ON THE DESIGN OF A SINGLE - PIXEL CAMERA

Kai Huang
Nelson Huang
Ryan Lin
Lawrence Pang

SPH4U0
Mr. H. v. Bemmel
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Component Choices and Descriptions

Genuino Mega 2560

The microcontroller selected for this project was the Genuino Mega 2560 (identical to the Arduino Mega 2560). Original plans for the project utilized a Genuino Uno microcontroller, however, it was quickly discovered that the 14 digital output pins on the Uno were simply insufficient for the purposes required.

The Genuino Mega has 54 digital output pins, compared to 14 on the Uno, and 16 analog input pins, compared to 6 on the Uno. The increased versatility that this controller offered was considered to justify the $20 price difference.

The Mega operates at 5V, providing 40mA of power through each I/O pin. It interfaces with the computer using a USB type-B connection. The board can be programmed through the Arduino IDE, using conventional C/C++.

Detector System

The light detector selected was the SparkFun Ambient Light Sensor Breakout - TEMT6000. This detector is an NPN phototransistor. As more light is incident on the detector, analog potential on the signal pin increases. The detector is to be connected to the Genuino Mega providing analog input based off the voltage as a integer value between 0 and 1023. A detailed description of this process and the wiring is discussed later.

This light sensor has several features which are conducive to the construction of the camera.

The size of the sensor is small, with dimensions of about 4mm by 2mm (tolerance of 0.1mm). This will improve image quality, as the smaller the sensor, the smaller the pixel area, allowing for finer imaging of objects. Using a lens, the optics of the situation is indicated below:

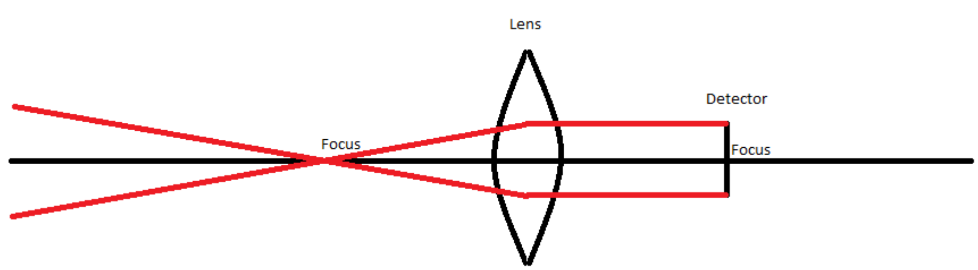

Fig. 1: The optical phenomenon when a lens is utilized with a detector.

By a similar triangle argument, it can be seen that the light gathered by a single pixel is reduced proportionally as the size of the detector is reduced. Therefore, blur is decreased.

The sensitivity of the detector peaks at about 550nm, as indicated in the graph below:

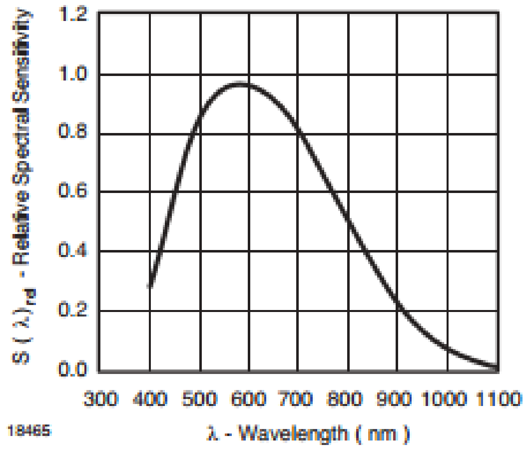

Fig. 2: The sensitivity of the detector plotted against the wavelength of the light.

This closely matches the sensitivity of human vision. Finally, the response of the sensor to increasing luminosity is as follows:

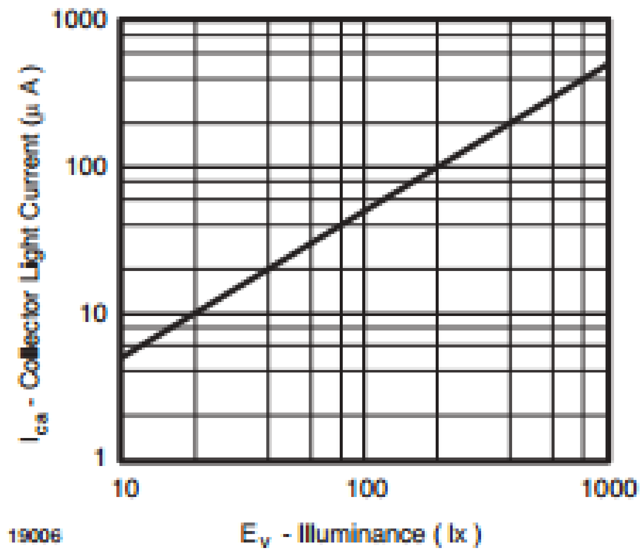

Fig. 3: The current compared to increasing luminosity.

The trend is linear as the graph uses a logarithmic scale on both axes. In conditions such as those within the camera, there will be comparatively greater sensitivity as opposed to a detector with exponential or polynomial gain.

However, the one potential downside of this detector is the lack of adaptability in sensing range. Preliminary tests indicate that this should not be an issue. Testing in several different rooms in a house lit at average brightness, the sensor continuously returned usable data, spanning from values of nearly zero to right above 800. Values of zero were achieved by covering the sensor, and values of 1023 were achieved by shining an LED flashlight directly into the sensor.

However, if it turns out to be the case that the detector is not sufficiently sensitive, an alternative is to use a light - dependent resistor (LDR). As the incident light intensity increases on an LDR, its resistance decreases.

The LDR outputs readings to the Genuino through the use of a voltage divider. Detailed diagrams and explanations are discussed later As a brief overview, by altering the other resistor in the voltage divider, the sensitivity of the detector can be adjusted.

Regardless of which detector is ultimately used, it will be mounted on the back panel of a long tube. The tube will be constructed out of a wooden dowel, and completely sealed, with the exception of an opening at the front end where a lens will be mounted. Such a system prevents any undesirable light bleed, and ensures that the detector is only picking up what it is precisely aimed at. The tube's dimensions will match the focal length of the lens such that the detector's position aligns with the focus of the lens.

The decision to choose a lens was somewhat based off the failure of the original test scenario with a pinhole camera. Through testing of the TEMT6000 as well as various low - cost LDR's, it was found that none of the sensors were able to determine a clear signal in the pinhole camera.

