SMARTPHONE HEMOCYTOMETER

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1 Introduction

1.1 Problem and Solution Overview

White blood cell counts and classification are critical measurements in medical settings as it alerts doctors to autoimmune diseases, immune deficiencies, and blood disorders and helps monitor the effectiveness of chemotherapy and radiation therapy for cancer. Most doctors use hemocytometers with microscopes to differentiate and count the number of white blood cells in a counting chamber, which is both bulky and inconvenient. This traditional method of cell counting is not suitable for point of care diagnostics, particularly in areas with poor medical resource settings. Very few portable cell counting products are designed for rapid documentation at the point of care. Bills et al. provides a smartphone- and paper-based solution for blood cell counting by integrating microscope attachment, LED and optical filter together with the smartphone camera. However, their product requires external device to operate the image processing algorithms and their blood cell image is only within one frame[BNY19]. Our project offers an integrated solution that allows doctors to diagnose disease from the blood sample without any external devices needed.

In our project, we propose to design and build a portable smartphone hemocytometer that enables testing and documentation at the point of care. Using the smartphone's camera with a microscope clip on, the project creates an automatic platform for taking panoramic microscopic images of the blood sample. On the electrical subsystem side, the smartphone hemocytometer consists of a power supply module that provides power for all devices in the circuit, a motion module of high precision linear motor to drive the blood smear on a linear slider, a microcontroller as the control module, and a communication module that serves as a bridge between the smartphone and the microcontroller. On the software side, an Android application will be devised to communicate with the microcontroller and to take photos. The project also provides a foundation for future development so that eventually doctors can run a machine learning identification algorithm on the smartphone hemocytometer to differentiate the five different types of white blood cells and complete said important item from blood test that would have taken hours.

Figure 1: visual aid [19c]

1.2 Visual Aid

As shown on the image above, a microscope clip-on will be attached to the smartphone, and the blood smear sample will be put closely under the smartphone camera. In our system, we will be linearly moving the sample along a slider, and the physical diagram of our system is shown in the next section.

1.3 High-Level Requirement

There are three major requirements for our design:

1. Mechanical Resolution

   There should be 30% overlaps in between two adjacent frames of white blood cell images in order to be successfully stitched into one panorama photo.

2. Software-Hardware Integration

   The Android software on smartphone should be able to communicate with the MCU and thereby control the whole electrical subsystem.

3. Visual Quality

   The images taken should achieve at least 85% as accurate as the golden sample dataset images from traditional microscope from human identifiers' judgement.

2 Design

2.1 Block Diagram and Physical Diagram

2.1.1 Block Diagram

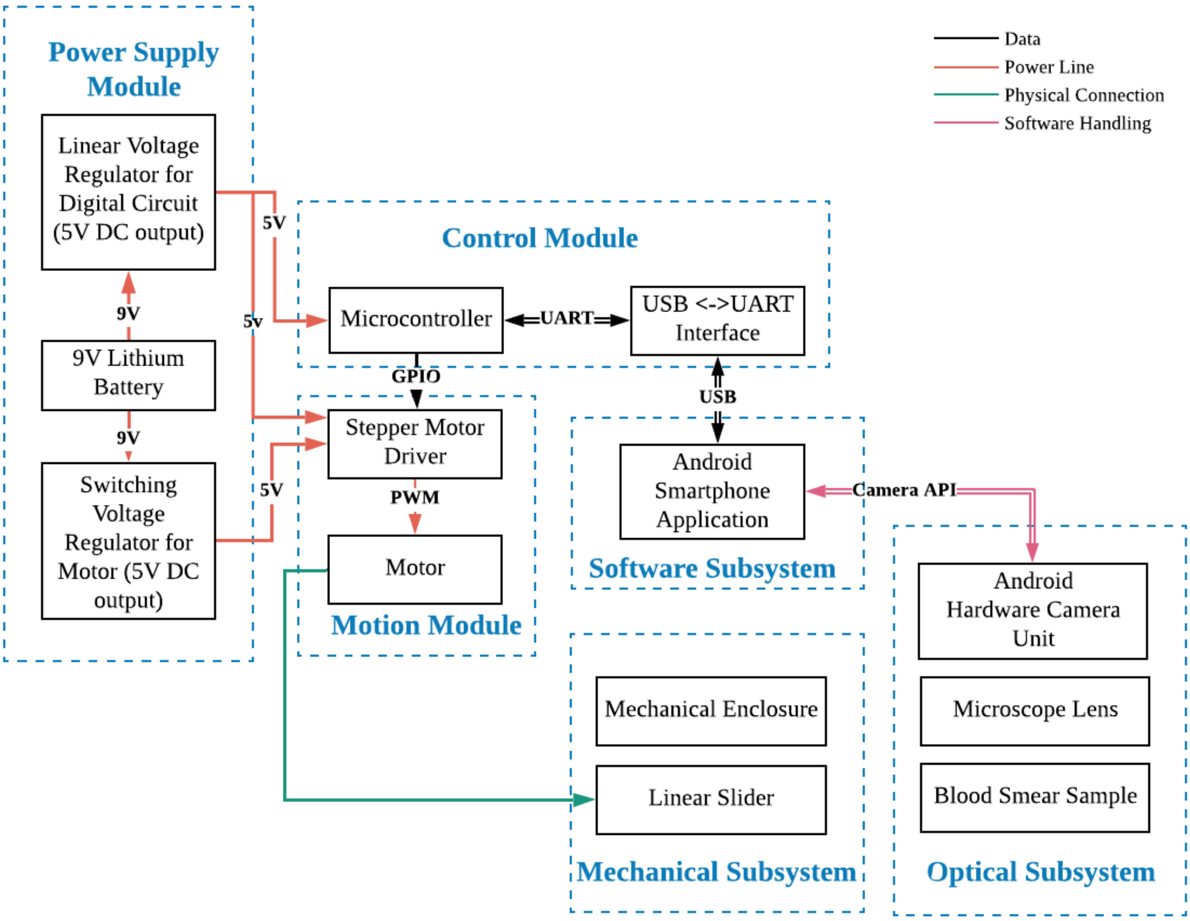


Figure 2: Block Diagram

2.1.2 Physical Design

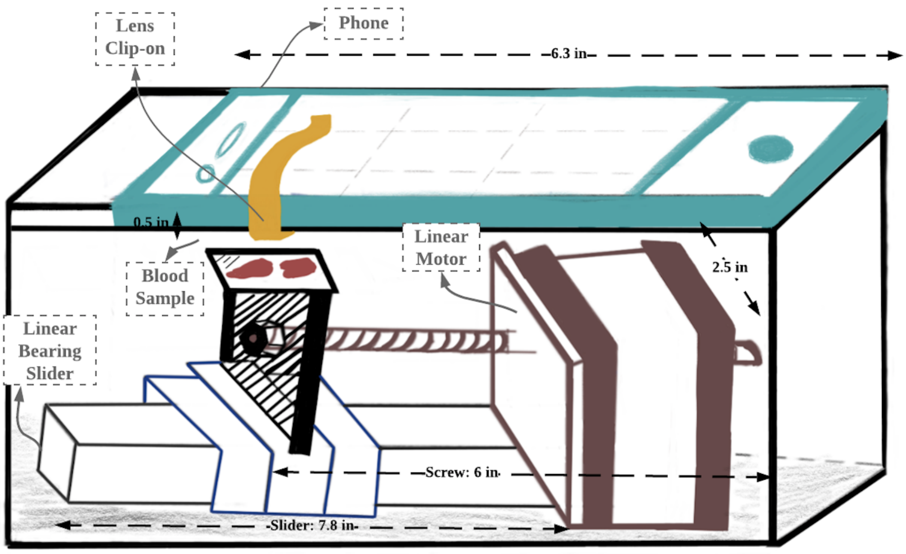


Figure 3: Physical Design

2.2 Functional Overview

2.2.1 Mechanical Subsystem

Linear Slider

We will purchase a ball bearing slider and place the blood smear sample on top of the slider. The external screw from the linear stepper actuator will push the slider to move the blood smear sample laterally.

