ZERO-FRICTION TACHOMETER PROSPECTUS

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I. Description of the Design and Discussion of its Optimization

The tachometer consists of a laser, a sensor and a black plastic enclosure for the main unit. This enclosure contains the circuitry to calculate rotations, RPM, and RPS, and a four-digit display to output the value selected by the user using a mode switch. The motor is outfitted with a circular disk containing 10 evenly-spaced slits, and the system works by detecting the radiation of the laser through these slits as the motor rotates.

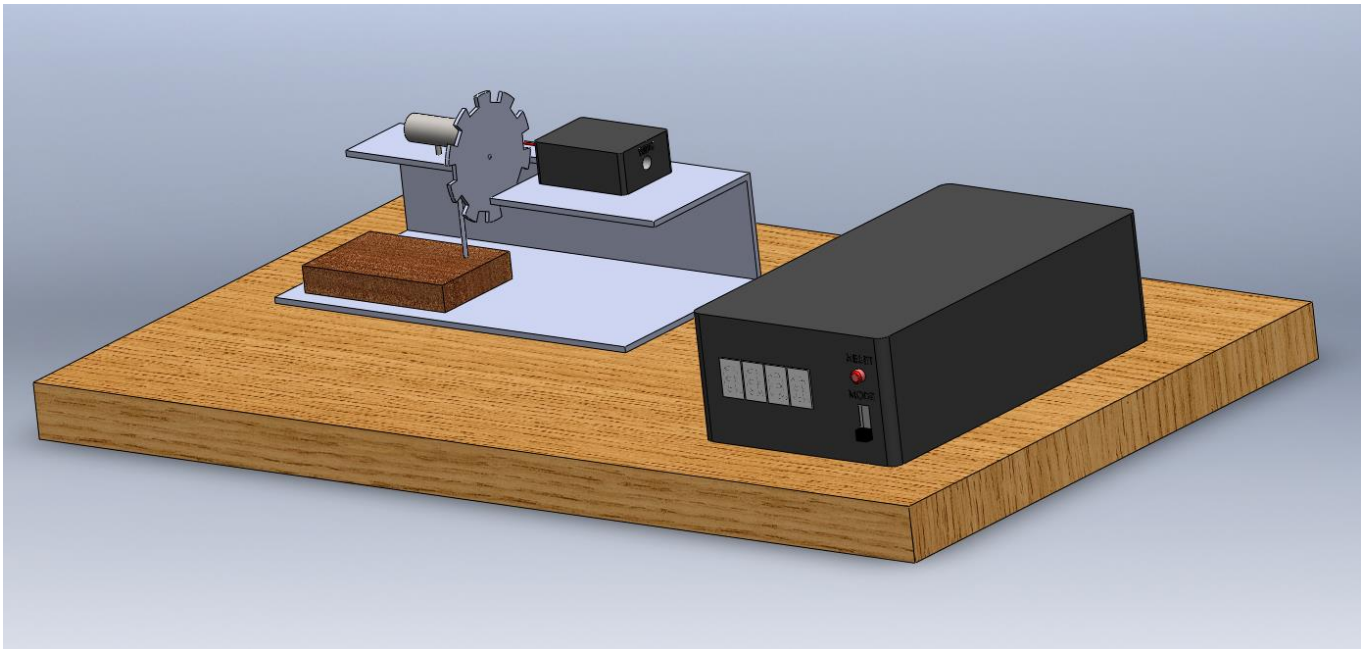
The design of the tachometer has been optimized for accuracy in several ways. Firstly, as it relies solely on the motor's regulation of light patterns, the tachometer exerts no friction whatsoever onto the motor. Because it does not inhibit the motor's torque, the resultant revolution speed that is measured is completely that of the motor, and is not tachometer-dependent. Secondly, the ten-slit disk that is an accessory of the tachometer allows for readings to be taken ten times per revolution and increases the precision tenfold compared with only having one slit. The precision in the count mode is 0.05 revolutions. The precision in the RPS mode is 0.05 RPS and in RPM mode, it is 0.8 RPM. Of note is that this setup allows for vastly more reliable readings at lower RPM. Finally, the optical nature of this system ensures that information travels from the motor to the sensor as quickly as possible, so that the method of data collection is effectively eliminated as a source of inhibition of the information transfer rate.

The concept has also been optimized for general use, as it can be quickly and easily implemented to any axle motor. The disk accessory need only be fitted to the motor and the laser properly aimed at the sensor. In this project, the concept is being demonstrated on a motor that is quite weak relative to commercial standard. This demonstrates that this tachometer really can be used on any motor without restricting its motion.

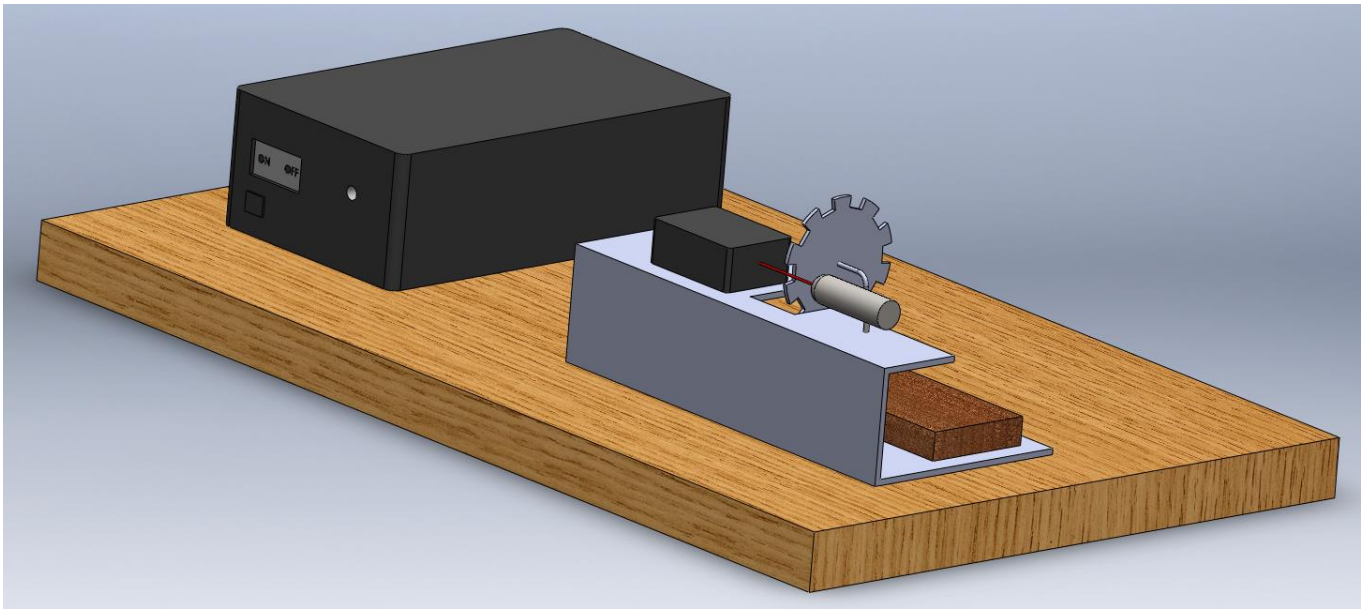
The design has been optimized for construction budget purposes. Using material bought from consumer electronics stores, this tachometer costs less than $150 CAD to build. The low price is attributed largely to the fact that the tachometer was built using only basic parts and chips. Under a supply chain implementation, this assembly of relatively basic parts could make for a product that is brought to the market at a fraction of the cost of the prototype presented here.