With the original aperture calculated to fit the focal length that was used, the sensors did not pick up any values other than zero, even when a flashlight was shined straight through the pinhole. The aperture was widened gradually, and inconsistent non - zero measurements slowly began to appear. By the time consistent non - zero measurements could be taken, the aperture was already over 3cm in diameter, and thus defied the entire principle of a pinhole camera: to take advantage of the rectilinear theory of light.

However, in the case of a lens, light rays are collected and focused. All light rays parallel to the axis and passing through the lens converge toward the focus. If the detector is placed at the focus, it will then receive all rays of light from an area equal to the size of the lens. This would resolve issues of the detector not being sufficiently sensitive to determine the signal.

Furthermore, a lens would produce a sharper image. By the fundamental law of images, an image is formed when all light rays from a point also converge to a single point. Practically, however, this is not the case. Light rays instead converge onto some area, creating blur. This blur area should be minimized. If a pinhole camera is used, the size of the pinhole will be similar to that of the detector. The following situation will occur:

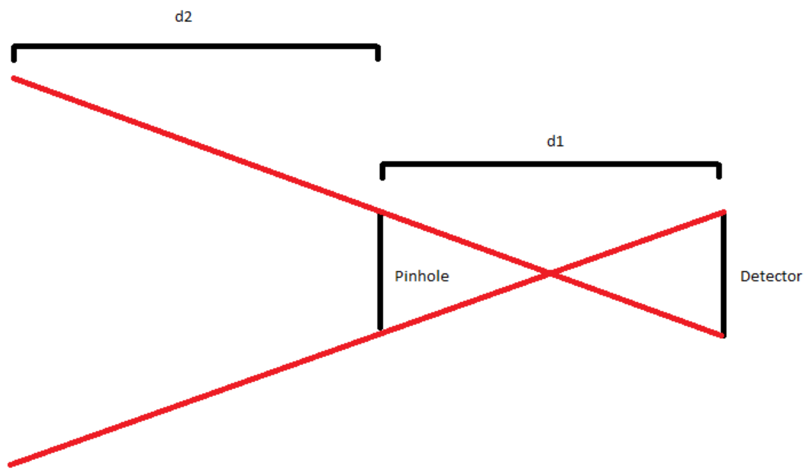

Fig. 4: The concerns in image quality when utilizing the pinhole camera concept

Let d_1 be the distance from pinhole to detector, which may be around 10cm. Let d_2 be the distance from pinhole to the object being imaged, which may be around 3m. The pinhole and detector are similarly sized, on the order of a few mm. Then, by a law of similar triangles, the light gathered through the pinhole and projected onto the detector will originate from an area approximately 10-15cm across. This is only one pixel in the image. For an image of 300x300 pixels, the imaging area will have to be some 30 or 40 meters across, which is clearly impractical. A smaller imaging area will mean significant blurring. Therefore, the pinhole camera will significantly degrade image quality.

Using a lens, the following effect occurs:

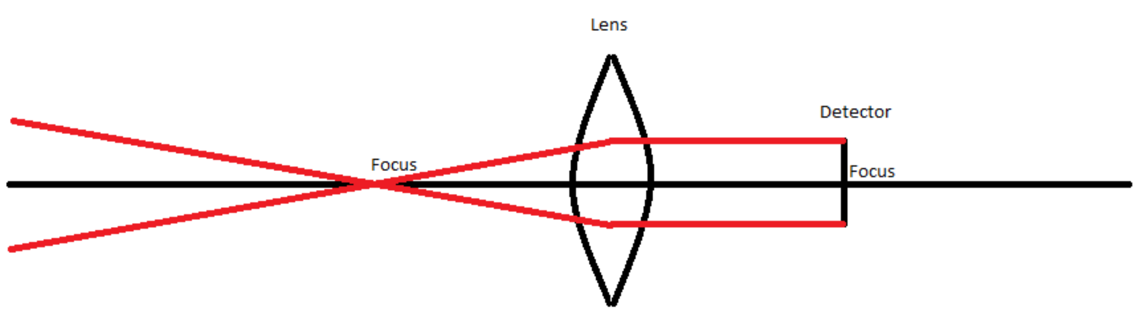

Fig. 5: The optical properties when using a lens.

In this case, the focal length is approximately 10cm, and the lens diameter a few cm. All other distances remain as above. Then, the slope of the light rays leading out towards the object is far more gradual. Through a similar geometrical calculation, one pixel would cover a diameter of approximately 2-3cm. Then, with a 300x300 image, the imaging area would need to be 5-10m across. While this is still not necessarily realistic, it is far more practical than the pinhole. The blur could also be decreased by increasing the focal length of the lens. Therefore, it can be concluded that the lens will produce a brighter and higher quality image than the pinhole camera.

The type of lens must be converging, otherwise an image will not be formed on the detector. The lens to be purchased is the Pop-Tech Optical Glass Lens for Google Cardboard VR. Its diameter is 34mm and its focal length is 45mm. The lens will be placed at the front of the tube. A hole will be removed of appropriate size to accommodate the lens. A simple locking mechanism will be implemented to secure the lens (see appended blueprints). Altogether, the lens and sensor make up the detector system.

Rotational System

In order to aim the detector system through 300 x-coordinates and 300 y-coordinates, a rotational system will be implemented that allows for effective and efficient automated panning and tilting. Two concerns were focused on when it came to designing the rotational system, the first being accuracy, and the second being speed.

The design utilizes two different motors. For panning, a HS-425BB servo motor is to be used. This motor is adequately powerful to support the rest of the rotational assembly as well as the detector assembly. As a servo motor, it is also reasonably fast and can be controlled with relative ease.

For tilt control, a NEMA17 bipolar stepper motor will be used. The stepper motor will have a 0.9° step, allowing for 400 steps per revolution. By microstepping this motor, the required resolution can be achieved.

The detector system will be calibrated to synchronize its operation with the rotational system. Scanning will begin in the top left pixel and then work right, across the row. The HS-425BB servo will simply be set to sweep a wide angle across the field of view. Experimentally, the period of the servo's motion will be determined, and thus the 300 measurements required will be obtained by setting the sensor to pause at calculated intervals.

After each sweep by the servo, the stepper immediately steps one notch down, upon which the servo immediately sweeps across the field of view again, with the same process as before, simply in the opposite direction. This entire sequence is to be repeated until the stepper has stepped 300 times.

Precise details in the electronics and wiring for this system is discussed later in this report.

Display System

As required per the specification assigned, the design incorporates a display system that can alternate between displaying the x - coordinate, y - coordinate, and intensity of the pixel being currently measured.

In order to display these numerical values, three seven-segment displays will be implemented, each with a paired up 74LS47 decoder chip. Each display will receive output from the Genuino and display it as a numerical value.

