Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 01, January-2016

A Simple Analog Line Tracer for Mechatronics Education

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***Abstract*—This paper introduces a simple analog line tracing robot which has been used as a design project for an introductory mechatronics course in mechanical engineering. Our line tracing robot is composed of optical sensors, operational amplifiers and transistors, with no microcontrollers. We have found that a design and development of such a line tracer could provide students fundamental ideas and concepts for a mechatronics system design.**

***Keywords*— Liner Tracer, Automatic Guidance Vehicle, Mobile Robot**

I. INTRODUCTION

Mechatronics is a multidisciplinary filed. Most departments and schools in the field of mechanical engineering provide mechatronics-related courses including elementary electrical circuit theory and automatic control. Mechatronics however remains as a nonmainstream subject in a standard curriculum of a mechanical engineering. Indeed mechatronics is a highly multidisciplinary subject and is composed of various topics from diverse fields of engineering. As a result of this, it is a challenging task to make students in mechanical engineering courses learn even basic knowledge of diverse topics in the field of mechatronics.

It is our experience that students in a mechanical engineering school are overwhelmed by the *mechanical* part of mechatronics such as solid mechanics, thermodynamics, dynamics and fluid mechanics. As a consequence of this, many mechanical engineering students often underestimate the importance of the *electronics* part of the mechatronics. For a better balance in mechatronics education, it is very important to provide those students strong motivations for learning the electronics engineering within a limited curriculum.

The *Introduction to Mechatronics* course in our department consists of 2 hours' lecture and 2 hours' laboratory experiment per a week for 15 weeks. Most attendees of this course are second year students majoring mechanical engineering. A key aim of this course is to make those mechanical engineering students understand fundamental concepts and knowledge in electrical / electronic engineering.

In our mechatronics course, the following topics are dealt for 26 hours' lecture (4 hours are reserved for evaluations);

- DC circuit theory (6 hours)
- AC circuit theory (2 hours)
- Diode and transistor (4 hours)
- Operational amplifier (2 hours)
- Sensors and actuators (2 hours)
- Digital logics and circuit (4 hours)
- Mechatronics system design (4 hours)

For the last *Mechatronics system design*, students make a simple analog line tracer which will be explained in this paper.

II. LINE TRACER DESIGHN

A. Overview

Fig. 1 shows a photo of our analog line tracing robot. The electronic components of our line tracer include four photo sensors, two operational amplifier, two Darlington transistors and a set of resistors.

Mechanical parts include two small geared DC motors with plastic wheels, a ball caster under the body and a frame which is an aluminium plate with 1mm thickness. The overall size is about 13 cm x 12 cm x 3 cm.

Both mechanical and electronic parts used for our line tracer are summarized in Table 1.

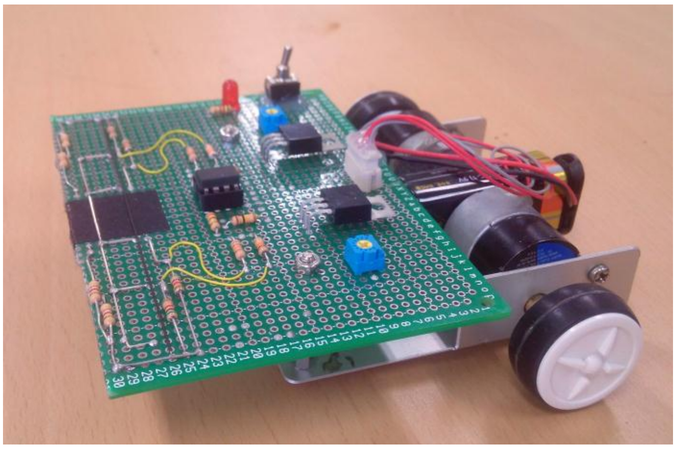

Figure 1 Photo of line tracer

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TABLE I. COMPONENTS SPECIFICATIONS

Mechanical Parts	Body	Aluminum Plate 75 mm x 89 mm Thickness 1mm
	Ball Caster	12 mm metal ball outer diameter 13 mm ball diameter 11.86 mm
	Wheel	Plastic & Lubber Diameter 26mm Width 11 mm
	Geared Motor	nominal voltage 4.5 V no-load speed 580 rpm nominal torque 50 gcm mass 60 g
Electronic Parts	Infrared LED	SI5315 (x4)
	Photo Transistor	ST5811 (x4)
	Operational amplifier	LM358 (x2)
	Darlington transistor	TIP102 (x2)
	Power RED	Red (x1)
	Trimmer	20k (x2)
	Power switch	Two ways, toggle
	PCB	Double sided 11.4mm x 8.0 mm
	Battery	9V alkaline
	PCB stand	Height 25 mm 3.0 mm female

B. *Sensor Design*

The line-sensing optical sensors of our line trancer is composed of four pairs of infrared LED's (SI5315) and photo transistors (ST5811) from AUK Semiconductors© [1]. A photo of sensors is shown in Fig. 2.

