DATA ACQUISITION & EXPERIMENTAL ANALYSIS OF POWER HARVESTING FROM SUSPENSION SYSTEM

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DECLARATION

I certify that this research work titled "*Data Acquisition & Experimental Analysis of Power Harvesting from Suspension System"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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ABSTRACT

Energy crisis and environmental problems such as oil shortage and atmospheric pollution have brought challenges for new development of an energy saving, efficient and environment friendly power transmission system in vehicles. This research is focused on how to use the vibrational energy of the suspension system to generate power that would otherwise go as waste. It is demonstrated that the potential energy of driving vibration is sufficient to be utilized as a sustainable energy. The vibrations experienced by the shock absorber of the vehicle when passed through some irregularities on the road are converted into useful energy by using a regenerative linear or rotary mechanism. As shock absorber effect formed, spring is compressed, and linear movement of rack is converted in rotary motion due to pinion moves as the rack is meshed with pinion. And the pinion is mounted on the shaft of the generator which then produce the power. It is then used to calculate the practical power generated from the regenerative shock absorber by taking the real vibrations amplitude data from the road. The vibrations amplitude data is acquired from the road by driving motorcycle on different road conditions with the setup installed in it to calculate and store the vibrations amplitude data. Later, the same data is applied to the testing rig by using pneumatic and Arduino to find out the voltage generated. The power that is practically generated by testing the mechanism on the rig is around 9.5 watts. The harvestable power from the suspension depends on the vehicle speed, road roughness and stiffness of the tire. This regenerated energy is used to charge the battery.

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1. INTRODUCTION

Today world is facing fuel shortages and fuel prices are skyrocketing. One reason behind all this is the excess amount of fuel usage in automotive and power generation sector. Automotive systems are not very fuel efficient and the research on different platforms is underway to enhance power output from these systems. Energy that is wasted in automotive needs to be utilized in order to overcome the low efficiency problems. Suspension system of vehicle is one major energy sink in automobiles. The vibrations of shock absorber are usually dissipated in the form of heat. In this research I will try to figure out a way in which this dissipated energy could be utilized in some useful form. This research is focused on how to use the vibrational energy of the suspension system to generate power that would otherwise go as waste. For that purpose, it is required to design a mechanism that coverts the waste energy from the suspension into electricity. The two main functions of the shock absorber are to keep the tires intact with the road all time and to provide smooth ride to the passengers. It does so by damping the vibrations and the energy associated with it dissipates in the form of heat. This vibration energy from the shock absorber of the vehicle which is otherwise going as a waste could be regenerated and would help in reducing the fuel consumption and exhaust emissions. In this project it is aimed to design and construct a simple mechanism consisting of rack and pinion which convert oscillatory motion of the suspension into unidirectional rotary motion, by connecting which to the generator, electricity can be produced. The energy can be used for charging the battery.

1.1. Problem Statement:

In all vehicles, cars, truck, bus, train car and military vehicles a high amount of energy is being wasted during the driving condition on the road due to the vibration of the suspension system. This energy is dissipated in the form of heat to the surroundings. Since the suspension is an important source of energy dissipation, it is feasible to harvest its vibration energy and convert into regenerative energy to improve the vehicle fuel efficiency. Instead of dissipating the vibration energy into waste heat, the damper in regenerative suspension will transform the kinetic energy into electricity. The stored energy can be used to power vehicle electronics to increase vehicle fuel efficiency.

The IC engines used in vehicles now a days have an efficiency of 30 to 40%. In this efficiency not only car runs and overcome tractive effect but also run the electrical components of a car like air conditioning, lights, ECU of automobiles etc. All of these electrical components are run by the battery which was charged by the alternator continuously. The alternator is coupled directly to the crankshaft of the engine and hence consume brake power. The amount of energy consumed by the alternator is approximately 4% of total energy generated. So, this creates a situation for us where need to replace the alternator to some system which will not add up to the engine load and also recover the waste energy which is dissipated to the surrounding.

1.2. **Research Idea & Concept:**

In automobiles, where many other sorts of energies are unused or lost, suspension system also dissipates energy in the form of heat as well. IC engine has to move the vehicle and along with that many car accessories are also powered by the alternator which itself use the brake power hence reduces the efficiency and increase the fuel consumption. So, the research idea is to a design a mechanism, like the regenerative braking system, that recovers the energy dissipated in the suspension system. The main purpose is to reduce the load on engine and increase the efficiency while using alternative energy available on other ends that were being lost otherwise.

Regenerative braking system is already there and is in use so now there is a need to develop a system that recovers the energy dissipated in the suspension system as well. Shock absorbers dampen the vibrations coming from the road by converting it into heat. The vibrational energy of the shock can be converted into electrical energy using some mechanical setup. The mechanism should convert the oscillatory motion of the shock absorber into the rotation motion. The alternator than used this rotation motion to generate power from those vibrations and it will than provide the power to charge the battery or give power to different accessories directly. When the automobile is running on the normal road, even than the shock absorber is working because of the irregularities on the road or sudden braking. This small amplitude of vibrations combined with the large mass of the vehicle results in the generation of considerable power. So, the concept is to design a prototype of the mechanism to harvest power from the suspension system and then deploy it on the testing rig to show how energy harvesting is possible and how much energy can we harvest from the single shock of the automobile.

