**ENERGY STORAGE MECHANISM AS GRAVITATIONAL POTENTIAL ENERGY**



***CLIENT AND ADVISOR***

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**CERTIFICATION**

We certify that the project report entitled “Energy Storage Mechanism as Gravitational Potential Energy” was prepared by all of us together. We have provided references to the material consulted in preparing this report and to the best of our knowledge and have not plagiarized anything.

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We have met the required standard for submission in partial fulfillment of the requirements for the award of BS (EE) degree at **National University of Computer and Emerging Sciences (FAST)**, Lahore Campus.

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I am the client of the product proposed in this document. I agree with the specifications listed herein.

**Ahmad Raza Malik, ­­­­­­­­­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ DATE \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

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The final year project proposed in this document is being submitted to the Department of Electrical Engineering with my approvals as an advisor.

**Ahmad Raza Malik, ­­­­­­­­­­­­­­\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ DATE \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**ACKNOWLEDGMENTS**

We would like to thank those people who helped us make the project prototype, especially Mr. Ahmed Raza Malik who was very cooperative and supportive as our advisor. The credit also goes to the faculty and staff of the Department of Electrical Engineering of FAST National University Lahore Campus, for providing us with the facilities & equipment, along with a lot of technical expertise all the way from the project’s conception to completion. This project was a team effort and we all share the due credit in the successful accomplishment of the project.

**ABSTRACT**

The Project is about making a prototype that explains the phenomena and the problems involved in making an Energy Storage Mechanism as Gravitational Potential Energy. The idea is that when you lift a mass to a height under gravity, energy is stored in the mass that is equal to the product of the mass value, gravitational acceleration and the height to which the mass is lifted.

**Chapter 1: Introduction to the Concept**

In today’s world, energy production is becoming a matter of the necessity. There has been an exponential increase in the requirement of energy, owing to the increase in the overall population of people all over the world. The current methods of producing energy include the burning of fossil fuels, hydroelectric energy and various others. Among these methods are a few that are characterized as Green Energy Methods, mainly because of their lesser carbon footprint. Green methods of producing energy are also being adopted because of their renewable characteristics and also cost effectiveness in the long term.

Every renewable source of energy, be it solar, wind or thermal, has to have an energy storage mechanism attached to it, because the energy availability is somewhat unpredictable, and also the energy could be required at a different rate, that is the energy production rate might differ from the energy consumption rate. It is for this reason why a storing mechanism is required.

These storing mechanisms are not very diversified, per se. Massachusetts Institute of Technology were trying to make a photovoltaic cell that could also store the energy either as light or electrical energy. But for a common individual, the only thing that comes to mind is a common chemical battery that stores the energy as chemical energy.

The basic properties of a common chemical battery are as follows;

1. Stores the energy in a converted form (as Chemical Energy)
2. Delivers power as per the requirement, that is, the rate of chemical reaction is synchronized with the electrical load (The more the load, the greater the rate of reaction)
3. Recharges by taking energy from another source of electricity (only Rechargeable Batteries)

There are drawbacks to a Chemical Storage as well, such as;

1. The charge capacity may be reduced over time
2. The leakage currents slowly deplete these batteries
3. The efficiency of these batteries is adequate but still should be improved
4. The Storage Capacity must also be increased
5. Need to be replaced over time, and the cost of replacement is high as well

It is due to these facts that there is a need to completely revise the concept of energy storage and to explore other possibilities. The system that should be implemented must at least satisfy the characteristics of the chemical batteries as discussed.

For the final year project, we are trying to make an Energy Storing Mechanism as Gravitational Potential Energy. The idea is that there is a mass suspended by means of a chord, which is further connected to a DC Motor mounted on a frame. When the power is provided to the system, the DC Motor winds the string around a pulley and lifts up the mass connected at the other end of the string. By lifting the mass, energy is being stored in the system, which is proportional to the mass value, the height and of course, gravity. The reasons why we believe that it might be a major breakthrough are as follows;

1. Design can be completely improvised based upon requirements
2. It is simple to understand and conceive
3. It can be scaled up to enormous sizes and even integrated within the architectural designs of the future
4. Absolutely not hazardous compared to chemical batteries, and maintenance is also less of an effort



Figure 1 Simplified Gravitational Potential Energy Model

**Chapter 2: Client Requirements/product specifications**

There are three modes of operation, STOP mode, CHARGING mode & DISCHARGING mode.

