IMPROVEMENT OF EFFICIENCY FOR SOLAR PHOTOVOLTAIC CELL APPLICATION

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DECLARATION

We hereby declare that this thesis is based on the results found by ourselves. Materials of work found by other researchers are mentioned by reference. This thesis, neither in whole nor in part, has been previously submitted for any degree.

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ABSTRACT

The world is using up all the resources to meet the daily demands of energy and it is quite expectable that in the near future we will run out of any naturally occurring ore/mineral/petroleum. As a result, renewable energy solution has achieved a great demand today to save the natural resources and also to tackle the crisis of energy. Solar energy is rapidly gaining its popularity as an important source of renewable energy.

But the efficiency of solar panel is a big factor. While the sun keeps following a parabolic path throughout the day, the panels which are used in our country are generally fixed to a pole or the roof of the house and hence, throughout the day, the efficiency decreases significantly.

In this thesis, we have constructed a 2 axis solar tracker which can track the sun throughout the day to obtain the maximum efficiency.

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CHAPTER I: INTRODUCTION

With the alarming rate of depletion of the major energy resources worldwide, it has become an urgent necessity to seek for renewable energy resources that will power the future. According to the worldwide market economy, the increasing demand for energy had forced to put a huge price tag on natural combustible sources of energies [1]. In fact, it has been predicted that in the near future the demand of energy will grow in such a rate that it will be completely impossible to find out or meet the demand with the resources that we had been using for so long, such as – oil, gas, coal, etc. This issue throws a positive challenge to the scientific community as more and more funds are being allocated for the research and development of new alternatives.

In this context we have concentrated our focus on the research of renewable energy. Among these renewable energy resources solar energy is one of a kind. In today's world there is a growing demand to find greener ways to power the world and minimize greenhouse gas emission. The sun is a natural power source that will keep on shining for an estimated 4 billion years. Solar power (photovoltaic) systems are a sustainable way to convert the energy of the sun into electricity. The expected lifetime of a system is 25-30 years [2]. The energy potential of the sun is immense, and it is one of the emerging energy sources, which is subsidized in order to secure the distribution of the technology worldwide. By tracking the sun the efficiency can be increased by 30-40% [3]. The photovoltaic technology allows the conversion of sunlight directly to electricity with a conversion ratio of about 15% [4].

1.1 Motivation

With all the above information, the rapid depletion of the natural resources of the world, we would soon meet a great demand for alternative source of energy. In the very near future, experts are predicting that we will be bound to move to renewable sources of energy, solar being one of them.

As long as our earth exists, the sun is there to give us unlimited solar energy. It is completely up to us how we are going to utilize this abandoned energy. Every hour, sun gives the same amount of energy to the world that the whole world uses in an entire year [5].

Not only the world but our country is in a severe crisis of electricity. There are many rural areas which are still deprived from the wonder of electricity. Due to the geographical location of our country, we get sun almost 300 days a year. Compared to many other countries like Canada and Norway, we are in a much better location for utilizing solar energy. It can be used in areas where there is no grid connection also.

Considering all the above things and the environmental friendliness, economically sound and the ease of implementation, we thought of working on it as we believe that in the near future, our country along with the whole world will be benefited from this source of renewable energy.

CHAPTER II: SOLAR TRACKER

Despite the unlimited solar energy, harvesting it is a challenged mainly because of the inefficiency of the panels. Recent works shows that different types of methodology have been proposed to improve the efficiency of solar panels [6]-[9].

Most of the panel installations that are done in our country are all fixed arrays. As the day passes, the sun moves away from the facing position of the panel and thus the power output of the panel decreases. The easiest way to overcome this problem is to adapt a moveable solar panel using sun tracking mechanism. We have adopted this system to improve the efficiency for photovoltaic cell applications.

2.1 What is solar tracker?

A solar tracker is a device for orienting solar photovoltaic panel towards the sun. The sun's position in the sky varies both with season and time of day as the sun moves across the sky. Solar powered equipment works best when pointed at or near the sun, so the solar tracker can increase the effectiveness of such equipment over any fixed position, at the cost of additional system complexity.

2.2 Motivation

All the solar arrays that are currently being installed in our countries are fixed on the rooftop or any favorable open space at approximately 23^o inclination with the surface. We went to BRAC Solar project and get to know that all the BRAC Solar Home System (SHS) are arranged in such a way that the battery will be charged within 5 hours in a day and at night, the people can use the battery to run home appliances accordingly. This seemed a lot inefficient since the sun in our country is high up in the sky for around 10 hours every day. So with this system, 50% of the sun energy are not being utilized and also this SHS does not allow the consumers to use electricity during day time.

In many developed countries, solar trackers are already being used commercially. Importing and maintaining those in our country would be very expensive, especially for the people in the rural areas who are the main consumers of solar energy. So we thought of adopting the sun tracking mechanism to see how much more energy we can utilize.

2.3 Types of tracker

There are various types of solar tracker; some of them are as mentioned below:

- Horizontal axle solar tracker
- Vertical axle solar tracker
- Altitude azimuth solar tracker
- Two axis mount solar tracker
- Multi-mirror reflective unit
- Active trackers
- Passive trackers
- Chronological tracker

2.3.1 Horizontal axle solar tracker

In this type of tracking system a long horizontal tube is supported on bearing mounted upon the tube and the tube will rotate on the axis to track the apparent motion of the sun through the day. As they do not tilt towards the equator so therefore they are not that much effective in during the winter midday (unless located near the equator), but these tracking system are very much productive in during the spring and summer season when the solar path is high in the sky. The devices are less effective at higher latitudes. The principle advantage is the inherent robustness of the supporting structure and the simplicity of the mechanism. Due to the characteristics of being horizontal the panels can be compactly placed on the axle tube without danger of self-shading and are also readily accessible for cleaning. A single control and motor may be used to actuate multiple rows of panels for active mechanisms.

2.3.2 Vertical axle solar tracker

In this type of tracking system the panels are mounted on a vertical axle at a fixed, adjustable or tracking elevation angle. Such trackers with fixed or (seasonably) adjustable angles are suitable for high altitudes. This is because at high latitudes the apparent solar path is not especially high but which leads to long days in summer, with the sun traveling through a long arc.

2.3.3 Altitude azimuth solar tracker

Here the mounting is done in such a way so that it supports the entire weight of the solar tracker and allows it to move in both directions and locate a specific target. The horizontal axis (called the azimuth) allows the telescope to move up and down, the axis, vertical, (called the azimuth), allows the telescope to swing in a circle parallel to the ground. This mechanism makes it easy as the telescope can swing around in a circle and then lift to the target. As tracking an object from the earth is more complicated due to the rotational movement of the earth. For this reason computer controlling is required.

2.3.4 Two axis mount solar tracker

In two axis mount, one axis is a vertical pivot shaft or horizontal ring mount that allows the device to be swung to a compass point. The second axis is a horizontal elevation pivot mounted upon the azimuth platform. Using this combination of the two axis any location in the upward hemisphere can be pointed. Such system needs computer control or tracking sensor to control motor drives that orient the panels toward the sun.

2.3.5 Multi-mirror reflective unit

This device uses multiple mirrors in a horizontal plane to reflect sunlight upward to a high temperature photovoltaic or other system requiring concentrated solar power. Only two drive systems are required for each device. Because of the configuration of the device it is especially suited for use on flat roofs and at low altitudes.

2.3.6 Active tracker

It uses motors and gear trains to direct the tracker in the direction of the sun. a controller is used to control the motors and the gear trains so that it moves accordingly and the panel faces the sun in the right direction required. The active two axis tracker uses a heliostat – movable mirror that reflects the sunlight towards the absorber of a central power station, or a light sensor to track the sun.

2.3.7 Passive tracker

Use a low boiling point compressed gas fluid that is driven to one side or the other to cause the tracker to move in response to an imbalance. As this is a non-precision orientation it is unsuitable for certain types of concentrating photovoltaic collectors but works fine for common PV panel types.

2.3.8 Chronological tracker

It counteracts the earth's rotation at an equal rate as the earth, but in the opposite direction. These trackers are very simple but yet potentially very accurate solar trackers specifically for use with a polar mount. The drive method may be as simple as a gear motor that rotates at a very slow average rate of one revolution per day (15 degrees per hour).

2.4 Our mechanism

Our team has designed and developed a prototype for a two axis solar tracker that will maintain the solar panel orthogonal to the sun, no matter what the sun's position is in the sky. The model consists of two parts; the upper part operates in horizontal axis while the lower part operates in vertical axis. Since both the part operates independently so therefore we included two stepper motors for controlling each axis. The design also includes four sensors, microcontroller with required circuits for controlling the motion and direction of the motor and hence the direction of the panel towards the sun. the difference in voltage output from the sensors are fed into the microcontroller, which then drives the stepper motor in the direction required.

CHAPTER III: OVERVIEW OF OUR SYSTEM

3.1 Architecture of the overall system:

Our system relies on automatic tracking mechanism instead of adaptive mechanism or predefined motion. The sensors are the main feedbacks of the system which send signals to the control system. The backbone of our control system is a microcontroller which determines which motor should move in which direction to adjust the system in such a way that the sun light falls orthogonally on the panel.

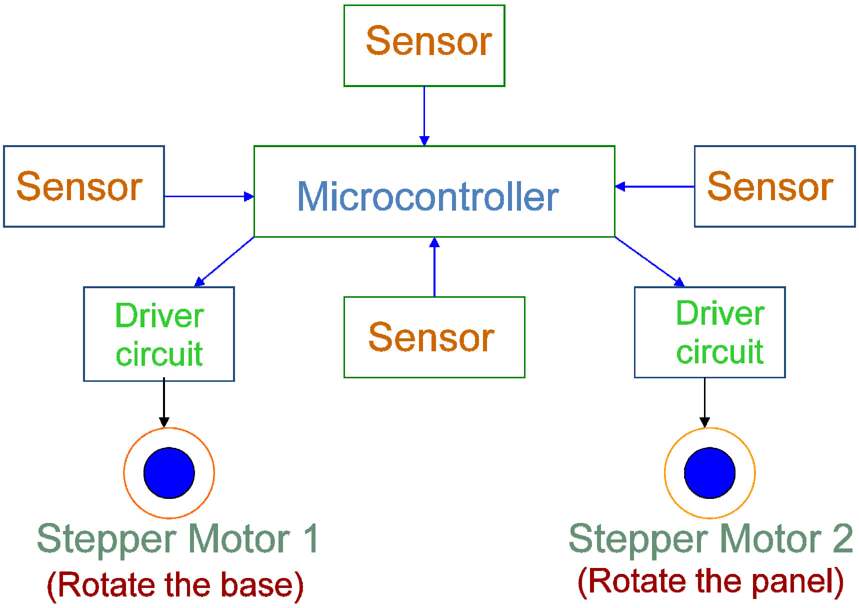

Fig. 3.1. Overview of the system

An illustration of how our system works is shown in figure 3.2.

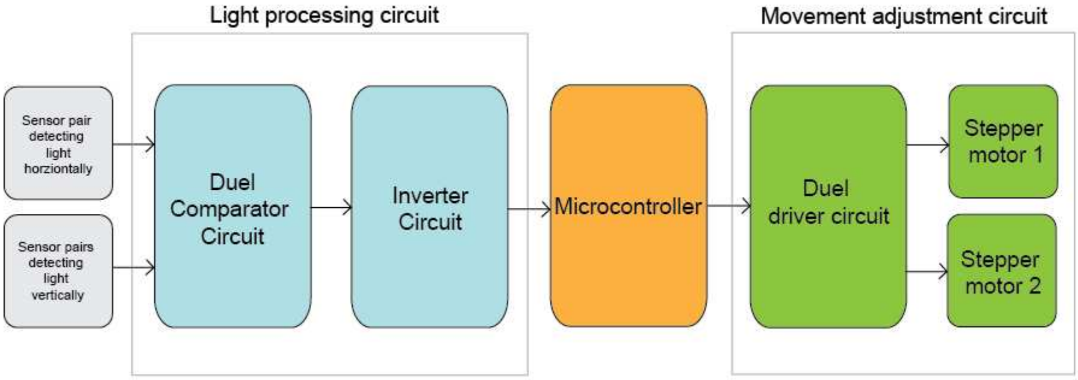

Fig. 3.2. How the overall system works

From the above illustration, we can see that there are 4 major parts in our control system:

1. Sensors
2. Light processing circuit
3. Microcontroller
4. Movement adjustment circuit

3.1.1 Sensors

Since our tracking system is based on automatic 2 axis tracking, so we used Light Dependent Resistors (LDR) which is the main source of input to our system. Each pair of sensors is used to take the light's position. One pair feeds the position of the sun in the vertical axis and the other pair feeds the information about the horizontal axis. This information is then transferred to the light processing circuit.

3.1.2 Light processing circuit

The position of the light in 2 axes is sent to this circuit by the sensors. This cell of circuits mainly consists of a duel comparator IC and inverter ICs. The duel comparator IC (consisting of two Operational Amplifiers) compares the inputs from the sensors and sends out high voltage or a low voltage from the comparator's two individual outputs. Since comparators cannot give HIGH (1 in binary) or LOW(0 in binary), we transferred the voltages to the inverters. Above a certain voltage their outputs are HIGH and below that, the inverters give LOW. This is then transferred to the microcontroller which can only understand binary inputs.

3.1.3 Microcontroller

This is the main backbone of our full control system. This determines the inputs from the light processing circuit and gives out outputs according to the required movement.

3.1.4 Movement adjustment circuit

This part of circuits deals with the mechanical part of the whole system. Depending on the outputs from the microcontroller, the driver circuit executes the proper sequence to turn the stepper motors in the required direction. One of the motors controls the horizontal axis movement of the sun while the other controls the vertical displacement.

CHAPTER IV: ARCHITECTURE OF THE MODEL

Since our project is of solar tracking in 2 axis system, we had to develop a very effective model which can move the panel in dual axis. For that, in the very beginning, we did a rough sketch of what the probable model would look like. After that, we constructed a prototype of the model using cardboard since that would give a better visualization of what the model will look like. Finally we constructed the model using plywood.

4.1 Model Overview:

Our whole system relies on two different rotational movements in two different axes. For that purpose, our model is simplified in two different parts: panel holder and the base. Each of the part of the base holds on stepper motor. Below are two pictures, figure 4.1 and figure 4.2, of the two different parts of the model:

Fig. 4.1. Upper part of the model

Fig. 4.2. The base of the model

The different parts of the whole system are shown in the figure 4.3.

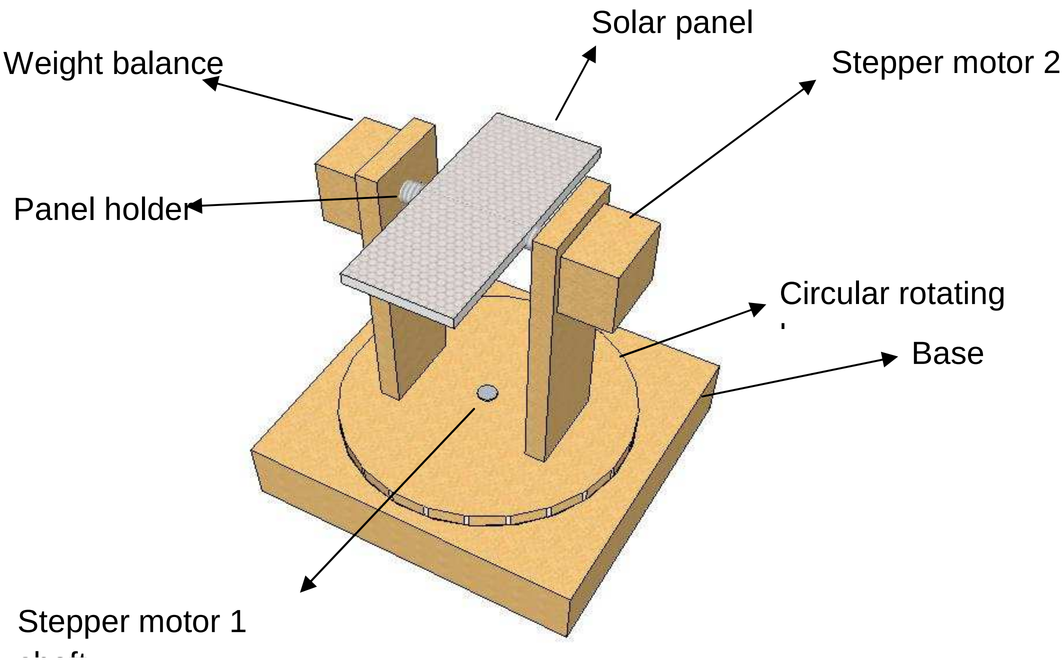

Fig. 4.3. The proposed model

The final constructed model is shown in figure 4.4.

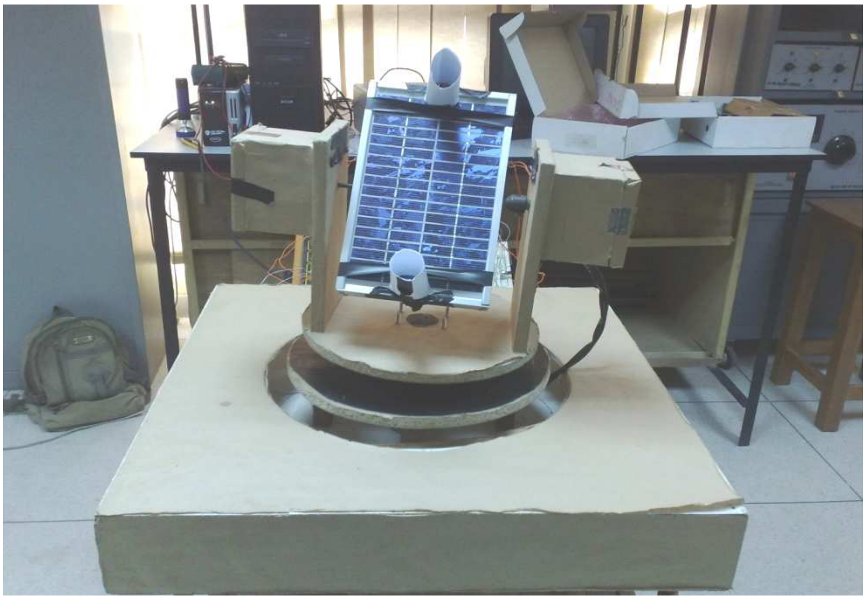

Fig. 4.4. The final model

4.2 Working mechanism:

As mentioned earlier, the model moves in axis with the help of two stepper motors. The motor with the medium rating is responsible for the movement of the panel and the motor with the higher rating is responsible for the movement of the panel holder. The upper part of the model (panel holder) tracks the sun linearly and the base is responsible for tracking the parabolic displacement of the sun. The movements are pointed out in the figure 4.5 and figure 4.6.

