EEE3099S Milestone 1

Group Number	5
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0 WORK DISTRIBUTION

Table 1: Work distribution for Milestone 1

Task Description	**Person(s) of Responsibility**
Creating digital designs	MRTDAN014
Concept 1	ARNJAM004
Concept 2	MRTDAN014
Concept 3	JRCRIC001
Design Comparison/Selection	MRTDAN014, MHTRON001, JRCRIC001, ARNJAM004
Improvements on final design	MHTRON001
Components list	JRCRIC001
White Lab Component List	MHTRON001
Mass Budget	MHTRON001
Velocity/Torque calculations	MRTDAN014
Modification of motor gearbox	MRTDAN014
Report refinement	ARNJAM004, JRCRIC001

1 DESIGN 1

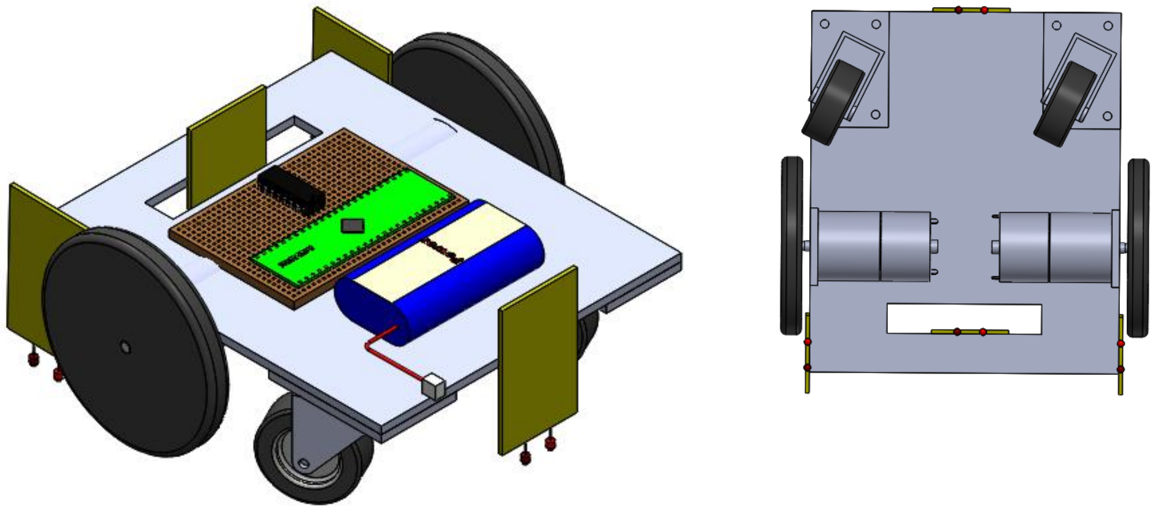

Figure 1: First concept design

1.1 DESCRIPTION

Rectangular shape with four sensors and four wheels. Sensors are placed one in the front and three in the back. The two outermost sensors on the back are used to detect turns. The middle, back sensor is used to make sure that the car follows the line and the front sensor is used to detect a circle and provide a distance measurement between the two middle sensors.

1.2 COMPONENT ON ROBOT

This design uses two motor wheels and two castor wheels for movement. It has a total of four sensors for detecting the black line with the microcontroller, driver and voltage regulator placed on a veroboard on top of the chassis. The battery is also placed on top of the chassis for even weight distribution

