Light Sensors for Solar Trackers

J. Rizk, A. Hellany, M. Nagrial

Abstract— The aim of this paper is to present a way in which the efficiency of solar power collection can be increased. It is to increase the efficiency of solar power conversion by increasing the amount of time that the solar panel is directly perpendicular to the sunlight. Efficiency is based on accurately positioning the solar panel throughout the day and thus stepper motors and Light Dependent Resistors (LDR) have been selected as the primary driving mechanism of this system.

***Keywords*— Solar Trackers, Solar Energy**.

I. Introduction

THE Global warming has increased the demand and request for green energy produced by renewable sources - like solar power. The solar cell market has to be as efficient as possible in order not to lose market shares on the global energy marketplace. There are two main ways to make the solar cells more efficient, either by improving the actual cell or by installing the solar panels on a tracking system that follows the sun.

The end-user will prefer the tracking solution rather than a fixed ground system because:

- The efficiency increases by 30-40% (= more money)
- The space requirement for a solar park is reduced, and they keep the same output
- The return of the investment timeline is reduced
- The tracking system amortises itself within 4 years (on average)

Tracking the sun from east in the morning to west in the evening will increase the efficiency of the solar panel by 20-62% depending on where you are in the world. Near the equator, you will have the highest benefit of tracking the sun.
For this manner, a tracking system is needed. Our aim is to offer a complete linear actuator system that moves the tracking base according to the sun. Our goal in this project is to catch the sunlight and increase the output of the solar panel.
Solar tracking is the process of varying the angle of solar panels and collectors to take advantage of the full amount of the sun's energy. This is done by rotating panels to be perpendicular to the sun's angle of incidence. Initial tests in industry suggest that this process can increase the efficiency of a solar power system by up to 50%. The increases are found to be more significant in the early morning and evening daylight hours.
Solar Trackers make use of an optical sensing system to track the sun's position. Typically the sun sensors are mounted on the controller base or around the panel itself, they are used to feed information regarding the amount of sunlight. This information is a form of analogue to digital conversion, this digital representation of sunlight information is fed into the control circuitry. As the system is operating in a closed loop state, the amount of sunlight is used to continuously monitor the position of the sun.
Based on this information, the controller seeks to equalize the sunlight received by opposing sensors for each axis. The controller circuitry automatically adjusts the tracker sensitivity accordingly. It increases the sensitivity with increased direct sunlight; and decreases the sensitivity with scattered or diffused light as in cloudy conditions. This enables the tracker to eliminate undue hunting in cloudy or overcast conditions when the sunlight is scattered.
A solar tracker also makes adjustments according to the total amount of light received by the sensors. Since it knows how much light is available, it enables the controller to rotate the panel so that both sensors return to an equal voltage state. This state signifies that the panel would be at the most perpendicular position to the sun.

II. THE POSITIONNING SYSTEM.

The tracker controller sends a signal to the motor which moves the photovoltaic array to a perpendicular position relative to the sun's rays. The motors are small, low horse power and low voltage which move the tracker to the correct position.
The motor that is used for the solar tracker positioning system can be either a DC stepper motor or a Brushed DC motor. There are advantages and disadvantages to using either motor, and these shall be explained in greater detail later on in this report.

When the controller wants the tracker to move, it sends a signal of the appropriate polarity to the DC motor. Once the tracker has moved to the "on track" position as determined by the controller, the controller electrically "breaks" the motor to stop movement which results in greater tracking accuracy. The extreme most positions of the tracker movement are set by internal or external limit switches. When a limit switch is activated, say for example full East position, the motor will be disabled from moving further East and can only move to the West when the controller sends a signal. Figure 1 shows the proposed design for a solar panel.

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Figure 1: Turning the panel in two directions

III. STEPPER MOTOR DRIVE CIRCUIT

The stepper motor drive circuit is based on simple and inexpensive electronics components and a low powered unipolar 5 wire, 2 phase stepper motor.

The stepper motor driver which is described below has been designed for low end application that does not require precision driving and high speed uses. The stepper motors that are compatible would be those that draw up to 1 Amperes per phase.

This stepper motor driver is able to supply basic control functions: forward, reverse and stop. The driver circuit also has a predetermined and calculated step rate adjustment range from 0.72 to 145 steps per second, although slower and faster step rates are also achievable.