The circuit has been built modularly so that errors that arise in design and construction can be isolated to one component. Headers will be soldered to each module so that modules can be disconnected and reconnected easily if a component malfunctions. In the circuit, crystal oscillators are used instead of an RC multivibrator since a great tolerance in the resistor or capacitor will cause great inaccuracy in the timing. It is of importance to ensure that the timing of the device is as accurate as possible for the RPS and RPM modes. The main unit of the tachometer is connected to the sensor via a ¼" TRS cable. This is done to account for various lengths of cable required and for easy replacement of broken components. As well for safety, it is preferable not to have a cable that is soldered to the main unit if the cable is in the proximity of a fast-running motor.

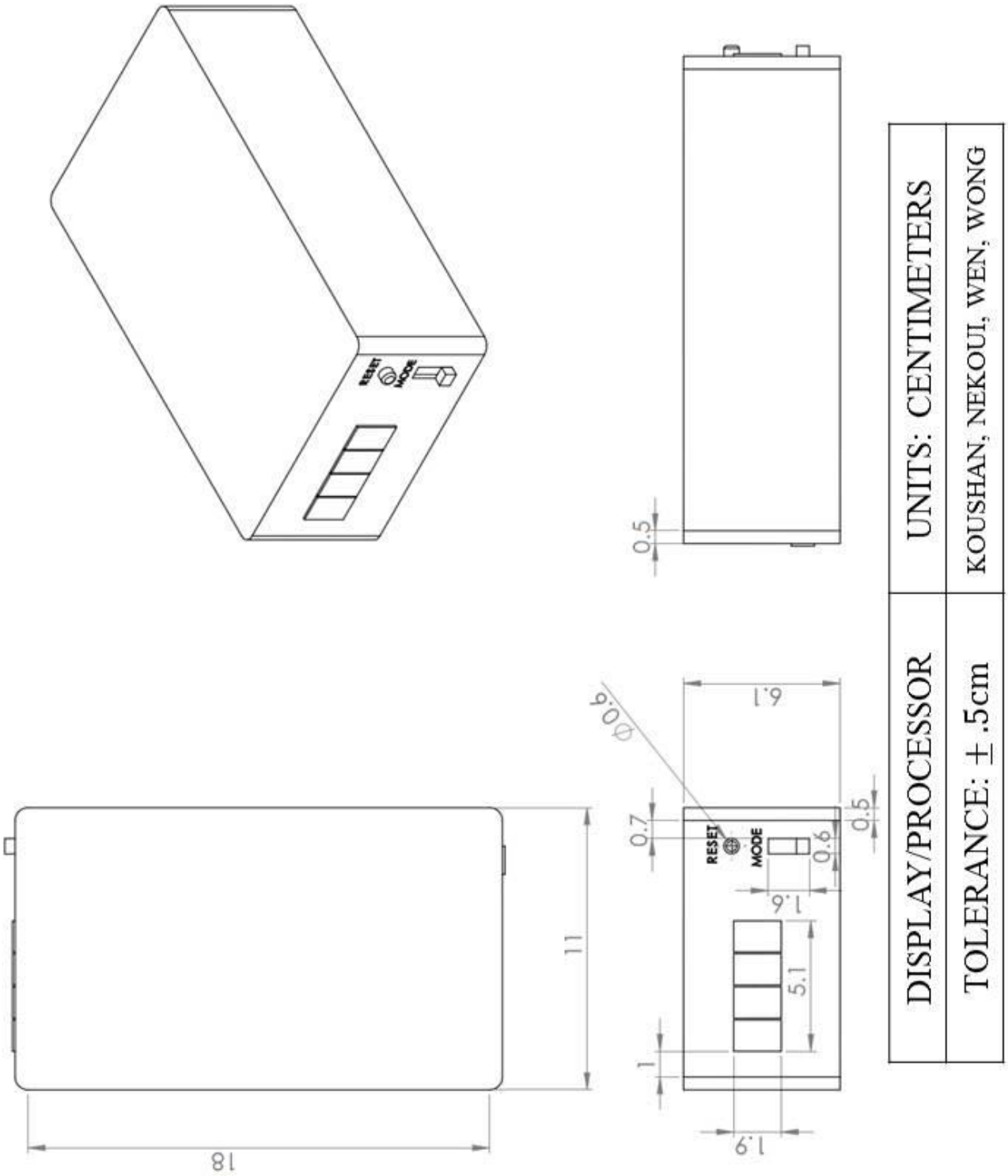
The tachometer is powered by a 5V DC adapter to avoid the use of batteries and to ensure a constant voltage supply.