Mechanical Enclosure The mechanical enclosure is a 3D printed box. We mount the linear slider and linear actuator on the bottom to avoid vibration and shaking of the system. The smartphone is positioned on top of the enclosure and there we leave a hole for the camera and flash light.

Requirement	Verification
The blood smear sample can be installed on the slider and external screw of the linear actuator. The slider is able to provide smooth linear movement with low friction.	1. Use the mechanical connector from machine shop to stitch the slider with the external screw. 2. Place and secure the sample in the pocket which is screwed on top of the slider. 3. Apply little step movement on the slider using the linear actuator, and check there is no vibration.
The mechanical enclosure should provide a flat bottom (±0.5 degree tolerance).	1. Check 3D printed model and use Caliper to check the tilt degree.

Table 1: R and V for Mechanical Subsystem

2.2.2 Optical Subsystem

Ball Microscope Clip-on

Figure 4 is the mechanical design for the clip-on. We will print it using 3D printer and then add a 3.5mm-diameter ball lens into the plastic housing. The clip-on is attached to the smartphone camera for 40X magnification.

Hardware Camera Unit

This unit modifies the smartphone camera hardware parameters in order to satisfy a good luminance condition and to have an efficient auto-focus mode. We intend to use the continuous-auto-focus mode of the android.hardware API, which allows us to only do auto-focus at the first time rather than auto-focus on every image. In order to satisfy the luminance condition that is required for seeing white blood cells, we intend to use the Flash-Mode-On function as it allows us to keep the flashlight on when the phone is taking a snapshot.

Blood Smear Sample

The blood smear samples are all prepared by Prof Cunningham. The estimated blood smear area size is around 20mm * 20mm.

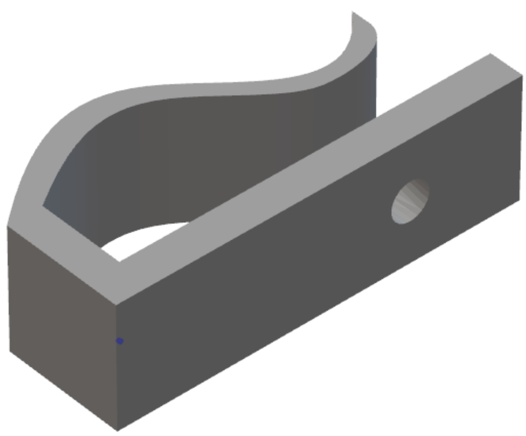


Figure 4: Microscope Clip-on [19b]

Visual Quality Assessment

One of the important goals of our project is to have blood cell images of high visual quality such that different blood cells can be identified correctly. In order to assess the image quality of the photos taken from our system, we will refer to a blood cell images dataset on kaggle as the golden sample dataset images. The designed convolutional neural networks on the blood images dataset can achieve as high as 97% accuracy on the validation set.[18a] To compare images taken from our system with the golden sample dataset, we will ask human identifiers with medical background to determine the cell types from both the golden sample dataset and the image dataset from our system. We will verify our image quality by examining if our system can achieve at least 85% of the correctness comparing to the golden sample dataset.

Requirement	Verification
The images taken from our system should high image quality such that human identifiers are able to identify different cell types, and specifically it should be able to achieve 85% of the correctness comparing to the golden dataset images from kaggle	1. Human identifiers will identify the cells on the image dataset on kaggle, and get a percentage P1 of how many cells they can identify out of all the cells 2. Human identifiers will identify the cells on the image dataset from our system, and get a percentage P_2 of how many cells they can identify out of all the cells 3. Our image quality is considered good if $$P_2 > P_1 * 85\% \quad (1)$$
The ball lens should fit into the hole on the clip-on.	1. Use Caliper to check the diameter of the ball lens. 2. Insert the bead lens into the hole reserved on smartphone clip-on and secure its position. Flip the clip-on over, the bead lens should not fall off.

Requirement	Verification
Able to provide 40X (± 5%) magnification.	1. Attach the clip on to the smartphone camera. 2. Use the smartphone software to turn on the flash light and set the magnification of the camera to the reset condition. 3. Take two blood cell images using the camera. One with no magnification (no zoom in on smartphone) on the camera, and the other one with largest magnification on camera. 4. Compare the field of view of these two images with the original field of view of the cellphone camera and calculate the actual magnification.
the smartphone camera should be able to provide a good lighting condition	1. We will write a function utilizing Flash-Mode-On function to test on the white blood sample. 2. We'll test if the phone can always take snapshots with flashlight
the camera should be able to continuously take snapshots without having to auto-focus every time when it takes a photo	1. We will write a function that utilizes the continuous auto focus mode from the android.hardware API. 2. Fixing the position of the phone, we will slowly slide the sample while continuously taking photos to test if the camera only does auto-focus at the first time.

Table 2: R and V for Optical Subsystem

2.2.3 Electrical Subsystem

The electrical subsystem of the Smartphone Hemocytometer consists of 5 main modules: Power Supply Module, Control Module, Communication Module, Display Module and Motion Module. We will integrate them on the PCB.

Power Supply Module
Input: 9V DC battery voltage.
Output: 5V and 5V DC voltage.
The power supply module provides power to the motion module (motor and motor driver) and other digital circuit components. The design needs two separate linear regulator to separate the current for motor and for digital circuit because motor current has a large difference between standby current and working current (0A to 1.5A) whereas the digital circuit current is consistent and low(< 100 mA).
Essential Components:

1. TPS76950 5 Volt Linear Regulator by Texas Instrument
2. TPS63061 5 Volt Switching Regulator by Texas Instrument

Pin	Function	Connection	Voltage
+9V	The main power input from 9V battery.	Connect from the battery to both regulators.	9V DC
+5V	Supply power to the motor.	Connect from the output of 5V linear regulator and extend to motion module.	5V DC
+5V (dgtl)	Act as the main power for digital circuit. Provide 0 to 100mA of current.	Connect From Pin 5 from linear regulator, extend to other modules.	5V DC
GND	Act as the ground voltage reference.	Connect from Pin 1,2 from the Power Connector to other modules.	0V DC