A 74194 - Bidirectional Universal Shift Register from the 74LS or 74HC - TTL families of logic devices to produce the stepping pattern. The LM555 timer shown in Figure 2 which is denoted as IC1 in the circuit diagram found at the end of this paper, is running in a stable mode.

It is due to this particular setup of the 555 timer which enables it to continuously oscillate from one state to another, hence forming a symmetrical and consistent clock pulse. The rate of clock pulses can be adjusted via the resistor denoted as RT. This clock pulse is then feed into PIN- 11 of IC2. IC2 is the denotation of the 4 bit bi-directional universal shift register, 74LS194. This shift register is a basic TTL- logic device which requires no programming, and being bi-directional it can produce a 4 bit shifted stepping pattern in both an up and down count. All that it requires to function is a clock pulse input and a instruction regarding shifting direction to produce the stepping pattern on pins 15, 14, 13, 12, as shown below in figure 3

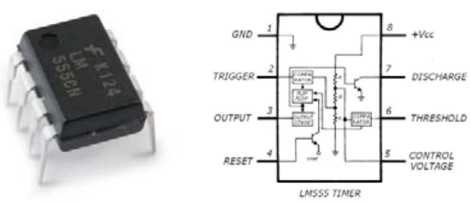
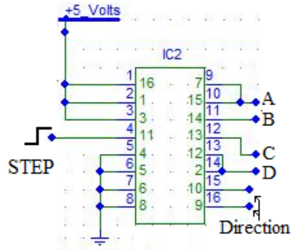


Figure 2: LM555 timer (IC1)



OUTPUT FROM THE 74194

		STEP 1	2	3	4
PIN	15	1	0	0	0
	14	0	1	0	0
	13	0	0	1	0
	12	0	0	0	1

Figure 3: Pin allocation for IC2 shift register and its output

As the clock input from the LM555 timer goes HIGH (positive state) the active state at IC2 - 74194's OUTPUT terminals, (Pin's 12, 13, 14, 15), is then able to be shifted either in the UP or DOWN count sequence. This shifting sequence of bits by one place only occurs on the high pulse of the clock input. This is also known as positive edge triggered logic, as can be seen in Figure 4.

As mentioned previously the shift register, IC2, will shift in both directions, although it needs to be directed to do so, otherwise the circuit will be in a locked rotor state. This state is an integral part of the design, as the stepper motor must maintain a holding torque on the solar panel in-order to withstand external forces such as wind or rain attempting to turn the panel out of alignment.

Pins 9 and 10 are the directional control pins on the Bi directional shift register, IC2. Upon initiation the circuit will reach steady state and operate in a locked rotor state. This is achieved by having both pins 9 and 10 on IC2 to be LOGIC HIGH, this is generally accepted to be on or very near to 5 volts DC.

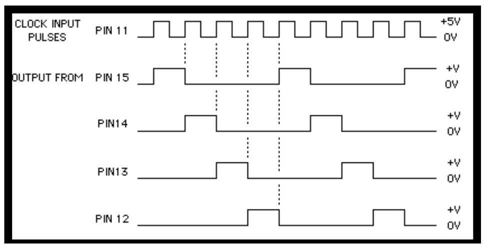


Figure 4: IC1 Clock pulses vs. shifted output from IC3 bi-directional shift register

Logic 5 Volts or TTL logic high is attained through resistors R16 and R17, with the ground being supplied by transistors T6 and T7. Since these two transistors are constantly pushed over the 0.7 volt threshold, collector is pulled to ground due to emitter-ground connection as shown in Figure 5.

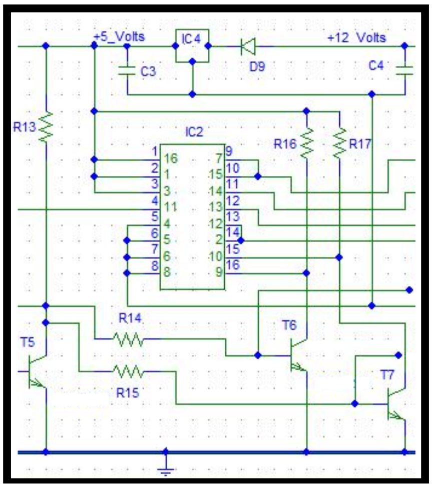


Figure 5: Circuit diagram highlighting IC2

For directional control of the shift register, IC2, either Pin 9 or 10 must be made TTL logic LOW. This can be achieved by making the base of either Transistors T6 or T7 lower than 0.7 volts. This will cause the chosen transistor to effectively stop current flow from either R16 or R17, hence removing the grounding point to either Pin 9 or 10.