1. In the STOP mode, the solar cell are disconnected for the motor and the DC load is also disconnected. The motor is also held stationary by the Regenerative Braking System in this mode.
2. In the CHARGING mode, the solar cell supply power to the motor to lift the suspended object up.
3. In the DISCHARGING mode, the motor acts as generator and supplies power to the DC load.

The intention is to make a simple prototype that would explain the different types of challenges that will arise in making an inspired product. For this we are using commonly available components and our knowledge of engineering to tackle these problems.

The following description takes you through the process of making the project prototype, all the way from the conception to completion.

At first, the purpose of the prototype was conceived, by keeping the following things in mind;

1. The prototype must incorporate a mass of adequate magnitude and a DC motor that will translate the electrical energy to mechanical work
2. In the spirit of Green energy, the project must not take energy from the mains, but instead, retrieve energy from a renewable source of energy, such as a solar cell
3. The cost of making the prototype must be kept low
4. It must have a control interface that provides the user to swap between different modes of operation
5. It should be able to store enough energy to drive a load for an adequate amount of time

With these targets and limitations in mind, it was time to start working on the prototype. Often engineering projects are progressed in the bottom-up approach that is, simulation, which also includes firmware writing, followed by the electronics, then the mechanics, which includes physical frame and chassis design. We for this project decided to skip the simulation phase all together and started off with the top-down approach instead. We figured that it would prove to be beneficial for us because the components used in our project, might have not been available as per our design, but the design could be modified as per the components that were available to us.

**Control Logic Circuit**

The circuit is based on Arduino Microcontroller that is used to control the relay switching, user inputs and the mode indications. The following is the schematic of the circuit;

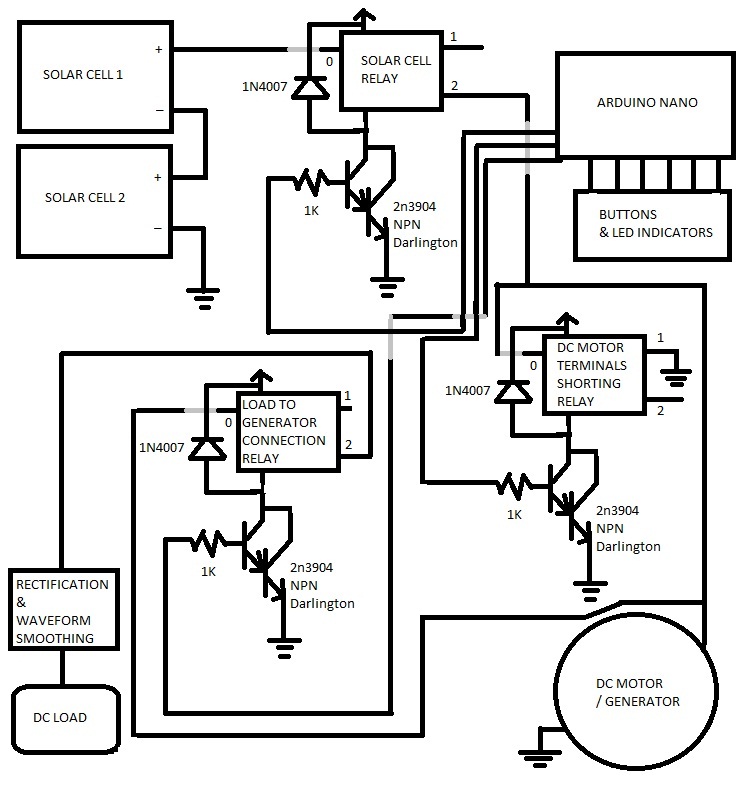


Figure 2 Actual Schematic of the Prototype

**Key Points**

1. The Relays pins in the circuit at default are connected between 0 and 1. When Transistors receive logic high from Arduino NANO the connection is established from 0 to 2.
2. Although, the waveform of the signal from the DC Motor, when used as Generator is similar to that of the a sine wave after being rectified through Full wave rectifier, the Full Wave Bridge Rectification is done to remove the dependence on the direction of rotation of the Motor. This is followed by a capacitor that smooths out the waveform to some extent, thus it has a greater DC component.