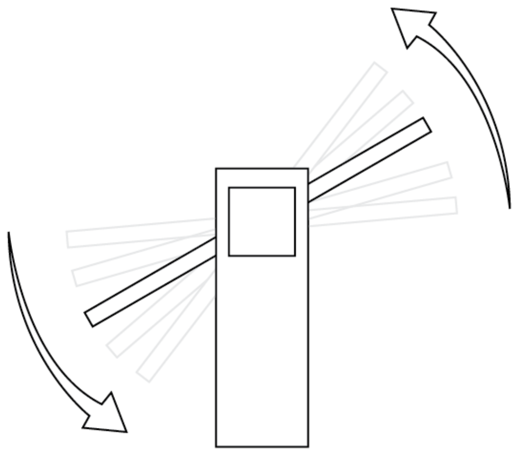

Fig. 4.5. The movement of the panel

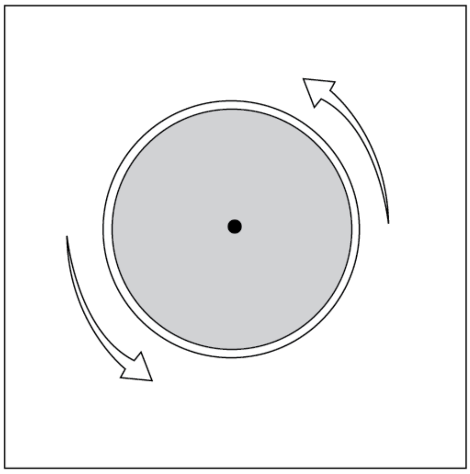

Fig. 4.6. The movement of the base

The above mechanism of the movement proved to be able to track any kind of parabolic movement of the sun.

4.3 Assembling the model:

This is one of the toughest challenges we have faced during our project. The construction, although seems fairly easy and straightforward, had many unexpected challenges.

Firstly, we constructed the panel holder to test one axis movement. The panel is attached with the shaft of the stepper motor 2 using a shaft lock and a rod which goes through the back of the panel. This mechanism ensured that no steps are missed in the solar panel movement.

The biggest challenge was to attach the panel holder with the shaft of the base stepper motor. The shaft of the stepper motor 1 is connected to the base using another shaft lock but the problem was the rotation required to be frictionless. So we made a gap between the panel holder disk (rotatable) and the base motor disk (fixed). Between the gap, we put some wheels to aid the movement but because of the weight of the panel holder, the wheels actually increased the friction, causing problem in rotation by missing steps. So we removed all the wheels and kept the air gap which actually worked a lot better than any movement-air mechanism.

CHAPTER V: HARDWARES

Throughout the world many research and work [10]-[12] is going on to make efficient automatic solar tracker so that the efficiency of the whole system can be improved. This higher efficiency will allow us to do more with solar energy and hence someday help to solve the energy crisis problem. The automatic solar tracker that we designed is a two axis tracker, which will track the sun on both horizontal and vertical axis. To achieve this we had to build a prototype that consisted of many individual parts. Some of the key hardwares that we have used are:

1. Stepper motors
2. Sensor circuit (LDR, resistance pot, LM1418 and HD74HC04)
3. ATmega32 microcontroller
4. Driver circuit (Tip122 and diode)

In order to make the system completely automatic, all these hardware had to be linked together. The function and working principle of each of these hardware uses are described below in details.

5.1 Stepper Motor

To build the two axis automatic solar tracker, we have used two stepper motors so that we can control the movement of the system more precisely. According to the requirement of the project, both the motors are different in ratings from each other. One of the motors which have a rating of 1.8v and 3.0A is responsible for the rotation of the solar panel. The solar panel will have a freedom of rotation from zero to 180 degrees in order to track the sun throughout the whole day. This stepper motor has a lower rating compared to the other one. Both the stepper motors used for this thesis project has a resolution of 1.8 degree/step. This means that when a pulse is applied to the stepper motor, the shaft will rotate by 1.8 degrees.

The other stepper motor used has slightly higher ratings because it will have to rotate a circular base as well as the panel, the smaller stepper motor and the associated structure. This stepper motor has a rating of 2.6v and 3.1A. This stepper motor will also rotate the base from zero degree to 180 degrees. As we know, that the sun does not always follow the same path throughout the year, so the mechanism that we developed will allow the system to automatically track the sun no matter which ever path it follows.

5.1.1 Characteristics

Stepper motors is a kind of DC motor that is brushless and has discrete rotation unlike DC motors [13]. This ability to rotate in discrete steps allows them to be very precise which makes it suitable for our project. The precision movement also has a very big advantage and that is no feedback system is required. Stepper motors are quite available as they are widely used commercially which makes them less expensive. They are easy to implement and also has longer life. Stepper motors works on the principle of energizing respective electromagnet hence they require additional circuitry in order to make them work.

The figure 5.1 show the working principle for a stepper motor. As it can be seen that a command is given to the stepper motor and it works accordingly. No feedback system is required hence making the system less complex. More details about the working principle of the motor will be discussed later.

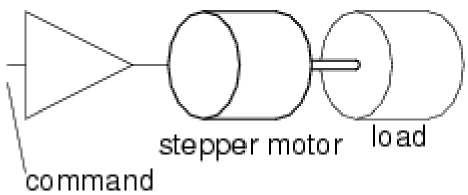

Fig. 5.1. Working principle of stepper motor

Stepper motors are a different kind of motors and they have a unique Torque vs Speed characteristic (figure 5.2). In general stepper motors have very high torque compared to the other type of motors but this torque decreases rapidly as the speed of the shaft in the motor increases. The torque of the stepper motor remains fairly constant as the speed starts to increase but after a certain “cutoff speed” is reached, the the torque starts to decrease rapidly until it becomes zero as the speeds keeps increasing.

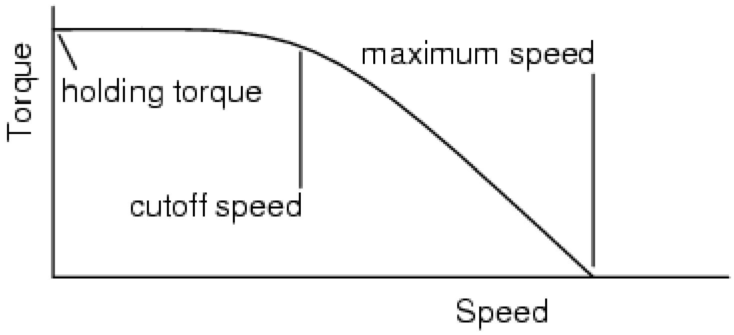

Fig. 5.2. Torque vs. speed characteristics curve

5.1.2 Working principle

There are many types of Stepper motors available in the market. The three main types are:

1. Permanent magnet (PM) stepper motor
2. Variable reluctance (VR) stepper motor
3. Hybrid synchronous (HS) stepper motor

For our project we have decided to use the Permanent Magnet (PM) type stepper motor. This type of motor is easily available in the market and the working principle is very simple hence expensive circuit is not required to make it work. Permanent Magnet (PM) type stepper motors usually has 4 electromagnets on 4 sides and a rotor/shaft sitting in the middle of these electromagnets. The shaft itself is magnetized with different polarity that is distributed evenly throughout the circular shaft. This unique design of the shaft/gear will enable it to move precisely when the electromagnets are energized.

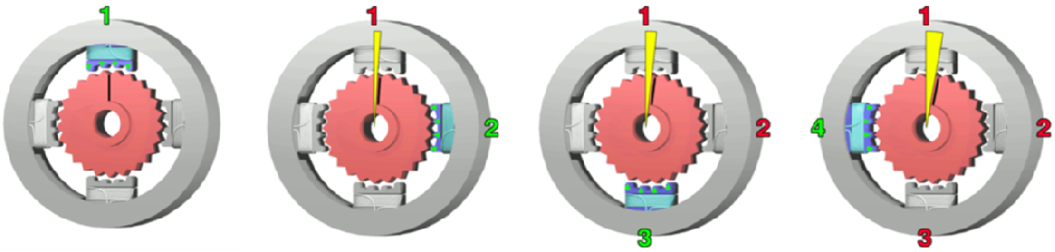

Fig. 5.3. Working principle of PM stepper motor

The figure 5.3 shows the energizing sequence of the electromagnets. The electromagnets are energized by an external control circuit, such as a microcontroller or even using a computer’s parallel port. To make the motor shaft turn, first one electromagnet is given power, which makes the gear's teeth magnetically attracted to the electromagnet's teeth. When the gear's teeth are thus aligned to the first electromagnet, they are slightly offset from the next electromagnet. So when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one, and from there the process is repeated [14]. Each of those slight rotations is called a "step". This way the movement of the stepper motor is precise and can be used for high accuracy movement.

Apart from the 3 different types of stepper motor, the is also another vital property of stepper motor that must be taken into consideration because this property will define the type of circuitry required to drive the motor. There are two types of division for the stepper motors. They are:

1. Uni-polar stepper motor (figure 5.4)
2. Bi-polar stepper motor (figure 5.5)

For our project we are using Uni-Polar stepper motor because the setup is easier and simple circuit is required to make it work.

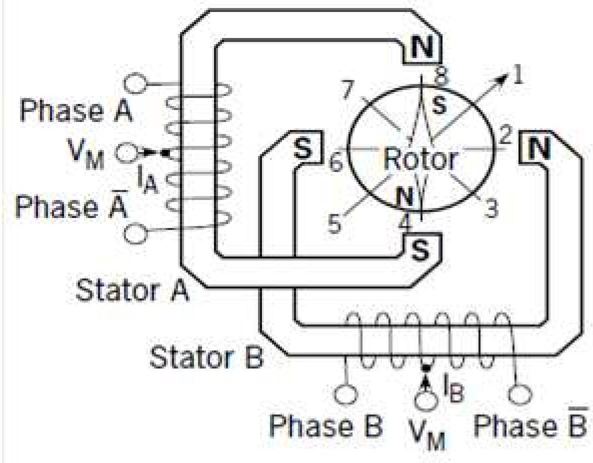

Fig. 5.4. Uni-polar stepper motor

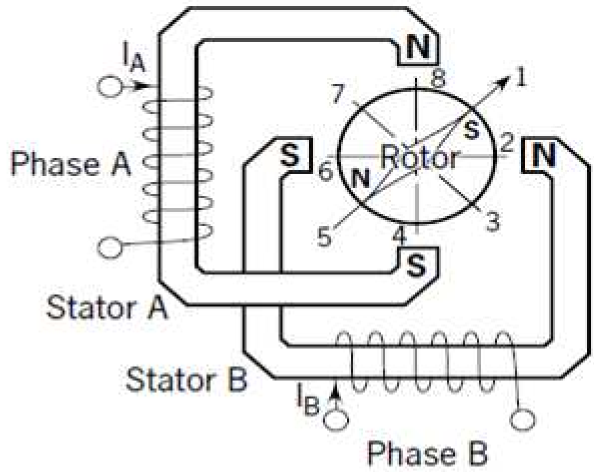

Fig. 5.5. Bi-polar stepper motor

The main difference between Uni-Polar and Bi-Polar stepper motor is that for Uni-Polar stepper change of current is not required to alter the direction of the magnet. In Bi-Polar the scene is completely the opposite. To reverse the direction of the magnet, change of direction of current is required and hence leads to a more complicated circuit and hence harder to implement because it is not always easy to reverse the direction of the current.

5.2 Sensor circuit

In order to make the system completely automatic it is necessary for the system to track the exact position of the sun so that it can align itself perpendicularly with the position of the sun. This will allow maximum power to be harvested from the sun throughout the day. This has been achieved by using a special design consisting of 2 LDR where the intensity of light falling on each LDR is compared by a comparator and the result fed to the microcontroller that makes further decisions. Before feeding the result from the comparator to the microcontroller, we have used a inverter to amplify the output of the comparator for the microcontroller. The output of the comparator depends on the input from the sensors and since the microcontroller can only detect digital 0 or 1, so we had to use a inverter that will convert the output from the comparator into zero or 1, which can be understood by the microcontroller. Each of these associated hardware are discussed in the proceeding sections.

5.2.1 LDR

LDR stands for Light Dependent Resistors. These are special kind of resistors whose resistance decreases with increasing incident light intensity [15]. LDR is also sometimes known as photo resistors. A photo resistor is made of a high resistance semiconductor. If light falling on the device has high frequency, photons absorbed by the semiconductor give electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance with the increase in light intensity.

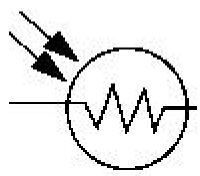

Fig. 5.6. Light Dependent Resistor (LDR) symbol

LDR are available in many sizes and shapes. For our project we decided to use a small sized LDR with acceptable response to the change of intensity of light since our prototype is comparatively small. LDRs are the key component for this project hence the positioning of the LDRs on the structure itself is crucial. To make a two axis solar tracker we required 2 LDRs for each axis hence we used total 4 LDRs. The respective LDRs that are mounted opposite to each other are compared and the output is used to decide the movement of the whole structure to track the sun. Two LDRs are mounted on the base of our structure itself that will aid in the circular movement of the base, and two other LDRs are mounted on the solar panel that we have used to aid the movement of the solar panel itself. These movements by comparison of the intensity of light from the sun will allow the system to track the sun throughout the whole day.

5.2.2 Dual operational amplifier (LM1458)

The Dual Operational Amplifier is basically 2 op-amps in one IC whose IC number is LM 1458. Both the op-amps in the IC has common VCC and Ground supply other than that they are completely separated from each other. This IC has 8 pins as shown in figure 5.7. Pin 8 is used to supply the IC with VCC supply and Pin 4 is used to supply the IC with Ground supply. The other Pins are used to give respective input to the op-amps and the outputs of the op-amps are taken from Pin 1 and Pin 7 respectively after comparison of the inputs.

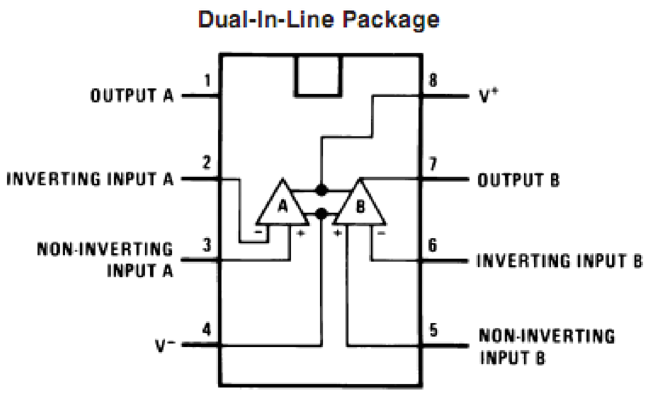

Fig. 5.7. Dual operational amplifier

5.2.3 Hex inverter (HD74HC04)

Another important component of our project is the inverter (figure 5.8) that we used. The IC number for the inverter is HD74HC04 [17]. The IC consists of 6 inverter with Pin 14 as common VCC and Pin 7 as common ground. The inverter was required so that the output from the Operational Amplifier can be converted into digital output of 1 or zero. This is required if we want to interface the analog system of the sensors with the digital system of in which the microcontroller works. Since our solar tracker is two axis so we required 2 Hex inverters to pair with each of the pair of sensors.

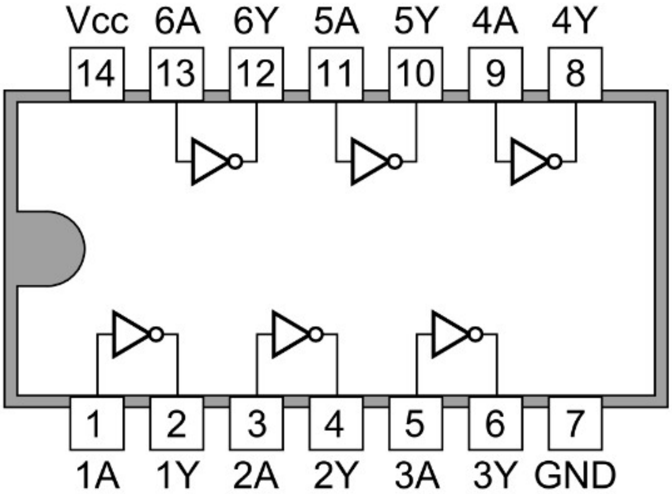

Fig. 5.8. Hex inverter

5.3 Microcontroller (ATmega32)

For our automatic solar tracker to work, we needed a device that can make decisions which way to rotate the whole system in order to track the sun. This was achieved by using a microcontroller which is ATMEGA 32 [18]. This microcontroller is from the AVR ATMEL family with built in 32 kilobytes of memory. The ATMEGA 32 is a 40 pin microcontroller with 4 ports for inputs or outputs. The diagram of the ATMEGA 32 is shown in figure 5.9.

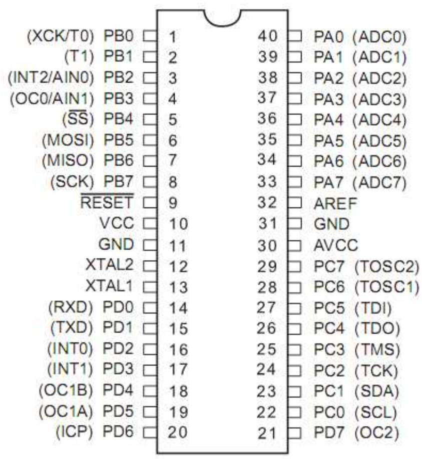

Fig. 5.9. ATmega32

From the figure it can be seen that Pin 10 is reserved for +Vcc which is +5v and Pin 11 is reserved from ground. For ATMEGA 32 to work properly a supply of 5v is required. For our purpose we used Pin 14,15,16 and 17 from PORT D as input. This 4 ports take inputs from the inverters and makes proper decisions which pulse to give and how to rotate the two stepper motors. The output from the microcontroller is taken from the Pin 1 – 8. Four outputs are connected to each of the 4, TIP 122 Darlington pair transistors that drives the motor. Four output thus drives 1 motor and so 8 outputs are used to drive both the motors that we used in our project. The other two ports (PORT A and PORT C) are unused because they were not required. This ATMEGA 32 received input from the inverters and gives proper pulses that is then fed to the Darlington pair transistors to amplify the current and then that drives the stepper motor which allows us to follow the sun accurately throughout the day.

5.4 Driver circuit

Since stepper motors are a special kind of motors that requires pulse in sequence to make them work, so they require driver circuit in order to make them work. Initially we decided to use ULN2003 IC which is specially designed for stepper motors. But our stepper motors were bigger and the ULN2003 was not sufficient to handle the ratings of our stepper motors. The pulse provided by the microcontroller (ATMEGA 32) is not sufficient to drive the stepper motors directly. To overcome this problem we came up with a solution and that is to amplify the current output from the microcontroller and then feed that as input to the stepper motors. To achieve this current amplification we used TIP 122 [19], which are also known as Darlington Pair Transistors.

Figure 5.10 shows how a TIP 122 Darlington pair transistor looks like. Like normal transistors it also consists of Base, Emitter and Collector. The TIP 122 comes with a extra metal that is used to connect external heat sink. Since TIP 122 can handle huge amount of current so it gets very hot and hence external heat sink is sometimes required. The diagram shows the configuration of how the base, collector and emitter are arranged in this transistor.

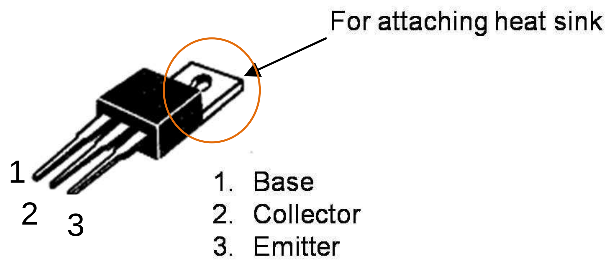

Fig. 5.10. Tip122 Darlington pair transistor

The figure below shows the internal configuration of the TIP 122 Darlington pair transistors. Two transistors are connected in the configuration show with respect to each other. Pulse from ATMEGA 32 microcontroller comes the base of the 1st transistor (Q1) and turns it on. The base of the 2nd transistor (Q2) is connected to the emitter of Q1 so that when Q1 is on, Q2 is also on. So when both the transistors are on, current can flow from collector to emitter for both the transistors and the emitter current for both the transistors are added up in the end. This adding up of current, amplifies the current that is given as input to the base of Q1, hence TIP 122 Darlington pair transistors work as current amplifiers.