After optical sensors were constructed, the sensor data were measured while changing the gap between the line to follow and the center of the car, as shown in Fig. 3. This gave the sensor output data in Fig. 4.

It is clear from Fig. 4 that the outputs of sensors S3 and S4 (see Fig. 3 for our sensor labels) change slightly compared to those of sensors S1 and S2, when the car has a positive (the left direction in Fig. 3) offset.

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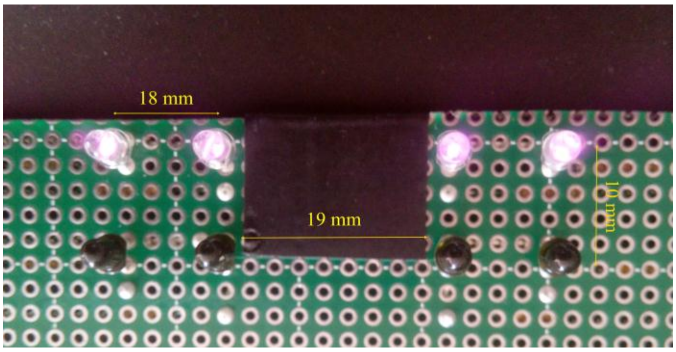

Figure 2 Line Sensor Configuration

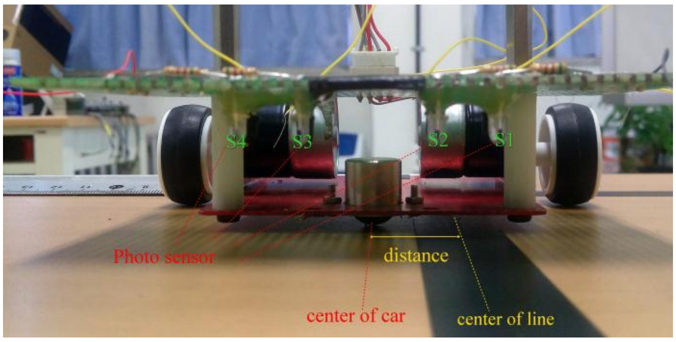

Figure 3 Sensor Experiment

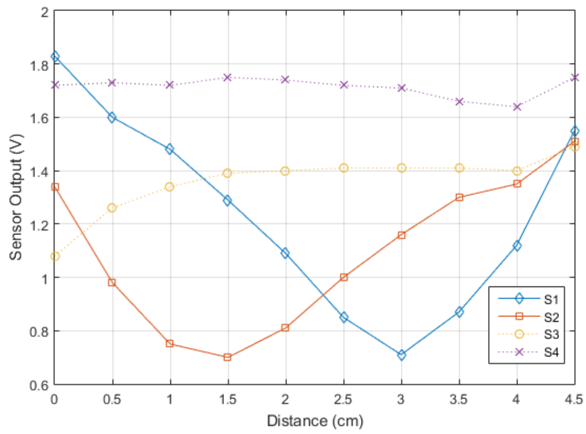

Figure 4 Sensor Output

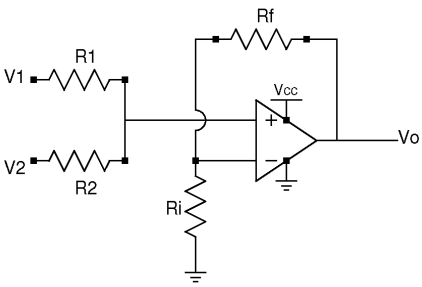

Figure 5 A Non-inverting summing circuit.

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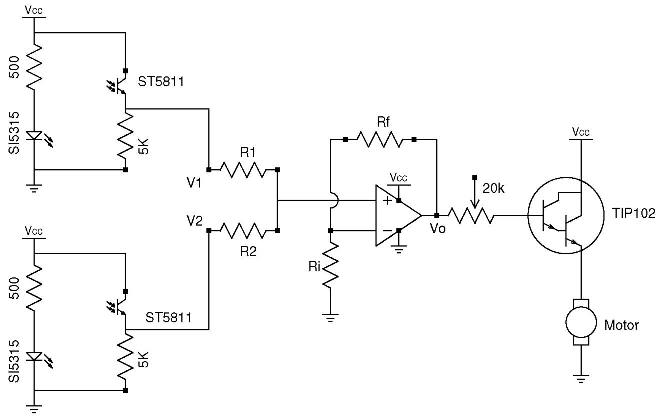