Table 3: Pin Layout Power Supply Module

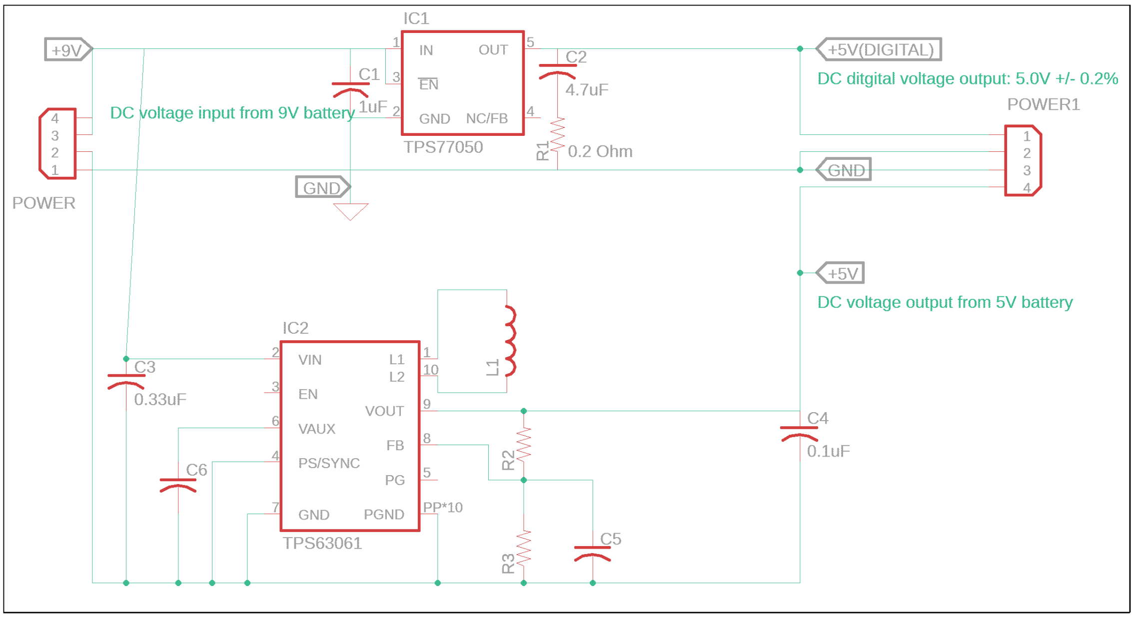


Figure 5: Power Supply Module Schematics

Requirement	Verification
Able to convert voltage ranging from 8.7V to 9.2V to 5±0.3V.	1. Provide 9V input voltage from DC power supply to the component. 2. Use digital multimeter to measure the output voltage. The output voltage should be 5±0.3V.
Able to provide a max of 100 mA current to power the digital circuits.	1. Use a clamp-on amp meter to measure the current consumption when the device is working. The maximum current should be below 100mA.
Able to provide a max of 1.5 A current to power the motor.	1. Use a clamp-on amp meter to measure the current consumption on digital circuit power line and motor power line when the device is working. The maximum current should be below 1.5A.

Table 4: R and V for Power Supply Module

Control Module

The control module contains a microcontroller responsible for controlling the motion module and a USB-UART IC responsible for building up a bidirectional bridge between the microcontroller and smartphone software. The module is powered by 5V DC from the voltage regulator in the power supply module. The signals will be converted to UART through this interface and send to the microcontroller. For the other direction, the UART signals sent out from the microcontroller are also converted to USB to send to the smartphone.

ATmega328P Microcontroller

Power Input:
5V DC, operating range (1.8V - 5.5V)

Data Input:
UART RX signals from the USB-UART interface in the communication module.

Data Outputs:
Control signals and high frequency PWM signal to the motor driver in motion module.
Control signals to the LEDs to show device status.
UART TX signals to the USB-UART interface in the communication module.

Description:
The ATmega328P is a low power, CMOS 8-bit microcontrollers based on the AVR enhanced RISC architecture.It has frequency up to 20MHz, and contains 32KB ISP flash memory with read-while-write capabilities, 1024B EEPROM and 2KB SRAM. It has a total of 32 pins, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes. It also supports serial programmable USART. [18b]
For our design, we will use a 5V output voltage regulator combined with the battery unit to supply power to the microcontroller. It can control the linear stepper motor driver using its high-speed digital outputs and timer outputs, communicate with the software in smartphone module through the USB-UART interface, and drive the LEDs to show device status.

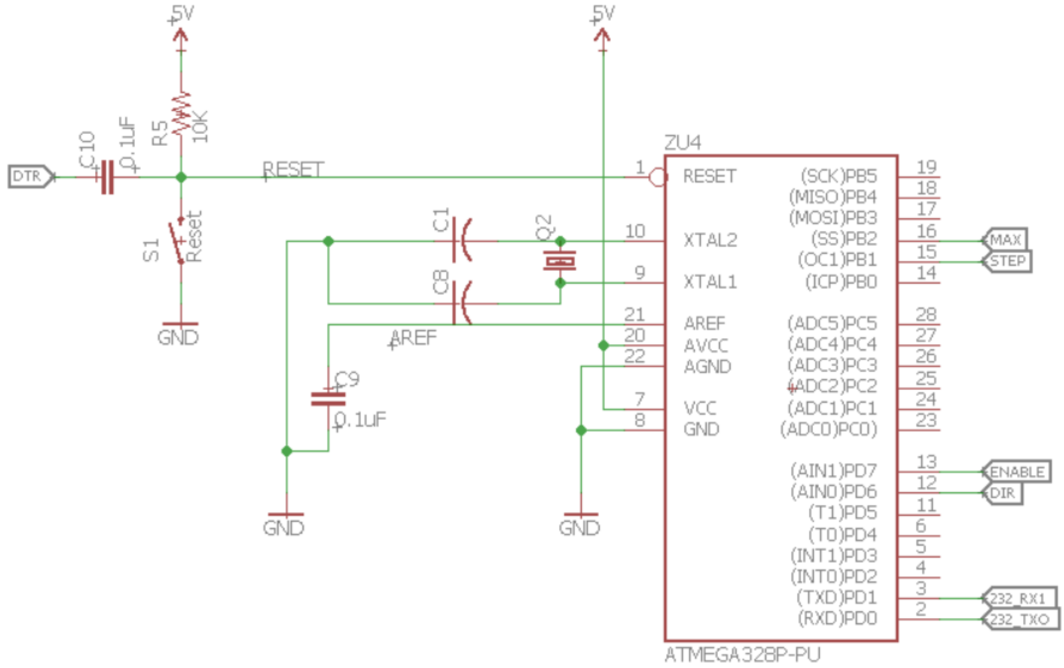


Figure 6: ATmega328P Microcontroller Schematic

FT232R USB UART IC

Power Input:
5V DC, operating range(1.8V - 5.5V)

Data Inputs:
UART TX signals from the microcontroller in the control module.
USB signals received from the smartphone.

Data Outputs:
UART RX signals converted from USB signals to the microcontroller in the control module.
USB signals converted from UART TX signals to the smartphone.