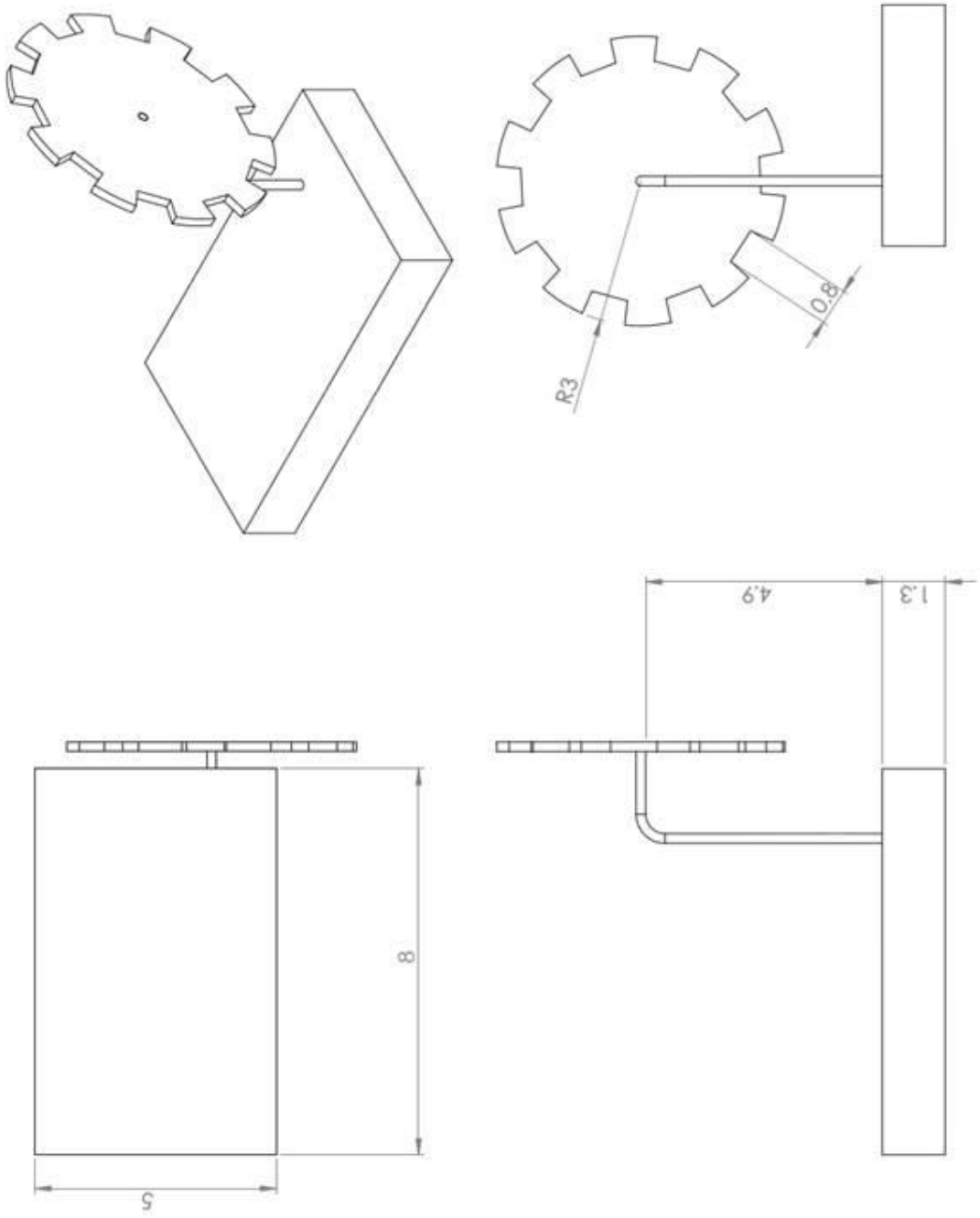
The front of the assembly features the 4 digit display, a 3 mode switch and a reset button



The rear hosts a 2.1 mm barrel DC power supply input and an on/off switch. The laser through the motor slots is clearly visible in this view. Also, note that all cables were omitted for clarity