Details about the electronics and programming associated with this is discussed below.

Other Considerations

Software

The backbone for the operation of this device will be written in c++, through the Arduino IDE. A series of loops will be effected to set up the previously mentioned sequence for the rotational system. During these loops, data will be read from the light detector. The Genuino takes in analog input between zero to five volts and converts it to an integer value between 0 and 1023. This detector scale is converted into greyscale values, where 0 represents pure white and 255 represents pure black. This is accomplished through a simple linear equation.

As this program runs, it constantly outputs the data into a raw text file. This file allows for the data to be read into a Java program that will form the front-end, acting as the user input and output device. The Java program will store the values in a 300x300 2D array and then utilizing 2D libraries display the values in real-time as they are generated. For maximum user - friendliness the program will have mouse control implemented and will give multiple technical readouts. An “advanced mode” will also be written in to allow for convenient control both during testing and in the actual demonstration, if necessary.

An immediate step, however, may be necessary depending on the results from testing. If contrast is discovered to be unacceptably low, or if the rotational nature of the motors causes excessive “fisheye” distortion in the final image, Matlab will be used to perform correction operations on the image matrix.

Colour

Should time and resources permit, colour photography will be implemented. To accomplish this, filters for the red, blue, and green wavelengths will be placed over the lens, allowing for three separate images. Afterward, all three are overlaid and processed to produce a colour photo.

The data collection mode would still be the same as for a greyscale photo, only that the individual pixels of the image are to be represented by an ordered pair of a singular value when read into the Java program. However, in order for this to meet the time constraint, each separate image must be taken in underneath 100s. Whether the current equipment setup would permit for such a high speed of data collection is still uncertain, and further testing is required.

Wiring Diagrams

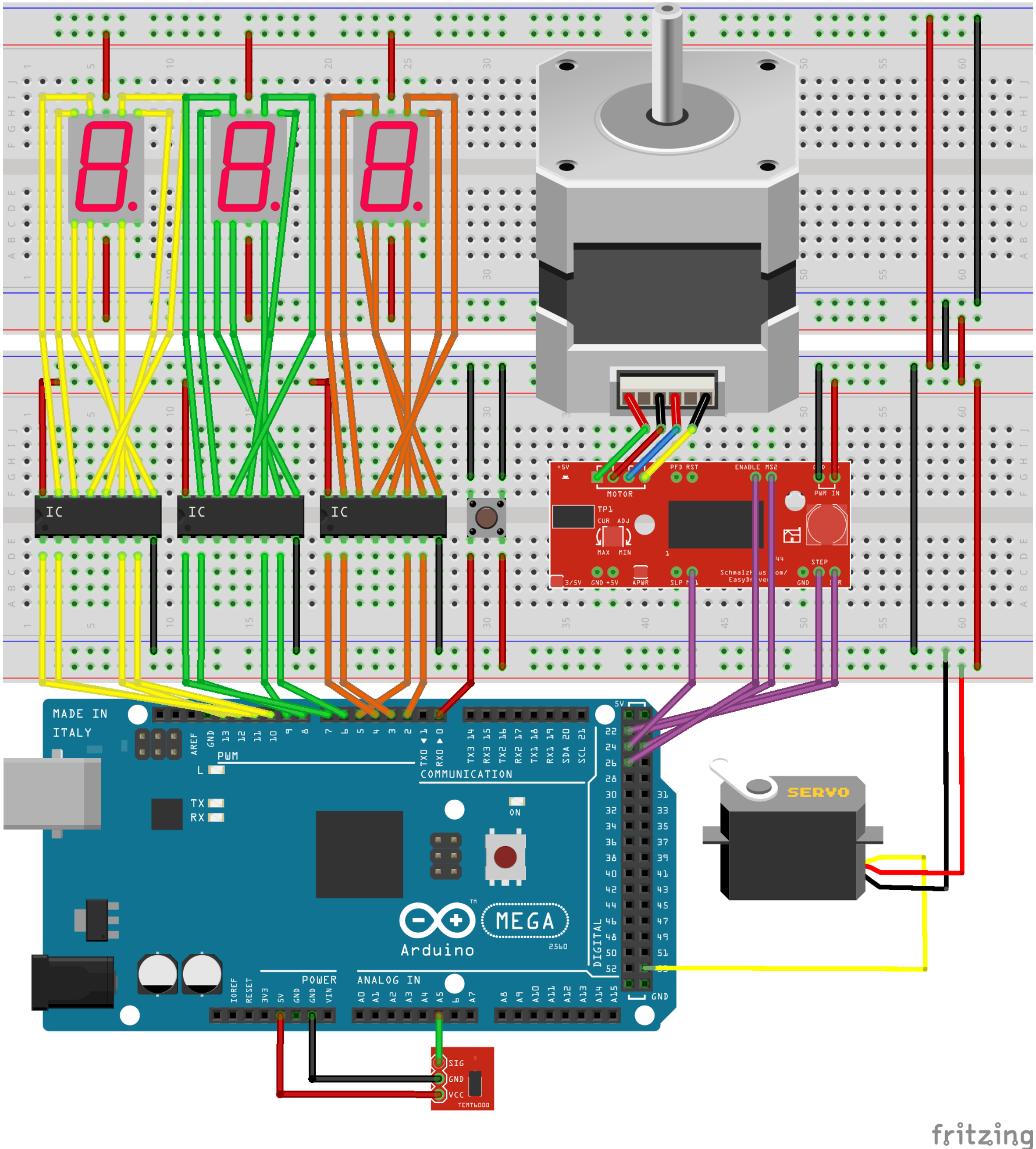

Fig. 6: The complete diagram of all electronic components and wiring that is to be done.

This diagram sets up all four systems of our design in one large diagram, and thus the positioning / mounting of all components are not accurate, and are better represented on the CAD outputs. The core of the design is the Genuino Mega 2560 microcontroller, represented here as an Arduino Mega 2560 (the two boards differ only in name; the Genuino name is the international branding for Arduino products).

The first system is the sensor system. This is a very basic system from an electrical point of view, only incorporating a TEMT6000 light sensor that is directly wired to the analog input on the Genuino. The alternatively possibility of using a LDR is addressed in the detailed description that follows.

Next is the servo motor system. The servo motor will be powered from a separate power supply rather than from the Genuino to ensure that its requirements are met. The only connection between the Genuino and the servo is a digital Genuino output that will allow the control over the servo.

Then is the stepper motor system. As with the servo, the stepper will be powered from a separate power supply for the same reason as stated above. However, the connection for the stepper is significantly more involved, and utilizes a SparkFun motor driver. A detailed explanation can be found in the specific description of this system.