Description:
This chip is a highly-integrated solution for USB - UART conversion that has USB transceiver, oscillator, and Universal Asynchronous Receiver/Transmitter (UART) in packages. This IC supports 5V operating

supply voltage and high data transfer rate, and compatible with USB 2.0 full speed. [19a]

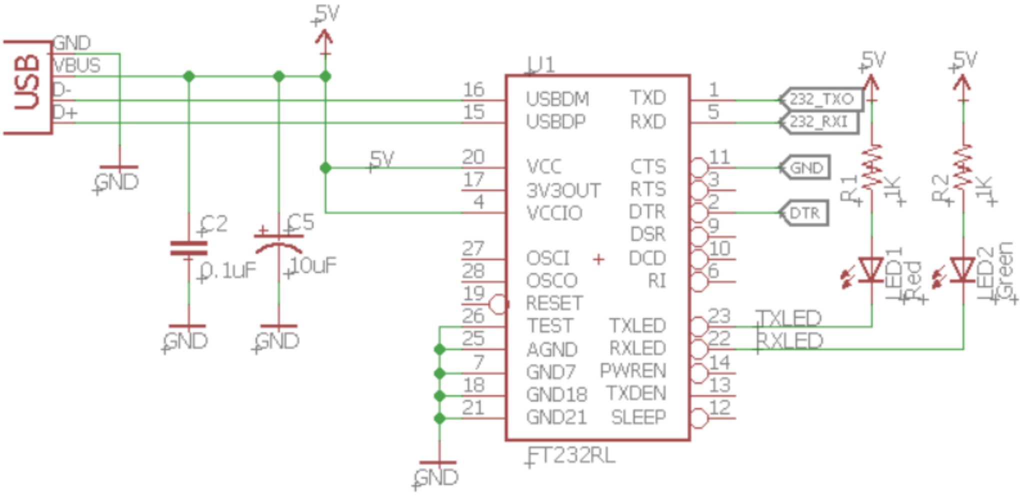


Figure 7: FT232R USB UART IC Schematic

Requirement	Verification
Microcontroller is able to output 1MHz (±0.1%) frequency GPIO signals and correct digital control signals to the stepper motor driver.	1. Connect the GPIO pins to an oscilloscope and check the duty cycle and frequency of the waveform. 2. check if the digital outputs' voltage levels match with what we specify in the microcontroller software.
Microcontroller is able to both receive and transmit over UART.	1. Connect the UART communication pins with a SparkFun FTDI Basic Breakout board. 2. Connect the board to a PC terminal via USB cables. 3. Use the Arduino software to check if we can both receive and transmit UART signals.
Microcontroller is able to use the digital output pins to drive LEDs for showing device status.	1. Connect the specific digital output pins to digital multimeter and check the voltage output levels.
USB UART IC is able to convert USB to UART data and vise versa, and support data transfer rates from 300 baud to 3M baud.	1. Check datasheet and try different baud rates at 300 baud rate, 30000 baud rate and 3M baud when testing with the SparkFun FTDI Basic Breakout board with microcontroller and PC terminal. 2. Verify the data transmission accuracy.
USB UART IC has driver support for USB communication with Android.	1. Check Datasheet and install the specific Android driver from FTDI's website. 2. Try sending and receiving back small data packages.

Table 5: R and V for Control Module

Motion Module
Input: Digital control signals, 5 Volt digital voltage input(Vcc), and 5 Volt load supply voltage input(VC+).
Output: 4 Motor control signal pins labelled as A,B,C,D.
Communication: GPIO logic sequence

The Motion Module receives the digital control signal from Control Module and drives the motor. The input and output are labelled in green boxes. The connector is illustrated on the top right. A test LED circuit is added to verify the motion of the motor.
Essential Components:

1. A3932 Bipolar Motor Driver with DMOS logic
2. Dual Motion 43F4P-233-099 Linear/Rotary Actuators by Haydon Kerk Motion Solution.

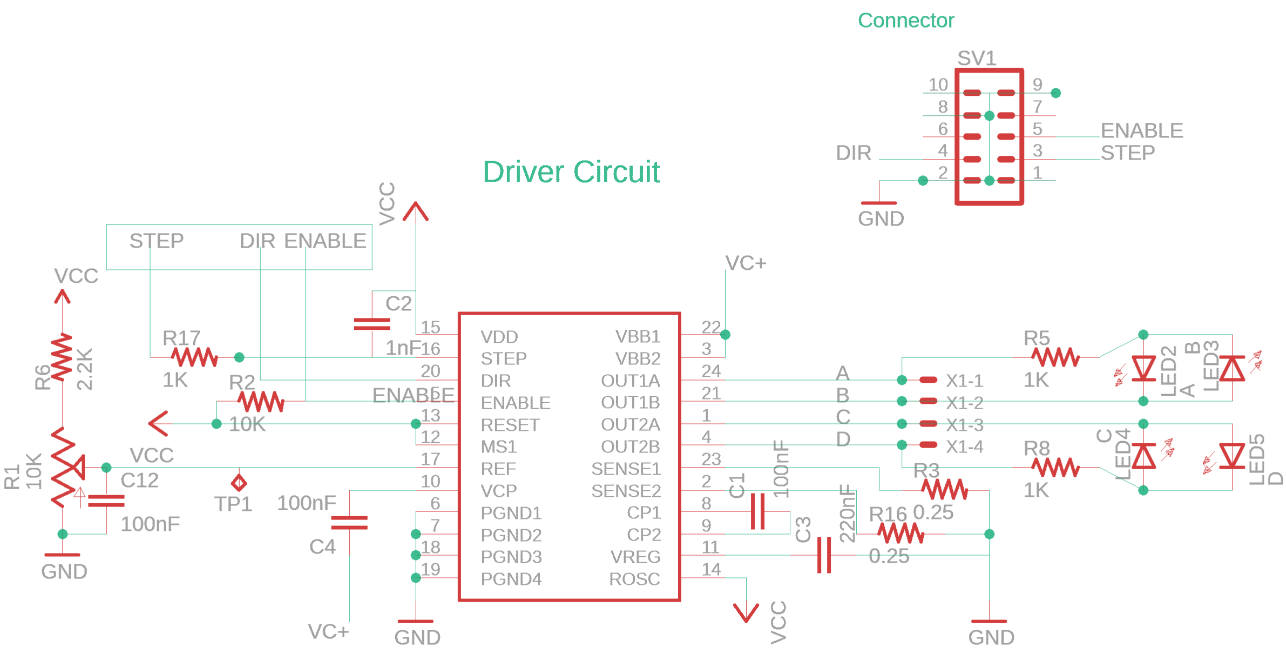
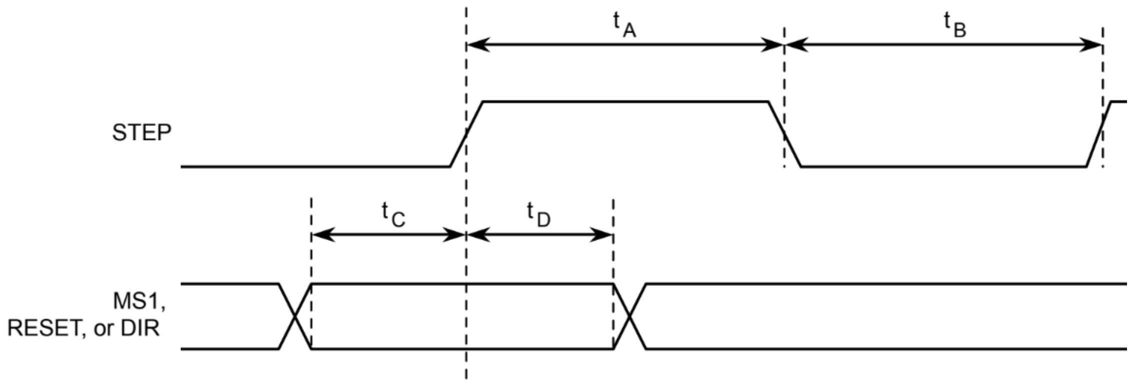


Figure 8: Motion Module Schematic

The GPIO communication sequence is included in figure 9. The graph shows that the GPIO are driven are driven in a frequency between$\mathbf{1/t_A = 1MHz}$ and $\mathbf{1/t_C = 5MHz}$, which is within range of the Control Unit.



