Imperial College of Science Technology and Medicine
Department of Electrical and Electronic Engineering
1st Year Electronics Laboratory
EEBUG Group Design Project

Report cover sheet

Please complete this cover page.
Save it to your PC, and then insert it as front page of your report.
Print the complete report as a pdf file, and check that the formatting has not been affected.
Finally, the **group secretary** must upload the pdf to Blackboard
(EE1-LABE EEE 1st Year Electronics Lab (2015-2016)/ Group Design Project assessments)

Tutor	Dr S Wright
Design Group *(tutor's initials, followed by group number)*	SWW - 2B
Report type	Stage 1
Submission date	Thursday, 17 December 2015

Checklist (see labweb for guidance)	Yes / No
Is the document within the word limit? Word count 2933 (max 3000) No of figures 8 (Max 8)	☒ / ☐
Are all figures and graphs clear and complete?	☒ / ☐
Have you made a full list of references?	☒ / ☐
Have you included all relevant diagrams?	☒ / ☐
(Stage 2 only) Have you included your component order form?	☐ / ☐
Have you read and understood the college plagiarism statement?	☒ / ☐

Plagiarism statement *"I certify that this report is our own original work, and that any other sources are fully acknowledged"*	*Group leader logon (eg xyz15)* *kbh15*

LATE SUBMISSION *The Department's publicised policy is that coursework submitted after the deadline automatically fails.* *However, if there are genuine extenuating circumstances which make it impossible to submit on time, please explain.*	*Reasons for late submission:*

Management

1. Structure

The team consists of 3 members. Koral Hassan is the Group Leader. Marek Hilton is the Treasurer. Hao Hao is the Secretary.

The Group Leader is in charge of scheduling group meetings, setting up and maintaining communication mediums, helping to identify and resolve personnel or red flag issues. It is his responsibility to assign work packages, ensure deadlines are met and objectives are accomplished.

The Treasurer is in charge of budgeting and accounting for all costs, so that the limit of £8 per bug is not exceeded. He will be making the final draft of which components should be bought for the initial prototype. Because of this, he will be highly involved in the designing stage. After testing the testing stage, he will be minimizing the costs of the team spent on improvements.

The Secretary will be the person keeping track of all progress up to date and future plans. He will have a record of all the documents and store them in an organized fashion. He will be the person that records the overall progress of the team. This will include him making summaries of topics discussed in meetings and the tasks set for the next week (minutes).

2. Communications

The group meets up weekly – usually on Wednesdays at 9 am for an hour – to discuss the progress of past week, decide on the deliverables and tasks of the next week. During these meetings a synopsis of contents is written.

The group has Facebook chat used to arrange the date, time, location and duration of these weekly meetings. It is also used to deliver urgent information of interest since everyone is instantly notified of all messages sent to this chat.

Slack is used for all files shared within the group as the platform is very versatile, making it convenient to share all documents across.

3. Project Plan

3.1 Progress to Date

25th of November

Discussed “Analog vs Digital” for our bug. We decided to make an analog bug since:

- It implies less competition.
- There will be no coding involved which might have demanded learning a new programming language.
- It is an appealing intellectual challenge.
- It is expected to cost less money comparatively.

The major disadvantage of this choice was agreed to be the fact that it will not be as easy to modify the bug during testing and improvement stages.

The group agreed to each member collecting data on their own bug and preparing the data for the next meeting. Next week limitations would be defined based on these data and the description of the mission of the bug.

2nd of December

All the data collected was brought to the meeting. Limitations were discussed. The Secretary was tasked with the task of comparing the different bug types for their advantages and disadvantages. The Treasurer was tasked with expanding on the topic of enhancements for next week. The Group Leader was tasked with creating a rough timeline for the project.

9th of December:

The rough drafts of the tasks from the last meeting were discussed. The Secretary had also run simulations on the different types of bugs to obtain additional data and proof check the current data. Another meeting was scheduled for Friday at 1 pm before the client meeting to discuss the drafts again after improvements.

3.2 Future Plans

11th of December – 18th of December

Finish final draft of the Management Report. 18th of December is the deadline for the Secretary to submit the Management Report on Blackboard.