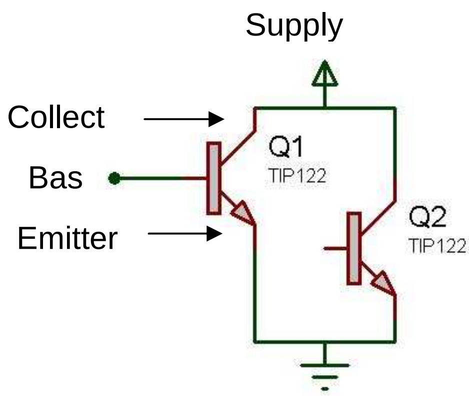

Fig. 5.11. Internal diagram of TIP122

5.4.1 Driver circuit configuration

The figure 5.12 shows the TIP 122 Darlington pair transistor configuration for a single stepper motor. As we already know that a stepper motor consists of 4 electromagnets, hence 4 pulse are required in sequence to make a stepper motor work. This 4 pulses comes from the 4 separate TIP

122 Darlington pair transistors as shown in the diagram. In the diagram, Q1, Q2, Q3 and Q4 represent the simplified version of TIP 122 drawn just like a normal transistor. D1,D2, D3 and D4 are respective diodes that stops reverse current to flow that may damage the transistors. Pulse is received by the Darlington pair transistors from the ATMEGA 32 microcontroller in the base of the transistors. Then the current in the base is amplified and that is then fed in sequence to the stepper motor. This allows the stepper motor to move very precisely as the pulse given dictates the direction of movement of the stepper motors.

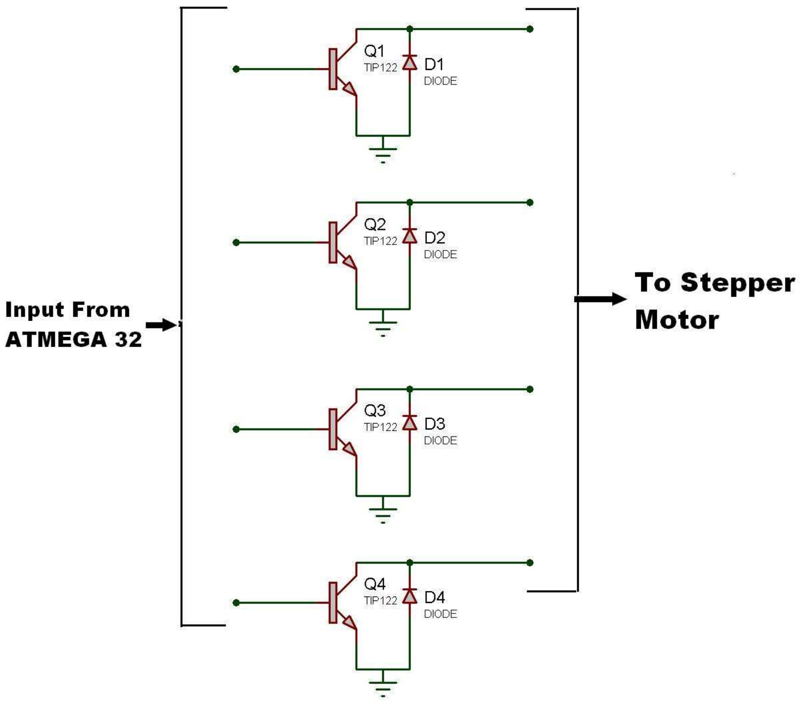

Fig. 5.12. TIP122 arrangement for a single stepper motor

The output from the TIP 122 Darlington pair transistors are taken from the Collector with respect to emitter which is actually grounded. So in fact the output is taken from the collector with respect to ground. As the current is at first amplified by the Darlington pair configuration itself, so the output that is obtained is amplified with respect to the input that is given to the base of the transistors. It is very important that stepper motors receive the pulse in sequence or the motors will move forward and backward in disorder. This sequence is maintained by the ATMEGA 32 microcontroller that gives the correct pulse in correct sequence so that the motors moves exactly as it is required. The diodes are normal diodes that are used to avoid reverse current from flowing or else it will damage the transistors. For our project we have used two pairs of the circuit shown, hence 8 Darlington pair transistors are used for the two stepper motors that tracks the sun throughout the day on two axes to improve the efficiency of the whole system.

5.5 Final circuit

In order to make the automatic solar tracker, we had to link together all the components so that they work in unison to track the sun. It was very important to design the system carefully so that slightest movement of the sun can be tracked and this was achieved by the circuit we designed. The complete circuit used to track the sun is shown in figure 5.13.

As the circuit shows we used 4 LDRs in order to track the sun on two axis. Each pair of LDRs are responsible for tracking the sun on each of the two axis. At first the light intensity on two adjacent LDRs are measured and that output is fed to each of the two comparators for each section. The 100 KΏ Pot is used to calibrate the two LDRs with equal light falling on it. The 20 KΏ Pot is used to adjust the sensitivity of the LDRs so that it can track very slight change of light intensity. After the comparators compare the inputs from the LDRs it gives a outputs from its output terminal. This output is analog in nature and if we directly feed this output to the microcontroller, then the microcontroller will not be able to detect it properly. So we had a challenge to make this into a digital output. This was achieved by simply using a NOT gate (inverter) that will invert the input given out by the comparators. Although the input was inverted but corresponding coding in the ATMEGA 32 microcontroller was done so that proper results were obtained.

From each pair of comparators we got 2 outputs, thus 4 outputs in total for the two axis tracking. After inversion we had to deal with 4 outputs that would individually determine which way the system should rotate in order to track the sun. These 4 outputs were then fed into the microcontroller in PORT D. Pin 14,15,16 and 17 were used to take inputs. As each stepper motor have 4 electromagnet so 4 pulse are required from the microcontroller for each of the stepper motors. For this purpose PORT A is used as output and Pin 1-4 is used for one stepper motor and Pin 5-8 is used for the other stepper motor.

Since the stepper motors have high current rating so the pulse generated by the ATMEGA 32 microcontroller is not sufficient to drive the stepper motors. So to amplify the current output from the microcontroller we used TIP 122 Darlington pair transistors that are basically current amplifiers. For each of the total 8 outputs we required a total of 8 separate TIP 122 transistors. The pulse from the microcontroller is given to the base of the transistors and the amplified current is taken as output from the collector terminal of the transistors.

As the pulse are given in sequence from the microcontroller so the stepper motors receive the pulse accordingly telling them which way to move and how many steps to move. This mechanism allows the whole system to continuously track the sun throughout the whole day.

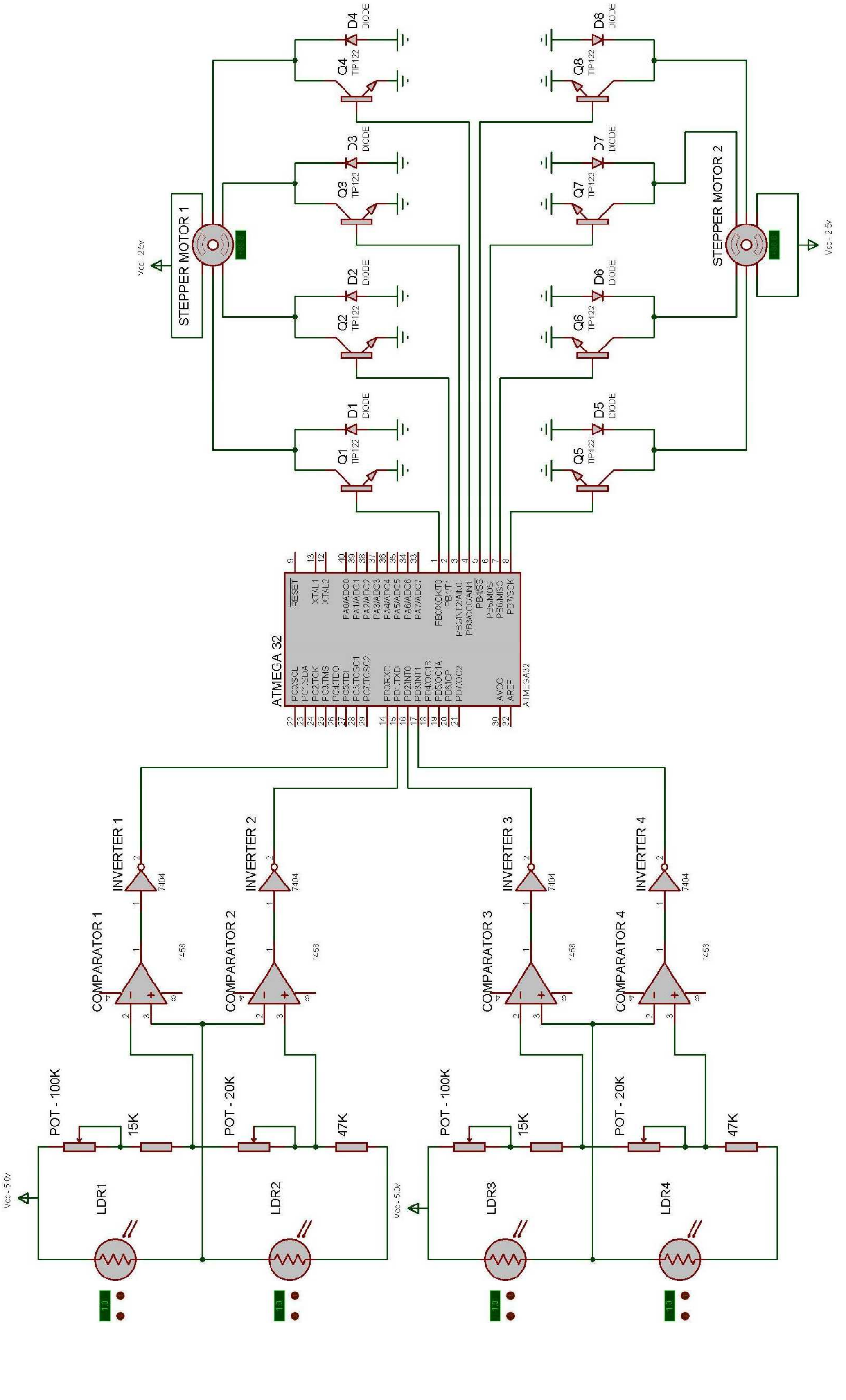

Fig. 5.13. Circuit diagram of the whole system

CHAPTER VI: ALGORITHM AND SOFTWARE

6.1 The algorithm of the system

To make our automatic solar tracker, we had to use a microcontroller from the AVR ATMEL family which will make decisions which way to move the whole structure in order to track the sun. For our purpose we used ATMEGA 32 microcontroller with 32 kilobytes of memory.

For the coding purpose, we had to use AVR Studio 4 which is a special kind of software specially made for microcontroller coding. The program is basically written in C language but for the microcontroller the syntax are a bit different from the general C coding. This is due to the fact that microcontroller has Pins that has to be specified so that we can take inputs or outputs from specific Pins. At first some standard libraries are called to use with the code and the speed of the microcontroller is defined. As we are using 4 pins to take inputs for the two pairs of sensors so it was necessary to understand which combination of inputs means what has to be done. With 4 inputs 16 different types of combinations are possible so code had to be written in such a way so that all 16 possibilities are scanned before giving output to move the whole structure. It was decided that we will use PORT D to take inputs and PORT B to give outputs because that are both on the same side of the microcontroller.

Before starting the coding, a list was made to understand which combination meant which motor has to be rotated in which direction. Just to give an example the combination ’1000’ means that motor 1 has to move in the forward direction and motor 2 will remain in a stop/stand still position. Again the combination ‘1001’ means motor 1 has to move in the forward direction and motor 2 moves in the reverse direction reverse. The first 2 bits in the combination like for the last example ‘10’ is for the motor 1 and the last 2 bits of the combination ‘01’ is for the motor 2 movement. It was taken to make things simple that ‘10’ would mean forward direction movement and ‘01’ would mean reverse direction movement. Also if anytime the inputs are like ‘0000’ or ‘0011’, this suggests that both the motors will be stand still that means both the two pairs of sensors are getting equal light so no movement is required. ‘00’ or ‘11’ refers to equal intensity of light falling on both the adjacent LDRs.

As we already know that each stepper motors require 4 pulse in order to make them work, so the code was written in such a way so that 4 pulse are given for each case. But again all the 4 pulse are not required always so before giving each of the 4 pulse, the microcontroller checks again if it really needs to give the next pulse. If required it gives the pulse or else it won’t give the pulse. The flowchart for our solar tracker and also the coding is given in figure 6.1.