Time Duration	Symbol	Typ.	Unit
STEP minimum, HIGH pulse width	t_A	1	μs
STEP minimum, LOW pulse width	t_B	1	μs
Setup time, input change to STEP	t_C	200	ns
Hold time, input change to STEP	t_D	200	ns

Figure 9: Digital Input Scheme

The choice of using L/R driver mode instead of the more popular chopper driver mode is that with L/R drives peak force and speeds are reduced, which is better for our control. The graph of torque versus Pulse Rate for different driver demonstrates that. At the same Pulse Rate, e.g. 200 full step/sec, L/R Drive has a lower thrust, therefore limits the possibility of overshooting by high speed.

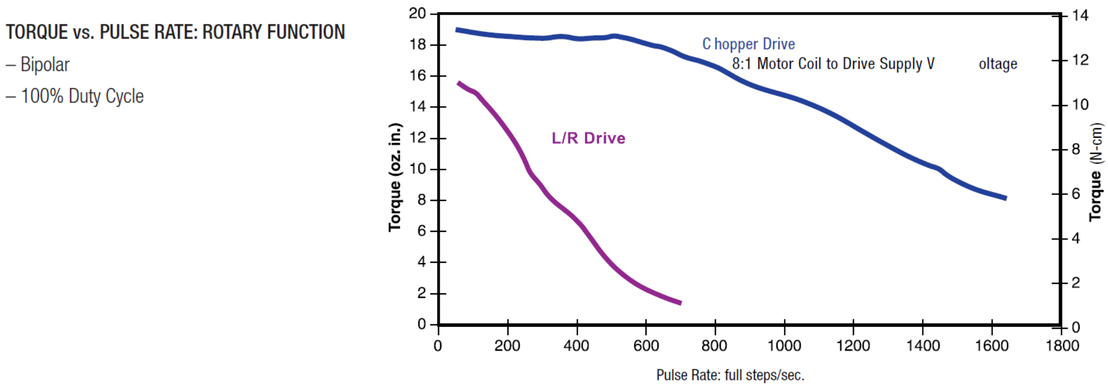


Figure 10: Digital Input Scheme

The choice of motor is essential to our project. Since in the high level requirement we need to have seamless movement between frames, it is critical to choose a motor that has a high precision. 43F4P-233-099 provides 50 sets of polar inductor pairs in the front and another 50 in the back, in total of 100 pairs of inductors. Therefore the smallest step size d_{min} is:

$$d_{min} = \frac{180^\circ}{100 inductorpairs} = 1.8^\circ \quad (2)$$

The minimal step is dependent on both the motor and the motor driver. According to the motor driver minimal step control sequence table and the output sequence from the motor driver, it is clear that the motor driver is able achieve the minimal step of the motor because the full step is small enough to achieve the desired accuracy. There is no need for microstepping. The required field of view which is 100um, which in terms of minimal steps translates to:

$$NumberofMinimalStep = \frac{100um}{3um/step} = 33steps \quad (3)$$

If the driver operates the motor at 1 kHz, each movement between two frames is 33ms, which is efficient enough for our application.

43000 Series: 1.8° Step Angle				
Linear Travel / Step		Load Limit		Order Code I.D.
inches	mm	lbs	N	
0.00012	0.003*	30	133	N

Figure 11: Motor Minimal Step Specification

Pin	Function	Connection	Data/Voltage
STEP	A low-to-high transition on the STEP input sequences the translator and advances the motor by one increment.	Connect from control module digital input to Pin 16 on the motor driver.	Logic high and low sequence. Figure 9 shows the communication scheme.
ENABLE	This signal turns on or off all of the DMOS outputs(A,B,C,D). When set to a logic high, the outputs are disabled.	Connect from control module digital input to Pin 5 on the motor driver.	Logic high and low sequence.
DIR	This determines the direction of rotation of the motor. When low, the direction will be clock-wise and when high, counterclockwise. Changes to this input do not take effect until the next STEP rising edge.	Connect from control module digital input to Pin 5 on the motor driver.	Logic high and low sequence. Figure 9 shows the communication scheme.
A,B,C,D	The motor pin outputs regulate the operating point of the motor.	Connect from the output pins on the driver to the bipolar motor connection.	Typically 0V or 5V output with max of 1.3 A current.
REF	The REF pin combined with the selection of RSx determines the maximum value of current limiting.	Connects the voltage dividing resistor circuit and Pin 17 on the driver.	Voltage between 0V to 5V

Table 6: Pin Layout Power Supply Module

1. The DMOS full bridge motor outputs are able to drive motor at 5.0V±0.3V and supply 0-1.3A and does not operate beyond this range.	1. Use clamp-on Amp Meter and Volt Meter to determine the operating point for the duration of 5 full forward movement and back.
2. The motor drives 25 steps between frames and makes the slide to travel 75 ± 10um.	1. Use Smartphone Microscope Camera to pick a reference point before travel. 2. After 25 steps, measure how many pixels the reference point has travelled. 3. Calculate how far physically the slide has travelled by converting pixels travelled to length travelled.
3. Shut off load power supply in less than 1us to ensure precision	1. Use Amp Meter and Oscilloscope to track the shut off transition time.

Table 7: R and V for Motion Module

2.2.4 Software Subsystem

Our software subsystem consists of two applications - a high-level application that runs on a smartphone and a low-level application that runs on a microcontroller. The android application will take a series of photos of different regions on the blood sample and stitch these photos together into a panorama and display the panorama on the phone. The microcontroller software will control the motor movement and communicate with the android application regarding when to move the motor and when the application should take a photo. The FSM and the flowchart are shown in figure 12.

