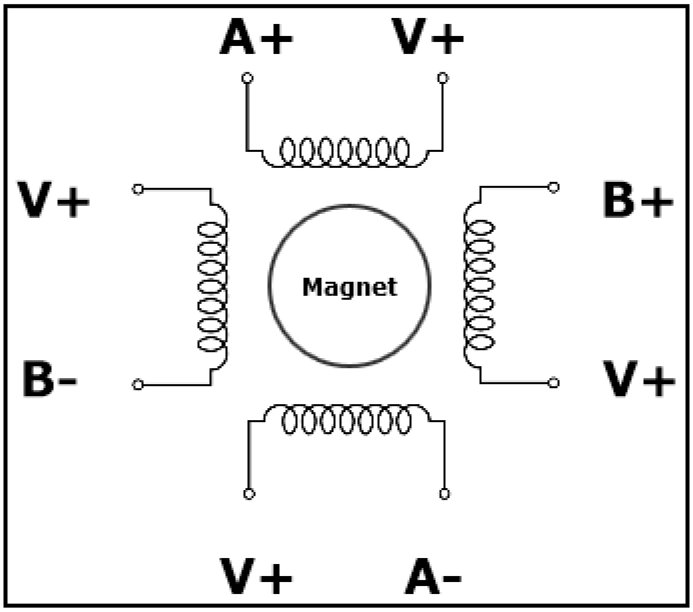

Figure 17 – Stepper motor signal diagram

The rotational speed of the motor can be controlled by using different time delays between each pulse. For example, if `delay(1)` was used as the delay, the step signal will be 1ms at the high peak and 1ms at low peak, which will cause the stepper motor to rotate 500 steps/second. If `delay(1)` has been change to `delay(10)` or `delayMicroseconds(100)`, then the steps per second will become 50 or 5000 respectively.

6.2 Microcontroller Logic

The microcontroller algorithm can be broken down as follows:

1. Wait for a signal from the local workstation signifying the completion of image processing by calling `Serial.Read()`.
2. After the signal has been received, set 'Enable' to 'HIGH'. When the 'Enable' signal changes to 'HIGH' it will cause the motor to spin
3. The main loop continuously checks the 'Enable' signal, and if it has been asserted, the motor will spin
4. After the main loop moves the rail the required distance, it will set the 'Enable' signal to 'LOW', which will stop the motor

7. Image Processing Specification

7.1 Image Processing Design Overview

The image processing subsystem can be broken into the following three main components:

1. The camera sensor input
2. The processing algorithm
3. The output video feed and control parameter

The camera sensor input consists of a real-time (neglecting the small transmission delay between the sensor and the processing software) video feed that is sent to a local workstation through a USB cable. The local workstation is running the software that is responsible for importing the video feed for processing, running the processing algorithm, and returning a control parameter that will be sent as serial data to the microcontroller. If the software can be treated as a black box entity, then the input would be the real-time video feed from the CMOS sensor. This black box would contain two outputs. The first would be a real-time video feed showing the user what the sensor is currently observing. The second would be the control parameter that is to be sent to the microcontroller. The internals of this black box would be the image processing algorithm.

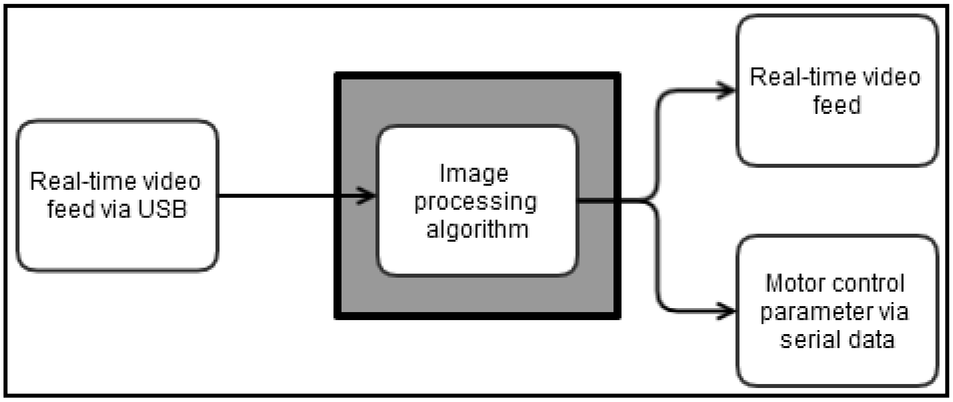

Figure 18 – Image processing black box diagram

The image processing algorithm is at the core of the image processing subsystem. It is responsible for deciding whether an image is in focus or not, and then from that decision, returning a value that will correspond to an appropriate amount to move the motor. In effect, the black box described above is a feedback system that serves to 'zero-in' on an ideal target image. In this context, 'ideal' is meant to be any frame from the real-time video feed that a user would deem to be in focus. The exact precision required to reach an 'ideal' image frame is still being determined through further development and testing, but for now, best judgement will be employed. At this stage in the design process, two primary algorithms are being researched and developed. The first algorithm can be described as a "luminance maximizing" process. The second can be described as a "frequency maximizing" process. The details of these algorithms will be detailed in the next section.