The reason why a DC Motor outputs a waveform similar to that of a full wave sinusoid rectifier is because a DC Motor contains split ring that maintain their polarity after 180 degree rotation within the constant magnetic field inside the motor, as oppose to slip rings that are continuous and change their polarity thus provide an AC voltage output.

1. The Transistor 2n3904 has a Beta value of about 200-300 Amperes per Ampere. That is not enough to cause the relays to switch. So we used Darlington Paired Transistors to enhance the Beta value to almost the following level;

Equivalent Beta = Original Beta^2 + 2\*Original Beta

= 40400-90600 Amperes per Ampere

1. In the BUTTONS & LED INDICATOR Module, Push Buttons are used to take user inputs that change the mode of operation. These are also in series with pull down resistors.

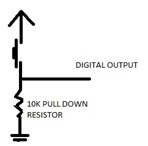


Figure 3 Push Button Circuit

1. The Diode 1N4007 is used for the Rectification process as Full Wave Bridge Rectifier and also with the relays to prevent the inducted back emf of the relays to damage any sensitive component on the Arduino NANO.
2. The Solar Cells are of 3 Watts each, the Peak Power ratings of the Solar Cells are;

Solar Cell1 Open Circuit Voltage = 10.8 V, Short Circuit Current = 0.38 A  
Solar Cell1 Open Circuit Voltage = 21.6 V, Short Circuit Current = 0.16 A

The Braking mechanism is maintained on the principle of Lenz’s Law. The Law states that;

An induced [electromotive force](http://en.wikipedia.org/wiki/Electromotive_force) (emf) always gives rise to a current whose magnetic field opposes the original change in [magnetic flux](http://en.wikipedia.org/wiki/Magnetic_flux). (Source Wikipedia)

According to this law, a back emf is generated when a generator drives a load, and the magnitude of the back emf is proportional to the current that is driven through the circuit. The current is inversely proportional to the load at the load end. So if we short out the terminals of DC Motor used as a generator, we cause a high current to flow through the circuit, because the short circuit has a resistance approaching zero. Thus the high back emf generated by the motor is enough to jam the motor shaft. Therefore if we have a relay that is controlled by the microcontroller that on a low state, shorts out the terminals of the motor, the motor tends to stop. Another added advantage to this strategy is that when the prototype is powered off, the terminals of the motor are still shorted. Therefore the energy that is stored by lifting the mass up will not leak away, when you pull the plug.

The reason why we had to use a gear motor is because it has some fundamental properties that are appropriate to our needs;

* Increased Output Torque
* Decreased Output RPM

Additionally we also have an Infrared (IR) Tranceiver Module integrated within the prototype for wireless mode switching. The Mode changes are triggered by the IR Remote Control when it sends a high signal to the Receiver Module. The Logic that is fed into the Arduino is that the modes are switched in the following sequences;

Figure 4 Infrared Remote Control Triggering Sequence

The changes are maintained by the arduino. It is suggested that the sketch of the arduino is studied for complete understand of the algorithm.

The schematic for the IR Transmitter and Receiver are shown as follows. In actual hardware implementation of the IR receiver module, the phototransistor is covered in a plastic tube to prevent the ambient light to trigger the circuit unintentionally. Some symbols of circuit components are taken from the Internet. The schematics are modified forms of the schematics available of Google Image Search. When IR falls on the phototransistor, the module sends a low voltage state to the arduino.

**Transmitter:**



**Receiver:**



**Chapter 3: Architecture**

1. **Hardware Design**



This is a simplified block diagram of the project prototype. It can be modified to make another prototype of the required specifications. There are three relays used in this block diagram that are controlled by the Microcontroller. The relays can also be controlled by bistable multivibrators or latches. The DC load is kept constant for the prototype but the system should be able to adjust itself according to the load attached, for example if a load of larger impedance is connected then the motor will rotate at more revolutions per minute, as compared to the situation when a load of smaller impedance is connected.