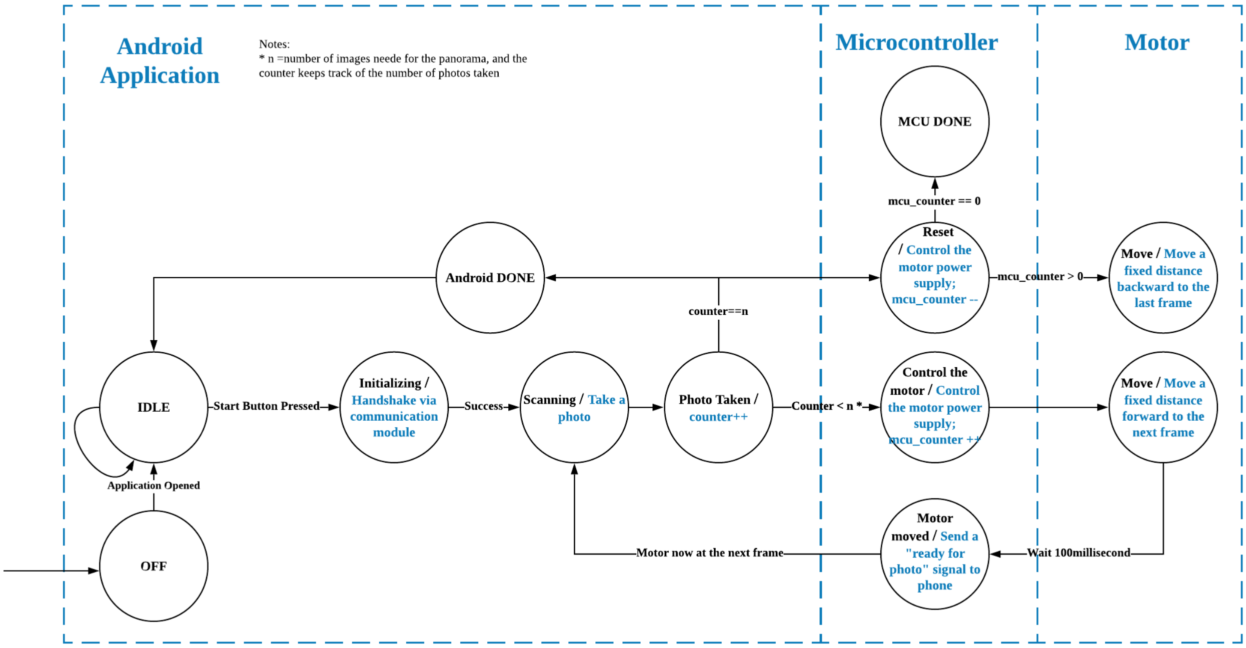


Figure 12: FSM of Software Operation

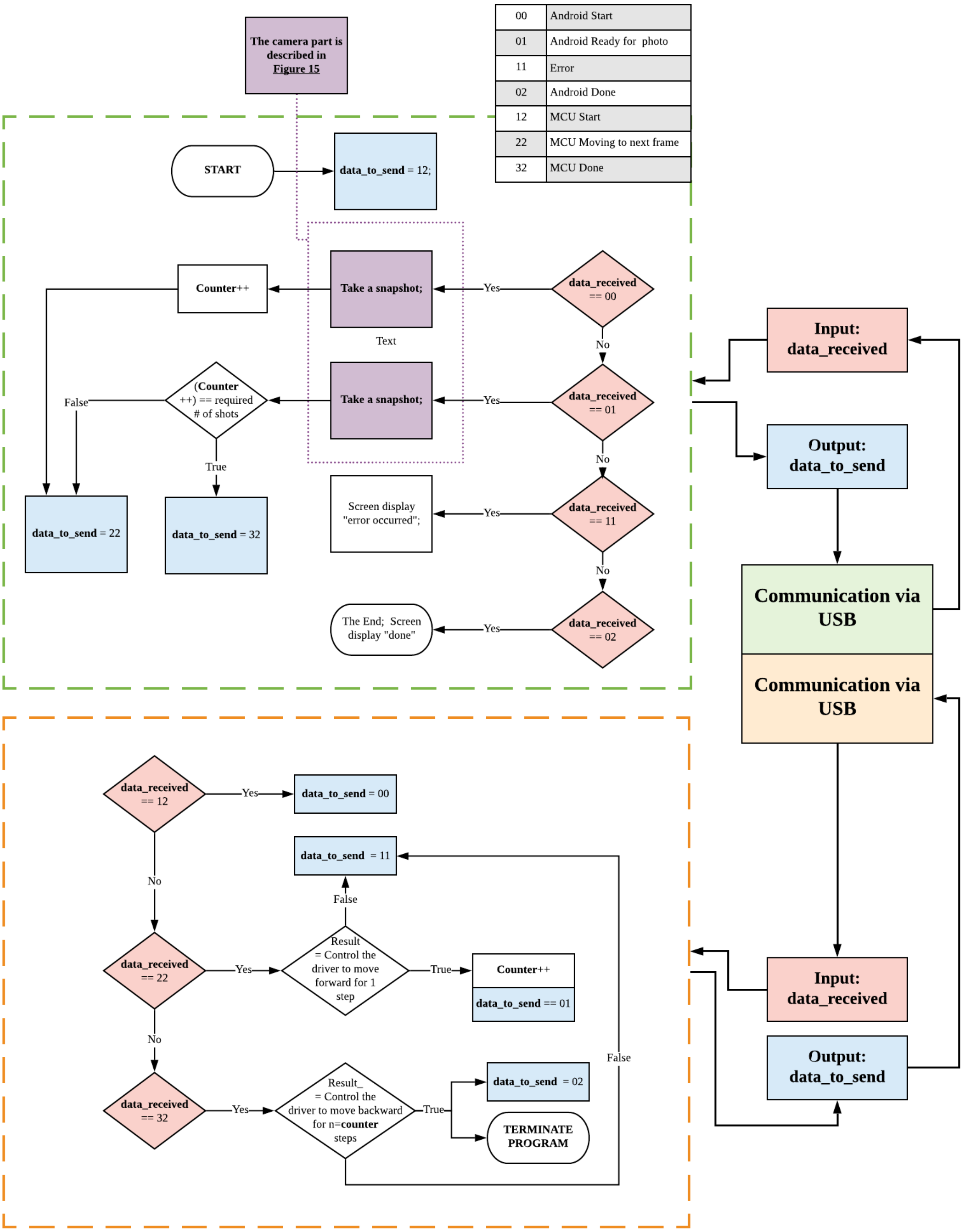


Figure 13: Software Flowchart

Android Application
Once the user opens the application, the FSM would go to the idle state and waits for the user to click "start". After the user clicks that “start” button on the screen, the mobile application will start checking its connection with the microcontroller by handshaking with the microcontroller via communication module. If successful, the phone will take the first photo and send a “next frame” signal to the microcontroller. After the motor moves to the next frame, the microcontroller will send a “ready for photo” signal to the phone, and the phone will take another photo. This process repeats until a required number of photos are taken. After scanning, the android application will send a ending signal to the microcontroller, and it will wait for the microcontroller to send a ending signal back to finish the process. The application will then stitch the images together into a panorama.

1. Communication Unit: In order to communicate with the microcontroller, we will use android.hardware.usb API, and the designed flowchart is shown in figure 14.

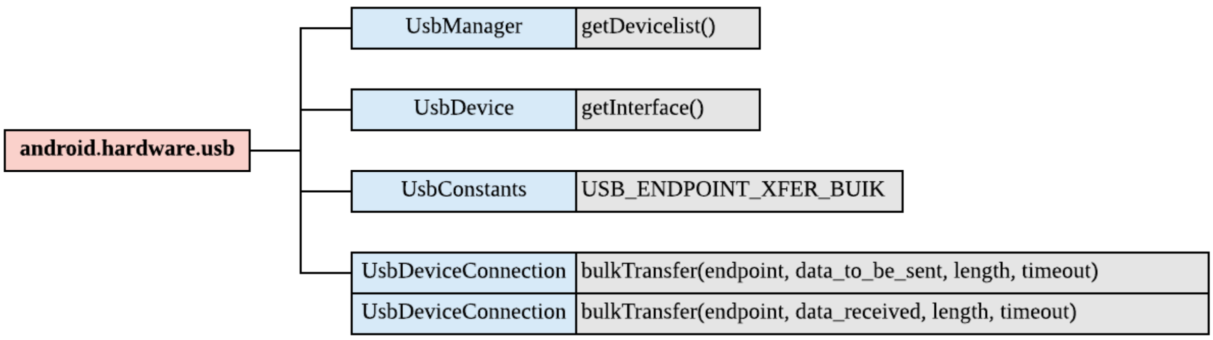


Figure 14: Communication Flowchart

2. Camera Unit: The input of this unit comes from the communication unit. Once received the “ready for photo” signal, the application would initialize the process of image capturing. As described in the optical system, some of the parameters on the camera hardware like flashlight_always_on need to be modified in order to meet the optical requirements prior the capture session. The application will then utilize the android.hardware.camera2 API to capture an image on a thread. The application will first initialize a

CameraDevice, and then create a CaptureSession. During the CaptureSession, the system will send capture request to the camera, and the camera will return CameraMetadata. After the process completes, the android application will send the "next frame" signal to the microcontroller. The designed image capture process flowchart is described in figure 15.