MILESTONE: SUBMISSION OF MANAGEMENT REPORT (18.12.2015)

11th of January – 18th of January

Finish high level design for the first prototype of the bug. Decide on all general modifications that need to be made on the bug.

18th of January – 1st of February

Finish low level design for the first prototype of the bug. Design all the circuitry for each function.

1st of February – 8th of February

Choose all the components that will be bought. Calculate costs. All deliveries should arrive within this span of time if components are ordered online.

8th of February – 15th of February

Build first prototype of the bug.

MILESTONE: FIRST BUG PROTOTYPE BUILT (15.02.2016)

15th of February – 22nd of February

The product design video "Pimp My Bug" will be edited and finalized.

22nd of February – 7th of March

These two weeks will be dedicated to testing and improvement of the bug. New components will be ordered and the circuit will be redesigned if the need arises.

MILESTONE: DESIGN FINALISED

7th of March – 14th of March

The final draft of the "Design Report Part 1: Process" will be written up.

14th of March – 23rd of March

The final draft of the "Design Report Part 2: Outcomes" will be written up. Both parts of the Design Report will be submitted on Blackboard by the Secretary by the 23rd of March, which is the deadline.

MILESTONE: DESIGN REPORT SUBMITTED

23rd of April onwards

There will be an individual viva voce on the 17th of May. Each member of the group will be marked based on oral and demonstration of the individual enhanced bug.

4. Conclusion

All tasks mentioned in future plans will be delegated as sub-tasks between the 3 members of the team as equally as possible. To ensure deadlines are met and that everything is going smoothly the weekly meetings will continue to be held.

Analysis

1. Analysis of original bug functions and circuits

1.1 Overview of bug functions

The bug consists three main parts: sensors, control circuit and motors. The sensors generate inputs signals according to the radiant intensity. The control circuit receives the inputs from the sensors and generates the corresponding output signals which are voltages applied on each motor. Thus the movement of the bug can be controlled.

1.2 Original bug control circuits

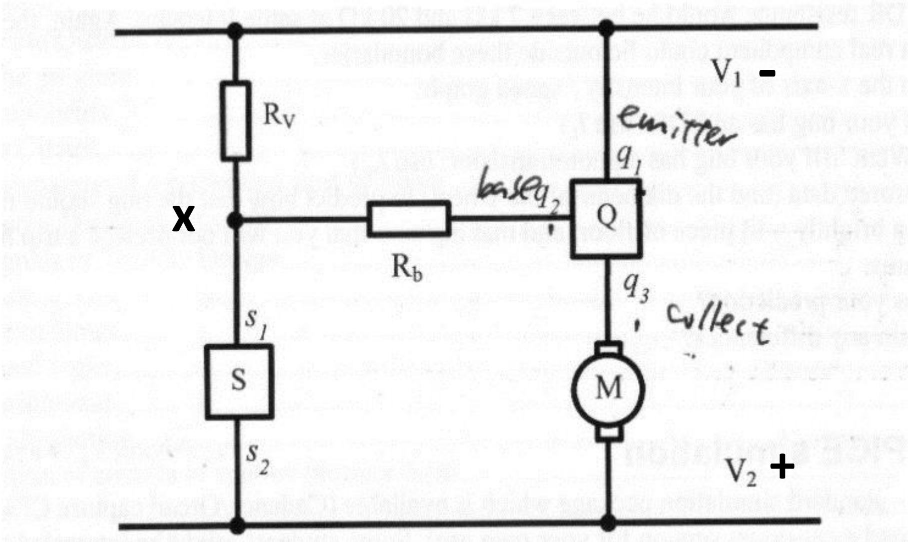

Figure 1-1: A simplified version of the (right-hand) control circuit

M represents the motor;

S represents the sensor;

Q represents the transistor;

R_V is a potentiometer and a 100Ω resistor, shown as a single component;

R_S represents the resistance of the sensor.

Depending on the type of the bug, the sensors and the transistors used in the circuit vary.