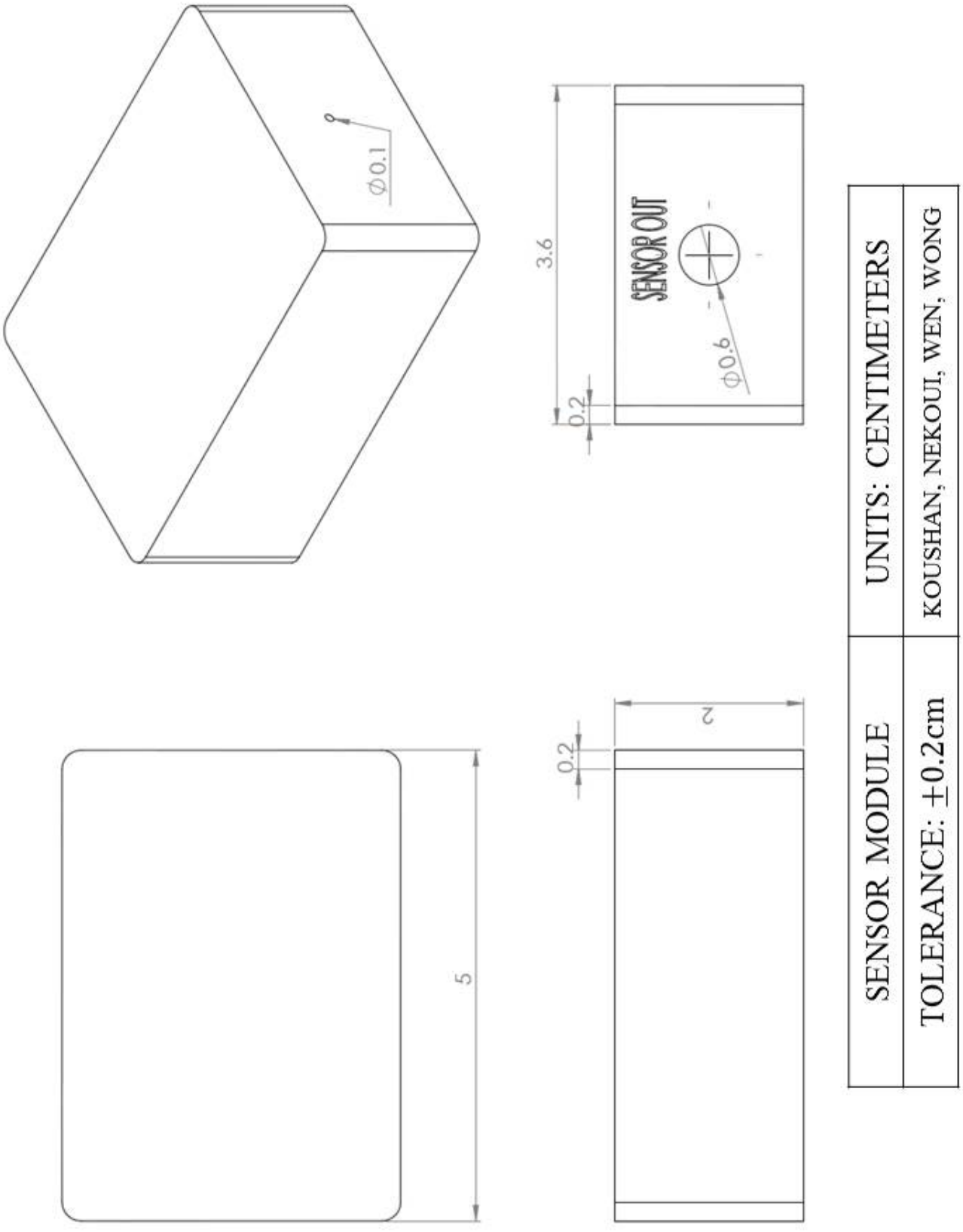


DISPLAY/PROCESSOR	UNITS: CENTIMETERS
TOLERANCE: ± .5cm	KOUSHAN, NEKOUI, WEN, WONG



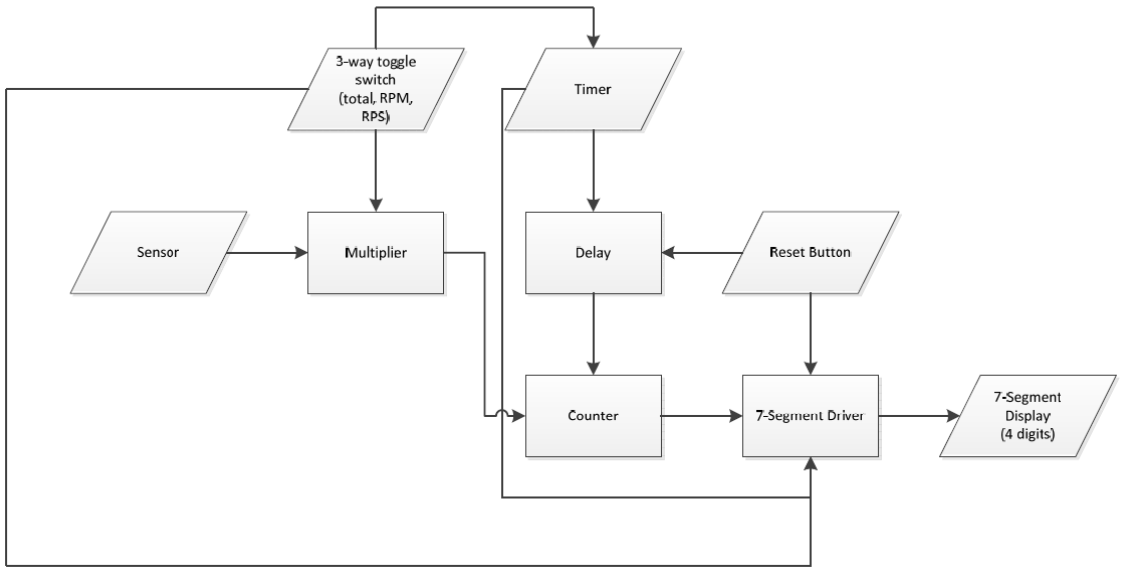
Note: stand, coil, magnet, and power source omitted for simplicity