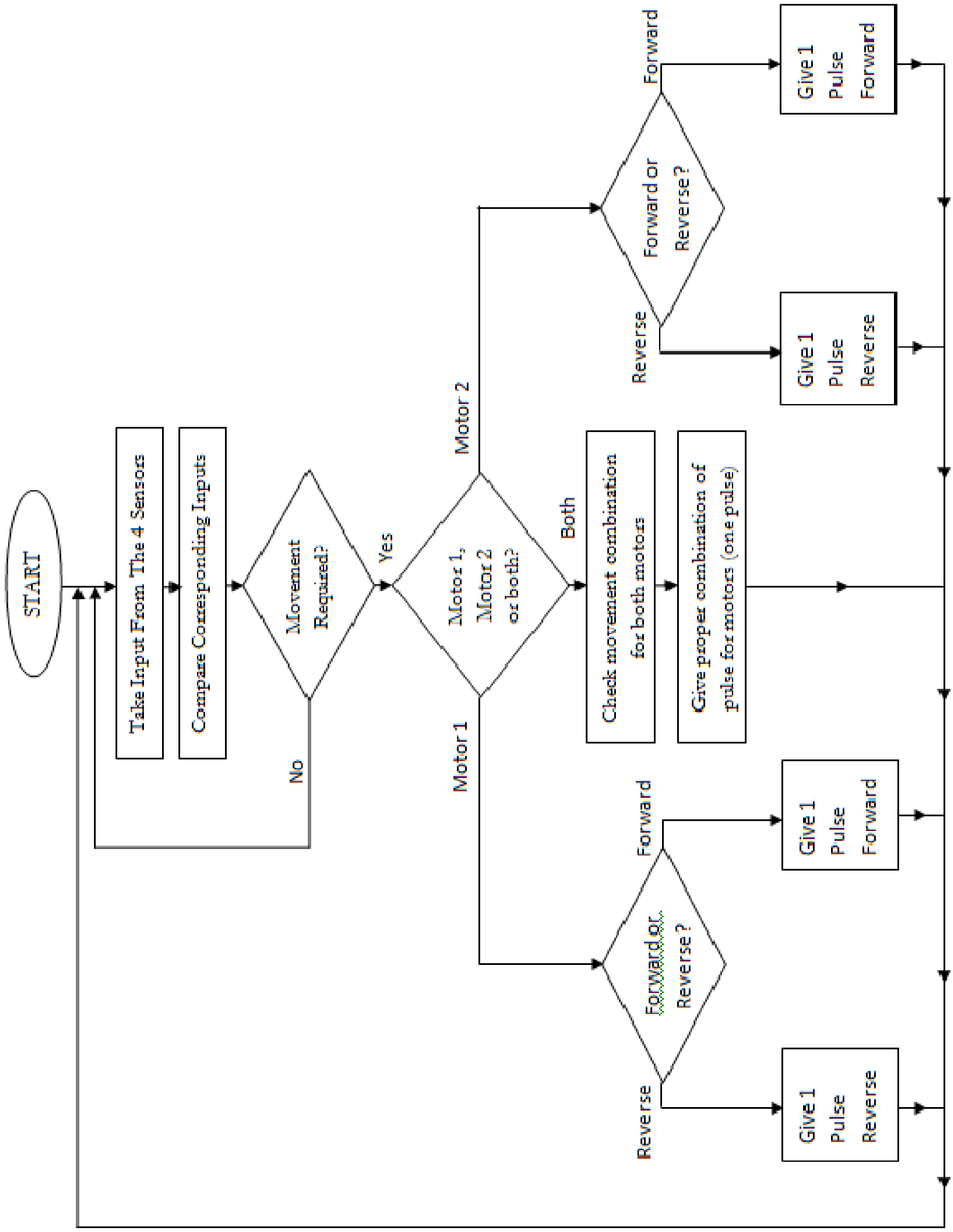

Fig. 6.1. Flowchart of the algorithm

6.2 Microcontroller code

```
#include <avr/io.h>
#define F_CPU 8000000UL
#include <util/delay.h>

/*

This code is copyright of the "Improvement of Efficiency In Solar
Photovoltaic Cell Applications" thesis group which is supervised by
Dr. AKM Abdul Malek Azad.
This code is copyright to the thesis members Raquib Ahmed,Khademul Islam and
Md. Raied Hasan

*/

void delay_ms(unsigned int ms){

   while(ms){
            _delay_ms(1.000);
            ms--;
            }
}



int main(){


DDRD=0b11110000;  //Input PIN 14,15,16,17
DDRB=0xFF; //PORTB is output, PIN 1-8


while(1){

if((PIND & 0b00000001) && (PIND & 0b00000010)
&& (PIND & 0b00000100) && (PIND & 0b00001000)){ // All 4 sensors have Equal Light,
No Movement

PORTB=0b00010001;

}else if(((PIND & 0b00000001) && (!(PIND & 0b00001110)))||
((PIND & 0b00000001) && (PIND & 0b00000100) && (PIND & 0b00001000))){ //Motor 1
Forward,
//Motor 2 Stop

if(((PIND & 0b00000001) && (!(PIND & 0b00001110)))||
((PIND & 0b00000001) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00010001;
delay_ms(500);
}

if(((PIND & 0b00000001) && (!(PIND & 0b00001110)))||
((PIND & 0b00000001) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00010010;
delay_ms(500);
}
```

```
if(((PIND & 0b00000001) && (!(PIND & 0b00001110)))||
((PIND & 0b00000001) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00010100;
delay_ms(500);
}

if(((PIND & 0b00000001) && (!(PIND & 0b00001110)))||
((PIND & 0b00000001) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00011000;
delay_ms(500);
}

}else if(((PIND & 0b00000100) && (!(PIND & 0b00001011)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00000100))){ //Motor 1
Stop,
                                                                      //Motor 2
Forward

if(((PIND & 0b00000100) && (!(PIND & 0b00001011)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00000100))){
PORTB=0b00010001;
delay_ms(500);
}

if(((PIND & 0b00000100) && (!(PIND & 0b00001011)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00000100))){
PORTB=0b00100001;
delay_ms(500);
}

if(((PIND & 0b00000100) && (!(PIND & 0b00001011)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00000100))){
PORTB=0b01000001;
delay_ms(500);
}

if(((PIND & 0b00000100) && (!(PIND & 0b00001011)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00000100))){
PORTB=0b10000001;
delay_ms(500);
}

}else if(((PIND & 0b00000010) && (!(PIND & 0b00001101)))||
((PIND & 0b00000010) && (PIND & 0b00000100) && (PIND & 0b00001000))){ //Motor 1
Reverse,
//Motor 2 Stop

if(((PIND & 0b00000010) && (!(PIND & 0b00001101)))||
((PIND & 0b00000010) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00011000;
delay_ms(500);
}

if(((PIND & 0b00000010) && (!(PIND & 0b00001101)))||
((PIND & 0b00000010) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00010100;
```

```
delay_ms(500);
}

if(((PIND & 0b00000010) && (!(PIND & 0b00001101)))||
((PIND & 0b00000010) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00010010;
delay_ms(500);
}

if(((PIND & 0b00000010) && (!(PIND & 0b00001101)))||
((PIND & 0b00000010) && (PIND & 0b00000100) && (PIND & 0b00001000))){
PORTB=0b00010001;
delay_ms(500);
}

}else if(((PIND & 0b00001000) && (!(PIND & 0b00000111)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00001000))){ //Motor 1
Stop,
//Motor 2 Reverse

if(((PIND & 0b00001000) && (!(PIND & 0b00000111)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00001000))){
PORTB=0b10000001;
delay_ms(500);
}

if(((PIND & 0b00001000) && (!(PIND & 0b00000111)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00001000))){
PORTB=0b01000001;
delay_ms(500);
}

if(((PIND & 0b00001000) && (!(PIND & 0b00000111)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00001000))){
PORTB=0b00100001;
delay_ms(500);
}

if(((PIND & 0b00001000) && (!(PIND & 0b00000111)))||
((PIND & 0b00000001) && (PIND & 0b00000010) && (PIND & 0b00001000))){
PORTB=0b00010001;
delay_ms(500);
}

}else if((PIND & 0b00000001) && (PIND & 0b00000100)){ //Motor 1 Foward,
                                                                 //Motor 2
Forward

if((PIND & 0b00000001) && (PIND & 0b00000100)){
PORTB=0b00010001;
delay_ms(500);
}

if((PIND & 0b00000001) && (PIND & 0b00000100)){
PORTB=0b00100010;
delay_ms(500);
}
```

```
if((PIND & 0b00000001) && (PIND & 0b00000100)){
PORTB=0b01000100;
delay_ms(500);
}

if((PIND & 0b00000001) && (PIND & 0b00000100)){
PORTB=0b10001000;
delay_ms(500);
}

}else if((PIND & 0b00000010) && (PIND & 0b00000100)){ //Motor 1 Reverse,
                                                                //Motor 2
Forward

if((PIND & 0b00000010) && (PIND & 0b00000100)){
PORTB=0b00011000;
delay_ms(500);
}

if((PIND & 0b00000010) && (PIND & 0b00000100)){
PORTB=0b00100100;
delay_ms(500);
}

if((PIND & 0b00000010) && (PIND & 0b00000100)){
PORTB=0b01000010;
delay_ms(500);
}

if((PIND & 0b00000010) && (PIND & 0b00000100)){
PORTB=0b10000001;
delay_ms(500);
}

}else if((PIND & 0b00000001) && (PIND & 0b00001000)){ //Motor 1 Forward,
                                                                //Motor 2
Reverse

if((PIND & 0b00000001) && (PIND & 0b00001000)){
PORTB=0b10000001;
delay_ms(500);
}

if((PIND & 0b00000001) && (PIND & 0b00001000)){
PORTB=0b01000010;
delay_ms(500);
}

if((PIND & 0b00000001) && (PIND & 0b00001000)){
PORTB=0b00100100;
delay_ms(500);
}

if((PIND & 0b00000001) && (PIND & 0b00001000)){
PORTB=0b00011000;
```

```
}else if((PIND & 0b00000010) && (PIND & 0b00001000)){ //Motor 1 Reverse,
                                                     //Motor 2
Reverse

if((PIND & 0b00000010) && (PIND & 0b00001000)){
PORTB=0b10001000;
delay_ms(500);
}

if((PIND & 0b00000010) && (PIND & 0b00001000)){
PORTB=0b01000100;
delay_ms(500);
}

if((PIND & 0b00000010) && (PIND & 0b00001000)){
PORTB=0b00100010;
delay_ms(500);
}

if((PIND & 0b00000010) && (PIND & 0b00001000)){
PORTB=0b00010001;
delay_ms(500);
}

}else{
PORTB=0b00010001;
}


}// End while
return 0;
}// End main
```

CHAPTER VII: EXPERIMENTS

The sole purpose of this thesis was to improve the efficiency of the solar photovoltaic cell applications. And for that purpose we adopted the automatic solar tracking system. During our thesis, we conducted various experiments to find out the feasibility of improving efficiency through automatic sun tracking system and with the results, we progressed to finalize the system. Alongside, we also conducted experiments to find out the characteristic curves of the solar panel.

7.1 Finding the characteristic curves of the solar panel:

This is the very first experiment we conducted in our thesis. This was a very important experiment because it is obvious that we must know about the characteristics of the panel with which we will be working on throughout our thesis.

The characteristics of solar panel are mainly determined by the current voltage curve (I-V curve) and power voltage curve (P-V curve). So, we carried out the experiments to determine those curves of the panel we worked with.

7.1.1 Current Voltage characteristic curve of the solar panel:

This experiment was carried out in a very basic manner. It is obvious that to find a current verses voltage curve, we need to change the load against the solar panel and take the corresponding current and voltage reading. We gradually changed the load across the terminals of the solar panel and took reading of the current and voltage for that specific load. Sets of voltage and current values are taken by gradually increasing the load. The values which we got from the experiments are shown in the table 7.1.

Table 7.1
Voltage and current with varying load

Voltage / V	Current/ mA
0	166.5
4.65	159.7
6.19	160.4
9.05	158.7
11.82	156.7
16.5	147.1
17.5	121.2
17.8	116.1
18.1	104.3
18.6	80.8
19.1	54.7
19.3	41.5
19.4	33.2
19.5	27.7
19.6	23.8
19.7	18.6
19.8	8.4
20.3	0

After getting the entire required datum, we used MATLAB© (version R2007) to construct the I-V curve (figure 7.1).

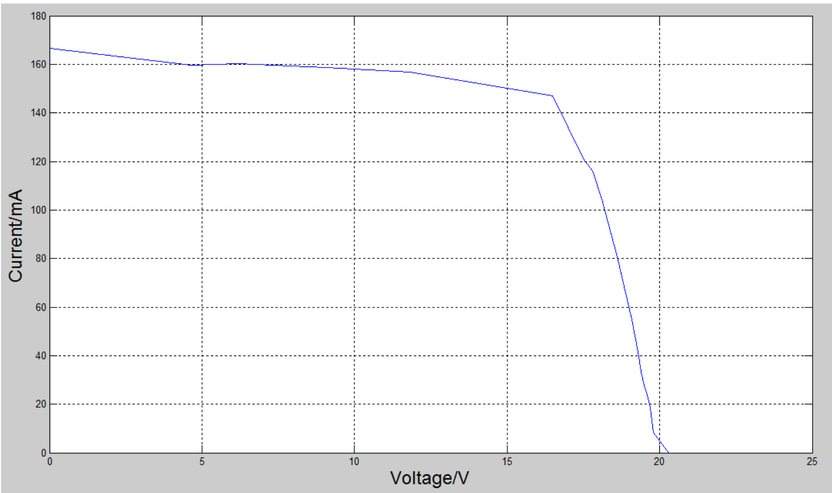

Fig. 7.1. I-V characteristics curve

7.1.2 Power Voltage characteristic curve of the solar panel:

Solar panel's most important parameter is the amount of output power that it can efficiently deliver. And that is why power verses voltage curve is very crucial. The rated power of the panel that we used for the project is 3 watt. But we expected the power to be less than that because of the inefficiency of the cells of the panel and also because of some loses due to the internal resistance of the panel and the wiring. But since we need to know the maximum power output of our panel, we had to find the power voltage characteristic curve of our panel.

For this panel, we did not need to conduct any experiment since we can relate power with the voltage and current that we have found in the previous experiment. We know that:

Power = Voltage x Current (P = VI)

Hence, we can easily find the power of the corresponding voltage by simple taking the product of the current and voltage. The table is shown in table 7.2.

Table 7.2
Power and voltage with varying load

Voltage / V	**Power/mW**
0	0
4.65	742.605
6.19	992.876
9.05	1436.235
11.82	1852.194
16.5	2427.15
17.5	2121
17.8	2066.58
18.1	1887.83
18.6	1502.88
19.1	1044.77

19.3	800.95
19.4	644.08
19.5	540.15
19.6	466.48
19.7	366.42
19.8	166.32
20.3	0

After calculating all the powers, we again used MATLAB© (version R2007) to plot the P-V curve (figure 7.2).

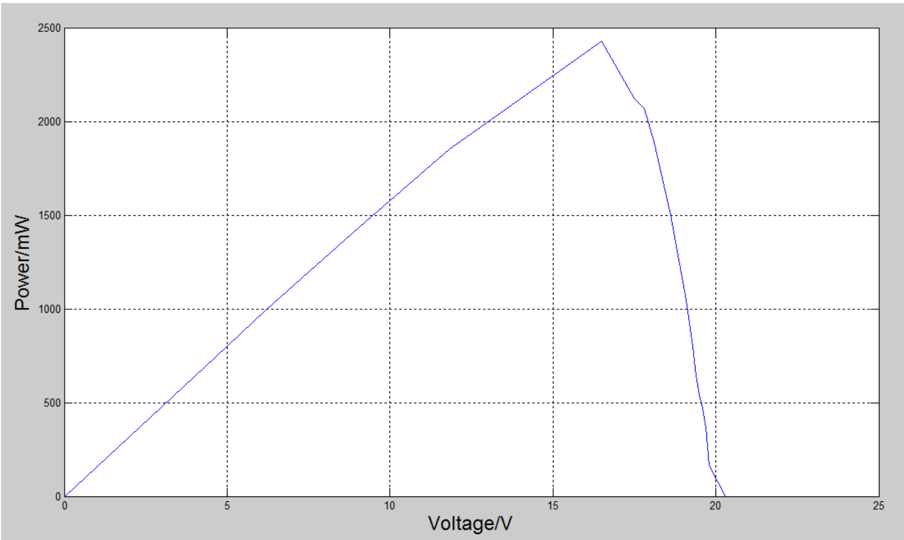

Fig. 7.2. P-V characteristics curve

7.1.3 Analysis of the curves:

The graphs which we obtained are the expected ones. From the I-V curve, we can find that the maximum voltage that our panel can attain is 20.3V, which is also known as the open circuit voltage and the maximum current of the panel is 166.5mA, which is known as the short circuit current of the panel. Also we can see from the P-V curve that the maximum energy of our solar panel is almost 2400mW attainable at a load of approximately 120 ohm load.

$$2400 = 17 \times I$$

$$I = 2400/17 = 141.18 \text{ mA}$$

$$17 = R \times (141.18 \times 10^{-3})$$
$$R = 120 \text{ ohm (approx.)}$$

So for this specific panel, we need to use a load closer to 120ohm to get the maximum power output from the panel.

7.2 Characteristics of the individual cells of the panel:

This experiment was carried out to find out how each of the individual cell behaves to the sunlight and their impact on the open circuit voltage (Voc) and short circuit current (Isc).

Out panel is a 36 cells polycrystalline type solar panel. In this experiment, we covered the whole panel with a light impenetrable card board and then exposed one row of crystals (consisting of two crystals), taken the Voc and Isc reading and then kept on exposing two crystals at a time and taking the corresponding readings.

7.2.1 The readings:

Here, we got 18 sets of reading (2 crystals were exposed at a time) consisting of three parameters: no. of crystals exposed (no. of modules), Voc (open circuit voltage) and Isc (short circuit current). Here we are considering that 2 crystals are making up one module of solar panel. Thus there are 18 modules of solar cells. The data are shown in table 7.3.

Table 7.3
Number of modules exposed, open circuit voltage and short circuit current

No. of modules	Voc/V	Isc/A
1	6.5	0.068
2	7.78	0.085
3	9.12	0.102
4	10.2	0.113
5	11.01	0.128
6	11.48	0.133
7	12.47	0.146

8	13.31	0.158
9	14.25	0.168
10	15.3	0.182
11	16.09	0.192
12	16.81	0.2
13	17.74	0.212
14	18.44	0.22
15	19.06	0.228
16	19.61	0.235
17	19.94	0.239
18	20	0.241

7.2.2 The experimental curve:

Since there are three parameters in this experiment, we had to use the 3 dimensional graph plot using MATLAB© (version R2007). The graph we obtained is show in figure 7.3.

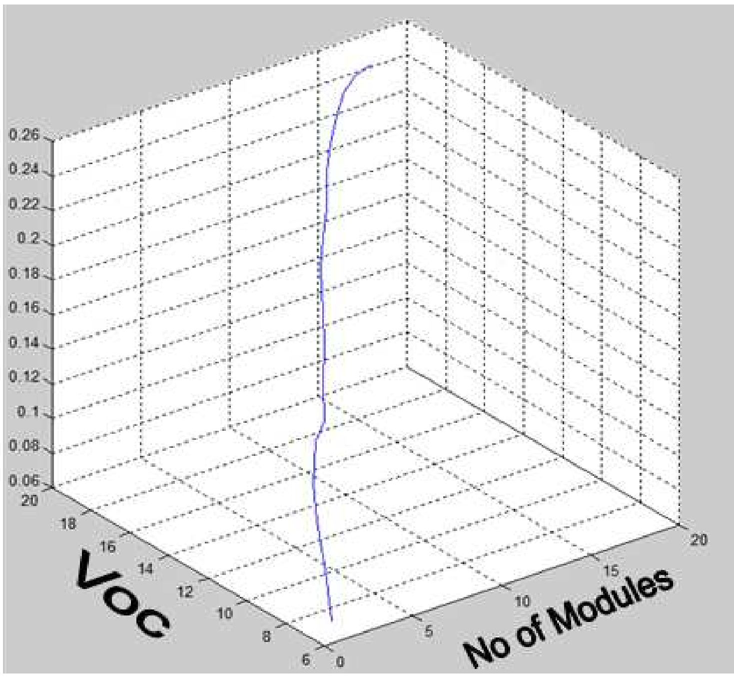

Fig. 7.3. The 3 watt panel (left) and the 3 dimensional graph (right)

7.2.3 Conclusion from the experiment

We did not have any reference on how the characteristics would be. But the result we got and the 3 dimensional curve is quite logical so came to conclusion that the three parameters are linearly co-related among each other. Since this is not an ideal case and there were some internal loses, the curve is not perfectly linear but from what we got, we can conclude that a linear relationship exists between the three parameters.

7.3 Effect of shadow on the output of solar panel:

This was a very important experiment for our project. Since we were dealing with efficiency of solar panel, one of the prime reasons for the efficiency to be minimal is because of the shadow falling on the panel when the sun moves away. So we needed to know who a shadow would affect the output of the panel.

7.3.1 The process of the experiment:

The process of the experiment is quite simple. We used a light impenetrable object to cast shadows at different lengths from the panel and took the open circuit voltage and short circuit current of the panel. After getting enough data to satisfy our requirement, we plot a graph to see the results.

7.3.2 The results and the graphs:

Table 7.4
Variation of Voc and Isc with the distance of the object

Distance of the object	Voc/V	Isc/mA
6in	17.31	14
1ft	17.88	19.2
2ft	17.89	24.5
5ft	18.15	27
6.5ft	18.3	29.5

After tabulating the above data, we used Microsoft Excel to plot two bar diagrams since they can illustrate the phenomenon much better than line graph (figure 7.4 and figure 7.5).

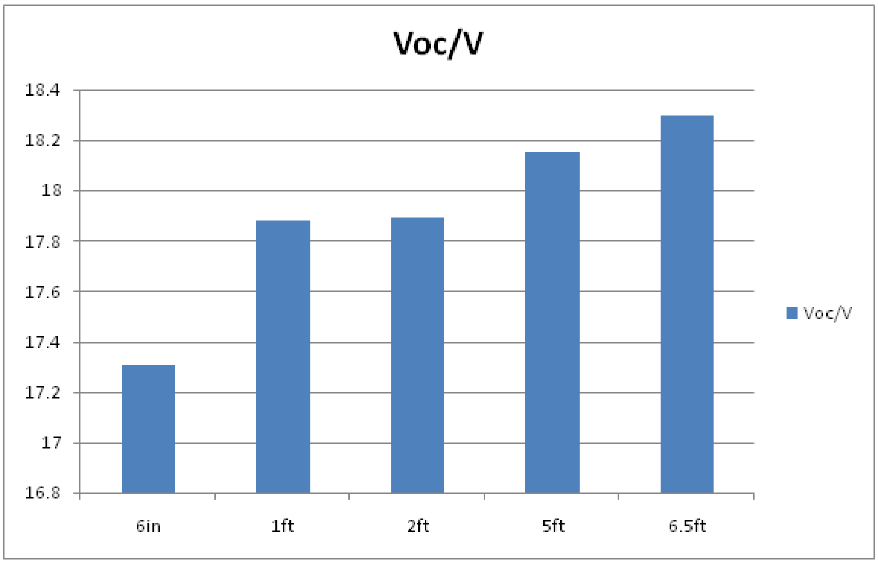

Fig. 7.4. Voc vs. distance bar chart

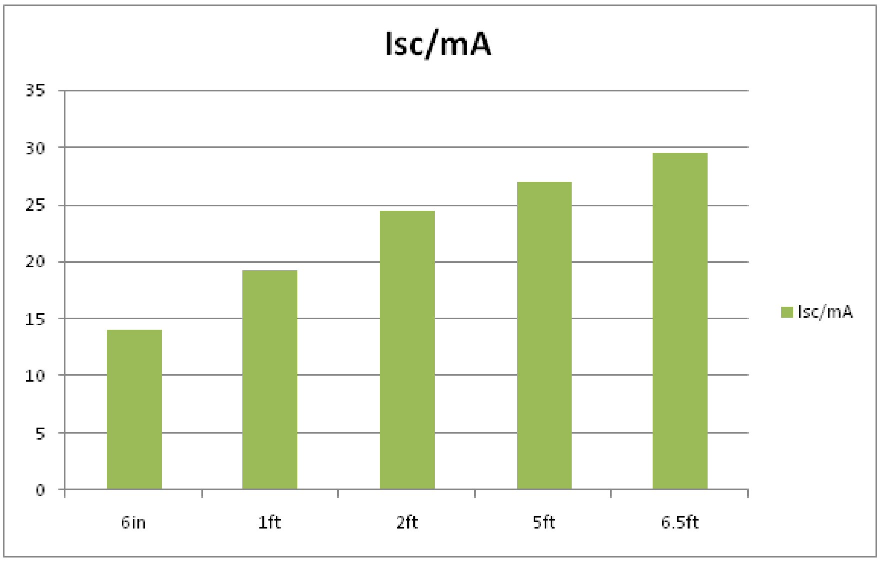

Fig. 7.5. Isc vs. distance bar chart

7.3.3 Conclusion from the experiment

In both the cases, we can see that open circuit voltage and short circuit current increases as the object that is casting the shadow moves away from the panel. But, the notable change is in current. Current varies more with the shadow than the variation of voltage.

Current is the most important factor since it is the main parameter which determines the rate of charging a battery. So shadow causes a major drawback in how quickly the panel can charge the load battery – a prime factor which inspired us for the automatic solar tracking system which can easily overcome the shadow problem.

7.4 Power improvement of movable solar panel

This is the most important experiment of our thesis which proves the feasibility of our project. We took the whole day readings of the voltage and current from two different solar panels: our 3w panel and an industrial 50w panel [20] to see how sun tracking mechanism can improve the efficiency by manually moving the panels to face the sun and also took the readings for fixed positions of the panel. Alongside, we have also tested our automatic solar tracking system to see how it behaves.

7.4.1 Output of fixed 3 watt and 50 watt panels

At the beginning of the day, we marked a spot which we considered to be the fixed position for the panels. After every 30 minutes, we put the panel in the position and took the current and voltage readings through and across the load respectively. For the 3 watt panel, the load we used was a 100 ohm resistor (since the panel gives maximum power output at a load around 120 ohm) and the bigger 50w panel had a 12 volt battery connected to it. The results for both the panels are shown in table 7.5 and table 7.6.