Finally, there is the display system. This makes use of three seven-segment displays that are all controlled through 74LS47 decoder chips to display numbers based off of 4-bit output from the Genuino. The button shown in the diagram will be used to manipulate the Genuino into switching between the three different outputs: x - coordinate, y - coordinate, and intensity.

All diagrams in this section are generated using the open - source Fritzing software. For specific parts are not available in the software, substitutes were used for sake of representation, and are discussed in the descriptions.

Systems

While the complete diagram is informative in a more complete sense, the sheer complexity in the various connections adds a considerable amount of “clutter”, thus making it user-unfriendly to read. In the following sections, each system will be described in full detail, alongside a wiring diagram that only contains the necessary electronic components for that system.

Light Sensing System

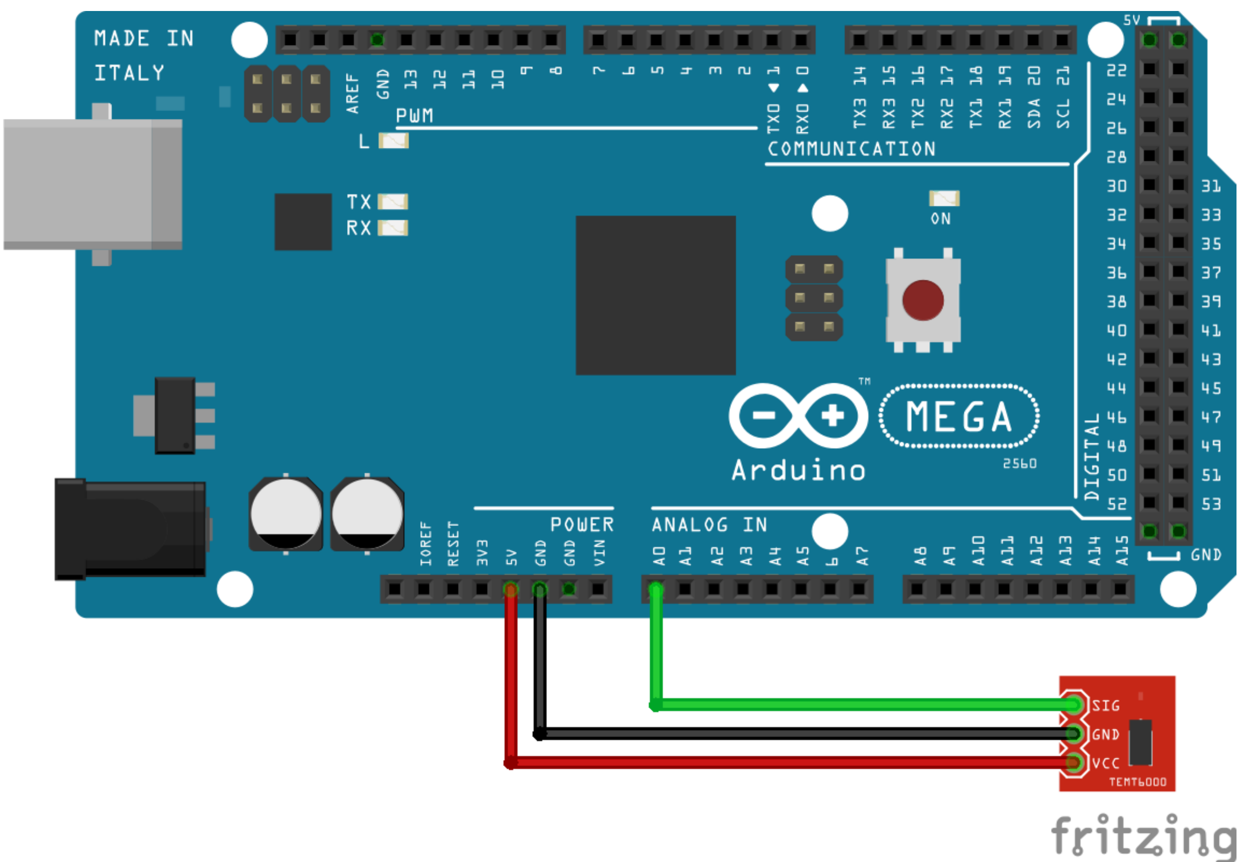

Fig. 7: The light sensor system, in its configuration utilizing the TEMT6000.

The current plan for the light sensing system is to use a TEMT6000 sensor attached to a SparkFun breakout board as the sensor for the camera. The wiring is fairly straightforward, with the GND and +5V on the Genuino board connecting to the GND and VCC on the TEMT6000, respectively. The analog signal that the TEMT6000 then returns is transmitted to any of the analog pins on the Genuino, where its voltage is converted to a digital value between 0 and 1023.

The TEMT6000 sensor does not allow for wires to be simply attached after stripping off the leads in the same matter that a breadboard does, and thus the wires will be soldered on. While the Genuino does allow for the wires to be simply attached, the possibility of unstable power to the sensor and faulty input, as well as the risk of a short-circuit prompts for a more secure option, hence, jumper wires will be used to ensure a stable operation.

As described above, there are concerns with the sensitivity of the TEMT6000 sensor, and thus, a contingency plan in case the TEMT6000 is too (in)sensitive has been put into place. A light - dependent resistor (LDR) can be used as a substitute, with its varying resistance detectable when it is wired through a voltage divider. The main benefit to using the LDR setup is that the second resistor in the voltage divider can have a wide range of values, which allows for the sensitivity of the sensor in such a configuration to be adjusted at will. The setup utilizing the LDR is as follows:

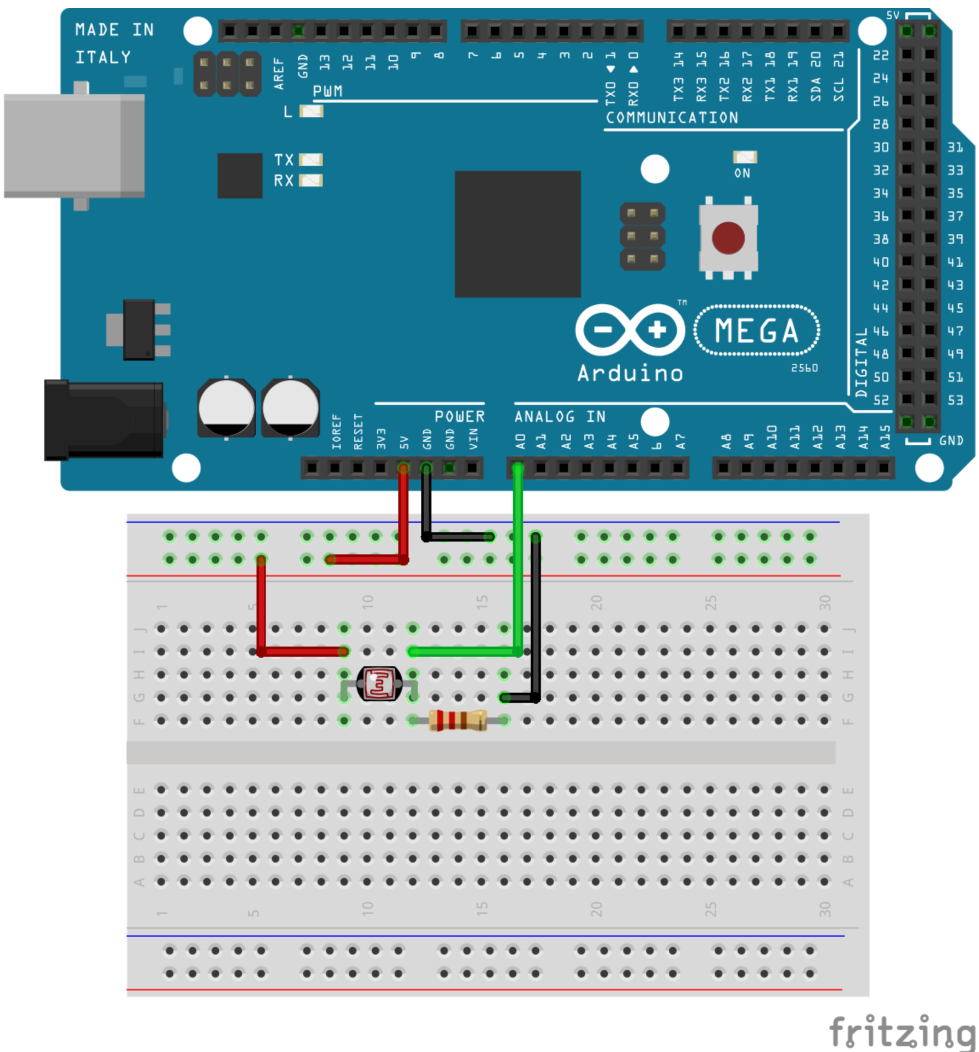

Fig. 8: The sensor system setup in its configuration with a LDR in a voltage divider

The LDR configuration is essentially a voltage divider with R_1 being the LDR and R_2 being a separate fixed resistor. To determine the amount of voltage that will be output, the voltage divider equation can be used:

$$V_{out} = V_{in}\left(\frac{R_1}{R_2}\right)$$

Thus, by changing the value of R_2 we can manipulate V_{Out} and thus control the sensitivity.

Servo Motor System

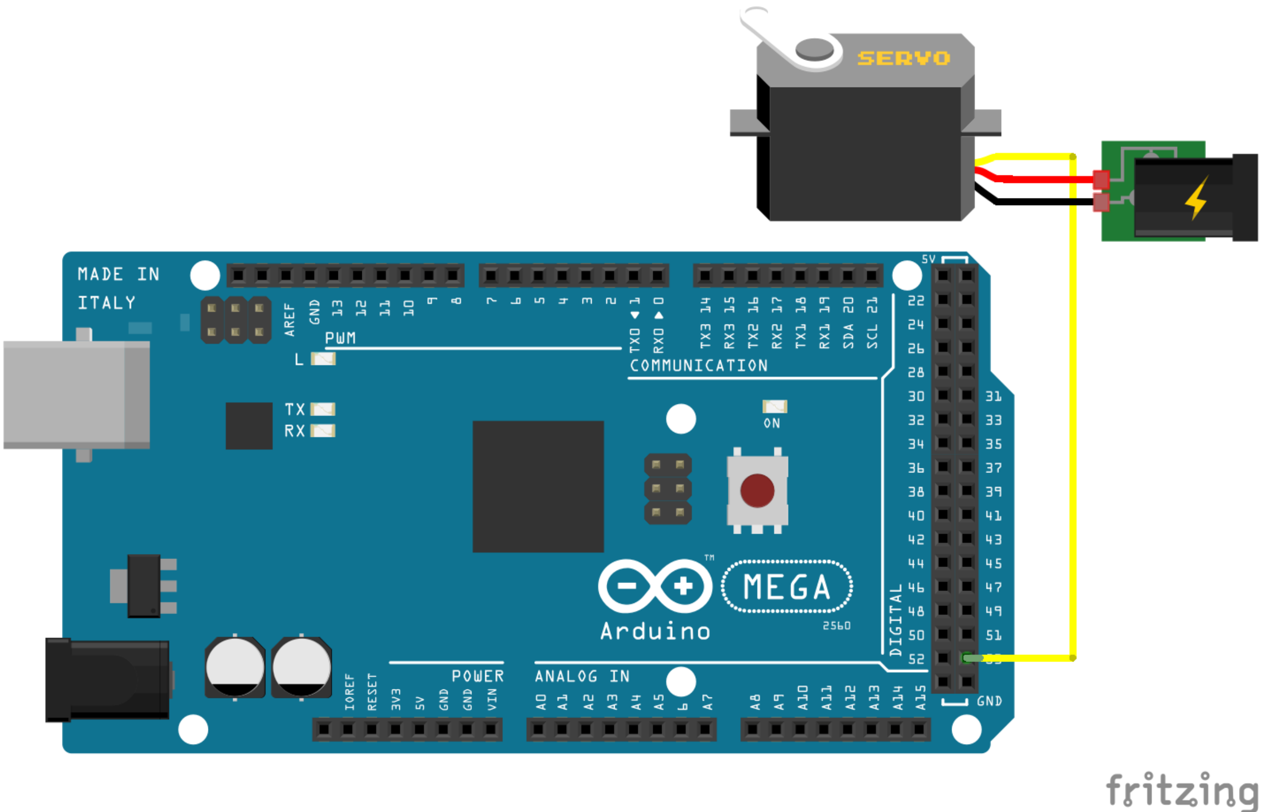

Fig. 9: The wiring diagram for the servo motor system.

The servo motor system is what is responsible for the panning of the sensor. The wiring is fairly self - explanatory, with the servo being powered through positive and negative input from an external power supply. To ensure stability, a breadboard will most likely be used to mount the connection of the external power supply, with the servo power and ground being connected through wires from said breadboard's power rails. To ensure a secure connection to the servo motor, the wires will most likely be soldered on, and certainly attached through heat-shrink tubing. The single input to the servo from the Genuino is through a digital output pin.