2 DESIGN 2

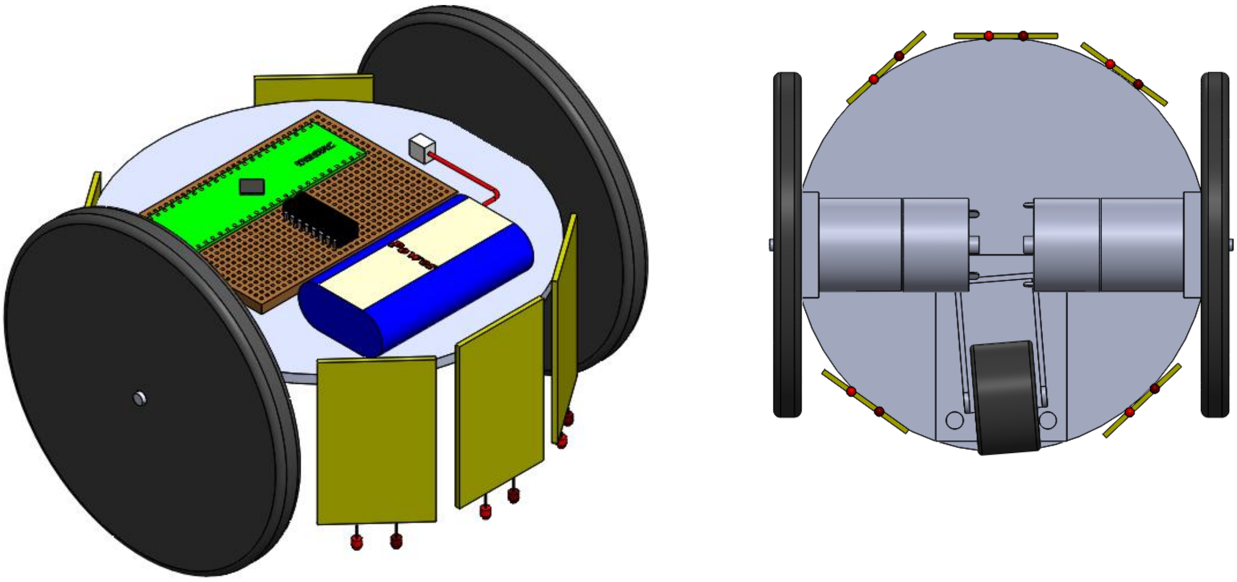

Figure 2: Second concept design

2.1 DESCRIPTION

Circular design with 5 sensors. The two outermost front sensors would be used to identify when the robot has entered the circle. The back two sensors are used to detect turns and the front middle sensor keeps the robot on track.

2.2 COMPONENT ON ROBOT

This design has 3 sensors in the front of the robot and two on the back. There are two wheels on the underside, each connected to a motor respectively. There is also a caster wheel on the underside towards the back of the robot. Both the battery and the Veroboard containing the motor controller, voltage regulator and the STM are on top of the circular board.

3 Design 3

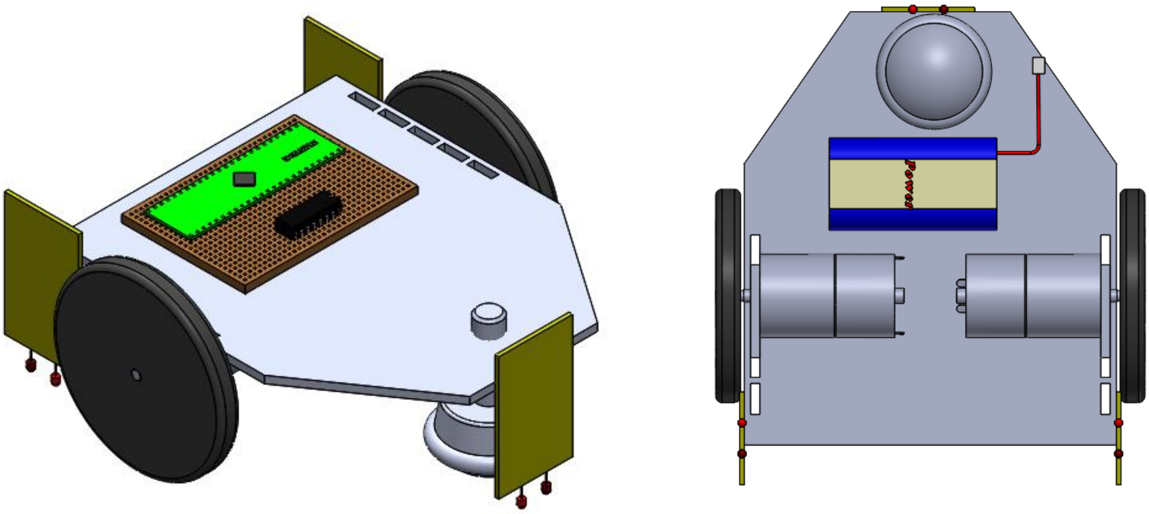

Figure 3: Third concept design

3.1 Description

Irregular hexagon with 3 sensors with an option for a fourth. This design is lighter than the other 2 options by having less board and fewer sensors. It is also simple and less power hungry by only using 3 sensors. A ball unit transfer caster wheel has also been used as opposed to a caster wheel. The slots close to the wheels are for adjusting the position of the motors and the wheels.

3.2 Component on Robot

In this design, the battery is on the underside of the robot, with the veroboard containing the STM, voltage regulator and motor controller on top. There are two normal wheels on the underside as well as a ball transfer caster wheel.