Table 7.5
Change of output power of 3 watt panel with time (fixed)

Time	Initial		
	Volt/V	**Current/mA**	**Power/W**
11:15am	11.9	104	1.2376
11:45am	13.43	118.3	1.588769
12:15pm	12.6	111.1	1.39986
12:45pm	12.29	106.3	1.306427
1:15pm	12.45	110	1.3695
1:45pm	11.6	101.2	1.17392
2:15pm	9.21	80.5	0.741405
2:45pm	9	79.5	0.7155
3:15pm	7.75	55.9	0.433225
3:45pm	4.88	41.1	0.200568
4:15pm	3.4	28.8	0.09792
4:45pm	2.59	21.9	0.056721

Table 7.6
Change of output power of 50 watt panel with time (fixed)

Time	Initial		
	Volt/V	**Current/A**	**Power/W**
11:15am	13.8	1.55	21.39
11:45am	14	1.74	24.36
12:15pm	13.8	1.44	19.872
12:45pm	13.14	1.5	19.71
1:15pm	13.29	1.76	23.3904
1:45pm	13.39	1.62	21.6918
2:15pm	13.18	0.96	12.6528
2:45pm	13.18	1.19	15.6842
3:15pm	12.93	0.82	10.6026
3:45pm	12.8	0.51	6.528
4:15pm	12.88	0.3	3.864
4:45pm	13.19	0.22	2.9018

7.4.2 Output of adjusted 3 watt and 50 watt panels

Besides taking data for the fixed position, we also adjusted the panels to face the sun so that lights from the sun fall orthogonally on the panel and took the readings in the same way as that of fixed position experiment. The data are in the table 7.7.

Table 7.7
Change of output power of 3 watt panel with time (manual adjustment)

Time	Adjust		
	Volt/V	**Current/mA**	**Power/W**
11:15am	11.9	104	1.2376
11:45am	13.64	121.5	1.65726
12:15pm	13.43	119.6	1.606228
12:45pm	14.52	128.3	1.862916
1:15pm	15.2	133.5	2.0292
1:45pm	15.29	136	2.07944
2:15pm	13.43	119	1.59817
2:45pm	12.1	103	1.2463
3:15pm	11.36	96.8	1.099648
3:45pm	8.67	72.6	0.629442
4:15pm	6.82	57.4	0.391468
4:45pm	5.32	44.8	0.238336

Table 7.8
Change of output power of 50 watt panel with time (manual adjustment)

Time	Adjusted		
	Volt/V	**Current/I**	**Power/W**
11:15am	13.8	1.55	21.39
11:45am	13.9	1.74	24.186
12:15pm	13.44	1.83	24.5952
12:45pm	13.12	2.01	26.3712
1:15pm	13.48	2.13	28.7124
1:45pm	13.52	2.27	30.6904
2:15pm	13.11	1.84	24.1224

2:45pm	13.1	2	26.2
3:15pm	13.06	1.68	21.9408
3:45pm	12.85	1.05	13.4925
4:15pm	13.01	0.99	12.8799
4:45pm	13.23	0.62	8.2026

7.4.3 Output of the 3 watt panel using automatic sun tracking system

Since the prototype that we have constructed is for the 3 watt panel, we took it to the roof to test how the system automatically adjust itself to face the sun and took the same readings as that of fixed and manual adjustment readings. The data are tabulated in table 7.9.

Table 7.9
Change of output power of 3 watt panel with time (automatic adjustment)

Time	Auto		
	Volt	**Current**	**Power/W**
11:15am	13.98	0.121	1.6958
11:45am	14.2	0.129	1.8318
12:15pm	14.02	0.136	1.90672
12:45pm	13.5	0.147	1.9845
1:15pm	12.64	0.14	1.7696
1:45pm	13	0.13	1.69
2:15pm	10.37	0.1	1.037
2:45pm	10.51	0.11	1.1561
3:15pm	8.18	0.08	0.6544
3:45pm	7.8	0.08	0.624
4:15pm	2.2	0.02	0.044
4:45pm	2.3	0.01	0.023

7.4.4 Current voltage bar graph of the experiments

Below are the bar diagrams (figure 7.6-7.9) of voltage verses time and current versus time for 3 watt panel and 50 watt panel.

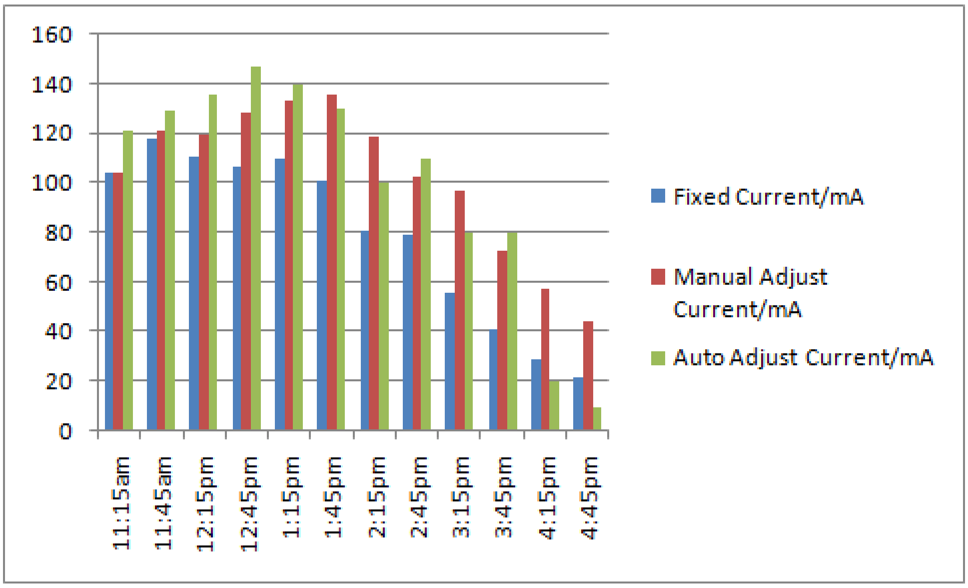

Fig. 7.6. Current vs. time for 3 watt panel

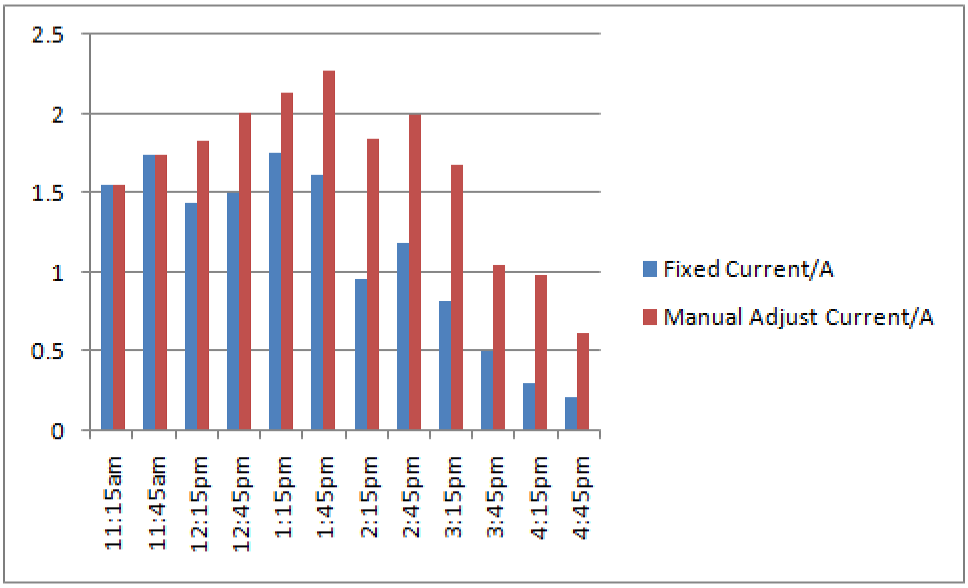

Fig. 7.7 Current vs. time for 50 watt panel

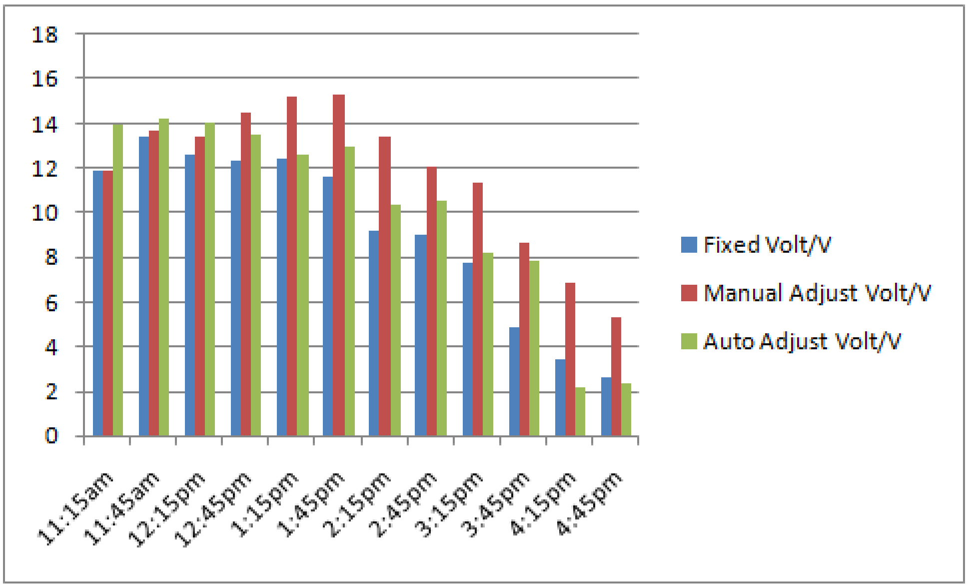

Fig. 7.8. Voltage vs. time for 3 watt panel

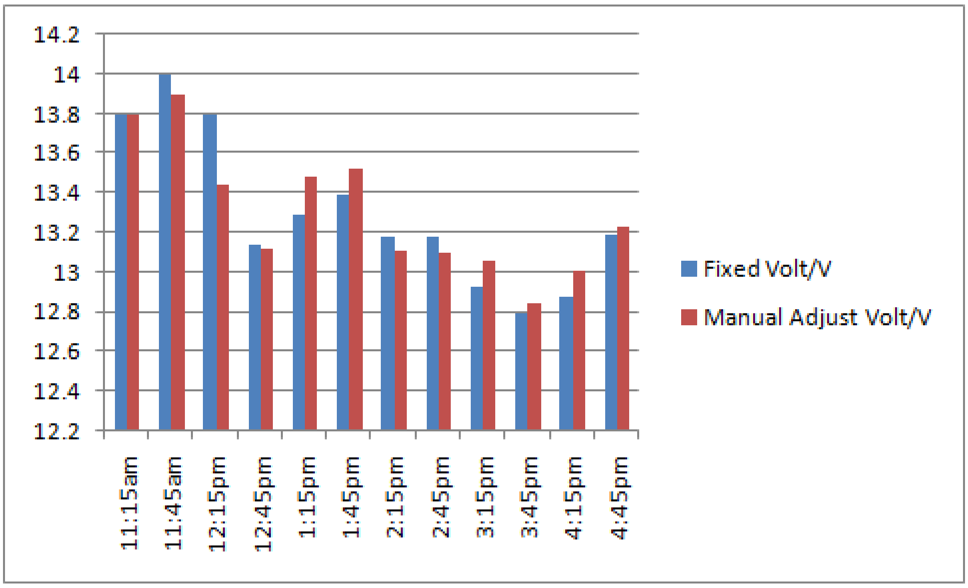

Fig. 7.9. Voltage vs. time for 50 watt panel

7.4.5 Power output of the 3 watt panel and the 50 watt panel

This was the main result for which we conducted this experiment – to find out how much more power we can get by manually adjusting the panel and how much more power our automatic sun tracking system can actually give. This part of the experiments can prove that moveable arrays of solar panel can significantly improve the efficiency of solar panel.

Below is the line graph (figure 7.10) of the three phenomenon (fixed, manual adjustment and auto adjustment) of the 3 watt panel:

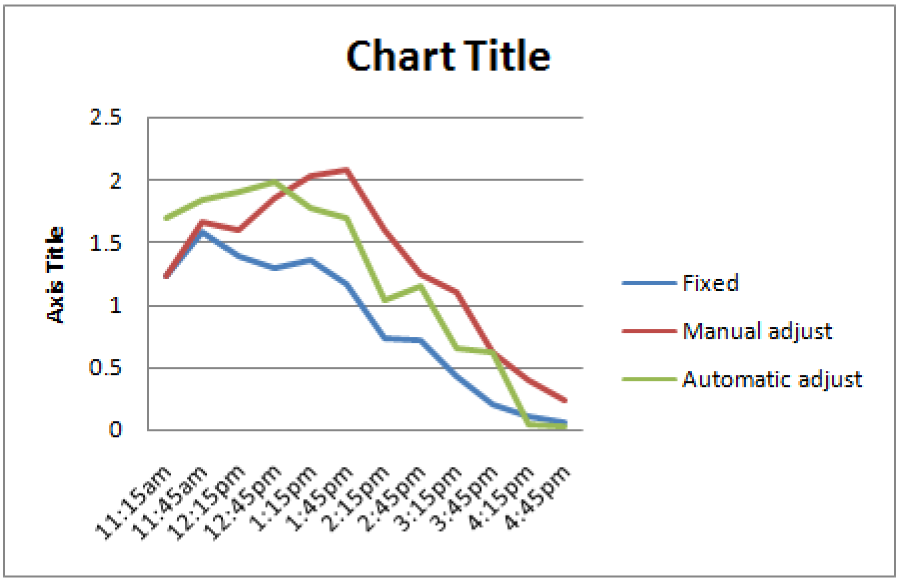

Fig. 7.10. Power vs. time curve for 3 watt panel

From the graph, we used trapezium rule in MATLAB© (version R2007) to find out the total area and hence total power under each of the line graph. Then using the fixed solar panel as the base condition and used it to find how much more power we are getting by manual adjustment and automatic adjustment. The calculations are as follow:

Total power of the fixed panel = 10.32142 watt

Total power of the manually adjusted panel = 15.67601 watt

Total power of the automatically adjusted panel = 14.41692 watt

Power improvement by manually adjusting the panel:

{(15.67601 –10.32142)/10.32142} x 100 = 52% (approx.)

Power improvement by automatically adjusting the panel:
{(14.41692 – 10.32142)/10.32142} x 100 = 40% (approx.)

So, from the above calculation, we found out that our system is approximately 40% more efficient than a fixed array of solar panels.

Below (figure 7.11) is the line graph of two phenomenons (fixed and manual adjustment) of the 50 watt panel:

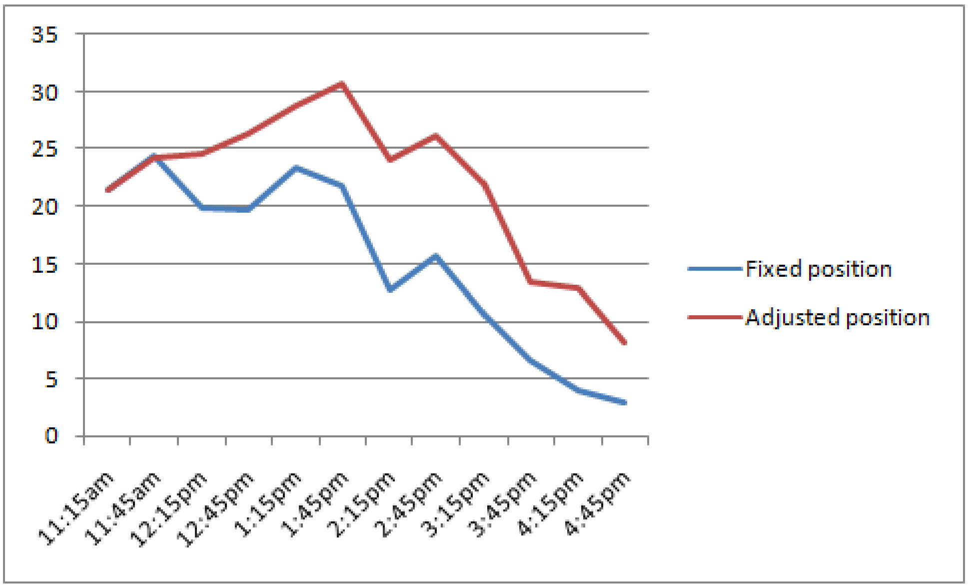

Fig. 7.11. Power vs. time curve for 50 watt panel

In the similar way, we found out the power improvement for the 50 watt panel.

Total power of the fixed panel = 182.7 watt
Total power of the manually adjusted panel = 259.78 watt
Power improvement by manually adjusting the panel:
{(259.78 – 182.7)/182.7} x 100 = 42% (approx.)

7.4.6 Conclusion from the experiment

So from the experiment, we get the clear results to prove that moveable arrays of solar panel can improve the efficiency around 40% and more which is almost 1.5 times more than the amount we get from a fixed panel. Thus, it can be concluded that it is feasible and practical to make the solar panel moveable to make it more efficient because at the current moment of the world, even a 1% improvement would be worthy – and the automatic sun tracking system can be of 40% more efficient than fixed panels; an appropriate way to harvest more solar energy.

CHAPTER VIII: IMPLEMENTATION AND DISCUSSION

8.1 Positioning the sensors:

System overview, hardware constructions, circuitry and codes are all described in the previous chapters. But the main implementation of the system relies on the sensors which will be giving the feed to the microcontroller to adjust the position accordingly.

The positioning of the sensors was very important since their position would eventually determine how the system is going to adjust with the change in position of the sun. For each axis movement, two sensors are responsible. So in total, we have four sensors in our system. The sensors are arranged and their sensitivity is set in such a way (through trial and error method using a torch light) that only when the concentrated beam of the light in at the equilibrium point (as shown in the figure 8.1), only then will the system be at no movement condition. Else, if the beam moves in any of the possible directions, the panel will adjust automatically depending on the quadrant where the light beam is concentrated on.

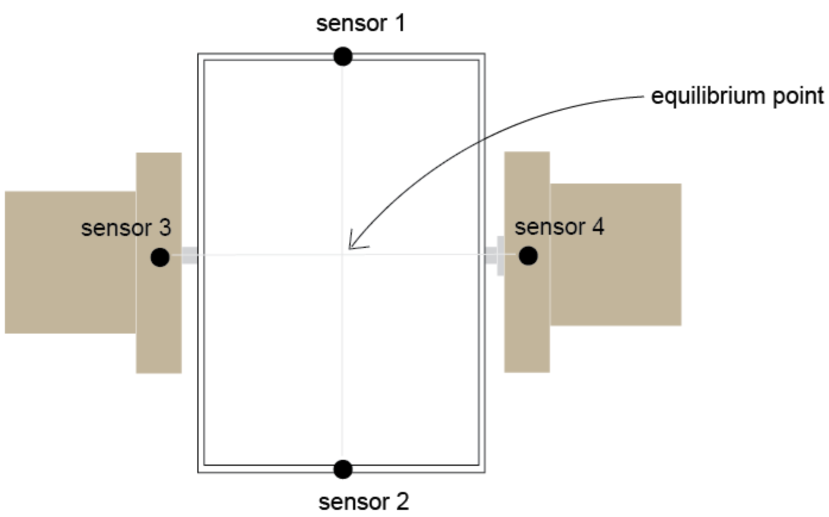

Fig. 8.1. Arrangement of sensors

Alongside, we also had to put cylindrical shapes (figure 8.2) around the sensors so that slight change in sunlight can be detected by the sensors. The illustration of the cylinder is shown below:

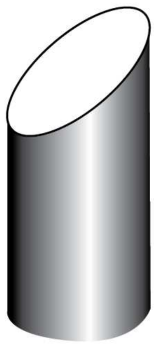

Fig. 8.2. Illustration of the cylindrical figure

8.2 Methodology of the system

As mentioned earlier, the sensors are the main feedback of the system. All the inputs are directly handled by the four LDR (light dependent resistors) mounted on the panel holder. Each pair of sensors is then used to compare the direction where the intensity of the light is more and the two comparators trigger the microcontroller accordingly. And the microcontroller sends the required pulse in the required direction to the motor(s) and this method continues till the comparators cannot find any difference in light from the sensors.