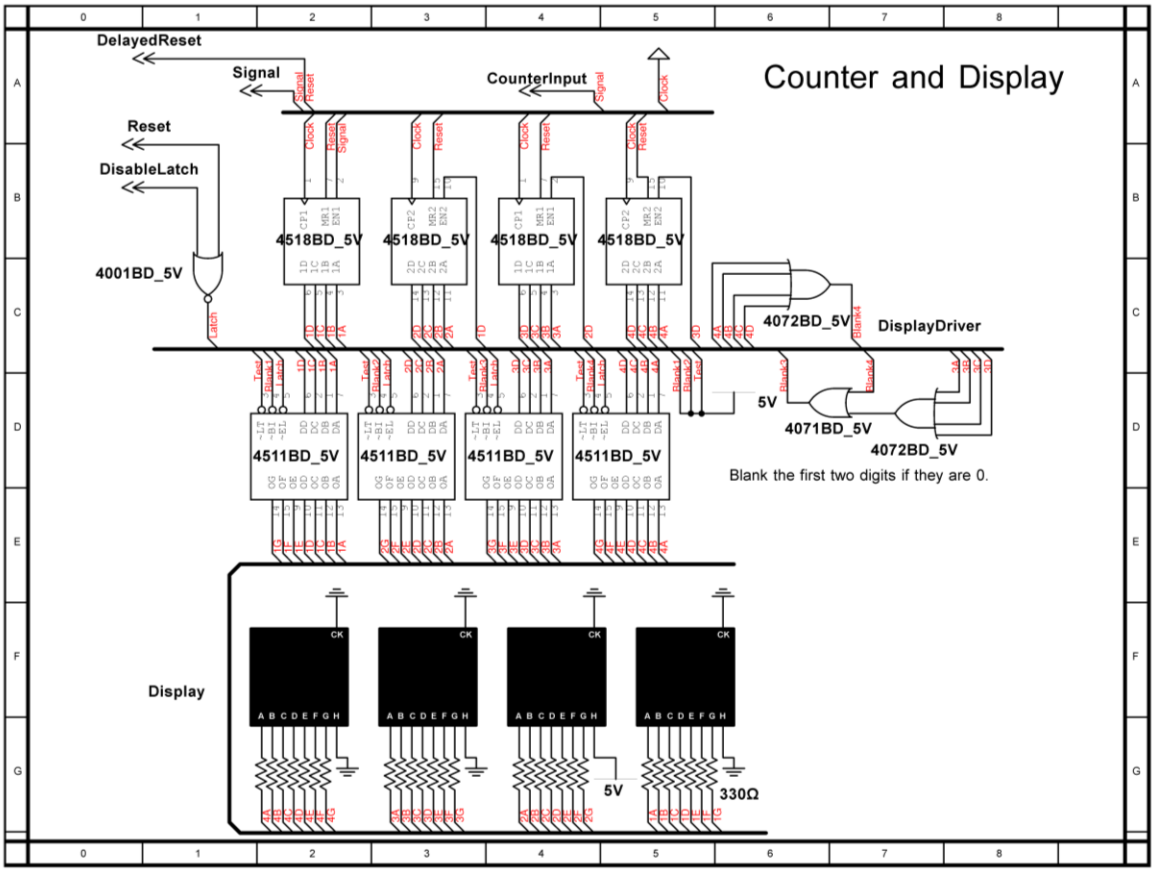
SIMPLIFIED MOTOR	UNITS: CENTIMETERS
TOLERANCE: ±1cm	KOUSHAN, NEKOUI, WEN, WONG

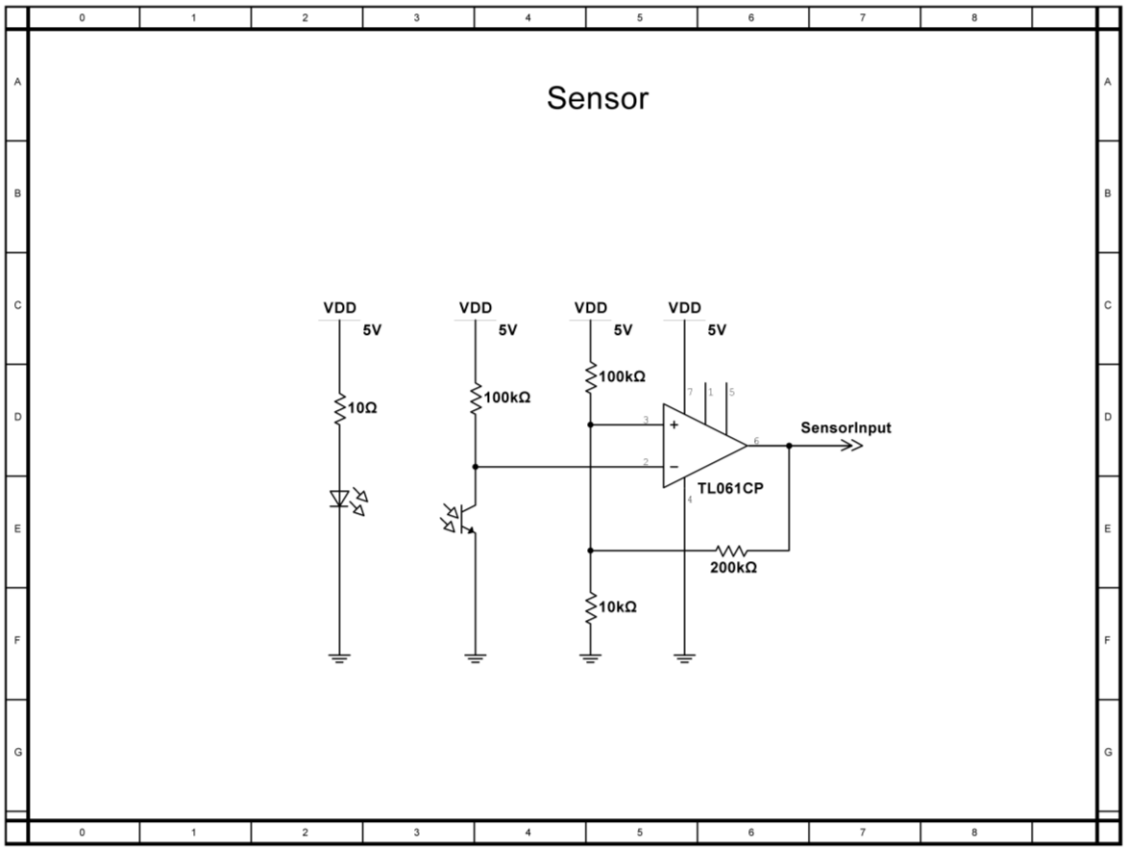

Φ0.1
3.6
SENSOR OUT
Φ0.6
0.2
0.2
2
5
SENSOR MODULE
TOLERANCE: ±0.2cm
UNITS: CENTIMETERS
KOUSHAN, NEKOUI, WEN, WONG

II. SCHEMATICS

Digital Logic Flowchart



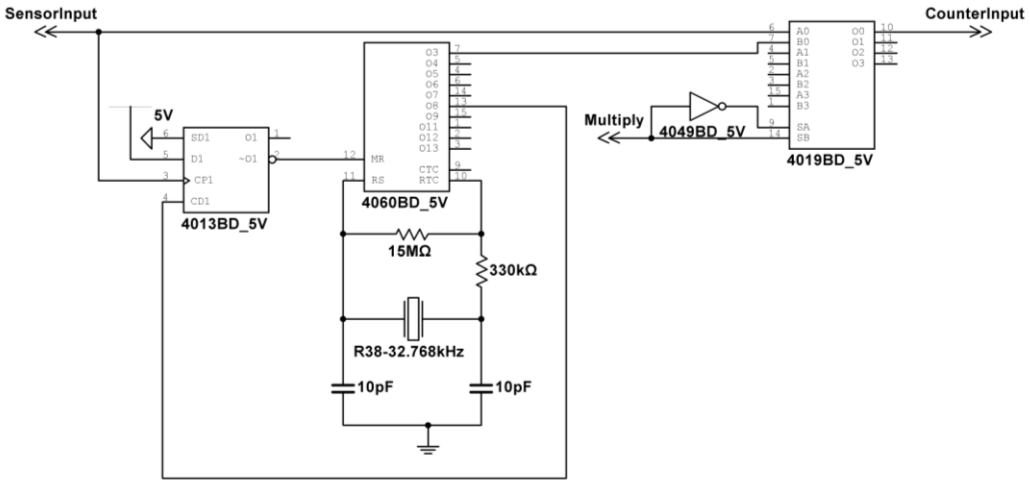

Counter and Display
DelayedReset
Signal
CounterInput
Reset
DisableLatch
4001BD_5V
4518BD_5V
4518BD_5V
4518BD_5V
4518BD_5V
4072BD_5V
DisplayDriver
5V
4071BD_5V
4072BD_5V
Blank the first two digits if they are 0.
4511BD_5V
4511BD_5V
4511BD_5V
4511BD_5V
Display
5V
330Ω