As the Arduino language contains a pre existing servo library, the use of this servo will be fairly straightforward from the electronics and programming standpoint. However, there are still concerns with the functionality of the servo mechanically, and this will be discussed later.

Stepper Motor System

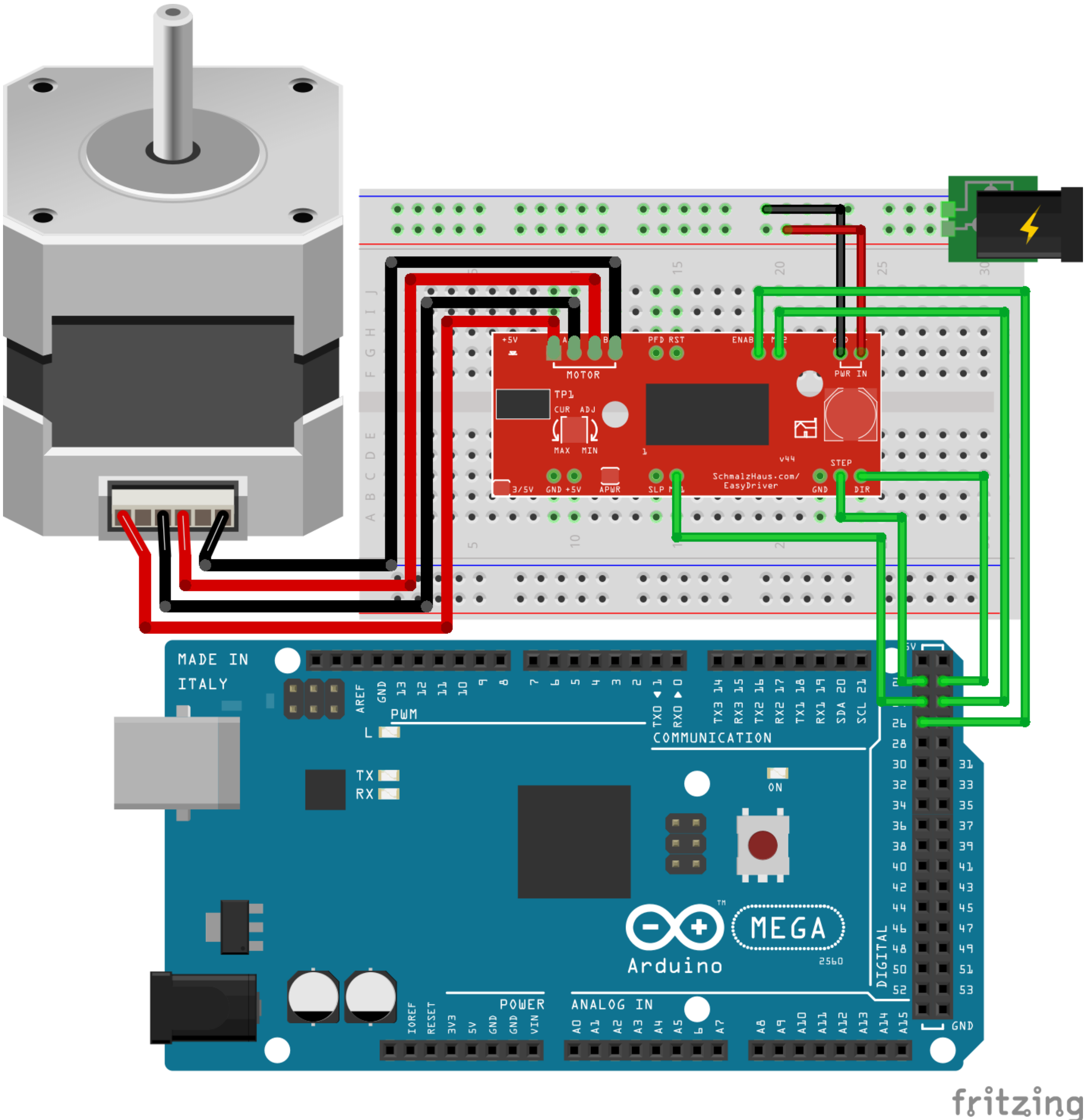

Fig. 10: The wiring diagram for the stepper motor system.

The stepper motor system is to allow the sensor assembly to tilt. Unlike with the servo, the stepper's wiring is fairly involved. As with the servo, the stepper is to be powered through an external power supply. The power connectors will be mounted to the rails on the breadboard, and provide power to the driver board. The driver board connects to the four pins on the stepper, with 2 pins for each stepper pole.

On the top of the driver board, the two other connectors used are MS2 and ENABLE. ENABLE is fairly self - explanatory, pertaining to the stepper's field-effect transistors (FETs) which must be enabled by setting this pin to LOW before the driver can drive the motor. The MS2 input works with the MS1 input on the bottom of the board to provide logic input, varying the microstep resolution of the stepper. MS1 and MS2 inputs correspond to the following truth table:

MS1	MS2	Resolution
LOW	LOW	Full Step
HIGH	LOW	Half Step
LOW	HIGH	Quarter Step
HIGH	HIGH	Eighth Step

Fig. 11: The logic truth table for inputs MS1 and MS2 on the stepper motor driver board

This function is crucial to the performance of the stepper motor in this case, as we need enough resolution to point the stepper at 300 distinct points. It is highly unlikely that any resolution beyond that of a half step will be used, as accuracy suffers substantially. However, testing will still be done to identify the maximum resolution that can be achieved.

The two final pins at the bottom of the board are STEP and DIR. Both of these are logic inputs. STEP is dependent on the input shifting from LOW to HIGH, which will advance the stepper forward precisely one step. As with the servo motor's movement, Arduino comes with a library that simplifies this process substantially, and thus the process is quite straightforward from purely the electronics / programming point of view. DIR simply controls the direction of motor rotation, and is affected changes in state from HIGH to LOW or vice versa.