1. **Software Algorithm and Code**

The following is the arduino sketch written for the project prototype. It is written for the Arduino NANO v3.0, so it is recommended that the pinout of the board be properly monitored.

int actu\_relay = 12; // Actuator Relay

int chrg\_relay = 11; // Solar Controlling Relay

int disc\_relay = 10; // DC Load Connection Relay

int stop\_btn = 9; // User Input for Stop

int chrg\_btn = 8; // User Input for Charging

int disc\_btn = 7; // User Input for Discharging

int stop\_led = 6; // Indication for Stop Mode

int chrg\_led = 5; // Indication for Charge Mode

int disc\_led = 4; // Indication for Discharging Mode

boolean charge= false; // Flag Variable for the code

void setup() // Initial Settings for the Arduino

{

pinMode(chrg\_relay, OUTPUT);

pinMode(actu\_relay, OUTPUT);

pinMode(disc\_relay, OUTPUT);

pinMode(stop\_btn, INPUT);

pinMode(chrg\_btn, INPUT);

pinMode(disc\_btn, INPUT);

pinMode(stop\_led, OUTPUT);

pinMode(chrg\_led, OUTPUT);

pinMode(disc\_led, OUTPUT);

digitalWrite(stop\_led, HIGH);

digitalWrite(chrg\_led, LOW);

digitalWrite(disc\_led, LOW);

}

void loop() // Repetition Code for the Arduino

{

if(digitalRead(stop\_btn)==HIGH) // Stop Button Pressed

{

digitalWrite(chrg\_relay, LOW);

digitalWrite(disc\_relay, LOW);

digitalWrite(actu\_relay, LOW);

digitalWrite(stop\_led, HIGH);

digitalWrite(chrg\_led, LOW);

digitalWrite(disc\_led, LOW);

}

if(digitalRead(chrg\_btn)==HIGH) // Charging Button Pressed

{

digitalWrite(chrg\_relay, HIGH);

digitalWrite(disc\_relay, LOW);

digitalWrite(actu\_relay, HIGH);

digitalWrite(stop\_led, LOW);

digitalWrite(chrg\_led, HIGH);

digitalWrite(disc\_led, LOW);

}

if(digitalRead(disc\_btn)==HIGH) // Discharge Button Pressed

{

digitalWrite(chrg\_relay, LOW);

digitalWrite(disc\_relay, HIGH);

digitalWrite(actu\_relay, HIGH);

digitalWrite(stop\_led, LOW);

digitalWrite(chrg\_led, LOW);

digitalWrite(disc\_led, HIGH);

}

if(analogRead(A0) < 450) // IR Remote Control Triggered

if(digitalRead(stop\_led)==HIGH)

{

if(charge == false)

{

digitalWrite(chrg\_relay, HIGH);

digitalWrite(disc\_relay, LOW);

digitalWrite(actu\_relay, HIGH);

digitalWrite(stop\_led, LOW);

digitalWrite(chrg\_led, HIGH);

digitalWrite(disc\_led, LOW);

charge = true;

delay(500);

}

}

if(analogRead(A0) < 450) // IR Remote Control Triggered

if(digitalRead(chrg\_led)==HIGH)

{

digitalWrite(chrg\_relay, LOW);

digitalWrite(disc\_relay, LOW);

digitalWrite(actu\_relay, LOW);

digitalWrite(stop\_led, HIGH);

digitalWrite(chrg\_led, LOW);

digitalWrite(disc\_led, LOW);

delay(500);

}

if(analogRead(A0) < 450) // IR Remote Control Triggered

if(digitalRead(stop\_led)==HIGH)

{

if(charge == true)

{

digitalWrite(chrg\_relay, LOW);

digitalWrite(disc\_relay, HIGH);

digitalWrite(actu\_relay, HIGH);

digitalWrite(stop\_led, LOW);

digitalWrite(chrg\_led, LOW);

digitalWrite(disc\_led, HIGH);

charge = false;

delay(500);

}

}

if(analogRead(A0) < 450) // IR Remote Control Triggered

if(digitalRead(disc\_led)==HIGH)

{

digitalWrite(chrg\_relay, LOW);

digitalWrite(disc\_relay, LOW);

digitalWrite(actu\_relay, LOW);

digitalWrite(stop\_led, HIGH);

digitalWrite(chrg\_led, LOW);

digitalWrite(disc\_led, LOW);

delay(500);

}

}

The algorithm is presented so that the reader of the document is able to understand and edit the code according to the platform of development.