Sensor
VDD
5V
10Ω
100kΩ
100kΩ
SensorInput
TL061CP
200kΩ
10kΩ

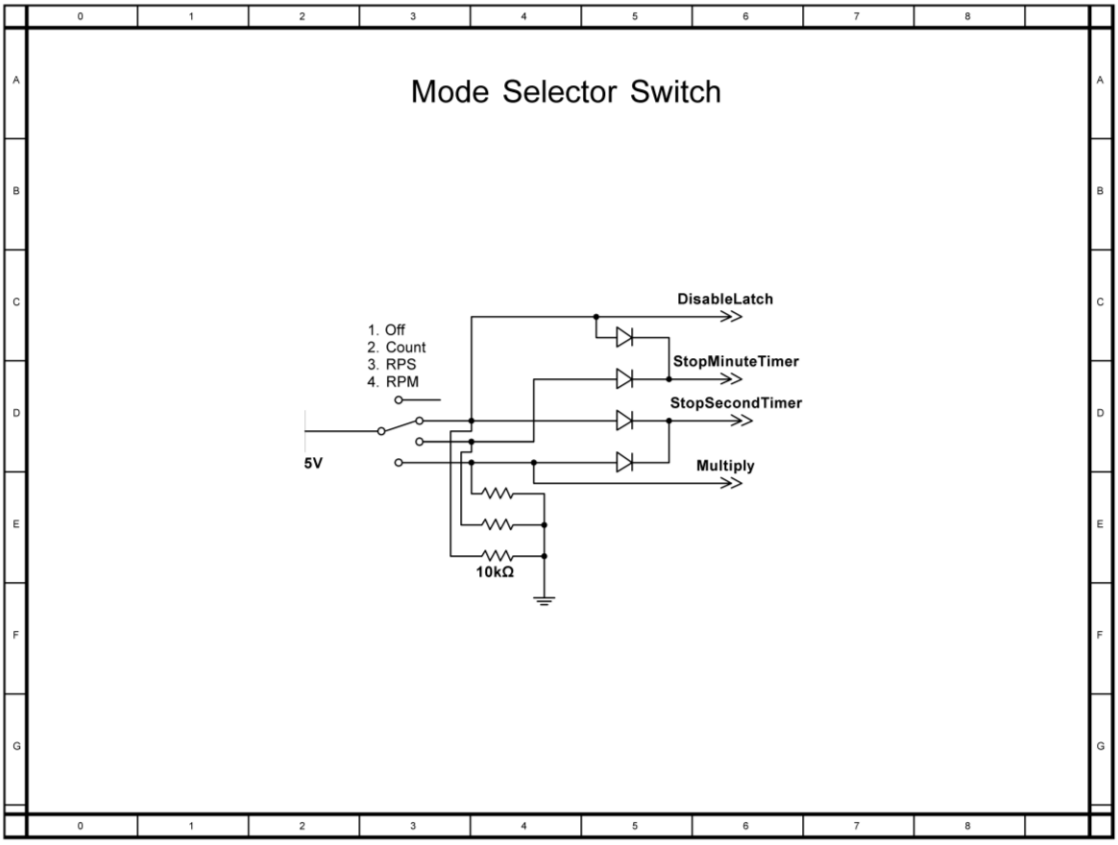
Delay

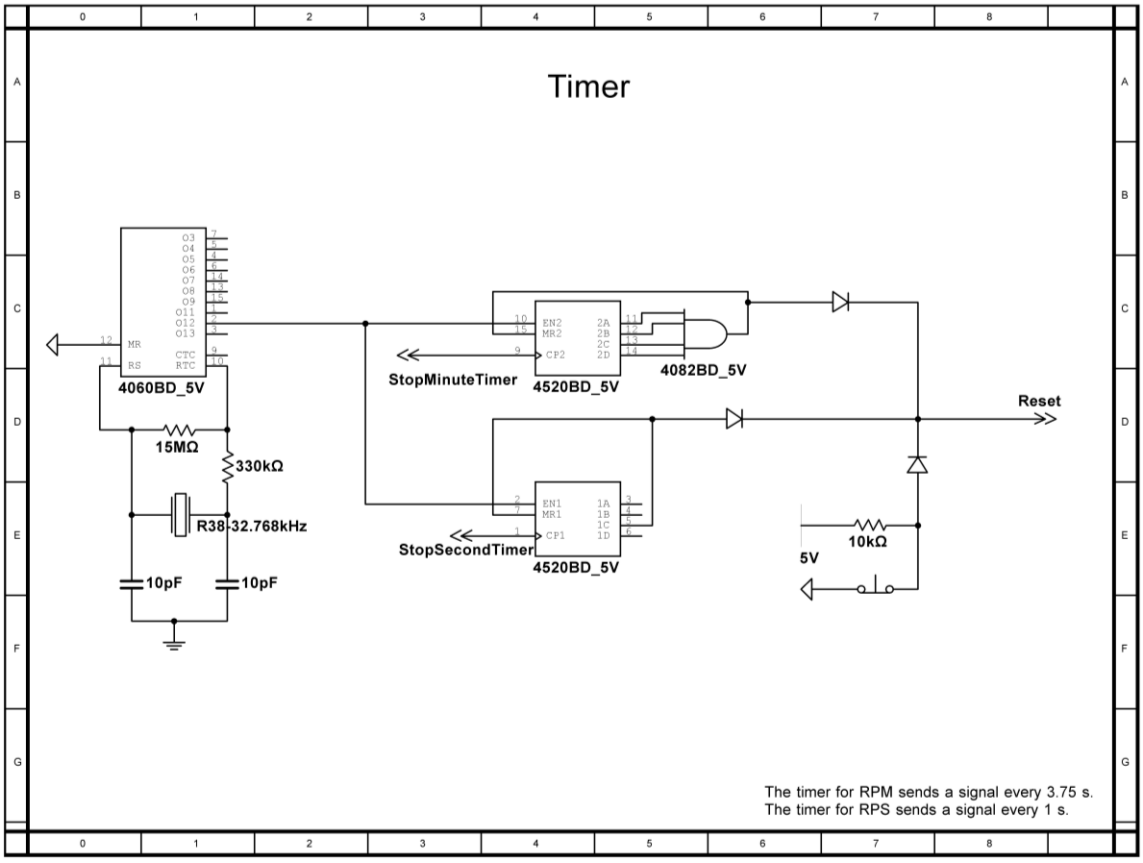
The reset signal passes through 6 NOT gates to delay the signal.
This is done to prevent the counters from resetting before the 4511 chips latch.

Multiplier



Sends out 16 pulses for every pulse received if Multiply is high.


Mode Selector Switch
1. Off
2. Count
3. RPS
4. RPM
5V
DisableLatch
StopMinuteTimer
StopSecondTimer
Multiply
10kΩ


Timer
4060BD_5V
15MΩ
330kΩ
R38-32.768kHz
10pF
10pF
StopMinuteTimer
4520BD_5V
4082BD_5V
StopSecondTimer
4520BD_5V
Reset
10kΩ
5V
The timer for RPM sends a signal every 3.75 s.
The timer for RPS sends a signal every 1 s.