All the signals and pulses that are processed within our methodology are purely dc (direct current) type with voltages ranging from 2.5v to 5v. All the triggers to the stepper motors are direct current 8 bit pulses.

8.3 Limitation of the system

The main aim of our thesis was to prove that signification percentage of efficiency can be improved by using solar tracking mechanism. And for that, we aimed to develop a prototype of the system which can help us to accomplish our objective.

The sun tracking mechanism that we developed is efficient and reliable but there are few limitations of it.

1. It required external DC supply to run the motors and circuitry.
2. The motors we used consumed a lot of current compared to the panel which we used.
3. The 3 watt panel that we used was not enough to charge any form of sealed lead acid (SLA) battery that is generally used to in solar home systems.
4. The lower stepper motor, while moving the base, executed a lot of jerking effect in which we believed that lots of energy is wasted.
5. The whole system is quite bulky for a 3 watt panel.

Despite all the above limitations mentioned, the prototype did accomplish the purpose of our thesis.

8.4 Paper based on this thesis "Output power improvement of photovoltaic cell using automatic sun tracking system":

During our thesis, we had our first publication based on our readings and works were accepted in "International conference on renewable energy: generation and application" (ICREGA '10) held in Al-Ain, U.A.E during 8-10th March, 2010. We attended the conference and people over there really appreciated our project and the results that we got .

8.5 Problems faced and the solutions

The complexity of our project was very challenging for us. First of all, solar energy was something with which we were very unfamiliar with. How a solar panel works, the characteristics of the panel, the parameters which determines how the panel would behave – all these things were very vague to us. As a result, lots of studies had to be done before we got ourselves familiar to this form of renewable energy.

Then was the challenge of learning about the basics of stepper motor and how to drive it since this type of motor was very new to us. But because of the rich information available on the web, we familiarized ourselves with stepper motor.

Stepper motor requires sequential DC pulses to generate rotational flux. As a result it requires external driver circuit. Previously, another thesis group which worked with stepper motor used ULN2003 IC to drive the stepper motor. But the problem with this specific driver IC is that it could not provide the high current required by our stepper motors which caused the IC to overheat and burn. After lots of searching, we found a solution and that was to use individual darling pair IC, TIP122, to drive each phase of the motor.

Designing the model was not a big problem but building it up was very challenging. Atfirst, we constructed the panel holder but the problem was how to mount the panel with the construction. The first mechanism which we used was very inefficient, caused many miss steps so we could not adopt that. Later we were able to make a shaft locking mechanism between the panel and the motor’s shaft which solved the problem.

When the panel holder worked as expected, we moved to the construction of the base. The construction was fairly simple but the main problem came when we had to fix the two parts together. We tired wheels between the air gaps of the two parts but the friction was much more than the work that the lower stepper motor could do. We tried to figure out many different ways to reduce it: using various forms of wheels, lubrication on the surface on which the wheels needed to rotate and bearing. But none of them worked accordingly. So we left the air gap only without any form of support in it and the motor could rotate the top panel with ease.

Microcontroller is the backbone of our whole system. Feeds from the sensors are taken and microcontroller does the rest of the job of assigning which motor should the pulses. The microcontroller which we used, ATmega32, was reasonably easy to understand but the programming was a big issue for us. We learnt Java in the courses but the microcontroller required the knowledge of C programming. That was also something new which we had to get familiar with.

Weather was a big issue for all of our experiments. Sometimes, we had to repeat our experiments because of the unfavorable weather conditions. Although solar energy harvesting should be possible in all form of weather conditions, we had to know how much more energy we can harvest in our project rather than the worst case scenario and hence it was a big factor for us.

There were some issues with the circuitry like the calibration of sensors using variable resistor (pot) which would eventually change even with a slight movement of the circuit and the interfacing of the sensors with the microcontroller.

8.6 Future works

Currently, Bangladesh is going through a major electricity crisis. Government is taking various projects on implementing solar panels to provide a secondary method to provide electricity. But for the time being, all the projects are collecting solar energy and storing them to a DC battery instead of using the energy to support a locality through grid.

In many developed countries, solar arrays are connected to grids and from there; the energy is distributed to the neighborhood. This technology is yet to come to our country.

Also, those grids are supported by moveable arrays of solar panels so that maximum output can be harvested. But unfortunately, all the panels that are currently used in our country are all fixed arrays and thus energy depletes with the sun changing its position. Importing sun tracker from abroad would make solar home system even more expensive.

We have made the tracker a prototype to see whether it actually can increase the efficiency by significant amount and since it does, we can now think of commercializing it.

Our prototype needs DC source to work but that would be much unexpected if we do not find an alternative for this. So we will have to make this model better in such a way that it can drive the motor and the consumers at the same time without any requirement of external power supply.

Also, we have plans for implementing the whole system in a larger scale and in a more efficient way (in both commercial and economical way) and carry out further research on it to see how much feasible and beneficent it can be for our country. Our country is in a severe power crisis and we can expect this to rise to an unbearable level if something is not done soon enough. Being a sunny country (statistically it is shown that Bangladesh is exposed to intense sunlight for around 300 days per year), we can utilize this rarely used form of energy to our own benefit.

CHAPTER IX: CONCLUSION

Firstly, we chose to work on solar project because of the enormous scope of development and implementation in our country. Because of this marvelous form of harvesting energy, many houses in rural areas can now enjoy the blessing of electricity.

But solar energy utilization in rural area is not the answer to the question throw by solar energy. We have to harvest it efficiently and use it to our full benefit. And through our thesis, we effectively tried to propose the solar panels to have sun tracking mechanism. Although this technology is nothing new to this world but it is something new for our country.

Commercially, two axis sun tracking is still rare even in countries where a significant part of electricity is being generated by solar energy as they claim that single axis tracking is doing the job. But dual axis tracking can significantly increase the efficiency – the prime objective of our thesis.

Through our experiments, we have found that dual axis tracking can increase energy by about 40% of the fixed arrays. With more works and better systems, we believe that this figure can raise more. And since the world will face energy crisis because of the limited amount of resources in the future, it is always wise to start early. Even 1% improvement in efficiency would save tons of fuels and ores in a year and that is not a small amount.

Solar energy is unlimited, solar panels are easy to maintain and has a very long lifetime. All these favor the use of it in our country. With a system that can track the sun – this renewable energy can be harvested even more efficiently and maybe two houses can be supplied with electricity using the panel that could only support one house without any tracking mechanism. We hope that there will be more research on this and our country will move forward to implement sun tracking system to minimize the electricity crisis that is hitting us at the very moment.

List of references

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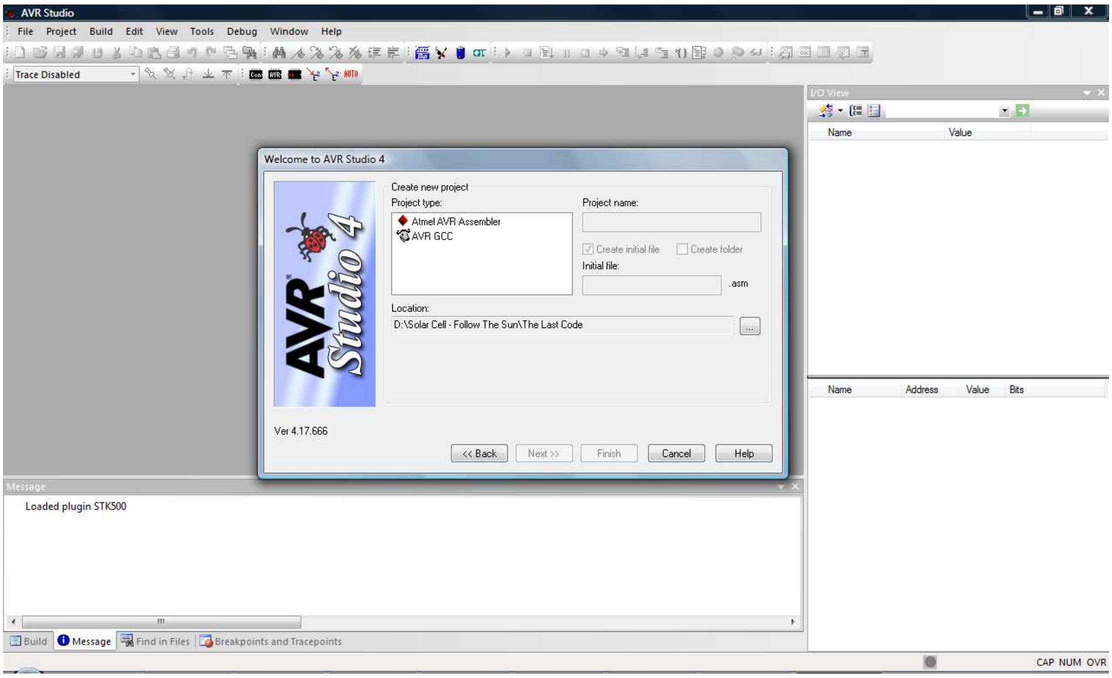
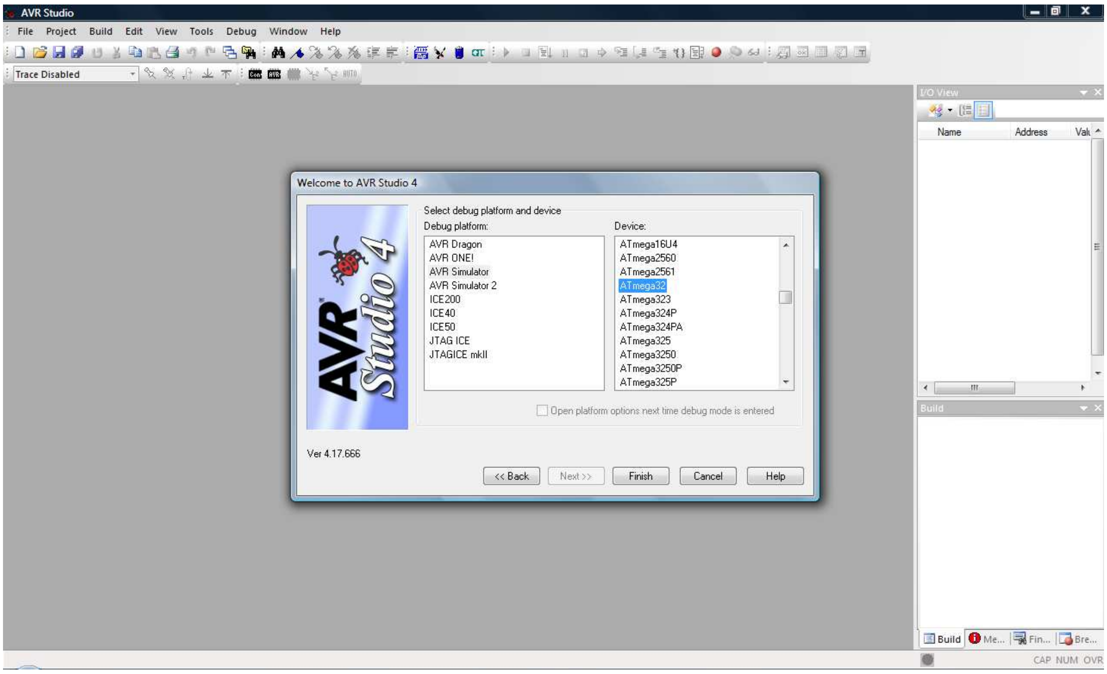
APPENDIX A