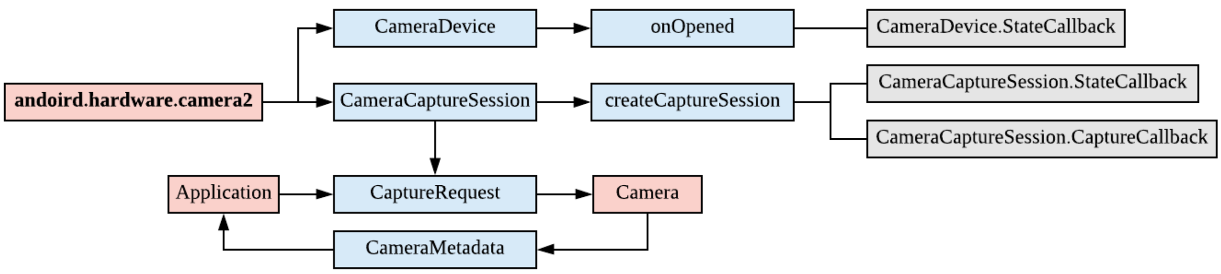


Figure 15: Camera Unit Flowchart

Microcontroller Software

The microcontroller software sends control signals to the motor driver to drive the linear stepper motor to travel a fixed distance after it receives the “next frame” signal from the android application. The microcontroller software will wait 100 milliseconds after the control signal terminates, ans it will return the “ready for photo” signal after the motor completes its action. When the microcontroller receives an ending signal from the android side, it will control the motor driver to move the motor backwards to reset the position, and the microcontroller will send a ending signal back to the android application to end the process.

Requirement	Verification
the micro controller should be able to control the motor driver to make the motor move a fixed distance	we will write a function on the microcontroller that controls the motor driver to move the motor to a fixed distance.
Once the microcontroller is connected to the android phone, the android application should be able to find the microcontroller device, and to send and receive messages	we will write a function in the android application that identifies the microcontroller from the device list, requests permission from the user, and initializes the transfer channel. Then we will test the function by "buck-Transfer" a data segment to the microcontroller, and at the same time we'll write a function on the microcontroller to send back a data segment to the android application if it receives the data from android.

Table 8: R and V for Software Subsystem

2.3 Supporting Material

2.4 Calculations

Motor Steps

Estimated blood smear sample size: 20mm * 20mm
40X microscope clip-on magnification FOV (Field of View) : 100um * 100um
We decide to take 50 images in one direction in order to cover total FOV of 5mm * 0.1mm

$$50 * 100um = 5000um = 5mm \tag{4}$$

Power Consumption

Idle Mode:
0.75 uA - ATMega328p microcontroller [18b]
70 uA - FT232R USB UART IC
7000 uA - A3982 driver
Total current consumption at Idle Mode:

$$0.75 + 70 + 7000uA = 7070.75uA = 7.07mA \tag{5}$$

Working Mode:

(motor is not moving)
14 mA - ATMega328p microcontroller [18b]
15 mA - FT232R USB UART IC
12 mA - A3982 Driver
0mA - Hayden 43F4R-5-800 Linear Actuator

Total current consumption at Working Mode (motor is not moving):

$$14 + 15 + 12 + 0mA = 41mA \tag{6}$$

(motor is moving)
14 mA - ATMega328p microcontroller [18b]
15 mA - FT232R USB UART IC

12 mA - A3982 Driver
700mA - Hayden 43F4R-5-800 Linear Actuator

Total current consumption at Working Mode (motor is moving):

$$14 + 15 + 12 + 700mA = 741mA \tag{7}$$

Battery Lifetime:
Based on the datasheet of ENERGIZER L522 9V Lithium Battery, the typical capacity is 750mAh.
We keep our assumption that the device will need to go through 50 frames per sample and spend 2s for each frame, 1s for sample movement and 1s for taking photo, we will need to consume totally

$$50 * (1 * 41 + 1 * 741)/3600mAh = 10.86mAh \tag{8}$$

Therefore, our battery can finish approximately

$$750/10.86 = 69 \tag{9}$$

operations. We also need to include the current consumption at Idle mode. Therefore, we can make a conservative estimation that our battery can guarantee supporting the device to take 50 panoramic images.

2.5 Tolerance Analysis

Mechanical Precision

Based on the motor control sequence table and the motor driver output sequence diagram in figure 16, it is clear that the motor driver can fully control the motor step by step.

Based on the PPR CPR table in figure 18 and the motor's minimal step specification in figure 16, the standard resolution of the motor is calculated using 200 CPR, following this equation:

Hybrids: **Stepping Sequence**

EXTEND CW ↓ / RETRACT CCW ↑

Bipolar	Q2-Q3	Q1-Q4	Q6-Q7	Q5-Q8
Step				
1	ON	OFF	ON	OFF
2	OFF	ON	ON	OFF
3	OFF	ON	OFF	ON
4	ON	OFF	OFF	ON
1	ON	OFF	ON	OFF

Note: Half stepping is accomplished by inserting an off state between transitioning phases.

Figure 16: Motor Control Sequence

$$Resolution = \frac{360^\circ}{CPR} = \frac{360^\circ}{200} = 1.8^\circ \tag{10}$$

Since the high level goal is to have frames of images stitched without gaps. The precision of the sample displacement needs to be at most ± 10um. Again referencing from motor's minimal step specification, the minimal step is 3um. Therefore the maximum error the pulse signal is allowed is:

$$\#oferrorpulsesignalcycles = \frac{errorlength}{unitlengthofonecycle} = \frac{10um}{3um} \tag{11}$$