4 DESIGN COMPARISON

4.1 ADVANTAGE, DISADVANTAGE & UNIQUENESS

Table 2: Advantage, disadvantage and uniqueness of concept designs

Design #	**Advantage**	**Disadvantage**	**Uniqueness**
1	Stability	Heavy	Four wheels used to provide the robot with greater stability
2	Ease of programming	Single option for wheel placement	5 sensor configuration for ease of programming and data capture.
3	Simplicity, adjustability	Only 3 sensors, so more intensive on the algorithm side	Chassis is made to be lighter by altering the shape. Battery is placed underneath which lowers the centre of gravity

4.2 Design Metric

4.2.1 Design metric criteria selection

1. Modularity: The robot must be easily separated and/or assembled for it to be flexible to changes.
2. Sensor placement: The sensors must be placed in a way which allows for tracking the black line during straight paths, corners, junctions and the circular finish track. They should also be able to detect the line successfully from 5mm to 30mm above the line.
3. Stability: The robot must be able to stand ground and not tip over during turnings i.e. it should have a stable base.
4. Simplicity: The robot design must be easily understandable and should be aimed at the core functionality of being able to detect and follow the black line.
5. Cost: The required components for building the robot should be readily available and at a relatively reasonable cost.
6. Shape: The robot must not exceed dimensions of 150mm x 150mm x 100mm and should be designed to distribute the weight evenly on the chassis. It should be able to optimize space availability of the components.
7. Weight: The robot must have a relatively low weight to allow for ease of movement and low energy consumption.

4.2.2 Design metric

Table 3: Weighting of the different design categories

Category	**Design 1**	**Design 2**	**Design 3**
Modularity (20)	16	17	17
Sensor placement (20)	16	14	17
Stability (20)	18	14	16
Simplicity (10)	7	6	5
Cost (cheap – high score) (15)	9	8	11
Shape (5)	3	2	4
Weight (low - better) (10)	6	6	8
Total/100	**73**	**67**	**78**

5 Design selection

Improvements

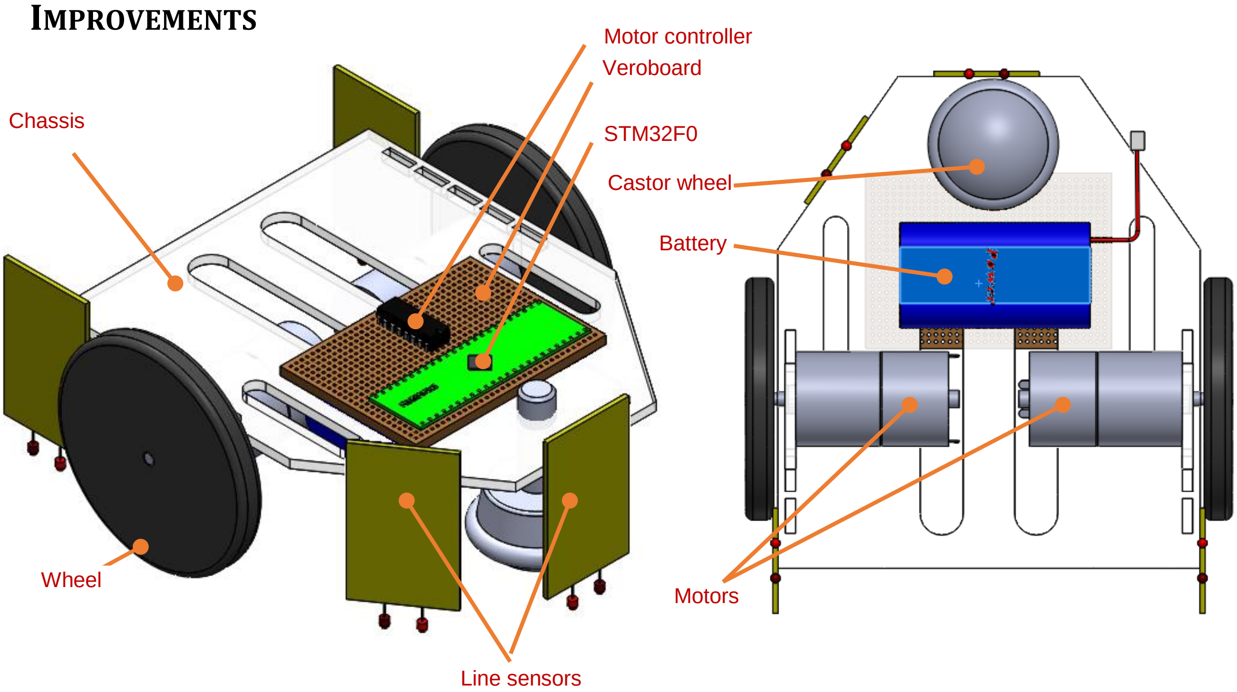

Figure 4: Final design

(Smaller components like resistors, capacitors, voltage regulators etc. are not included on the diagram)

Holes have been cut into the chassis in order to reduce weight and to allow wires to be passed from the underside to the top. It is also noted that there are now four sensors. The various components on the robot have also been thoughtfully placed to ensure better stability.