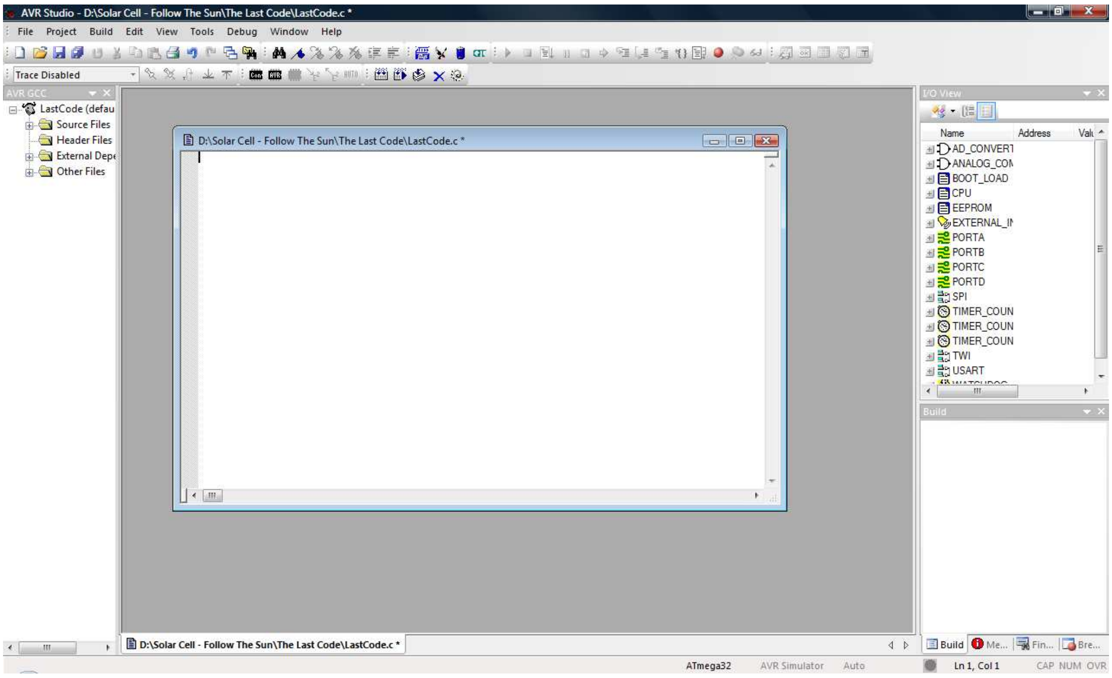
Screenshots of Programming



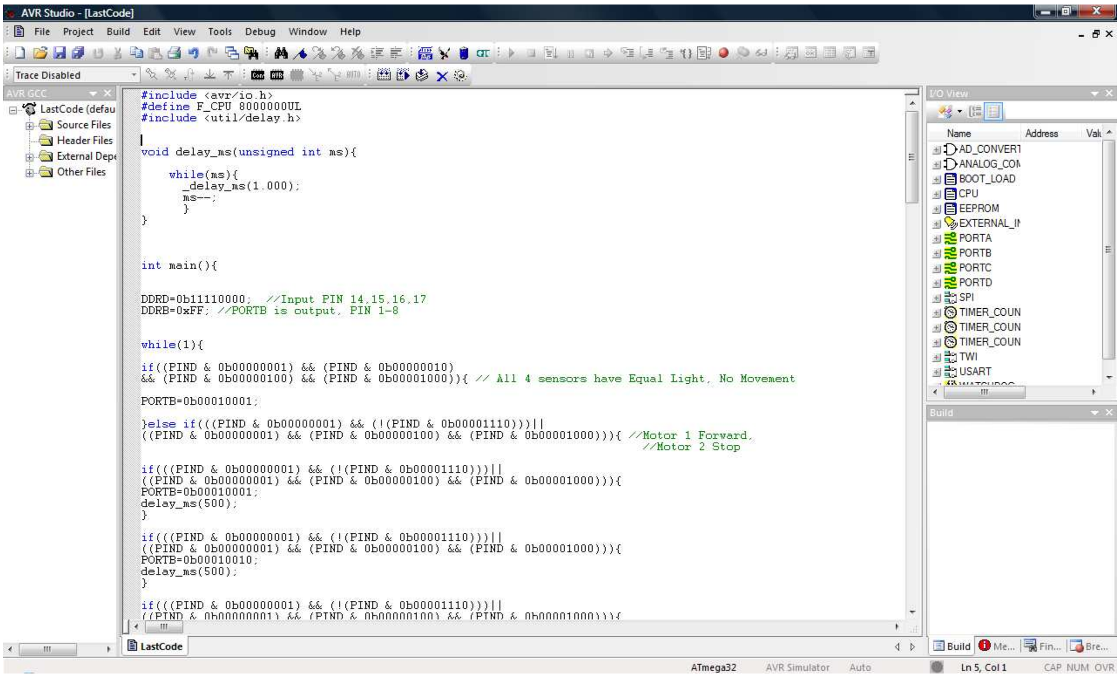
Opening AVR Studio 4.0



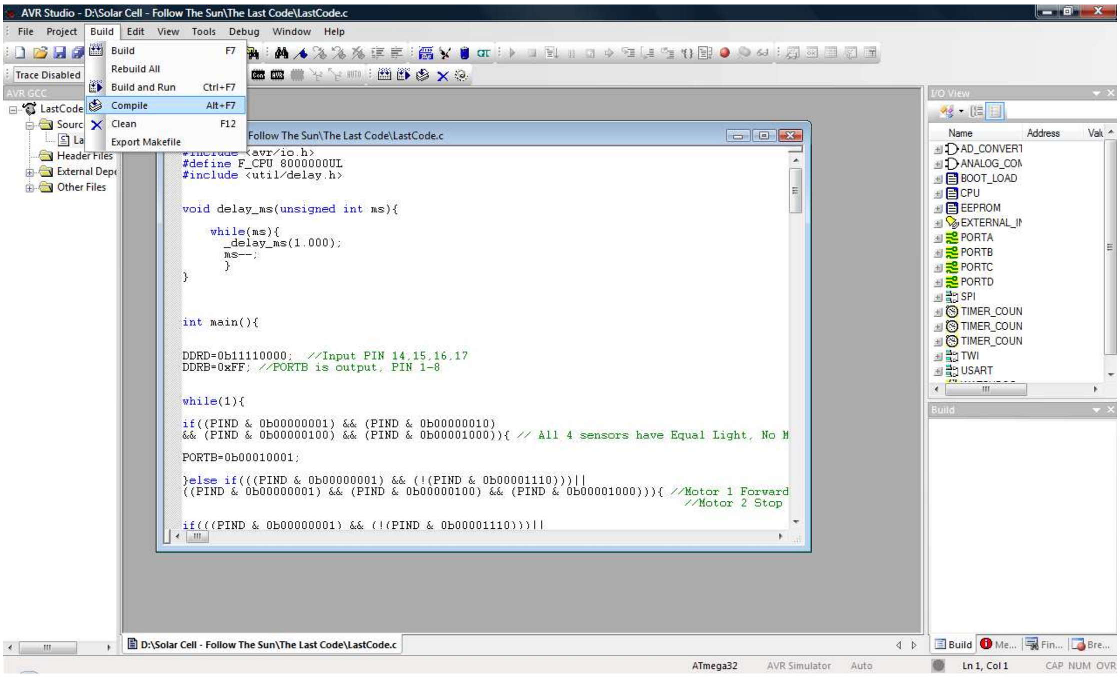
Selecting ATMEGA 32 as Device



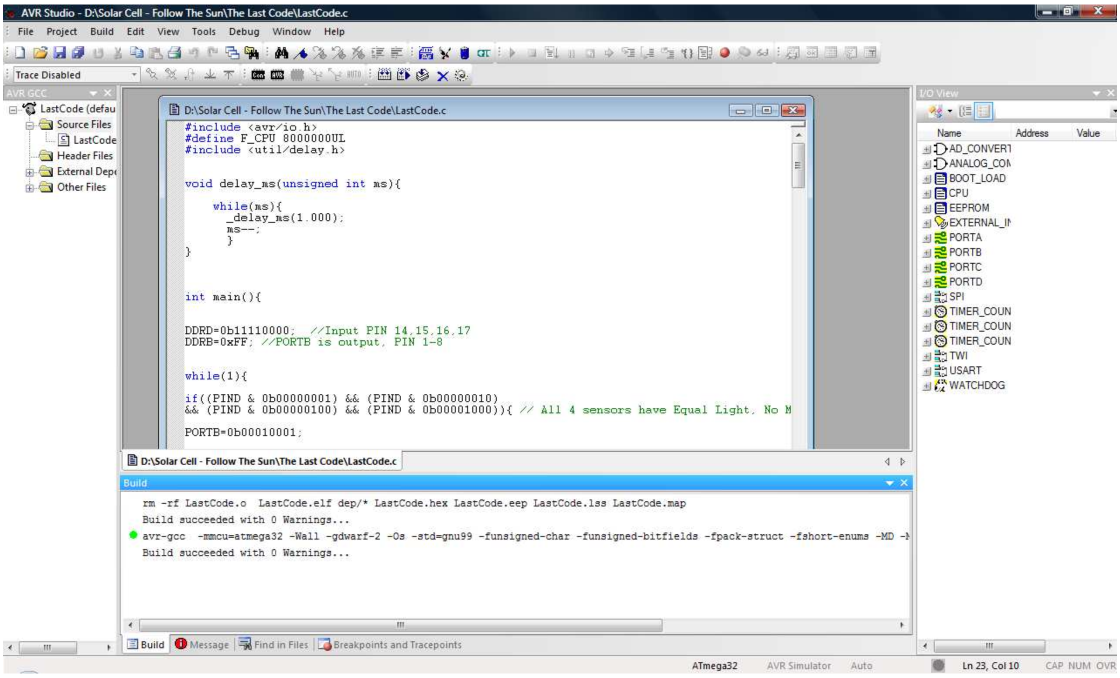
Code writing environment



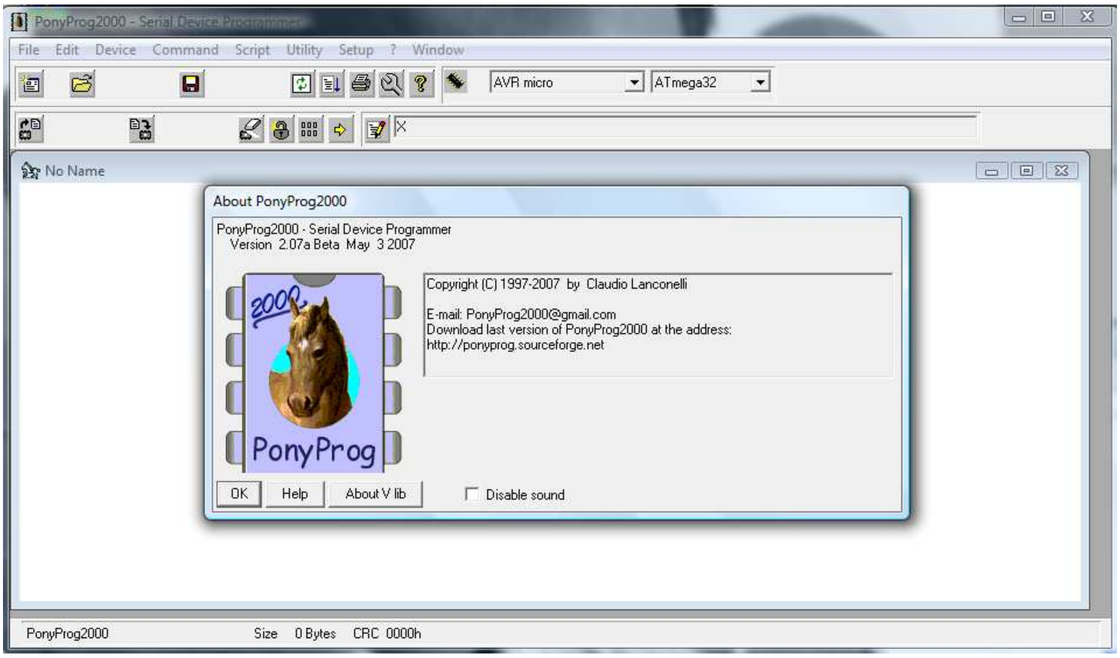
Showing the written code for ATMEGA 32



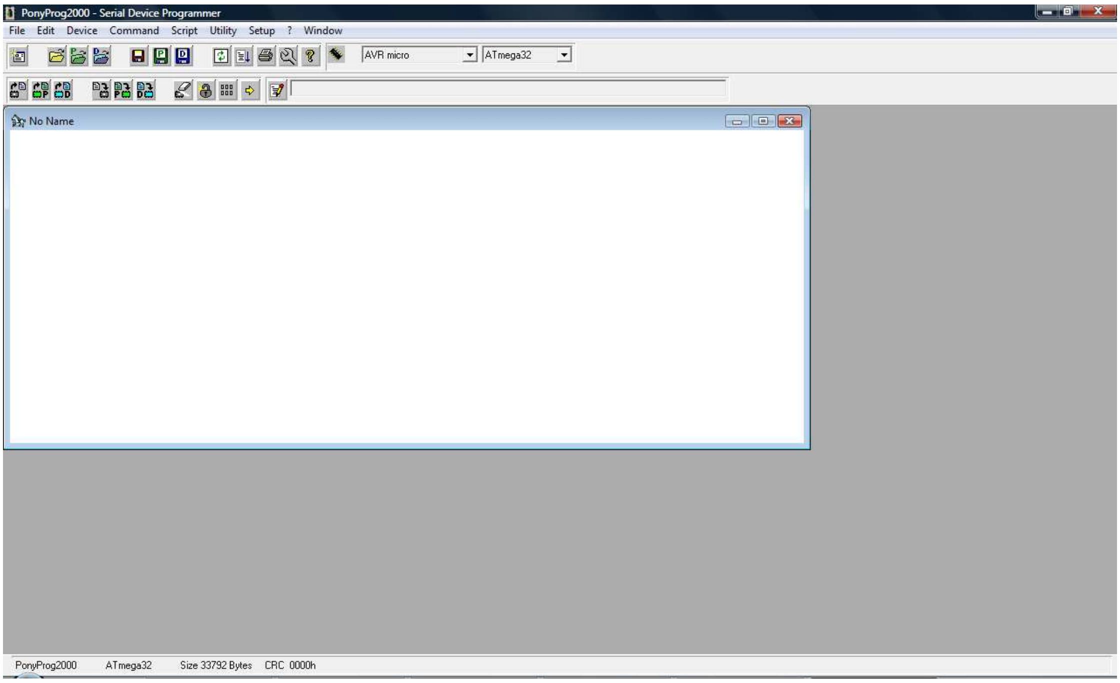
Showing process to compile the code



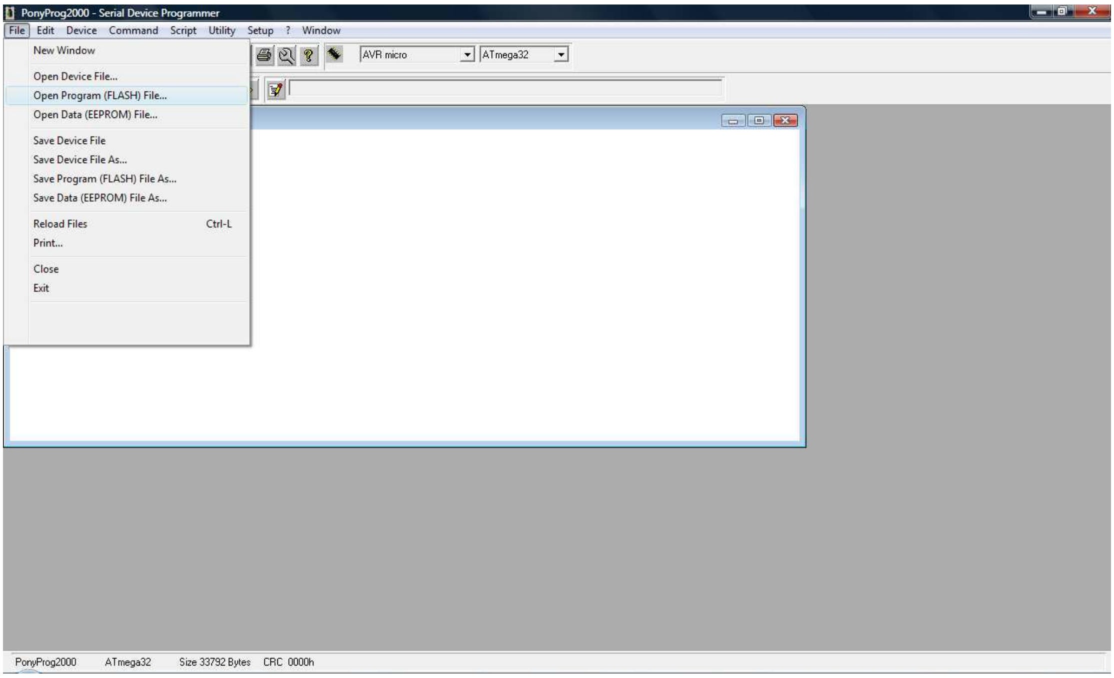
Showing Compilation Complete



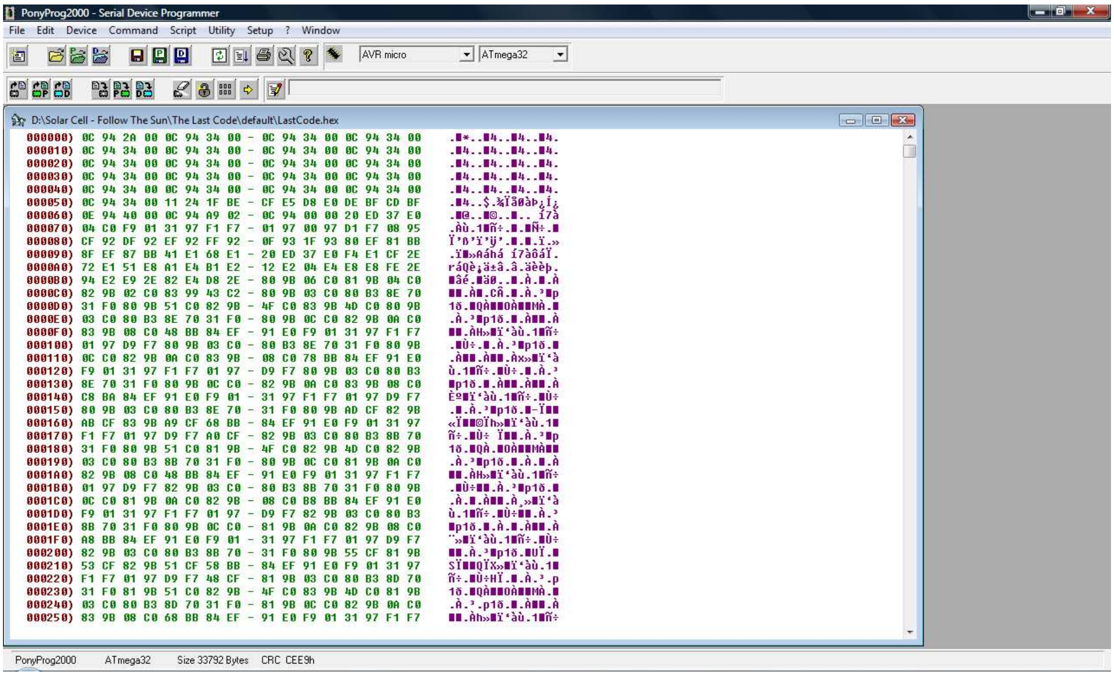
Opening PonyProg2000 To Download Program to ATMEGA