III. BILL OF MATERIALS

Component	Quantity	Contingency	Total	Cost/pc.	Cost in Use	Total Cost	Description
10Ω	1	1	**2**	$0.03	$0.03	**$0.06**	
330 Ω	32	5	**37**	$0.03	$0.80	**$0.93**	
10 kΩ	6	2	**8**	$0.03	$0.15	**$0.20**	
100 kΩ	2	2	**4**	$0.03	$0.06	**$0.12**	
200 kΩ	1	1	**2**	$0.03	$0.03	**$0.06**	
330 kΩ	2	1	**3**	$0.03	$0.05	**$0.08**	
15 MΩ	2	1	**3**	$0.03	$0.05	**$0.08**	
Potentiometer	1	0	**1**	$1.50	$1.50	**$1.50**	
10 pF	4	2	**6**	$0.10	$0.40	**$0.60**	
100 nF	3	1	**4**	$0.10	$0.30	**$0.40**	
1N4001 Diode	7	1	**8**	$0.10	$0.70	**$0.80**	1A 50V DO-41
2.1 mm DC plug	2	0	**2**	$2.50	$5.00	**$5.00**	
5V 2A DC Adapter	1	0	**1**	$10.00	$10.00	**$10.00**	
3.2768 MHz Crystal Oscillator	1	0	**1**	$1.50	$1.50	**$1.50**	
32.768 kHz Quartz Crystal	1	1	**2**	$1.50	$1.50	**$3.00**	
CMOS 4001	1	1	**2**	$0.50	$0.50	**$1.00**	Quad 2-input NOR gate (14)
CMOS 4013	1	1	**2**	$0.50	$0.50	**$1.00**	Dual D-Type Flip-Flop (14)
CMOS 4019	1	1	**2**	$1.00	$1.00	**$2.00**	Quad 2-input multiplexer (16)
CMOS 4049	2	1	**3**	$0.50	$1.00	**$1.50**	Hex Inverting Buffer (NOT gate) (16)
CMOS 4060	2	1	**3**	$0.70	$1.40	**$2.10**	14-stage binary counter + oscillator (16)
CMOS 4071	1	1	**2**	$0.50	$0.50	**$1.00**	Quad 2-input OR gate (14)
CMOS 4072	1	1	**2**	$0.50	$0.50	**$1.00**	Dual 4-input OR gate (14)
CMOS 4082	1	1	**2**	$0.50	$0.50	**$1.00**	Dual 4-input AND gate (14)
CMOS 4511	4	2	**6**	$1.40	$5.60	**$8.40**	BCD to 7-Segment Latch/Decoder/Driver (16)
CMOS 4520	1	1	**2**	$0.70	$0.70	**$1.40**	Dual Binary Counter (16)
CMOS 4518	2	2	**4**	$1.40	$2.80	**$5.60**	Dual BCD Counter (16)
16 pin IC socket	14	3	**17**	$0.25	$3.50	**$4.25**	
14 pin IC socket	6	2	**8**	$0.25	$1.50	**$2.00**	
LCD CC 7-Segment Display	4	2	**6**	$0.33	$1.32	**$1.98**	
On/Off (SPST) Switch	1	0	**1**	$1.00	$1.00	**$1.00**	
SPTT Switch	1	0	**1**	$3.00	$3.00	**$3.00**	
NC Push Button	1	0	**1**	$1.00	$1.00	**$1.00**	
Wire	1	0	**1**	$5.00	$5.00	**$5.00**	
Female Headers (40 pins)	2	1	**3**	$1.50	$3.00	**$4.50**	
1/4" TRS Stereo Female	2	0	**2**	$1.00	$2.00	**$2.00**	
1/4" cable	1	0	**1**	$8.00	$8.00	**$8.00**	
Project Box	1	0	**1**	$15.00	$15.00	**$15.00**	14895 on Sayal (7.5" X 4.3" X 2.4")
Project Box	1	0	**1**	$5.00	$5.00	**$5.00**	78778 on Sayal (2.0" X 1.4" X 0.8")
Breadboard PCB	2	0	**2**	$9.00	$18.00	**$18.00**	
Sheet of construction paper	1	1	**2**	$0.02	$0.02	**$0.04**	
Scotch Tape	1	0	**1**	$0.50	$0.50	**$0.50**	
D-cell battery holder	1	0	**1**	$3.00	$3.00	**$3.00**	
D-cell battery	2	1	**3**	$1.00	$2.00	**$3.00**	
Insulated Copper Wire	1	0	**1**	$1.00	$1.00	**$1.00**	18 ft 35 AWG
Ceramic magnet	1	1	**2**	$2.50	$2.50	**$5.00**	
1/4" screws	2	0	**2**	$0.01	$0.02	**$0.02**	
1m 12 gauge copper wire	1	0	**1**	$3.00	$3.00	**$3.00**	
Laminate floorboard piece	1	0	**1**	$0.05	$0.05	**$0.05**	
OP-Amp	1	0	**1**	$0.50	$0.50	**$0.50**	OP-AMP SINGLE BIPOLAR/8P DIP TL061CP
Phototransistor	1	0	**1**	$0.96	$0.96	**$0.96**	PT481
Laser Diode	1	1	**2**	$1.00	$1.00	**$2.00**	KIE-7305-1P on Sayal
Glue Gun Sticks	5	0	**5**	$0.10	$0.50	**$0.50**	
Solder	1	0	**1**	$7.50	$7.50	**$7.50**	
Total	**140**	**43**	**183**		**$126.94**	**$148.12**	

IV. Procedures to Construct and Test the Device

Prior to the construction of the circuit, the circuit was designed and simulation with a demo version of *NI Multisim 12*. The schematics attached in this document were generated using this program. The circuitry was designed in modules which were tested individually in *Multisim*. This was done to isolate potential errors and to avoid the slow simulation that occurs in *Multisim* with a large circuit.

After designing all the components, each component was built on a solderless breadboard and tested individually. An *Arduino Uno* was used as a function generator. An *Arduino Mega* was used as an oscilloscope. The functionality of the timer was verified by confirming the proper delay between signals. This could not be done with an *Arduino* since the signal lasted for a very short period of time. Instead, the timer was connected to a counter which was analyzed with the *Arduino.* It was confirmed that the timer sends out a pulse every second or every 3.75 seconds depending on the mode. The functionality of the multiplier was verified by counting the pulses that were sent out for every pulse input with an *Arduino*. It was confirmed that the multiplier sends out 16 pulses for each pulse received. The BCD counter and 7-segment driver were tested by connecting them to a 7-segment display.