5.1 Final Design Description

The final design is an improvement upon the concept 3 design. The front right sensor will be primarily used to detect the circle. The back two sensors are responsible for detecting a turn and the front middle sensor is used to keep the robot on the line. The robot will also make use of two main wheels as well as a single caster wheel.

5.2 Final Component Layout

The final component layout consists of having the Veroboard with the voltage regulator, motor driver and STM on top of the robot. The battery, motors and caster wheel will all be on the underside of the robot. There will also be four sensors. Two on the back of the robot, one in the front in the centre and one slightly on the right in the front.

5.3 Final Component Requirement

Table 4: Components to be purchased from White lab

White Lab Component List					
Item #	**Purpose**	**Component**	**Reasoning**	**Characteristics**	**Distributer**
1	Sensor part	SFH205FA Photodiode	To be used to detect Infrared radiations of wavelength 900nm without much delay	120° viewing angle, 20ns response time, spectral range 800nm - 1100nm	White Lab
2	Sensor part	TSAL6100infrared LED	To transmit infrared radiation of wavelength 900nm using minimal power	940nm peak wavelength, 160mW, 100mA	White Lab
3	Sensor part	Red LED	To be used as an indicator to detect if the IR sensor detects black line or not. Has the lowest forward voltage drop in terms of RGY LEDs.	1.8V forward voltage drop, 60mW power dissipation	White Lab
4	Sensor part	Resistors	To provide resistance in the sensor circuit	1kΩ, 10kΩ etc resistances with 5% tolerance	White Lab
5	Sensor part	Trimmer potentiometer	Used for setting reference voltage at comparator's negative terminal	10kΩ resistance with 10% tolerance	White Lab
6	Decoupling	Ceramic Capacitor	Most of them to be used as decoupling capacitors	100nF capacitance with 10% tolerance	White Lab
7	To use as a circuit breaker	563-677 fuse	The motor has a rated current of 200mA, there is a possibility of the motor to rupture if current exceeds double the rated value	315mA current rating, 415.9mΩ resistance	White Lab
8	To indicate the start of the race	Push button	Must not delay when button is pressed	Contact bounce: max 5ms Contact resistance: max 100mΩ	White Lab
9	Oscillator for microcontroller	Crystal	Specifies the frequency range of the microcontroller	8 MHz crystal oscillator	White Lab

10	Voltage regulator	LM317 regulator	Be able to regulate voltage from around 8V to 3V3	Adjustable output voltage down to 1V2 with 1% tolerance, 1.5A output current	White Lab

Table 5: 3 sets of components to be purchased from RS Components

Set 1					
Item #	**Distributor**	**Manufacturer Part Number**	**Manufacturer**	**Description**	**Quantity**
1	RS Components	L293D	STMicroelectronics	Motor Driver ($I_{out(max)}$ = 0.6 A, Internal diodes)	3
2	RS Components	MCP601-I/P	Microchip	Opamp (rail to rail output)	5
3	RS Components	721-00019	Parallax Inc	Wheels	2
4	RS Components	30021330	ALWAYSE	Castor Wheel	1

Set 2					
Item #	**Distributor**	**Manufacturer Part Number**	**Manufacturer**	**Description**	**Quantity**
1	RS Components	A4973SB-T	Allegro Microsystems	Motor Driver (Single Full Bridge, Internal diodes)	3
2	RS Components	MCP602-I/P	Microchip	Opamp (as Set 1)	5
3	RS Components	721-00018	Parallax Inc	Wheels	2
4	RS Components	30021330	ALWAYSE	Castor Wheel	1

Set 3					
Item #	**Distributor**	**Manufacturer Part Number**	**Manufacturer**	**Description**	**Quantity**
1	RS Components	L293E	STMicroelectr onics	Motor Driver (Same as set 1, no internal diodes)	5
2	RS Components	MCP606-I/P	Microchip	Opamp (Same as previous sets)	5
3	RS Components	721-00019	Parallax Inc	Wheels	2
4	RS Components	30021330	ALWAYSE	Castor Wheel	1

6 CALCULATION

6.1 MASS BUDGET

Table 5: Mass of components

Item #	Description	Quantity	Mass (g)
1	Sensor + Veroboard	5	15
2	Microcontroller+ motor driver + Veroboard	1	30
3	Wheels	2	50
4	Chassis	1	49
5	Motors	2	160
6	Battery	1	46
7	Caster wheel	1	80
Total:			**430**