1.3 Analysing the circuit of the original bug

Method: KCL

The circuit can be analysed by using KCL and **node X**:

I_S = the current through the sensor, S; (Flows into node A16)

I_V = the current through R_V; (Flows out of node A16)

I_b = the current through the base of the transistor. (Flows out of node A16)

According to KCL:

$$(-I_S) + I_V + I_b = 0$$

$$I_S = I_V + I_b$$

According to the measurements of bug A, B and C:

For LDR: (Type A&B)

The resistance of the LDR decreases as the radiant intensity increases.

For Phototransistor: (Type C)

The collector current, I_C and the emitter current, I_e both increase as the radiant intensity increases.

Conclusion:

For bug type A, B and C:

As the radiant intensity increases, so will **Is**, leading to an increase in I_b, above some threshold value, this will lead to an increase in the current supplied to the motor, enabling the motor to start running.

2. Comparison of measured data with simulation/analysis

2.1 Experimental data

L /cm			1/L2 /cm-2			Radiant Intensity /LUX			V+ /V			Vb /V			Vmotor /V			Motor Speed /rpm		
A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Column	Column1	column3	Column16	Column17	Column18	Column19	Column20	Column21	column7	colume8	Column9	Column10	Column11	Column12	Column13	Column14	Column15	column4	column5	Column6
5.0		8.5	0.040		0.014	408		141	5.92		6.00	0.68		1.31	5.60		5.13	9576		8640
5.1		9.0	0.038		0.012	387		125	5.92		5.90	0.67		1.30	5.50		5.12	9576		9360
5.2		9.5	0.037		0.011	377		113	5.91		5.90	0.65		1.28	5.20		4.80	9000		9360
5.3	5.3	9.7	0.036	0.036	0.011	367	367	108	5.90	6.10	5.90	0.63	0.68	1.27	5.00	5.00	4.60	9000	9630	7920
5.4	5.4	9.8	0.034	0.034	0.010	347	347	106	5.90	6.10	5.90	0.60	0.67	1.26	4.90	4.50	4.50	9000	9360	7920
5.5	5.5	10.0	0.033	0.033	0.010	336	336	102	5.90	6.10	5.88	0.57	0.66	1.26	4.70	4.10	4.00	8496	8640	7200
5.6	5.6	10.2	0.032	0.032	0.010	326	326	98	5.90	6.10	5.86	0.55	0.65	1.25	4.50	3.40	4.20	7992	7200	6984
5.7	5.7	10.4	0.031	0.031	0.009	316	316	94	5.90	6.10	5.86	0.52	0.63	1.22	4.10	2.50	3.50	7200	6048	6480
5.8	5.8	10.6	0.030	0.030	0.009	306	306	91	5.89	6.10	5.86	0.51	0.62	1.22	3.80	1.50	3.00	7200	5400	5544
5.9	5.9	10.8	0.029	0.029	0.009	296	296	88	5.89	6.10	5.86	0.48	0.61	1.22	3.50	0.19	2.80	6552	4536	3816
6.0	6.0	11.0	0.028	0.028	0.008	285	285	85	5.88	6.20	5.84	0.45	0.61	1.21	3.20	0.11	1.90	5760	3960	3816
6.1		11.2	0.027		0.008	275		82	5.88		5.80	0.44		1.19	3.00		1.80	5112		2880
6.2			0.026			265			5.87			0.42			2.80			4824		
6.3			0.025			255			5.87			0.40			2.60			3960		
6.4			0.024			245			5.87			0.38			2.40			3240		

	Type A	Type B	Type C
Potential setting/kΩ	0.37	1.2	0.56

(**Table 1-1** shows the measured data for Bug A, B and C)