Display System

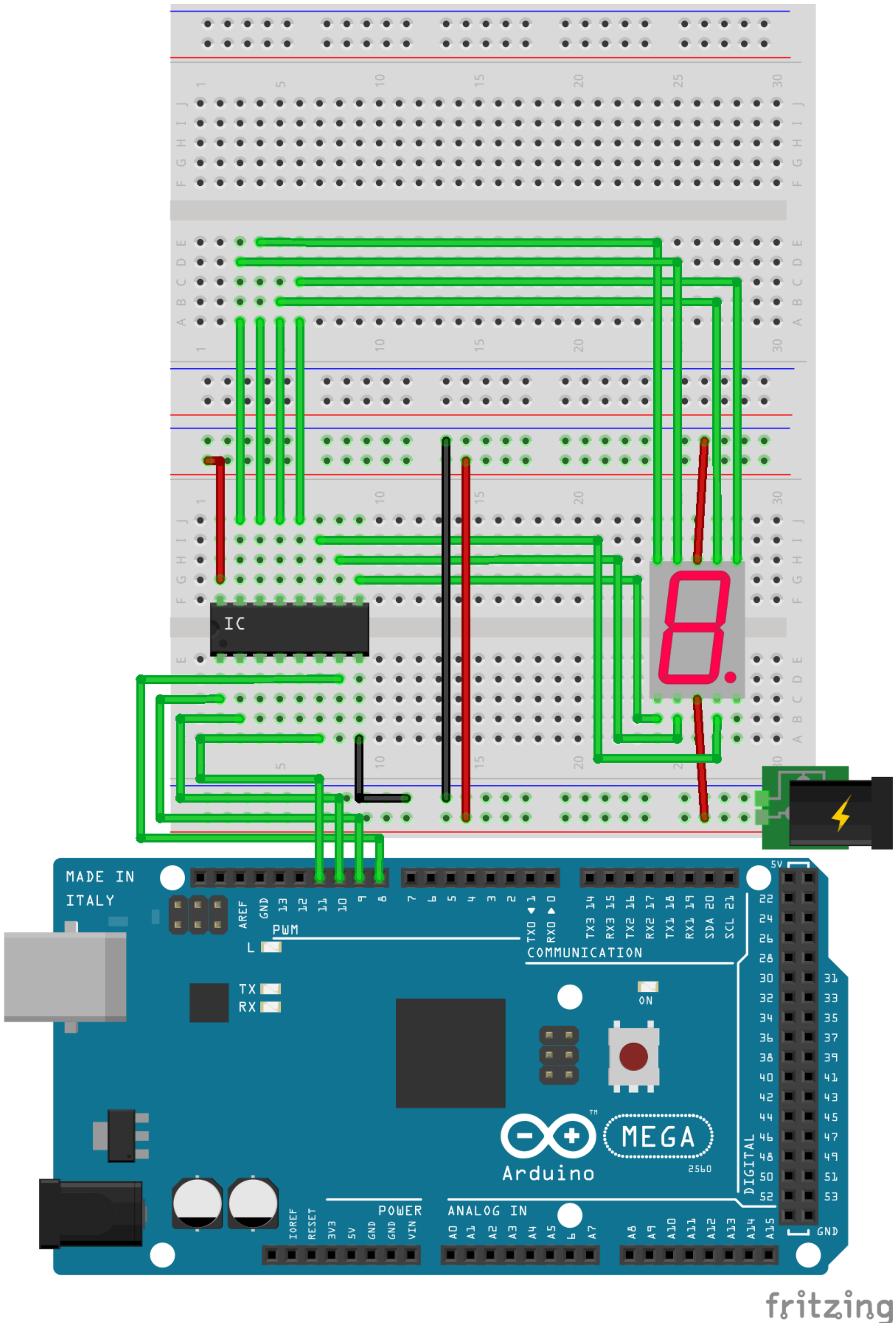

Fig. 12: The display system, simplified to only show a single seven - segment display for clarity

The display system consists of three seven-segment displays with corresponding 74LS47 decoder chips, as can be seen in the original diagram (Fig. 6). In this diagram, two of the pairs have been removed, allowing for a clear look at the circuitry behind a single seven-segment / decoder pair.

The seven-segment displays that are to be used are common-anode seven-segments, meaning that the positive input is charged amongst all the pins, and pins are triggered individually by grounding them, allowing for circuit completion.

The Genuino sends an output of 4 bits to the decoder chip. These 4 bits represent the number between 0 to 15 in binary, though only numbers up to 9 will be used for the purposes of this experiment. The decoder reads these and then grounds the necessary pins that correspond to segments on the seven-segment display.

Component Testing Procedures

Prior to construction, the properties of each component will be thoroughly tested. The following is a list of elementary electrical and optical components involved in this project:

Light sensors: TEMT6000, possibly an LDR

Testing of this component will be accomplished through shining lights of various intensities (e.g. a flashlight) on the detector, and moving it away repeatedly. The readings should indicate clear peaks and troughs corresponding to the presence or absence of the light source, and the curve should be close to linear. After it is established that the component gives reasonable readings, it will be placed into a sealed box of some sort. A small slit will be cut into the box to allow for some light to seep through. If the component is able to give consistent, meaningful readings, it will be deemed sufficiently sensitive to low-light conditions.

Resistors

All resistors that are to be used in this setup will first be tested using a multimeter and comparing the values returned to its advertised values.

Motors

The motors will be set up running without having any component mounted. For the servo motor, testing will involve utilizing the Genuino to effect a controlled rotation at various angles. Measurements will determine whether the motor is reasonably accurate. Afterwards, angular velocity tests will also be performed, to ensure that the motor is able to perform as it is required to.

The stepper motor will be tested in a similar manner, though, angular velocity is not as much of a concern in this case.

Lens

A light source will be directed at the lens, which will be pointed at a flat surface. At the point where the incoming light converges to a single point on the surface, the distance from surface to lens will be measured. This should correspond to the advertised focal length. Measurements of the dimensions of the lens will also be made to ensure that the lens is reasonably circular and smooth.

Seven-Segment Displays

The displays will first be mounted directly to the breadboard with the anodes connected, and each cathode grounded in turn by hand, as a first - step verification. Moving on from there, a program will be written for the Genuino that outputs the sequence of numbers through each seven - segment display.

Construction Procedure and Specification

The entire camera assembly will be divided into the following components for construction purposes. Refer to the appended blueprints for dimensions and tolerances for each component. Two exploded assembly diagrams have also been included to illustrate the connections between mechanical components.

Base

This will be constructed from a large sheet of plywood. The casing for the servo motor will be cut to the specified dimensions and assembled using either wood glue or nails.

Servo Motor

This will be purchased directly, only testing is required. The blueprint contains relevant dimensions sourced from the manufacturer.

Stepper Casing

A wooden block will be hollowed out to the specified dimensions. A drill will be used to create the holes at the specified locations with reasonable precision given the choice of drill head.

Stepper Casing Pin

The blueprints for this component illustrate a tentative design for a custom pin to secure the stepper casing to the servo motor. A wooden dowel will be chosen with the desired dimensions and the pinhead attached using a nail.

Stepper Motor

This will be purchased directly, only testing is required. The blueprint contains relevant dimensions sourced from the manufacturer.

Lens

This will be purchased directly, only verification of focal length (45mm) is required. The blueprint contains relevant lens thickness and connector dimensions.