Up count and down count for the shift register can be easily achieved by having a simple switch to ground tied to bases of T6 and T7. Having said this, a switch such as that mentioned, is still only a manual method in which to control the stepping direction of IC2, and will not help with the automated process required to track the sun through it's solar cycle.

In order for this solar tracker to be controlled only by the sun's movement throughout the solar cycle, a sensing circuit must be setup to replace the simple switch mentioned above in point 6.

A window comparator, LM1458 Dual op-amp, has been chosen to act as an automated switch enabling full directional control of the stepper motor. It operates by comparing 2 pre-determined limits with that of 2 variable inputs. The upper and lower limits provide a threshold for which the comparator can dictate the direction of the stepper motor. The 2 outputs of the comparator are then fed into the next stage of the circuit. These outputs can be tied together in a wired or configuration to produce the desired response.

The input variable voltage is compared to the pre-determined inputs, V_{Low} and V_{High}, and depending on whether that voltage is higher or lower than V_{Low} or V_{High}, the corresponding amplifier will be allowed to operate as can be seen in figure 6.

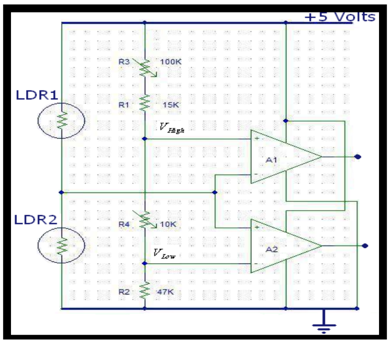


Figure 6: LDRs connected to the window comparator circuit

The H-bridge in figure 7 and 8, has been chosen to receive the two differential voltages from the window comparator in figure 6. In general a H-bridge is a rather simple circuit, containing four switching element, with the load at the centre.

The operating principles of the H-bridge are based upon the two reference voltages that are being received from the window comparator, figure 6. As these reference voltages change from high to low potential, the transistors denoted as T1 and T3 are also switched on in respect to the appropriate potential voltage, The 2 outputs of the comparator are then fed into the next stage of the circuit.

Instrumentation Amplifiers are high gain differential amplifiers with high input impedance and a single ended output. They are mainly used to amplify very small differential signals from strain gauges, thermocouples or current sensing resistors in motor control systems, and in this project we used the circuit below to amplify the difference between the two outputs of the **H-Bridge** circuit that was designed to run the **LDRs** and compare the change in voltage across the light sensors (LDRs) the instrumentation amplifier circuit that we have in figure 9 was designed to push the output voltage V_{out} over 0.7v so that the transistors T8 and T9 can operate.

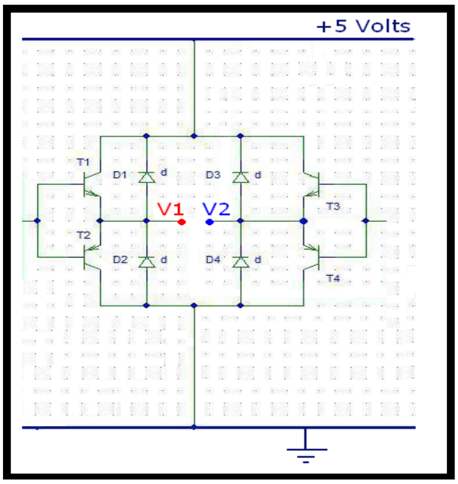


Figure 7: Implemented H-bridge for stepper motor

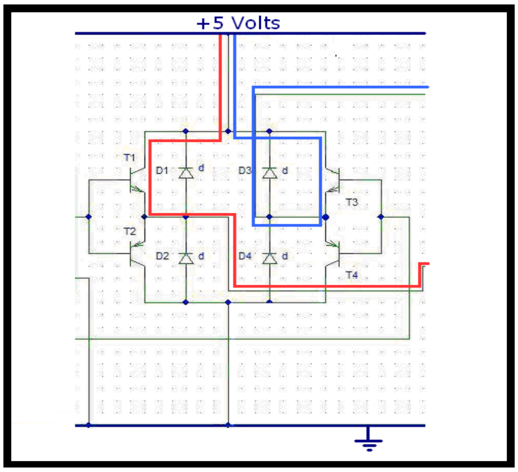


Figure 8: Current flow in the H-bridge

The transistors and diodes used in this circuit are:

- T1, T3 are BD139
- T2, T4 are BD140
- 4 Diodes- 1N4004

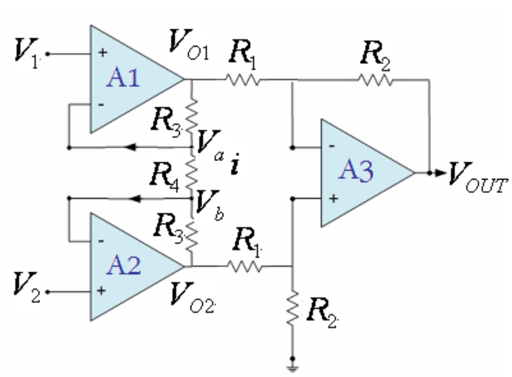


Figure 9: Instrumentation amplifier circuit

This voltage drop between points V_a and V_b is connected to the inputs of the differential amplifier as V_2 and V_1, which it then amplifies by a gain, G, which has been predetermined.

Noted below in Equation 1 is the general expression for overall voltage output of the instrumentation amplifier circuit as:

$$V_{out} = \frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_4}\right)(V_2 - V_1)$$

The values of the resistors R_1, R_2, R_3 and R_4 can be changed to achieve any amount of gain required for the circuit to be able to serve its purpose. For this project that aim is to correctly interface with the stepper motor driver circuit as directional control.

By nominating values for R_1, R_2, R_3 and R_4 , we arrive at an output of V_{out} :

$$R_1 = 15k, R_2 = 100k, R_3 = R_4 = 10k$$

$$V_{out} = \frac{100k}{15k}\left(1 + \left(\frac{2*10k}{10k}\right)\right)(V_2 - V_1)$$

$$V_{out} = 6.667*(3)(V_2 - V_1)$$

$$V_{out} = 20(V_2 - V_1)$$

Due to the nature of the instrumentation amplifier, it will give both a positive and negative output voltage. With particular values of resistances chosen, the outputs have been calculated to be either positive or negative 0.7 volts. The switching voltages represent a change in need for a change in direction of the stepper motor. Two diodes, D5 and D6, have been placed on the output pin 6 of op amp U6 in opposite directions to control current flow to the transistors T8 and T9, this connection can be seen in figure 10. Transistors T8 and T9, will cause the bases of T6 or T7 to drop below 0.7 volts as T8 and T9 are connected with emitter to ground. In doing so pin 9 or pin 10 will become logic low and enable the up or down shifting to begin in IC2, bi directional shift register.

The output of the instrumentation amplifier shown in figure 9, has been manipulated to give either a positive 0.7 volts or a negative 0.7 volts.

The outputs of the 74194 are fed to four sets of paralleled segments of a ULN2803 Darlington driver (IC 3). When an input of a ULN2803 segment is HIGH, its Darlington transistor will turn ON and that OUTPUT will conduct current through one of the motors coils as shown in figure 3.10.

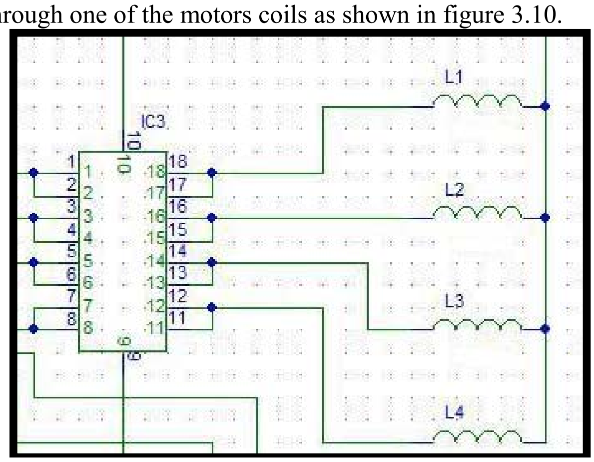


Figure 10: IC3 connection to stepper motor

The bidirectional shift register counts up or down, IC3 takes this input and based on the wiring diagram shown in figure 11, the stepper motor is wired up