2.2 V_{motor}—Radiant Intensity Characteristics

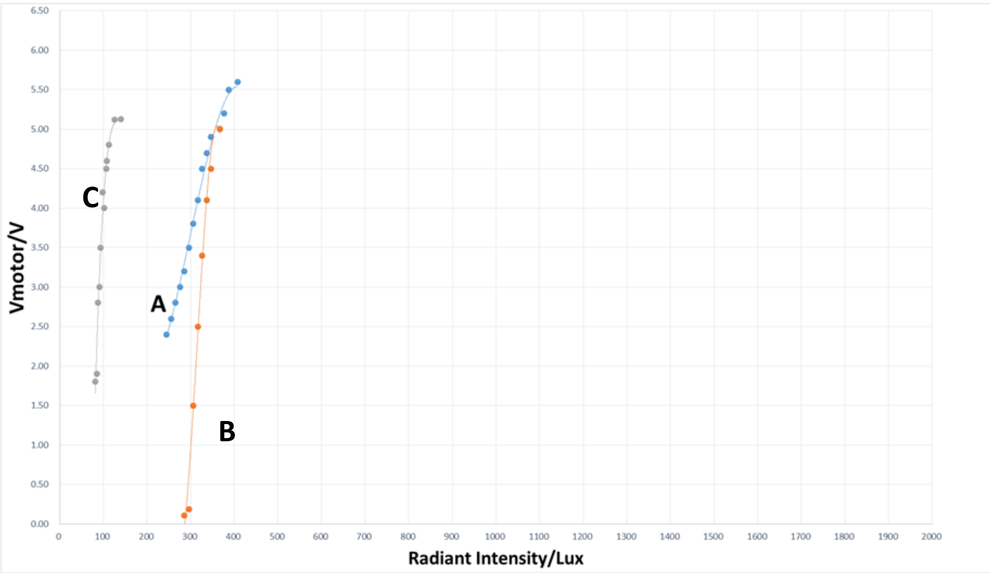

Figure 2-1: The V_{motor}--Radiant intensity graph obtain from the experimental data

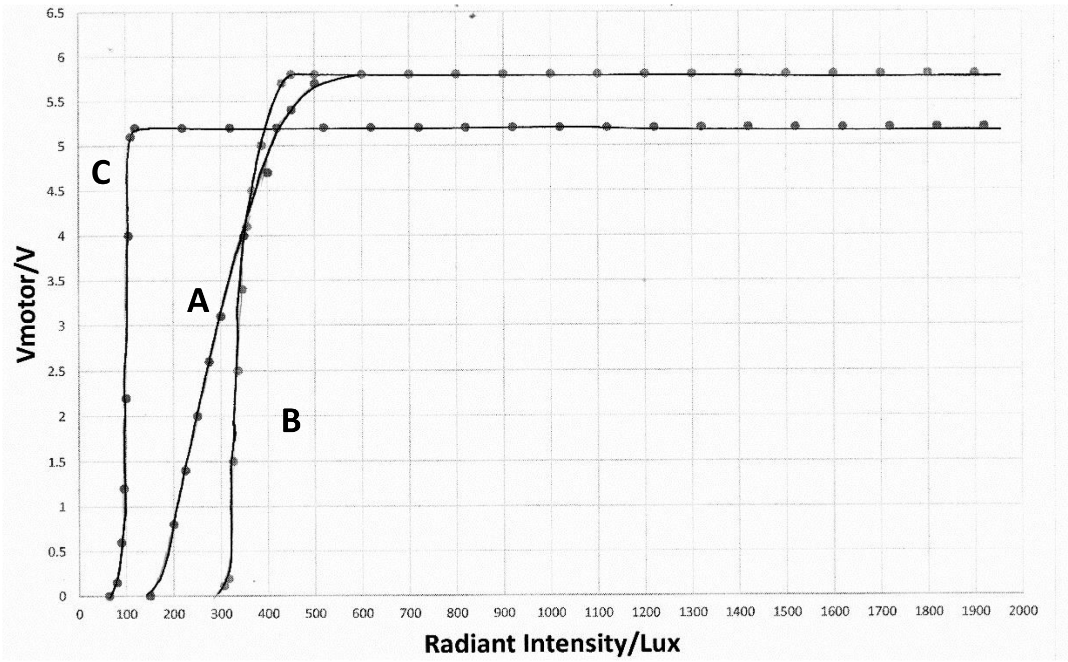

Figure 2-2: The Vmotor--Radiant intensity graph obtain from the PSPICE simulation

By comparison, the experimental data agrees with the PSPICE simulations and shows the correct characteristics which are: **Vmotor begins to increase from zero when the radiant intensity is above a certain threshold value, then Vmotor reaches its maximum value after the radiant intensity reaches some saturation value.**

2.3 Bipolar Transistor

Vb is the emitter-base voltage of the transistors used in the control circuits which is a vital parameter of the control circuits.