Sensor Tube

The main body of the sensor tube will be a wooden dowel of the indicated outer dimensions. A drill will be used to remove material and obtain the specified inner diameter. A small hand saw will be used to make an opening to house the TEMT6000 sensor. A scalpel will be used to create the notches that will hold the lens in place without the use of adhesives. An additional wooden block of the specified size will have a hole drilled through and wood glued to the base of the main body. This will serve to connect the motor shaft of the stepper motor to the imaging assembly.

TEMT6000

This will be purchased directly, only testing is required. The blueprint contains relevant dimensions sourced from the manufacturer.

Assembly

The components will be assembled in accordance to the diagrams attached. The lens will be inserted via the notches on the sensor tube in the proper orientation and rotated such that its extensions are secured within the designated slots. This allows for easy removal during testing and reduces the risk of lens aberration from the use of adhesives.

The sensor tube will be connected to the stepper motor shaft through the wooden block, supplemented with glue.

Wiring holes will be added for components housing the motors and sensor in the necessary locations, provided that the structural integrity of the assembly is not unduly compromised.

Testing of Subassemblies

Rotational System

This will consist of the basic frame of the camera, along with the two motors.

Testing will be done on two key properties of the rotational system: structural integrity and speed.

The motors will be run in the exact same sequence that they will be expected to during operation of the camera. Emphasis will be put on whether the framing used to support the assembly is sufficient to balance the forces acting upon it. If necessary, additional structural support will be added.

Furthermore, the system at this point is expected to be able to perform the entire sequence in less than 4 minutes. While the specification calls for the imaging to take place over a span of 5 minutes, the motors are running “light” in this case, and thus can only become slower once more components are added for them to support.

Once the rotational system has reached a satisfiable level of stability and can perform the sequence in the time allotted, it will be deemed to be qualified.

Detector System

This will consist of the lens and light sensor, along with related electronics, placed within a sealed box.

Manually, the box will be rotated to create a small image of 5x5 pixels. The object being imaged will be a simple, high-contrast surface such as a chess board. The output should clearly resemble the object. Less contrast than is visible will be tolerated, as contrast can always be enhanced through post-processing. However, it is important to check for consistent readings from one part of the image to the next. Any blurring effects will be noted.

Should the system pass this test, it will then be used to image a slightly more complex surface in a larger image of 10x10 pixels. At this stage, if the rotational system is also ready, the lens and sensor can be rotated using the motors rather than manually. Once again, the output will be compared to visual observation of the object.

Once both of these tests have succeeded, the detector system will be deemed to be qualified, although testing will still proceed if there is enough time to work with progressively larger images while not compromising the work done in other areas.

Display System

This will consist of the seven-segment displays, connected to the light sensor.

The display system testing will most likely simply be an extension of the individual component testing for the seven - segment displays, as no additional parts or construction is required for this system. A program will be written to increment the numbers from 0 through

999, and the display system will be deemed to be qualified. Once the rotational system is qualified, the display system will be used alongside it, displaying the basic coordinates as it scans.

Software

This includes all processing and post-processing algorithms.

In conjunction with testing of the display, the software will also be tested. Grayscale values will be checked for correspondence with sensor output. These values should match exactly. The resulting image will then be displayed. A general correspondence between grayscale values and image brightness would be fairly easy to observe. The post-processing system, which might include contrast enhancement and conversion from fisheye to rectilinear, will be tested first on sample images found online, and then on camera data.

Production Schedule

The schedule is given as dates, with a list of requirements that are to be met either on or before the specified date. The schedule is laid out in weeks, with each checkoff date being set on the Monday immediately following each weekend.

12 December

- Have all electronic parts purchased
- Basic test of all individual components completed
- Subsystems loosely wired for rudimentary testing
- Determine whether new components need to be purchased

19 December

- Basic program written to read data
- All construction parts purchased
- Testing of detector system completed for 5x5 and 10x10 image
    - Final decision made on LDR or TEMT6000 sensor

26 December

- All construction completed
- Rotational system testing completed
- Display system testing completed

2 January

- Finalizing programming
- Optimization of runtime sequence
- Preliminary simulated demonstrations done

9 January

- All systems fully functional
- Clean up wiring
- Secure construction into final setup
- Demonstration - ready

Budget

Genuino Mega 2560 Rev3 - $46.19, http://www.canadarobotix.com/arduino-microcontroller/1793-genuino-mega-2560-rev3

Hitec HS-425BB Deluxe Ball Bearing Servo - $16.99, http://www.canadarobotix.com/hitec-standard-servos/hitec-hs-425bb

Stepper Motor NEMA 17 400 steps/rev - $22.19, http://www.canadarobotix.com/stepper-motors/stepper-motor-68-oz-in-400steps-rev

SparkFun EasyDriver - $19.59, http://www.canadarobotix.com/stepper-motor-controllers/1801-sparkfun-easydriver-stepper-motor-driver

Breadboard - $4.99,
http://www.canadarobotix.com/solderless-breadboard/830-point-breadboard

TEMT6000 - $6.59,
http://www.canadarobotix.com/infrared/sparkfun-temt6000-breakout

Button - $0.49, http://www.canadarobotix.com/mechanical-switches/momentary-push-button-tactile-switch-6mm-square-breadboard

7 - Segment (x3) - $3.87,
http://www.canadarobotix.com/led-lighting/1887

Pop-Tech Biconvex Lens for Google Cardboard - $6.69,
https://www.amazon.com/Biconvex-Pop-Tech-Bi-convex-Diameter-Cardboard/dp/B012HYF4A2

Total: $127.59

Citations

Design Reference

Ardunaut. (2013, July 16). “Single Pixel Camera with Arduino Nano” (Arduining article). Retrieved 3 December 2016 from https://arduining.com/2013/07/16/single-pixel-camera-with-arduino-nano/

This video introduces the main pan and tilt assembly method of sensing that forms the rotational system for our project. However, its rotational system is considerably slower, moving the servo motors precisely the angle required to image each pixel. In our case, the servo motor simply makes a full turn at maximum speed, and the imaging speed is then calibrated. Furthermore, the tilt control for this camera utilizes a servo motor; we have instead opted to use a stepper to maximize resolution.

The detector system used in our design is also entirely different from the one described in the article. While they utilize a phototransistor similar to ours, their optical system simply utilizes a sizeable hole to only detect light from a single direction. We considered this to be too coarse of a method, especially with the large size of the hole, as well as potentially create a sensing environment too dark for our sensor, and thus our optical system utilizes a lens instead.

Finally, the only software written in this example is to convert the analog inputs into greyscale pixels on an image. Our software will offer additional optical correction tools and more dynamic user input.

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