Figure 6 Circuit of Line Tracer (one side)

The line tracking error is represented by a voltage signal $V_{left} = V_{left}(S1, S2)$ given by

$$V_{left} = \alpha \cdot S1(d) + \beta \cdot S2(d) \qquad (1)$$

for some constants (α, β) to be chosen and the distance (tracking error) variable d. The constants (α, β) were chosen from two considerations. First, the function $V_{left}(d)$ should be close to a linear function of the distance variable *d* for a wide offset range. This is because our line tracing robot is implicitly equipped with a proportional control law for performing a line-following motion. Second, as the voltage V_{left} will be served as a base voltage of a Darlington transistor which will derive a motor, the magnitude of V_{left} should be in an appropriate voltage range.

The relation (1) can be implemented with a non-inverting weighted summing circuit with an OP Amp (Operational amplifier) shown in Fig. 5.

An elementary analysis of the OP Amp circuit in Fig. 5 can show that the output is given by

$$V_o = \left(1 + \frac{R_f}{R_i}\right) \frac{R_2\, V_1 + R_1\, V_2}{R_1 + R_2} \qquad (2)$$

With the following resistors;

$$R_1 = 22k\Omega,\ R_2 = 27\ k\Omega,$$
$$R_i = 100k\Omega,\ R_o = 200k\Omega,$$

and a LM358 OP Amp from *Texas Instrument* [3], we have implemented the relation (1) as

$$V_{left} = 3\ (0.53 \cdot\ S1 + 0.47 \cdot S2) \qquad (3)$$

C. Motor Driver

The motors of our line tracing robot were derived by NPN Darlington transistors TIP102 from Fairchild semiconductors© [2]. Two sensor outputs V_{left} in (3) and V_{right} (which was designed with sensor outputs {S3,S4} in a similar way) were sent to the base terminals of two transistors via trimmers (variable resistors) of 20 kΩ.

The overall circuit diagram of our line tracer is given in Fig. 6 in which a power switch and a LED in Fig. 1 are omitted for simplicity.

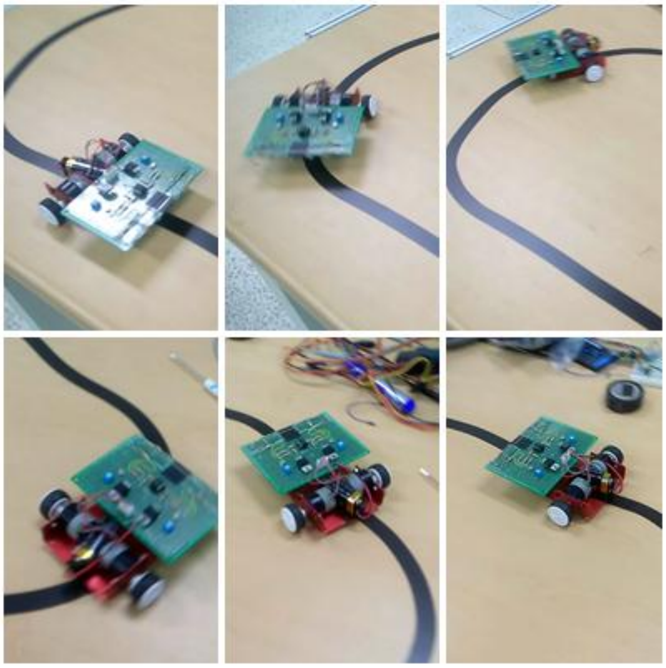

Figure 7 Line-tracing Experiment

D. Tunning

A standard procedure for tuning a line-tracer is as follows. Firstly, left and right trimmers should be tuned such a way that the car can slowly run in a straight line on a table with no lines marked. After that, in most cases, the car is ready to follow a black (dark) line on a yellow (bright) table. If a line-following motion works slowly then by tuning trimers again the speed of car can be increased.

If a table is darker than the colour of lines, then our line tracer can still work by swapping two voltages V_{left} and V_{right}, without any additional changes.

Fig. 7 gives snapshots of a successful line following motion.

III. Conclusion

In this paper we introduced a simple analog line-tracing robot which has been used as a design project topic in our *Introduction to mechatronics* course. Over last ten years, we have observed that students who do not have enough knowledge and backgrounds for handling micro-controller based mobile robots, really enjoy this design project and that they are highly motivated to learn additional knowledge and ideas in a mechatronics system design.

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