6.2 TORQUE, VELOCITY AND EFFICIENCY CALCULATION

First, the maximum torque provided by the motor (with no gearbox) was calculated as follows:

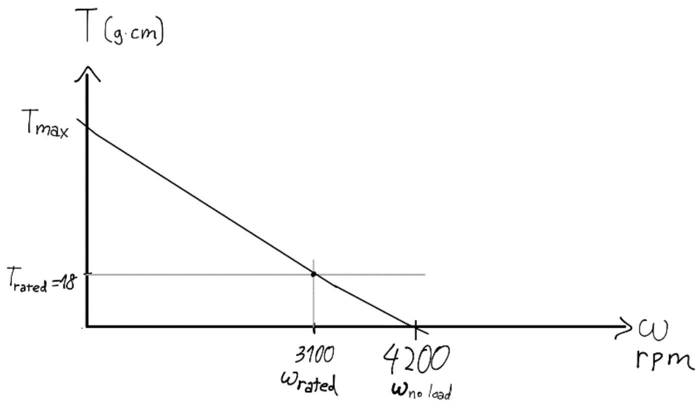

Figure 5: Torque/speed curve of motor with no gearbox

$$T_{motor\ max} = \frac{T_{rated} - T_{no\ load}}{\omega_{rated} - \omega_{no\ load}} \times \left(\omega_{@T_{max}} - \omega_{no\ load}\right) + T_{rated}$$

$$= \frac{18-0}{3100-4200} \times (0 - 4200) + 18$$

$$= 86.73\ g \cdot cm$$

$$T_{max} = T_{motor\ max} \times Reduction\ ratio = 86.73 \times 74.9 = 6496g.cm = 6.496kg.cm$$

The gear configuration inside the motor's gearbox was modified and, a reduction ratio of 74.9 was achieved. The maximum torque after going through the modified gearbox would then be:

$$\boldsymbol{\omega_{max} = \frac{\omega_{motor\ (no\ load)}}{Reduction\ Ratio} = \frac{4200}{74.9} = 56.1\ rpm}$$

This is the torque on the wheels when the car is at rest, with 100% duty cycle. On the other hand, the maximum angular speed would be:

For the robot to start moving, the net force on it should be greater than 0:

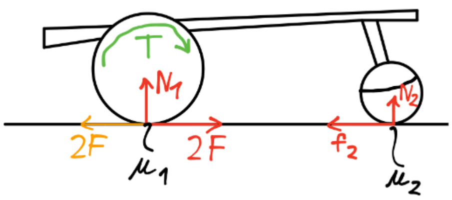

Figure 6: Force diagram of car

$$\Sigma F_x = ma = \frac{2T}{r} - f_1 > 0$$
$$ma = \frac{2T}{r} - (1-k)mg\mu_2 > 0$$
$$r < \frac{2T_{max}}{(1-k)mg\mu_2}$$
$$N_1 = kmg$$
$$N_2 = (1-k)mg$$
$$F = \frac{T_{max}}{r}$$
$$f_1 = (1-k)mg\mu_2$$

Where k is the fraction of mass supported by both motored wheels, μ_1 and μ_2 are the friction coefficients on the indicated surfaces, m is the estimated mass of the robot and r is the radius of the motored wheels.

If k is 0.6 (60% of weight at the back) and μ_2 is 0.4:

$$r < \frac{2 \times 6.496 \times 0.0989}{(1-0.6) \times 0.530 \times 9.81 \times 0.4}$$

$$r < 1.53\ m$$

The wheels are to be obtained from RS components (RS | world-leading distributor of electronic, industrial and maintenance, repair and operation products, n.d.), and they are 69mm in diameter, so the car will move. Even if μ_2 was 1.0, the radius would still be small enough. PWM will be used to regulate the starting torque, to ensure wheels do not slide.

With this wheel and the 56.1 rpm, the maximum speed will be:

$$V = \omega \times r = \left(56.1 \times \frac{\pi}{30}\right) \times \frac{0.069}{2} = 0.2027\ m.s^{-1} = 202.7\ cm.s^{-1}$$

7 REFERENCES

RS | world-leading distributor of electronic, industrial and maintenance, repair and operation products. (n.d.). Retrieved from Za.rs-online.com: https://za.rs-online.com/web/

Saddam. (n.d.). *Arduino Line Follower Robot Code and Circuit Diagram*. Retrieved from Circuitdigest.com: https://circuitdigest.com/microcontroller-projects/line-follower-robot-using-arduino