Pin No	MOTOR
1	B1
2	A1
3	A2.B2
4	B3
5	A3

Figure 11: Pin location for the chosen stepper motor

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Based on the switching sequence showing below in figure 12, the stepper motor will turn correctly. As can be noted, A_2B_2 is the common positive for the stepper motor

pins / phase	B1	A1	B3	A3	A2.B2
1	—			—	+
2	—		—		+
3		—	—		+
4		—		—	+

Figure 12: The switching sequence

IV. TESTING

Once the research was completed to gather the necessary information on the project, next step was to put the theory into practice. Firstly the circuits were tested in the laboratory to see its functionality, in order to troubleshoot and correct any problems that were associated with them. The circuits designed and utilised in this project were to work properly with accuracy so that once it is implemented in the project design it will achieve its purpose of tracking the sunlight with maximum efficiency. Therefore when the tests were carried out in the laboratories on these circuits, there were a number of errors and on many occasions they didn't work at all. These issues were overcome by carrying out rigorous circuit analysis to fault find and fix the problems. After spending some time to troubleshoot all the circuits involved in this project and fixing the problems with some additional modifications, the circuits started to work properly and giving out desired results.

There were a number of designs produced and tested to choose the optimum design. These designs were compared to each other to see which one is most efficient.
When tests were carried out on this design it was noticed that the primary axis rotation was very smooth. This was due to the application of the larger gear sets that replaced the small gear systems used in previous design. Also this smooth rotation was achieved by the implementation of a metal shaft which was stronger than the timber shaft used in the previous designs.
The rotation of the base of the housing system which is the secondary axis of rotation was also achieved successfully. The brushed DC motor implemented in this design provided enough torque for the satisfactory movement of the base via the belt drive system.
In this design, a problem was encountered with the rotation of the base. When the brushed DC motor was switched on, it was able to rotate the base in one direction, but by doing so, tension was lost in the belt driving system. This loss of tension did not allow any torque to be transmitted from the motor to the belt and hence the base could not be rotated back in the other direction. This problem was overcome by the implementation of an elastic band in line with the belt drive system. This elastic band was always under tension and therefore, maintained the required tension on the belt drive which enabled the successful rotation of the base.

Analogue electronics were used rather than the use of programmable ICs such as PIC16F877, in order to show an example of enhancing the practical understanding of circuit theory and design.

The first scenario involved removing the panel from the tracker and laying it in a flat orientation. The output was connected to a load that would dissipate 1.2W that would match the panel's rating. 1.2 Watts at 10.3 Volts corresponds to a current of 0.1165Amps, so by Ohm's law; a load resistance was calculated as being 83.586Ω. An 82Ω resistor was the closest value found and was connected to the panel. The tracking device still requires power, but a 12V battery that is connected in a charging arrangement with the solar panel supplies it. The voltage across and current through the load was monitored using two separate multimeters, and was recorded every half an hour on a clear day, with data entered into an Excel spreadsheet. The readings were taken on a span of days that possessed similar conditions including no cloud cover. The designed tracker is shown in Fig. 13, while the experimental results shown on Fig. 14. The total control circuit is shown in Figure 15.

Although the stationary panel was laid out on a flat surface for the comparison, you should never have stationary solar panels placed at less than 5° from the horizontal so that they don't collect too much dirt etc and they will automatically wash clean whenever it rains. By having the solar panels following the sun with a solar tracking device you can gain greater benefits in summer than in winter. This is due to the difference in the arc that the sun sweeps across the sky which is more than 180° in summer and less than 180° in winter. The degree of variation depends on latitude and weather patterns with the greatest gain coinciding with clear skies and summer.