**Chapter 4: Similar Projects**

The idea for the project is not original, in fact it was inspired by many people who made similar projects and posted their details on the internet. Some of the projects that we came across were as follows;

**Gravity Powered Lamp**



Figure 5 Gravity Lamp (Source How Stuff Works)

This project has been refined into a product that can be bought by consumers. This product has a brass mass that is lifted by means of a force and then allowed to fall. During its drop, its gravitational potential energy is used to power up a generator that in turns produces electrical energy. This electrical energy is used to power up LEDs connected at the output.

**Chapter 5: Prototype Testing Efficiency and its Applications Possibilities**

The wooden frame of the prototype is made in such a way that it is supposed to be placed on a table top. This will allow the height of the suspended object to increase. In this way we can have the storage capacity of the prototype to be increased as well. The minimum height which is the height of the wooden frame with respect to the suspended object is still a constant. So we will make our calculations based upon this height value. A different value can also be plugged into the following calculations if needed.

Mass of the Suspended Object = 0.23 kg

Minimum height = 0.6 meters

Drop time for the fixed electrical load = 6.35 seconds

So,

Storage capacity = 0.23kg x 0.6 m x 9.81 ms^-2

= 1.35 joules

This is the absolute energy which is stored in the suspended object when it is lifted to the minimum height. If the prototype is placed on the top of a table with a known height, then obviously the storage capacity would have been greater. The motor that has lifted up this object to the required height has done work on the object. The process of lifting the object has no relation with the drop time of the object, as that depends on the impedance of the electrical load attached. The gear ratio is a way to harness the maximum possible energy out of the suspended mass. Other ways are increasing the magnetic field inside the motor or increasing the number of turns inside the motor. All of these factors contribute to the increase in the efficiency of the conversion process. For example if the motor has done work on the suspended object, that has stored some energy in the object, in order for the motor to harness maximum energy out of that energy stored in the object, it must utilize every turn to the fullest. If the motor has a weak magnetic field inside or if it has lesser number of turns of the coil in the motor, then we are left with only increasing the gear ratio, because that way we can multiply the number of turns with respect to the motor and the output shaft of the gears. Since we have a fixed gear ratio motor, we are bound to just a fraction of the stored energy in the suspended object. If we were somehow able to harness the complete 100% of the energy, then it would be able to charge the following percentage in a single drop.

DC Load = 1110mAh Battery

Capacity in Coulombs = 1110 x 10^-3 x 3600

= 3996 coulombs

The drop time of the object for 0.6 meters = 6.35 seconds

Average Power = 1.35 / 6.35 = 0.21 Watts

Since the output voltage is maintained at 5 volts,

Average Supply Current = 0.21 / 5 = 0.042 ampere

So, Charge Supplied = 0.042 x 6.35 = 0.2667 coulombs

Percentage of the Battery Charged = 0.26667 / 3996 \* 100%

= 6.67%

This is far greater than real results.

Now let us review the supply power from the Solar cells. There are two solar cell used in the prototype, that have the same power but different open circuit voltages and short circuit currents. They are connected in series.

So,

V = 21.6 V + 10.8 V = 32.4 volts

I = 0.16 amperes

Supply power to the motor = 32.4 x 0.16

= 5.184 Watts

As we know that a solar cell has efficiency value of about 15 – 20 %, that means that out of the total energy the cell receives as sun light, only 15 – 20% of it gets converted into electricity. We will assume that the result obtained in the previous calculation are after the energy bottleneck. When this power is fed to the motor, it lifts the object in almost a second. So it is safe to assume that the energy supplied to the motor for lifting the object to the height of 0.6 meters is 5.184 joules.

With this information we can find out the motor efficiency. It comes out to be,

Motor efficiency = 1.35 / 5.184 \* 100%

= 26.04 %

So let us make the final model of the prototype efficiency. Since the motor efficiency will come twice during our calculations, once as a motor that takes power from the solar cell, and secondly as a generator, converting mechanical energy into electrical energy.