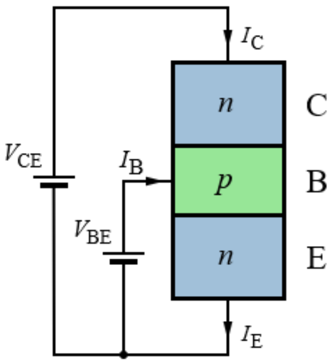

Figure 3-1: The structure of a NPN bipolar transistor

The bipolar transistor can be viewed as a **voltage-dependent current source**. In the bug circuit, the transistor functions as an amplifier than amplifies I_B and produces large I_C and I_E:

$$I_C = \beta I_B$$

$$I_E = (\beta+1)*I_B$$ (**β** is the **current gain**, the **β** of *npn* transistors typically range from 50 to 200)

The equation shows that as **Vb** increases, so will I_B, leading to increases in I_E and I_C, also **Figure 2** shows that the motor is connected in series with the collector on the transistor, hence we have:

$$I_{motor} = I_C$$

The following conclusions can be made,

- An increase in Vb will lead to an increase in the current through the motor, I_{motor};

- From the data sheets of transistor BC337 and BC517, there is also a maximum value for Vb (Vb saturation).

From the experiments

	Vb threshold/V	**Vb saturation/V**
Type A	0.37	0.68
Type B	0.37	0.69
Type C	1.17	1.40

From measured data

	Vb saturation/V
BC337(used in Type A and B)	0.70
BC517(used in Type C)	1.40

(**Table 2-1:** Comparison of saturation voltages between experimental and simulation data)

By comparison, the experimental data of **Vb** saturation for three types of bugs is approximately the same as the data obtain from the data sheet.

3. Pros & Cons of Different Circuit Types (A, B and C)

3.1 Comparisons of the experimental data between bug type A, B, and C

	Type A	Type B	Type C
Transistor, Q (connected to A5, E13 and X23)	NPN-Transistor BC337	NPN-Transistor BC337	NPN Darlington BC517
Sensor, S (connected to w23 and A16)	LDR GL5528	Phototransistor SFH300 3/4	LDR GL5528

Illumination /LUX			Vmotor /V			Motor Speed /rpm		
A	B	C	A	B	C	A	B	C
408		141	5.60		5.13	9576		8640
387		125	5.50		5.12	9576		9360
377	377	113	5.20		4.80	9000		9360
367	367	108	5.00	5.00	4.60	9000	9630	7920
347	347	106	4.90	4.50	4.50	9000	9360	7920
336	336	102	4.70	4.10	4.00	8496	8640	7200
326	326	98	4.50	3.40	4.20	7992	7200	6984
316	316	94	4.10	2.50	3.50	7200	6048	6480
306	306	91	3.80	1.50	3.00	7200	5400	5544
296	296	88	3.50	0.19	2.80	6552	4536	3816
285	285	85	3.20	0.11	1.90	5760	3960	3816
275		82	3.00		1.80	5112		2880
265			2.80			4824		
255			2.60			3960		
245			2.40			3240		

(**Table 3-1** show the experimental data focusing on the Vmotor and Smotor under different radiant intensity)

3.2.1 Type A vs Type B (LDR vs Phototransistor)

The sensitivity can be measured as the rate of change $\mathbf{V_{motor}}$ over radiant intensity.