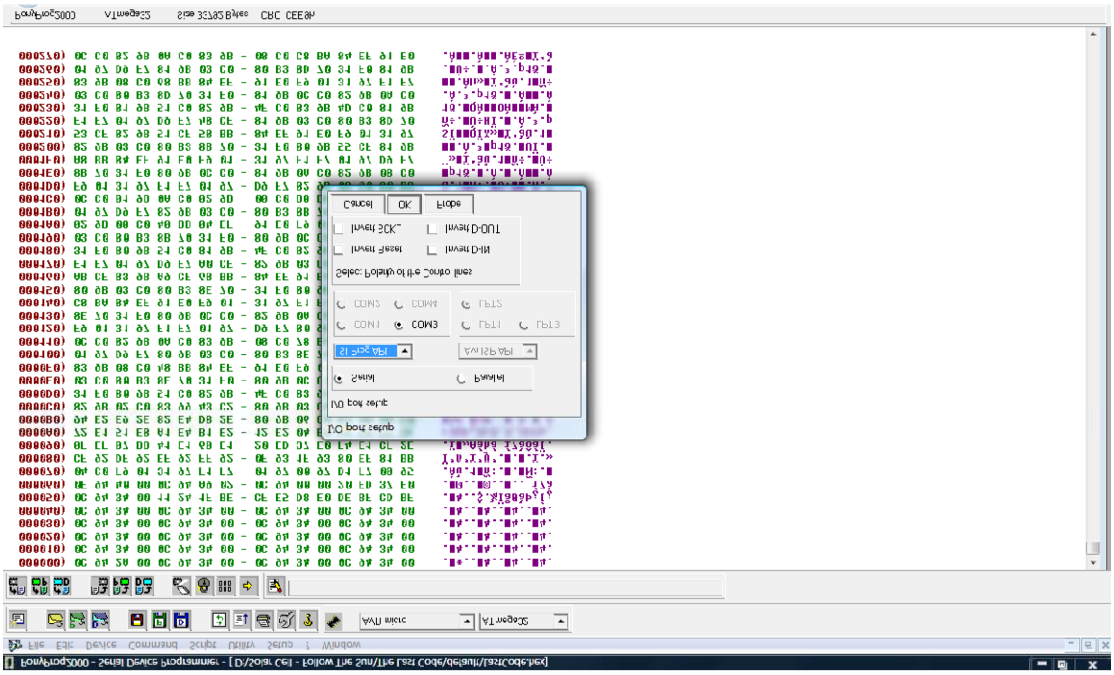
Space to Load the compiled HEX file



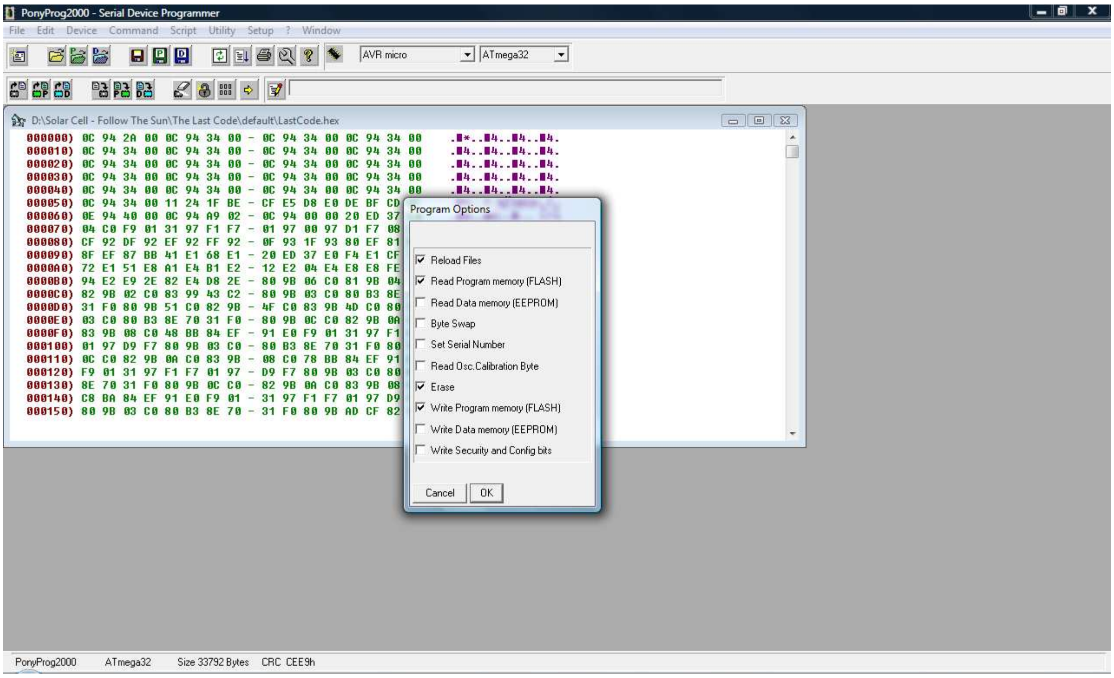
Opening The Hex File



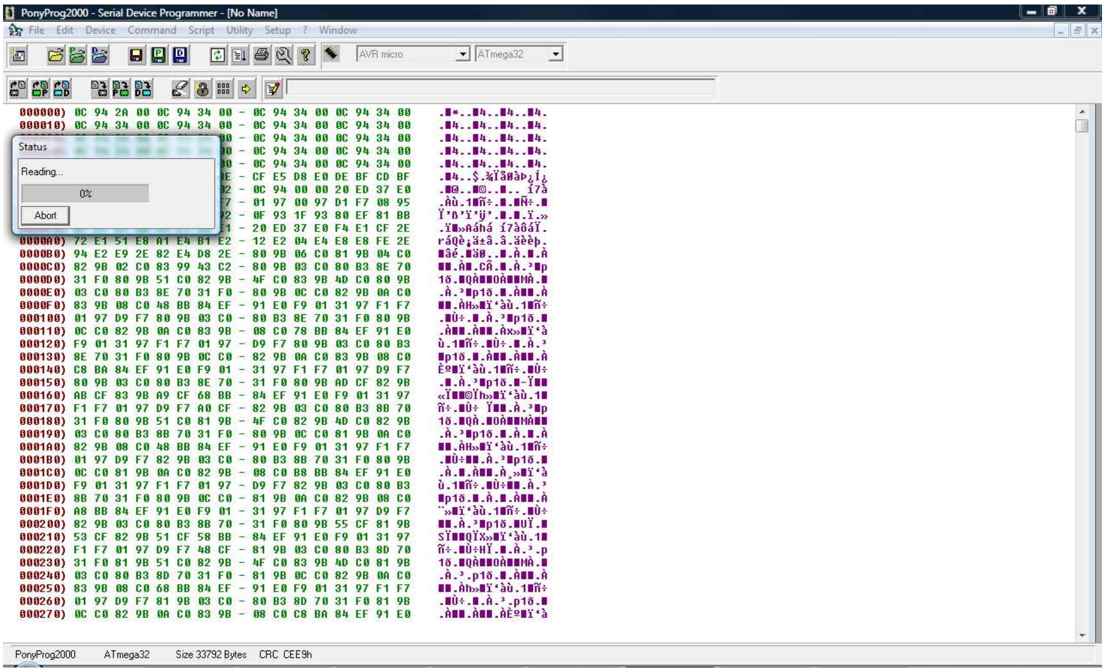
HEX file loaded



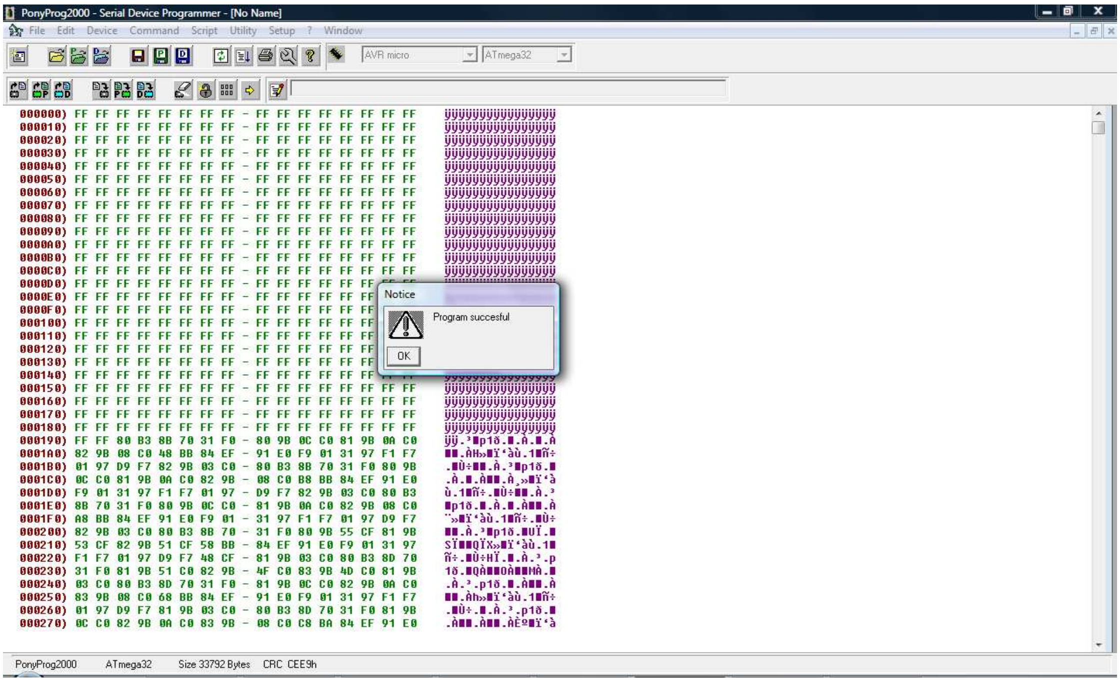
PonyProg2000 I/O Port Settings



PonyProg2000 Program Options



Reading The Hex File Preparing For Writing



HEX file successfully written to ATMEGA 32

APPENDIX B

HEX Code For ATMEGA 32 Microcontroller

```
000000) 0C 94 2A 00 0C 94 34 00 - 0C 94 34 00 0C 94 34 00    .”*..”4..”4..”4.
000010) 0C 94 34 00 0C 94 34 00 - 0C 94 34 00 0C 94 34 00    .”4..”4..”4..”4.
000020) 0C 94 34 00 0C 94 34 00 - 0C 94 34 00 0C 94 34 00    .”4..”4..”4..”4.
000030) 0C 94 34 00 0C 94 34 00 - 0C 94 34 00 0C 94 34 00    .”4..”4..”4..”4.
000040) 0C 94 34 00 0C 94 34 00 - 0C 94 34 00 0C 94 34 00    .”4..”4..”4..”4.
000050) 0C 94 34 00 11 24 1F BE - CF E5 D8 E0 DE BF CD BF    .”4..$.¾ÏåØàÞ¿Í¿
000060) 0E 94 40 00 0C 94 A9 02 - 0C 94 00 00 20 ED 37 E0    .”@..”©..”.. í7à
000070) 04 C0 F9 01 31 97 F1 F7 - 01 97 00 97 D1 F7 08 95    .Àù.1—ñ÷.—.—Ñ÷.•
000080) CF 92 DF 92 EF 92 FF 92 - 0F 93 1F 93 80 EF 81 BB    Ï’ß’ï’ÿ’.“.“.ï.»
000090) 8F EF 87 BB 41 E1 68 E1 - 20 ED 37 E0 F4 E1 CF 2E    .ï‡»Aáhá í7àôáÏ.
0000A0) 72 E1 51 E8 A1 E4 B1 E2 - 12 E2 04 E4 E8 E8 FE 2E    ráQè¡ä±â.â.äèèþ.
0000B0) 94 E2 E9 2E 82 E4 D8 2E - 80 9B 06 C0 81 9B 04 C0    ”âé.‚äØ..›.À.›.À
0000C0) 82 9B 02 C0 83 99 43 C2 - 80 9B 03 C0 80 B3 8E 70    ‚›.Àƒ.CÂ.›.À.³Žp
0000D0) 31 F0 80 9B 51 C0 82 9B - 4F C0 83 9B 4D C0 80 9B    1ð.›QÀ‚›OÀƒ›MÀ.›
0000E0) 03 C0 80 B3 8E 70 31 F0 - 80 9B 0C C0 82 9B 0A C0    .À.³Žp1ð.›.À‚›.À
0000F0) 83 9B 08 C0 48 BB 84 EF - 91 E0 F9 01 31 97 F1 F7    ƒ›.ÀH»„ï‘àù.1—ñ÷
000100) 01 97 D9 F7 80 9B 03 C0 - 80 B3 8E 70 31 F0 80 9B    .—Ù÷.›.À.³Žp1ð.›
000110) 0C C0 82 9B 0A C0 83 9B - 08 C0 78 BB 84 EF 91 E0    .À‚›.Àƒ›.Àx»„ï‘à
000120) F9 01 31 97 F1 F7 01 97 - D9 F7 80 9B 03 C0 80 B3    ù.1—ñ÷.—Ù÷.›.À.³
000130) 8E 70 31 F0 80 9B 0C C0 - 82 9B 0A C0 83 9B 08 C0    Žp1ð.›.À‚›.Àƒ›.À
000140) C8 BA 84 EF 91 E0 F9 01 - 31 97 F1 F7 01 97 D9 F7    Èº„ï‘àù.1—ñ÷.—Ù÷
000150) 80 9B 03 C0 80 B3 8E 70 - 31 F0 80 9B AD CF 82 9B    .›.À.³Žp1ð.›Ï‚›
000160) AB CF 83 9B A9 CF 68 BB - 84 EF 91 E0 F9 01 31 97    «Ïƒ›©Ïh»„ï‘àù.1—
000170) F1 F7 01 97 D9 F7 A0 CF - 82 9B 03 C0 80 B3 8B 70    ñ÷.—Ù÷ Ï‚›.À.³‹p
000180) 31 F0 80 9B 51 C0 81 9B - 4F C0 82 9B 4D C0 82 9B    1ð.›QÀ.›OÀ‚›MÀ‚›
000190) 03 C0 80 B3 8B 70 31 F0 - 80 9B 0C C0 81 9B 0A C0    .À.³‹p1ð.›.À.›.À
0001A0) 82 9B 08 C0 48 BB 84 EF - 91 E0 F9 01 31 97 F1 F7    ‚›.ÀH»„ï‘àù.1—ñ÷
0001B0) 01 97 D9 F7 82 9B 03 C0 - 80 B3 8B 70 31 F0 80 9B    .—Ù÷‚›.À.³‹p1ð.›
0001C0) 0C C0 81 9B 0A C0 82 9B - 08 C0 B8 BB 84 EF 91 E0    .À.›.À‚›.À¸»„ï‘à
0001D0) F9 01 31 97 F1 F7 01 97 - D9 F7 82 9B 03 C0 80 B3    ù.1—ñ÷.—Ù÷‚›.À.³
0001E0) 8B 70 31 F0 80 9B 0C C0 - 81 9B 0A C0 82 9B 08 C0    ‹p1ð.›.À.›.À‚›.À
0001F0) A8 BB 84 EF 91 E0 F9 01 - 31 97 F1 F7 01 97 D9 F7    ¨»„ï‘àù.1—ñ÷.—Ù÷
000200) 82 9B 03 C0 80 B3 8B 70 - 31 F0 80 9B 55 CF 81 9B    ‚›.À.³‹p1ð.›UÏ.›
000210) 53 CF 82 9B 51 CF 58 BB - 84 EF 91 E0 F9 01 31 97    SÏ‚›QÏX»„ï‘àù.1—
000220) F1 F7 01 97 D9 F7 48 CF - 81 9B 03 C0 80 B3 8D 70    ñ÷.—Ù÷HÏ.›.À.³.p
000230) 31 F0 81 9B 51 C0 82 9B - 4F C0 83 9B 4D C0 81 9B    1ð.›QÀ‚›OÀƒ›MÀ.›
000240) 03 C0 80 B3 8D 70 31 F0 - 81 9B 0C C0 82 9B 0A C0    .À.³.p1ð.›.À‚›.À
000250) 83 9B 08 C0 68 BB 84 EF - 91 E0 F9 01 31 97 F1 F7    ƒ›.Àh»„ï‘àù.1—ñ÷
000260) 01 97 D9 F7 81 9B 03 C0 - 80 B3 8D 70 31 F0 81 9B    .—Ù÷.›.À.³.p1ð.›
000270) 0C C0 82 9B 0A C0 83 9B - 08 C0 C8 BA 84 EF 91 E0    .À‚›.Àƒ›.ÀÈº„ï‘à
000280) F9 01 31 97 F1 F7 01 97 - D9 F7 81 9B 03 C0 80 B3    ù.1—ñ÷.—Ù÷.›.À.³
000290) 8D 70 31 F0 81 9B 0C C0 - 82 9B 0A C0 83 9B 08 C0    .p1ð.›.À‚›.Àƒ›.À
0002A0) 78 BB 84 EF 91 E0 F9 01 - 31 97 F1 F7 01 97 D9 F7    x»„ï‘àù.1—ñ÷.—Ù÷
0002B0) 81 9B 03 C0 80 B3 8D 70 - 31 F0 81 9B FD CE 82 9B    .›.À.³.p1ð.›ýÎ‚›
0002C0) FB CE 83 9B F9 CE 48 BB - 84 EF 91 E0 F9 01 31 97    ûÎƒ›ùÎH»„ï‘àù.1—
0002D0) F1 F7 01 97 D9 F7 F0 CE - 83 9B 06 C0 80 B3 90 E0    ñ÷.—Ù÷ðÎƒ›.À.³.à
0002E0) 87 70 90 70 89 2B 31 F0 - 80 9B 5D C0 81 9B 5B C0    ‡p.p‰+1ð.›]À.›[À
0002F0) 83 9B 59 C0 83 9B 06 C0 - 80 B3 90 E0 87 70 90 70    ƒ›YÀƒ›.À.³.à‡p.p
000300) 89 2B 31 F0 80 9B 0C C0 - 81 9B 0A C0 83 9B 08 C0    ‰+1ð.›.À.›.Àƒ›.À
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000310) 58 BB 84 EF 91 E0 F9 01 - 31 97 F1 F7 01 97 D9 F7    X»„ï‘àù.1—ñ÷.—Ù÷
000320) 83 9B 06 C0 80 B3 90 E0 - 87 70 90 70 89 2B 31 F0    ƒ›.À.³.à‡p.p‰+1ð
000330) 80 9B 0C C0 81 9B 0A C0 - 83 9B 08 C0 A8 BB 84 EF    .›.À.›.Àƒ›.À¨»„ï
000340) 91 E0 F9 01 31 97 F1 F7 - 01 97 D9 F7 83 9B 06 C0    ‘àù.1—ñ÷.—Ù÷ƒ›.À
000350) 80 B3 90 E0 87 70 90 70 - 89 2B 31 F0 80 9B 0C C0    .³.à‡p.p‰+1ð.›.À
000360) 81 9B 0A C0 83 9B 08 C0 - B8 BB 84 EF 91 E0 F9 01    .›.Àƒ›.À¸»„ï‘àù.
000370) 31 97 F1 F7 01 97 D9 F7 - 83 9B 06 C0 80 B3 90 E0    1—ñ÷.—Ù÷ƒ›.À.³.à
000380) 87 70 90 70 89 2B 31 F0 - 80 9B 96 CE 81 9B 94 CE    ‡p.p‰+1ð.›–Î.›”Î
000390) 83 9B 92 CE 48 BB 84 EF - 91 E0 F9 01 31 97 F1 F7    ƒ›’ÎH»„ï‘àù.1—ñ÷
0003A0) 01 97 D9 F7 89 CE 80 9B - 33 C0 82 9B 31 C0 80 9B    .—Ù÷‰Î.›3À‚›1À.›
0003B0) 0A C0 82 9B 08 C0 48 BB - 84 EF 91 E0 F9 01 31 97    .À‚›.ÀH»„ï‘àù.1—
0003C0) F1 F7 01 97 D9 F7 80 9B - 0A C0 82 9B 08 C0 18 BB    ñ÷.—Ù÷.›.À‚›.À.»
0003D0) 84 EF 91 E0 F9 01 31 97 - F1 F7 01 97 D9 F7 80 9B    „ï‘àù.1—ñ÷.—Ù÷.›
0003E0) 0A C0 82 9B 08 C0 08 BB - 84 EF 91 E0 F9 01 31 97    .À‚›.À.»„ï‘àù.1—
0003F0) F1 F7 01 97 D9 F7 80 9B - 5F CE 82 9B 5D CE F8 BA    ñ÷.—Ù÷.›_Î‚›]Îøº
000400) 84 EF 91 E0 F9 01 31 97 - F1 F7 01 97 D9 F7 54 CE    „ï‘àù.1—ñ÷.—Ù÷TÎ
000410) 81 9B 33 C0 82 9B 31 C0 - 81 9B 0A C0 82 9B 08 C0    .›3À‚›1À.›.À‚›.À
000420) 68 BB 84 EF 91 E0 F9 01 - 31 97 F1 F7 01 97 D9 F7    h»„ï‘àù.1—ñ÷.—Ù÷
000430) 81 9B 0A C0 82 9B 08 C0 - E8 BA 84 EF 91 E0 F9 01    .›.À‚›.Àèº„ï‘àù.
000440) 31 97 F1 F7 01 97 D9 F7 - 81 9B 0A C0 82 9B 08 C0    1—ñ÷.—Ù÷.›.À‚›.À
000450) D8 BA 84 EF 91 E0 F9 01 - 31 97 F1 F7 01 97 D9 F7    Øº„ï‘àù.1—ñ÷.—Ù÷
000460) 81 9B 2A CE 82 9B 28 CE - 58 BB 84 EF 91 E0 F9 01    .›*Î‚›(ÎX»„ï‘àù.
000470) 31 97 F1 F7 01 97 D9 F7 - 1F CE 80 9B 33 C0 83 9B    1—ñ÷.—Ù÷.Î.›3Àƒ›
000480) 31 C0 80 9B 0A C0 83 9B - 08 C0 58 BB 84 EF 91 E0    1À.›.Àƒ›.ÀX»„ï‘à
000490) F9 01 31 97 F1 F7 01 97 - D9 F7 80 9B 0A C0 83 9B    ù.1—ñ÷.—Ù÷.›.Àƒ›
0004A0) 08 C0 D8 BA 84 EF 91 E0 - F9 01 31 97 F1 F7 01 97    .ÀØº„ï‘àù.1—ñ÷.—
0004B0) D9 F7 80 9B 0A C0 83 9B - 08 C0 E8 BA 84 EF 91 E0    Ù÷.›.Àƒ›.Àèº„ï‘à
0004C0) F9 01 31 97 F1 F7 01 97 - D9 F7 80 9B F5 CD 83 9B    ù.1—ñ÷.—Ù÷.›õÍƒ›
0004D0) F3 CD 68 BB 84 EF 91 E0 - F9 01 31 97 F1 F7 01 97    óÍh»„ï‘àù.1—ñ÷.—
0004E0) D9 F7 EA CD 81 9B 33 C0 - 83 9B 31 C0 81 9B 0A C0    Ù÷êÍ.›3Àƒ›1À.›.À
0004F0) 83 9B 08 C0 F8 BA 84 EF - 91 E0 F9 01 31 97 F1 F7    ƒ›.Àøº„ï‘àù.1—ñ÷
000500) 01 97 D9 F7 81 9B 0A C0 - 83 9B 08 C0 08 BB 84 EF    .—Ù÷.›.Àƒ›.À.»„ï
000510) 91 E0 F9 01 31 97 F1 F7 - 01 97 D9 F7 81 9B 0A C0    ‘àù.1—ñ÷.—Ù÷.›.À
000520) 83 9B 08 C0 18 BB 84 EF - 91 E0 F9 01 31 97 F1 F7    ƒ›.À.»„ï‘àù.1—ñ÷
000530) 01 97 D9 F7 81 9B C0 CD - 83 9B BE CD 48 BB 84 EF    .—Ù÷.›ÀÍƒ›¾ÍH»„ï
000540) 91 E0 F9 01 31 97 F1 F7 - 01 97 D9 F7 B5 CD 48 BB    ‘àù.1—ñ÷.—
Ù÷µÍH»
000550) B3 CD F8 94 FF CF FF FF - FF FF FF FF FF FF FF FF    ³Íø”ÿÏÿÿÿÿÿÿÿÿÿÿ
000560) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
000570) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
000580) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
000590) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
0005A0) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
0005B0) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
0005C0) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
0005D0) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
0005E0) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
0005F0) FF FF FF FF FF FF FF FF - FF FF FF FF FF FF FF FF    ÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿÿ
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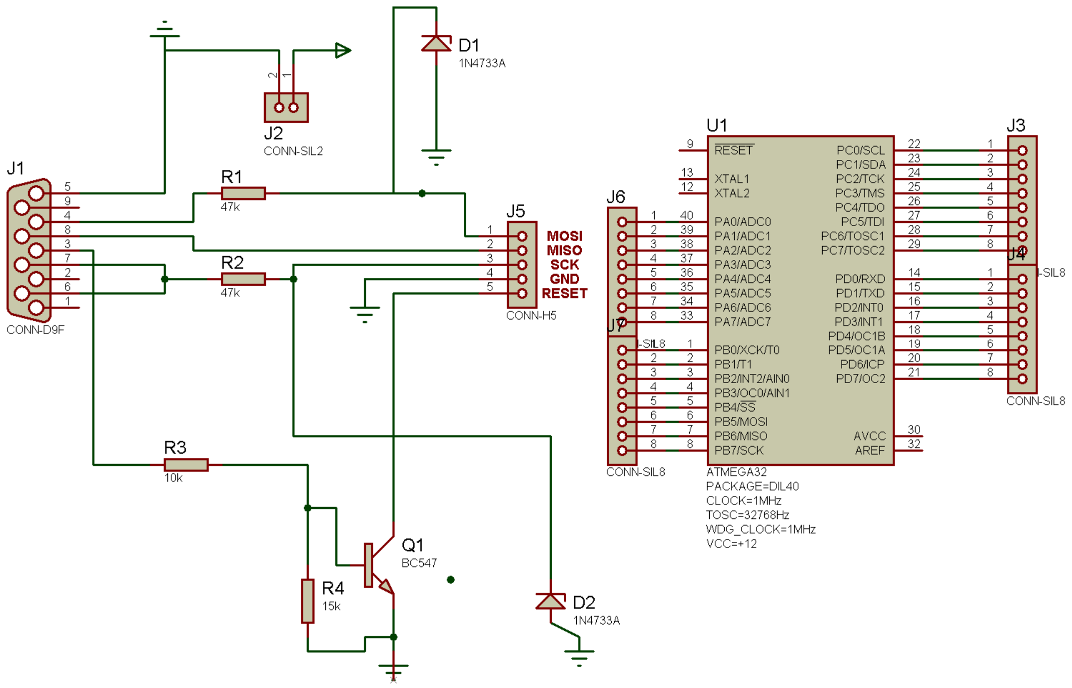
APPENDIX C

Circuit Diagram of The ATMEGA 32
Downloader



Circuit Diagram of the downloader