An issue arose with the integration of the timer with the counter and 7-segment driver. The timer was to cause the 7-segment driver to store the output from the counter then reset the counter. However, the counter was reset prior to the output being stored. This resulted in zeros being displayed always. To solve this, a delay was added to the reset of the counter. The reset signal is passed through 6 NOT gates to add a delay of approximately 360 ns which is greater than the required delay of less than 200 ns. The extra delay has a trivial effect on the accuracy of the tachometer while adding an extra buffer to the timing of the circuit.

The circuit now needs to be soldered on a circuit board. The circuit will be built on a PCB which mimics the connectivity of a solderless breadboard to mitigate the likelihood of mistakes arising from transferring the design over. The design will be transferred one component at a time and soldered one component at a time. The conductivity of the solder will be tested after every solder. ICs will not be soldered directly. An IC socket will be soldered and the IC will be inserted into the socket. Once the soldering is complete, the circuitry will be arranged inside the project box and organized to fit.

The circuit board will be positioned near the bottom of the plastic project box and secured with hot glue gun at the sides. Slits for controls, displays and peripherals will be cut in the sides of the box with a dremel or drill press as per the blueprints with the indicated tolerances to allow for imperfections. Each component will be secured to the box using hot glue from the inside for aesthetic value. This module will require a 5V DC power source input via a 2.1mm barrel connector. It will be connected to the sensor via a ¼” jack.

The sensor will be supplied with 5V power via the ¼” jack and will output signals to the processer module by the same line. Similarly, the hole will be drilled with a drill press and jack will be secured from the inside with glue. The sensor and Schmitt circuit board will be much smaller in size and will fit in the smaller project box. A small hole will be drilled on the opposite side of the jack to expose the phototransistor to the laser.

The sensor project box will be mounted to a stand that the laser diode and casing will also be mounted to via hot glue. These two items will be lined up prior to permanent mounting to avoid difficulties during testing and demonstration. The stand will be constructed from sheet metal. They will be cut to appropriate dimensions and fashioned by oxy-acetylene welding. A large slit in the middle will be cut to allow for the motor blades to intercept the laser. Detailed instructions to construct the motor are included as it was already built:

Drill two screws approximately 7 cm apart onto a piece of wood. Laminate floorboard works well as it is polished, cheap, and easy to work with. The screws' heads should protrude roughly 5 mm from the wood. For each screw, coil a 20 cm piece of 12 gauge wire in one full revolution under the screw, 8 cm from the end of the cable. Coil each of these 8 cm portions upwards, and with a pair of needle-nose pliers, create a loop at the end of the wire of the smallest diameter possible using the equipment. Coil 1.5 m of 35 gauge insulated copper wire into a circle about 2.5 cm in diameter, leaving 4.5 cm uncoiled on either side of the circle. Tie each of these uncoiled pieces through the coil so that the coil holds as a circle; pull the uncoiled ends outwards to form a straight axle. Adjust the knots such that the circle can balance rotationally on the axle. Then strip the bare 35 gauge wire on the axle. Carefully thread the axle through the loops created in the 12 gauge stand created earlier and straighten the axle. Construct a circle made of dark construction paper, 5cm in diameter. Cut a slit 6 mm wide and 10 mm long out of the disk, and using a protractor, cut nine similar slits every 36 degrees such that there are ten evenly spaced slits around the disk. Pierce the disk through the centre using the axle of the motor. Bend the axle of the motor upwards in a right angle and tape it to the disk so that the disk is stable. Connect the protruding 12 gauge wire to an electromotive force device providing 3–9 volts of potential difference across the leads. To control the RPM or torque of the motor, connect one lead to a potentiometer using copper wire before attaching it to the EMF device.

V. Production Schedule

5 September 2012

- Initial briefing of the end task of the project

7 September 2012

- Preliminary discussions of the goals of the project
- Research towards a viable design begins
- Cursory discussions regarding the assigning of roles

19 September 2012

- Meeting to conglomerate ideas regarding the general design and logistics of the project
- Consensus reached regarding the timeline for the following months
- Individual roles and intra-group collaborations planned

6 October 2012

- First sketches of product concept created
- Preliminary discussions on part purchasing
- Research on parts begins

26 October 2012

- Begin designing circuit on computer

5 November 2012

- Computer simulation of circuitry begins

25 November 2012

- Computer simulation of circuitry completed and verified by group

27 November 2012

- Design and construction of axle motor begins

28 November 2012

- Construction of axle motor completed
- Meeting to reconcile design of the motor to the design of the sensor

29 November 2012

- Parts-based design of sensor begins
- Breadboard prototyping of circuitry begins
- Prospectus outlined

1 December 2012

- Parts purchased for circuitry, motor control, and sensor assembly
- Breadboard prototype of timer and multiplier circuitry completed and verified by group

2 December 2012

- Meeting to discuss elevation design and presentation enclosure of product
- Prospectus completed
- Digital logic confirmed functional with video evidence

3 December 2012

- Prospectus submitted for review
- Complete construction of counter and 7 segment driver
- Begin soldering components

7 December 2012

- Soldering of digital logic complete
- Digital logic functionality after soldering confirmed with Arduino

11 December 2012

- Sensor individually tested and verified

14 December 2012

- Potentiometer added to control motor speed
- Stabilization of motor

15 December 2012

- Test assembly of sensor setup with motor, outside the final enclosure

23 December 2012

- Meeting to test all components of project in concert
- Final enclosure assembled

27 December 2012

- Verification of assembly and testing
- Video documentation of results
- Verification of accuracy using systematic video observation
- Aesthetic completeness of product assessed

28 December 2012

- Aesthetic completeness of product reconciled if necessary
- Photo shoot for marketing
- Meeting to discuss marketing strategies on pamphlet

3 January 2013

- Pamphlet completed
- Assessment of nonconformities to prospectus completed and documented

11 January 2013

- Product demonstrated and submitted for review

VI. SOURCES

http://www.datasheetarchive.com/
http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/schmitt.html
http://www.kpsec.freeuk.com/components/cmos.htm
http://mit.edu/cmse/educational/motor_lp_kristy.pdf