When the radiant intensity of bug Type A and Type B both increased from 285 to 367 Lux, the **Vmotor** of Type A increased 3.2 to 5.0 V over a range of 1.8V, whereas the **Vmotor** of type B increased from 0.11 to 5V over a larger range which is 4.89V, showing the rate of change of **Vmotor** in response to changing radiant intensity of Type B is larger than that of type A. Hence a conclusion can be drawn that the bug type B has a better sensitivity than type A; **SFH 300 3/4 Phototransistor is a more sensitive light sensor than GL5528 LDR.**

3.2.2 Type A vs Type C (NPN vs NPN Darlington)

Comparing the **Vmoto**r and the radiant intensity data for A and C, the motor on the type A started running at a radiant intensity of 245Lux, whereas the threshold radiant intensity for type B is lower which is 82Lux; also for type A **Vb** and **Vmotor** reached their maximum values at 408Lux, while for type B the intensity for the maximum **Vb** and **Vmotor** is 141Lux. Overall, the type B works with a lower radiant intensity than type A. The conclusion is that **BC517 enables the bug to function under lower radiant intensity than BC337 does.**

The combination of BC517 transistor and SFH 300 3/4 phototransistor is the most preferable, which provides high sensitivity and enable the motor to function at low radiant intensity.

Enhancement

1. Sensor Location

The location of the sensors (maximum two) is very important since it dictates the whole design approach. Two design choices need to be made, namely whether the sensors should be grouped in a pair and at which point on the EEbug chassis they should be mounted.

1.1 Paired sensors

This is the simplest configuration for the sensors consisting of a pair of sensors, one on either edge of the track. These can either be arranged to sit within or without the boundary, the only difference being that a change in state will be triggered by a sensor moving from white to black in **Figure 1-1** left and from black to white on the right.

***Figure 1-1**: Two implementations of paired sensors on a grey scale track*

When the sensing unit strays off the track one sensor will change state indicating whether the bug is straying off the track to the left or right. This information can be used to correct the speed of the motors and bring the bug back on course. For example, using the implementation on the left in **Figure 1-1**, if the direction the bug was pointing was not parallel to the track but pointing slightly off to the left then the sensor on the right would change state due to moving from white to black. This is illustrated in **Figure 1-2**.

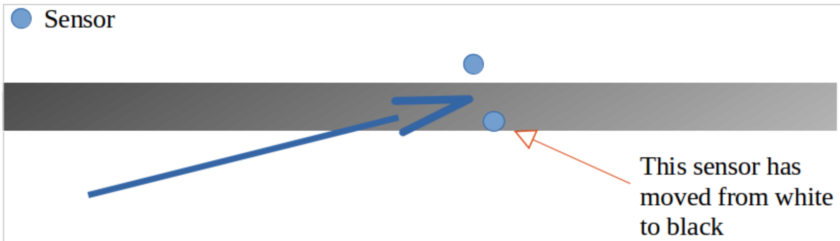

Figure 1-2*: Illustration of the sensor changing state due to Eebug straying off the track. The blue arrow indicates the direction the bug is facing*

This design has the advantage of having a relatively simple sensing circuit and also requires less modifications to EEbug chassis, since the chassis already has two terminals at the front two mount sensors.

This said, it may be more advantageous to mount the sensor pair on the rear of the bug and to drive it in reverse. This would create a larger displacement between the wheel axle and the sensors. The result would be that a small change in the direction the bug points would result in a much larger movement of the sensors. However this would require greater attention to designing the motor control circuit so that it won't overshoot the line before the change in state of the sensors can alter the speed of the motors. Another issue maybe that the pen will not accurately trace the track.

When trying to determine whether the track has ended or not the arrangement with both sensors inside the track (**Figure 1-1 (R)**) is preferable as the end of the track can be determined by both sensors coming to a the same 'white' value.

As recommended by the EEbug design comparison, the SFH 300 ¾ photo transistor would be preferable in this setup due to its high sensitivity.

1.2 Single sensor solution

Perhaps another more interesting approach would be to use a single sensor to follow the line. There are a couple of ways his could be achieved. First would be to mount the sensor close to the wheel axle centre. Since the sensor system would only be capable measuring changes in colour the bug would have to constantly turn left and right to intersect the line. As it crosses the line on a left turn it would then have to turn right in an attempt to re-intersect the line. The opposite would happen on a right turn. This could probably be implemented using flip-flop to toggle between a right turning and left turning state.