Prototype efficiency = 0.175 <Solar Cell> x 0.2604 <as motor> x 0.2604 <as generator>

= 1.19%

The calculations are done keeping in view of our limited understanding of the Power and Energy conversion concepts. The readers are strongly advised to receive citations for the credibility of these calculations. This is the small fraction of the energy which is provided to the electrical load, out of the full energy received as sunlight.

This is a manifestation of the fact that although this entire idea to storing energy as gravitational potential energy is a novel one, but due to very poor price to performance ratio, the prototypes made on this principle should not be scaled up to enormous level, as it will eventually turn out to be very disastrous during energy dependence.

But we can lose hope right now. In an attempt to provide complete coverage to the readers of this document, we have devised a strategy to increase the storage capacity of this system through hybrid method.

The idea is that a chemical battery has mass, and it can be utilized as a replacement for the suspended object in our prototype. When you get into the depth of this idea, you will have to study a concept called 'Specific Energy', which determine the storage capacity of a system (to store electrical energy as chemical energy) with respect to its weight. The following table shows that Lithium Ion batteries have the highest value of specific energy and Lead Acid Batteries have to the lowest value. This means that a kilogram of Lithium Ion battery will have more storage capacity than a kilogram of Lead Acid Battery.

**TABLE 1: SPECIFIC ENERGIES OF DIFFERENT CHEMICAL ENERGY STORAGES**

|  |  |
| --- | --- |
| **Storage Medium** | **Specific Energy in MJ/kg** |
| Li-Ion | 0.36-0.875 |
| Alkaline | 0.67 |
| Ni-MH | 0.288 |
| Lead Acid | 0.17 |

It will always be an optimization calculation that utilizes both the storage mechanism to obtain maximum overall storage capacity of the hybrid system.

As mentioned earlier that the purpose of this project is meant to demonstrate the idea in action by making a prototype based on the principles as mentioned in the project title. Therefore, as an example, if it is required to make an architectural design based on this concept, for example, somehow integrating a gravitational potential energy storage system into the design of a building, there can be various approaches through which it can be accomplished.

To start with, let us revisit the core concept that the Gravitational Potential Energy is equal to the product of three different quantities;

1. Mass of the suspended object

2. Gravitational Acceleration

3. Height of the object from the ground level

If you want to design such a system, you must work out the mathematics of the energy requirements of a facility, then try to come up with a balance between the mass of the object, and the height of the object to store adequate amount of energy. There are ways to even increase the effective gravity on the object. This can be done by the following ways;

1. Attached one end of a spring to the mass and the other end to the ground. In this way, when the object is lifted up from the ground, the spring gets pulled and according to the following expression, the downward force is increased. The negative sign implies the the force is opposing the displacement of the spring.

F = -k X

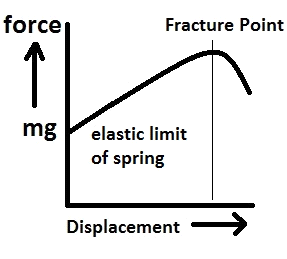
Where,

F = down force by spring

k = spring constant

X = displacement of the spring from rest position

According to the above expression, the downward force is proportional to how much the spring is stretched. Therefore the graph of the total downward force exerted on the object is as under. When the spring get stretched beyond its elastic limits then the spring become almost useless and exerts no downward force.



1. The second approach is about having a magnetic pull also affecting the net downforce. This requires that either the mass be made of a metallic material and there be a magnet at the ground pulling the object downwards, or vice versa.

**BILL OF MATERIALS**

The prototype that we are making is not aimed to be a finished product available to the consumers after completion. We mainly intend to convey the idea to the world that this approach could fulfill the energy storage requirements.

**Mechanical Parts**

Wooden Frame **1,200** rupees

**Electrical Parts**

Solar Panels **1,050** rupees

DC Motor/Generator **700** rupees

**Electronics Components ~2000** rupees

Resistors, Capacitors, Vero boards, wire etc

Arduino NANO

**GRAND TOTAL** 4,950 Rupees + 2,000 Rupees (Miscellaneous)

**= 6,950 Rupees**