The input real-time video feed can simply be routed directly to the output video-feed to give the user some visual feedback as to what the image sensor is currently observing. The second output is referred to as the control parameter of the motor control system (the Arduino microcontroller). This value is calculated by the image processing algorithm and is a numeric representation of how far to move the motor. This value will be passed to the microcontroller via the local workstation's COM port.

7.2 Image Processing Algorithms

Image processing is being done by using the Visual Studio development environment using C++ and the OpenCV third party open source library. OpenCV has proven to be a good choice, as it has been optimized for C/C++ and real-time processing. MATLAB with Simulink was briefly explored, however it didn't have the flexibility that the OpenCV library provides. Since the design of the algorithms is still in progress, the discussion herein will only cover them at a very high level.

The first algorithm that is being explored is dubbed the "luminance maximizing" algorithm. The idea here is to take each frame from the real-time video feed and calculate the average luminance across the image. Based on the value of this average, the control parameter can be set. For example, if the average luminosity is gradually increasing as the motor moves the sensor forward, then we might deduce that the image is becoming less blurry, and therefore is coming into focus. Likewise, if the frame's average luminosity is becoming smaller, then the sensor is likely getting further away from the focal plane.

The second algorithm being explored is referred to as the "frequency maximizing" algorithm. The general concept is that a Fast Fourier Transform can be performed on a selected frame, and a frequency spectrum of the contrast ratio between pixels can be computed. If an image is blurry, then the contrast ratio between two given pixels will be lower, and the net result will be a bunch of low-frequency points on the image spectrum. Similarly, if the image frame is in focus, the edges will be crisp, and the contrast ratio between pixels will be higher, generating higher frequency points on the image spectrum. The goal of this algorithm is to find the point at which the highest frequencies are obtained.

8. Testing Plan

The system test plan contains 3 parts:

1. Individual modules test plan
2. Combined modules test plan
3. Integrated system test plan

While all testing procedures will be performed, there will be an emphasis on the testing for the proof-of-concept. More specific testing procedures will be developed as development continues.

8.1 Individual Modules Test Plan

Each individual component will be tested immediately after they have been received. The testing will be focused on the functionality of each of the following components:

Lens – Lenses will be tested, and their flange focal distances and fixed focus distances will be recorded.

Image Sensor – Image sensors will be tested, and their image acquisition speeds and image data transfer rates will be measured.

Rail System – The rail system will be tested, and the straightness and motion smoothness will be measured.

Motor – The motor's tolerance and control cable connection will be tested.

Enclosure – The enclosure will be tested, and its ability to block external light will be assessed.

Image Processing – Image processing will be tested regularly for software defects and other problems that may produce undesirable results.

Microcontroller – The microcontroller will be tested by running a series of test programs, to verify that the microcontroller is capable of running our motor and facilitating the transmission of image data in real-time.

8.2 Combined Modules Test Plan

Lens and Enclosure – After the lens has been integrated into the enclosure, we can run another test to verify that there is still no light leakage around the enclosure.

Image Sensor and Image Processing – Once the image sensor has been tested, we can attempt to process data sent by the sensor and test the two components as a whole.

Image Sensor and Lens – After the image sensor and lens have been integrated, we can verify that the image produced after any optical calibration is still valid and usable.

Motor and Rail System – After the motor and rail system have been integrated, we can verify that the motor can be moved with fine precision, and without any errors.

Microcontroller and Motor – After the microcontroller has been tested thoroughly, we can verify that the motor is controllable to a set degree of precision.

8.1 Integrated System Test Plan

The integrated system test will be a safety test. Once the integrated system passes the safety test, the following systems will be tested: image capture, image processing and the feedback signal. The integrated system should meet all of the listed requirements in the proof-of-concept and prototype categories. Flexibility in the requirements may allow the design to be modified to achieve a better result. Any modifications and justifications will be explained in detail. The breakdown of the three main tests is as follows:

Safety – Start the motor and verify that the motor is automatically shut down when the image sensor carriage reach the end blocks.

Image Capture – Test the sensor’s image capture capability by putting objects at varying angles in front of the lens

Feedback Signal – Move the motor to a fixed location and measure the difference between the actual location and desired location.

9. Finances

Motus was granted a $500 fund from the Engineering Science Student Society (ESSS). This section covers the breakdown of expenses thus far.

Products	**Cost**	**Tax + Shipping**
Total budget available	$ 500.00 CDN	
Everything in this table should be converted to $CAN		
Motor System	$ 150.00 US	$ 84.51 US
Webcam	$ 23.99 CDN	$ 0.00 CDN
Microcontroller	$ 33.00 CDN	$ 3.96 CDN
Stepper Motor Driver	$ 45.00 CDN	$ 5.40 CDN
Power Adapter (12V, 3A)	$ 15.00 CDN	$ 1.80 CDN
Lens (2 lenses with different FFD)	$ 110.00 CDN	$ 0.00 CDN
Total Cost	$ 483.15 CDN	
Total remaining funds	$ 16.85 CDN	

Table 1 – Project expenses

10. Conclusion

This document has outlined the detailed design decisions made for Motus' ISSS project. Each system has been broken down into its constituent components and analyzed and discussed separately. Development is still ongoing, and designs are still being refined. Motus strives to create the best product possible, and that means constant revisions. As such, some of the information presented in this document may become outdated. Should this happen, further revisions may be released in order to keep all information current. The ISSS prototype is expected to be completed by early December, 2013.

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