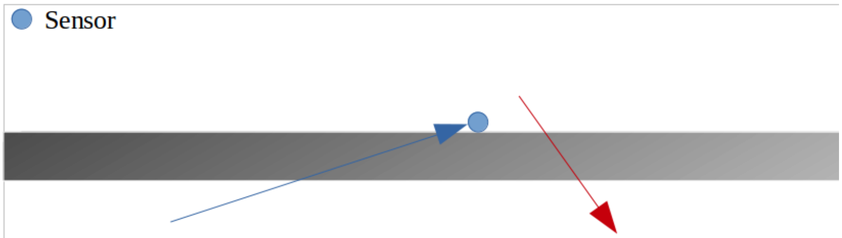

Figure 2-1: *Single sensor implementation moving into a right turn*

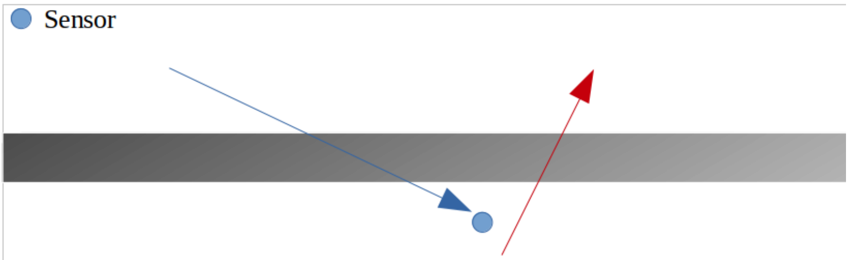

Figure 2-2: *Single sensor implementation moving into a left turn*

The advantage of this design is that it frees up another sensor to be used elsewhere. This could be for a variety of purposes. For example, the single sensor could be doubled up to increase redundancy. If one were to malfunction, another would still be working to take its place. Alternatively the spare sensor could be used to compare the white and greyscale track indicating when the bug has reached the end of the track. A disadvantage of this design would be it is liable to veer off when it reaches the end of the track, since it will still be turning. It also should be noted that a photo-transistor is more preferable for this design since its arc of sensing*[insert citation to GTA and client meeting] would allow the sensor to transition quicker when the bug crosses the line thus reducing the zig zag the robot will follow with his design.

1.3 Scanning from a stationary position

Another permutation on this design would be to make the bug 'scan' from a stationary position and then decide to move on when it has refound the line. Since the EEbug is two wheeled it can almost spin on the spot. The bug could turn on the spot to either side and find the line before moving on. In this manner, if it has reached the end of the line, it would not overshoot or veer off but would detect no line. This would also prove effective in avoiding running across the black border and off the 'pitch'.

2. Minimising reflective effects of polycarbonate and ambient light interference

A light source of some kind, most probably LED, will be required to illuminate the track for the sensors on board. However the polycarbonate covering of the track will most like reflect significant amounts this light. It is therefore essential to carry out some tests on the reflective and transparency qualities of the polycarbonate to find the ideal light source.

Varying ambient light conditions also have to be reckoned with. To this end the use of a cowling over each sensor and their independent light source would be useful in negating any interference.

3. Superbug proposals

The superbug features will be the major factor setting our bug apart from the others and guaranteeing a win.

The following are current ideas being considered as enhancements:

- Bug capable of doing a wheelie

- Radio to play a radio station as it moves. This is allowed if we use only one sensor, thus freeing one up to be occupied as an antenna.

Conclusion

Plan for next term

The tasks at the beginning of the next term will comprise three main stages, testing of components; design of the prototype; determining the budget of the prototype. This will culminate in the production of the first prototype for testing. To this end over the Christmas break the Secretary will research LEDs, phototransistors and polycarbonate properties. The Team Leader and Treasurer will expand further on the initial design ideas for the control circuit.

Reference

Razavi, B. (2008). *Fundamentals of microelectronics*. Hoboken, NJ: Wiley, pp.128-129.

Structure and use of NPN transistor. (2015). [image] Available at: https://upload.wikimedia.org/wikipedia/commons/4/49/NPN_BJT_-_Structure_%26_circuit.svg [Accessed 10 Dec. 2015].

Client meeting. (11-12-2015). Mr Dip Chakravorty