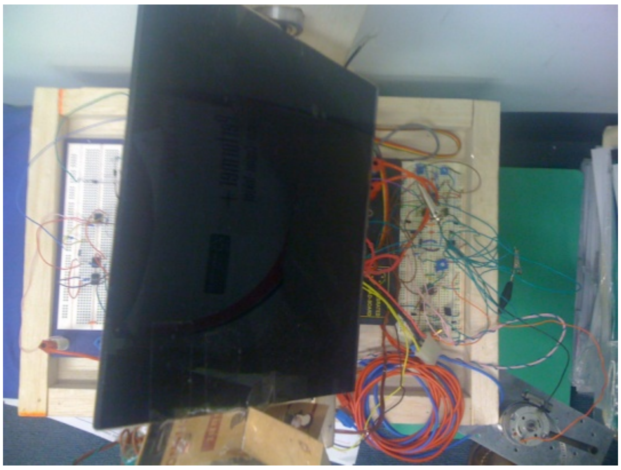

Figure 13: The designed solar tracker

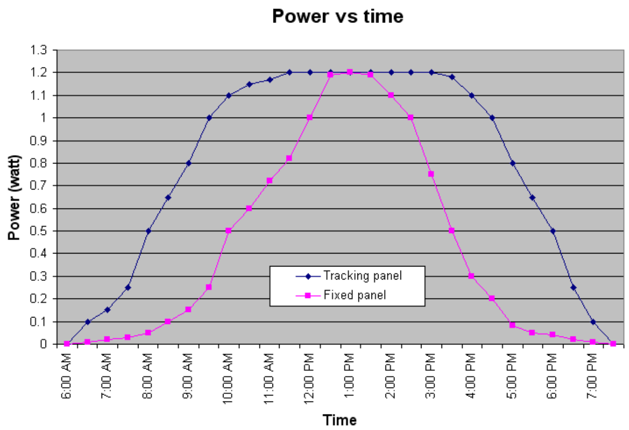

Figure 14: The experimental results

V. CONCLUSION

A new solar tracker is designed employing the new principle of using small solar cells to function as self-adjusting light sensors, providing a variable indication of their relative angle to the sun by detecting their voltage output. By using this method, the solar tracker was successful in maintaining a solar array at a sufficiently perpendicular angle to the sun. The power increase gained over a fixed horizontal array was in excess of 30%.

The areas that are deemed to be in need of improvement include that of, the base rotating system and implementation of the circuits onto printed circuit boards.

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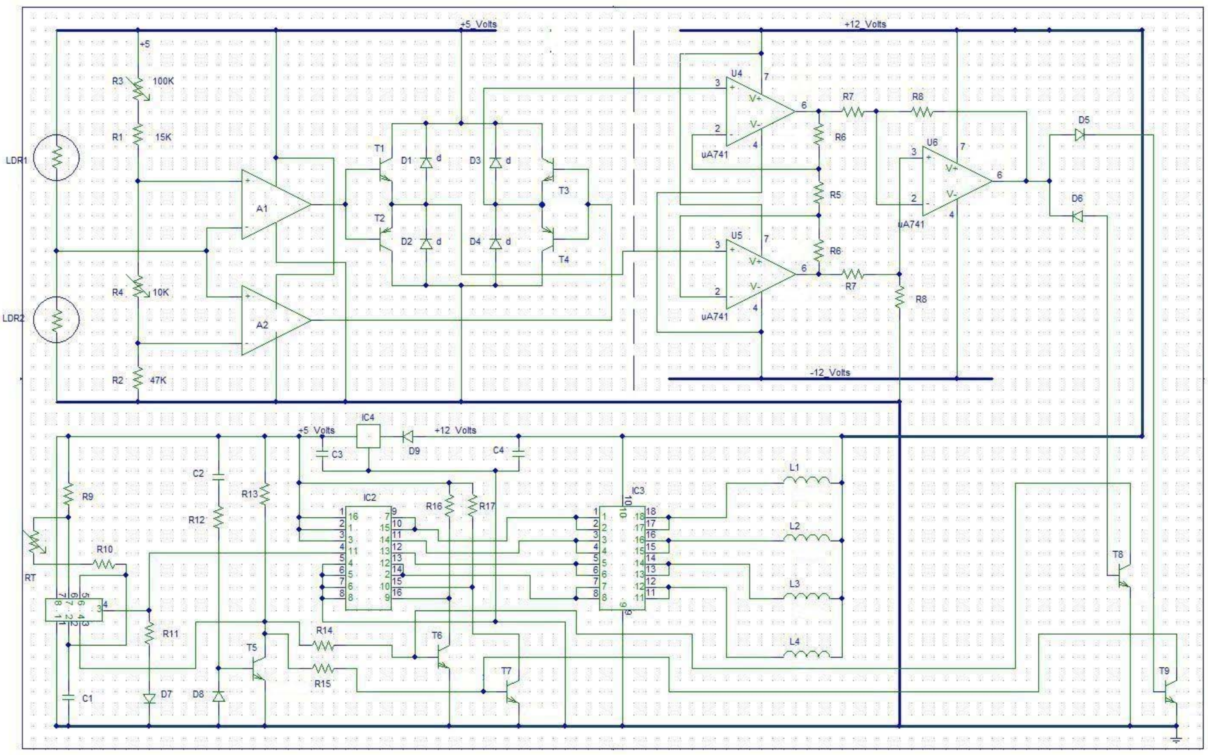

Figure 15: The controller circuit

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