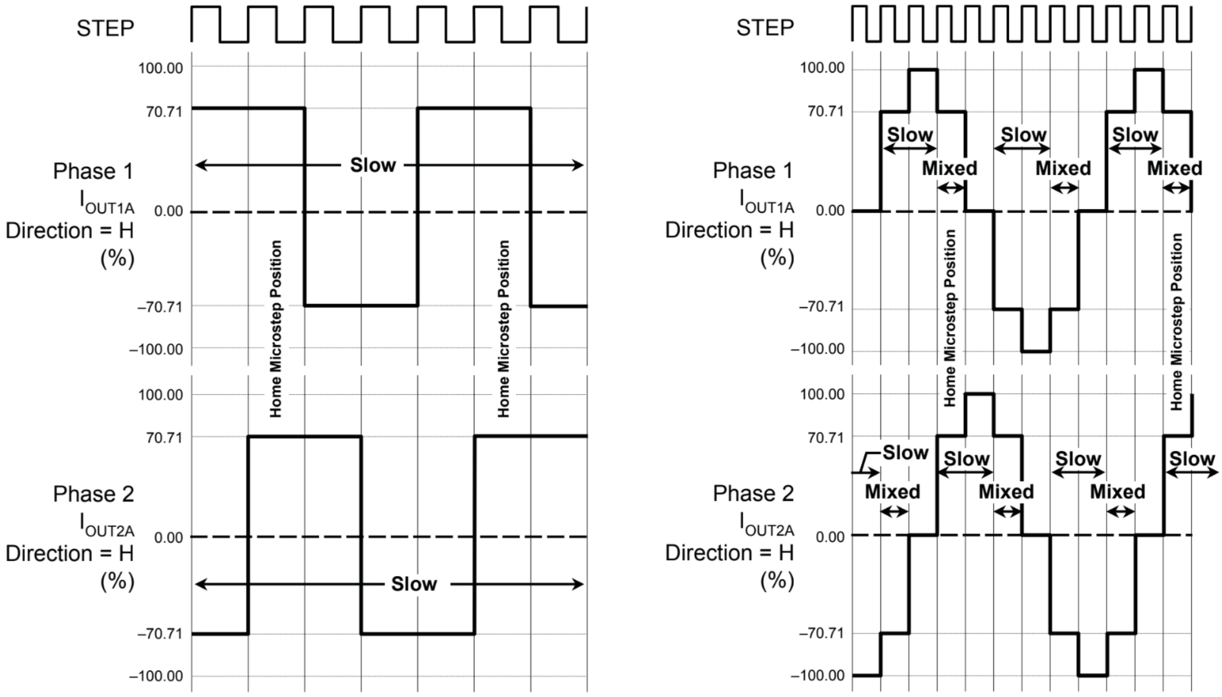


Figure 17: Driver Output Mode. Full Step Mode(left), Half Step Mode(right)

This demonstrates that we are allowed to have a maximum of 3 cycles of error in PWM pulse signal in order to reach a precision of 10um and achieve the high level goal of seamless photography.

Resolution				
4 Standard Cycles Per Revolution (CPR) or Pulses Per Revolution (PPR)				
Size 17	CPR	200	400	1000*
	PPR	800	1600	4000*

*Index Pulse Channel not available.

Figure 18: PPR CPR Table

43000 Series: 1.8° Step Angle				
Linear Travel / Step		Load Limit		Order Code I.D.
inches	mm	lbs	N	
0.00012	0.003*	30	133	N

Figure 19: Motor Minimal Step Specification

Motor Overshoot caused by Pulse Delay
The motor is driving the sample in a low velocity around 100um per second. Motor Driver Module: Delay from receiving:

$$D_{total} = D_{PWMGENERATOR} + D_{DMOS} = t_{crossoverdead} + t_{LowtoHigh} = 450ns + 200ns = 650ns. \quad (12)$$

Worst Case:

$$D_{total} = D_{PWMGENERATOR} + D_{DMOS} = t_{crossoverdead} + t_{LowtoHigh} = 800ns + 200ns = 1us. \quad (13)$$

Base on the delay calculated, the worst case error is

$$Distance = Velocity * Delay = \frac{100um}{s} * 1us = 10^{-10}m. \quad (14)$$

Therefore we should ignore error caused by digital system.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Cost

We estimate the labor cost to be $30 cost per hour, 12 hours/week for three people. The duration of the project is 16 weeks, so the labor cost is calculated as below:

$$2 * 3 * \$30 * 12 * 16 = \$34560 \quad (15)$$

3.1.2 Parts Cost

Description	Vendor	Manufacturer	Part	Quantity	Cost (prototype)	Cost (bulk)
Linear Bearing Slider	Amazon	Usongshine	MGN12H	1	$15.99	$15.99
Glass Bead	Biospec	Bio Spec	No.11079110	1	$1	$1
5V Switching Voltage Regulator for motor	TI	TI	TPS63061	1	$2.2	$2.2
5V linear regulator for motor	Digi-Key	Analog Devices	LT1086CT-5	1	$0.87	$0.50
9V Lithium Battery	Digi-Key	Energizer	L522	1	$12.47	$8.11
Microcontroller	Digi-Key	Microchip	atmega328p	1	$2.14	$1.78
FTDI USB-UART Converter	Digi-Key	FTDI	FT232R	1	$4.5	$4.5
Linear Motor	Haydon Kerk	Haydon Kerk	21L4(X)-V	1	$109.08	$109.08
Motor driver	Digi-Key	Allegro	A3982	1	$4.5	$2.83
Assorted resistors, capacitors, LEDs, connectors	SparkFun Electronics			1	$10	$10
Total Cost					**$179.75**	**$172.99**

Table 9: Costs

3.1.3 Total Cost

The grand total cost of the project consists of labor cost and parts cost:

$$\$34560 + \$179.75 = \$34739.75 \quad (16)$$

3.2 Schedule

Week	Fengmao	Simon	Rui
Oct 6, 2019	Design review; Design PCB board layouts for power supply module and motion module.	Design Review; Design PCB schematics and layouts.	Design review; experiment with and evaluate the robostness of image stitching on online blood sample dataset
Oct 13, 2019	Finish layout designs and confirm PCB order for power supply module and motion module.	Finish PCB circuit layout designs; Order PCBs and required ICs.	Start Coding the camera unit; Experiment with image de-noising and enhancement algorithms
Oct 20, 2019	Receive motor; Test motor with different PWM signals and record motor specifications.	Build MCU standalone circuit; Set up MCU and verify functionalities; Try USB-UART communication.	Continue coding the camera unit; Evaluate the robostness
Oct 27, 2019	Solder and debug the PCB for power supply module and motion module. Make sure it has the functionalities.	Solder and debug PCBs; Program and test communication module; Write MCU smartphone communication software.	Begin coding the communication unit; Finish up the camera unit
Nov 3, 2019	Modular test motion module to ensure it meets the precision requirement. Put in final PCB order.	Modify and order new PCBs (if applicable); Write embedded motor control software on MCU.	Continue coding the communication unit; Start incorporating communication unit to the camera unit
Nov 10, 2019	Design mechanical platform and integrate system.		Test the entire software subsystem
Nov 17, 2019	Test the communication between motor driver and MCU. Calculate margin of error. Test corner cases.	Hardware and software integration; System level function validation.	Incorporate the software into the entire system; Debug for the actual case
Nov 24, 2019	Fall Break; Wrap up unfinished work and final testing.		
Dec 1, 2019	Final Demo; Prepare for final presentation.		
Dec 8, 2019	Final presentation		

Table 10: Schedule by week

4 Ethics and Safety

The objective of our project is to simplify the process of blood cell differentiated counting such that doctors could diagnose within a shorter period of time, and this aligns with the IEEE Code of Ethics, #5 “to improve the understanding of technology, its appropriate application. . . ”[IEE].

There are several concerns regarding the safety and ethics of our project. The main safety hazard comes from the possibility of virus spreading via human blood sample. To mitigate the hazard, we will use horse blood as a sample of our senior design project to avoid the danger brought by human blood. The horse blood is extracted in a legal way by a veterinarian, and using horse blood wouldn’t form any threat to one’s health. After our senior design, the project might be dealing with human blood. Doing experiments with human blood involves dealing with biology safety level 2 hazard, and every individual involved in the project will be required to complete a safety level 2 training and to pass the safety quiz. In such way, people will be taught to appropriately dealing with blood sample, significantly reducing the possibility of getting virus, following the IEEE Code of Ethics, #9 “to avoid injuring others, their property. . . ”[IEE]. Another safety concern comes from the power supply, and we will be responsible for ensuring the voltage and current fed into different electronic modules won’t exceed their standard thresholds.

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