1.3. Aims & Objectives:

- To design the mechanism to harvest energy from suspension system of vehicle.
- Real time data acquisition of oscillatory motion from suspension system.
- To construct the prototype of this mechanism to demonstrate the functionality of mechanism.
- Apply the acquired data to find the power harvested.

2. LITERATURE REVIEW

Regenerative suspension system has gained much attention over time which used energy harvesting shock absorber because of its ability to provide dynamic performance and also to convert waste vibration energy into useful power. According to Zuo and Zhang's research, a normal passenger car has a potential energy of between 100 and 400W when it is moving at a speed of roughly 97 km/h on good or ordinary roads. Thus, at an energy conversion efficiency of 75%, 300W of electrical power can be produced, which equates to a 3% gain in fuel efficiency, per BMW's data on the electricity requirement for average passenger automobiles. Levant Power engineers also highlighted the positive impact on fuel savings if such a power loss is partially recovered, where an average power of 1 kW could be captured from a 3-axle truck on a highway, which may be sufficient to replace the high-power alternator from heavy-duty trucks or military vehicles. The power that is regenerated depends on the intensity of vibrations. The more intense the vibrations are, the more power could be regenerated, and more fuel could be saved which is the case in heavy vehicles and off-road vehicles.

To recover the energy dissipated in suspension system, different strategies for regenerative suspension system has been proposed and used. The energy harvested from the suspension system could be used practically to charge the batteries of a vehicle and to supply electrical power as a replacement to the alternator of the vehicle. The regenerative based shock absorbers are divided into different groups depending on how they transform the linear vibrations into electricity. Mainly these regenerative mechanisms are divided into two classes:

- **Linear Electromagnetic Harvesters:**
  The linear electromagnetic harvester converts the energy associated with the vertical oscillatory motion of the shock absorber directly into electrical energy by using a simple structure with electromagnetic induction.
- **Rotary Electromagnetic Harvesters:**
  The rotary electromagnetic harvester converts the vertical oscillatory motion first into rotary motion by using a vertical to rotary motion mechanism. This rotary motion is than transmitted to the shaft of the alternator which than produces electricity.

The rotary based electromagnetic harvesters use two types of methods to convert linear motion to rotary motion which are mechanical based transmission and hydraulic based transmission. The mechanical transmission-based harvester has been developed rapidly because of its simple construction, greater efficiency, and considerable average power. The energy dissipated in directly proportional to how intense the vibrations are and so how heavy the vehicle is. The energy dissipates is maximum in heavy vehicle like trucks and military vehicles. The fuel efficiency improvement is maximum in hybrid electric vehicles and off-road vehicles.

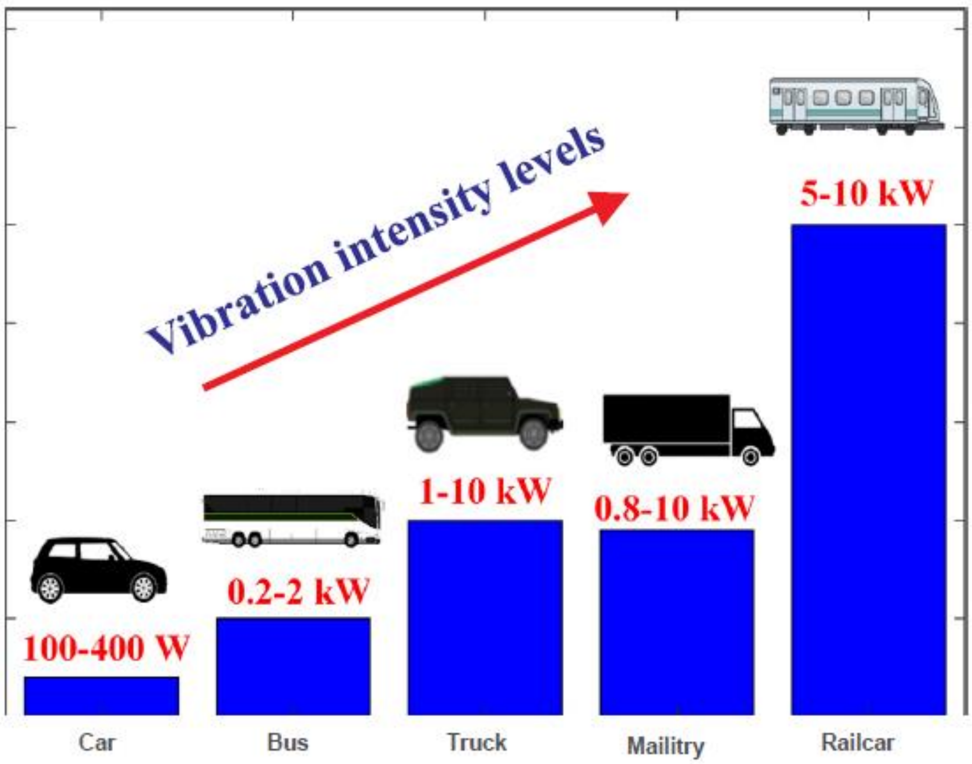

Figure 1. Power Harvesting Capacity of Different Vehicles

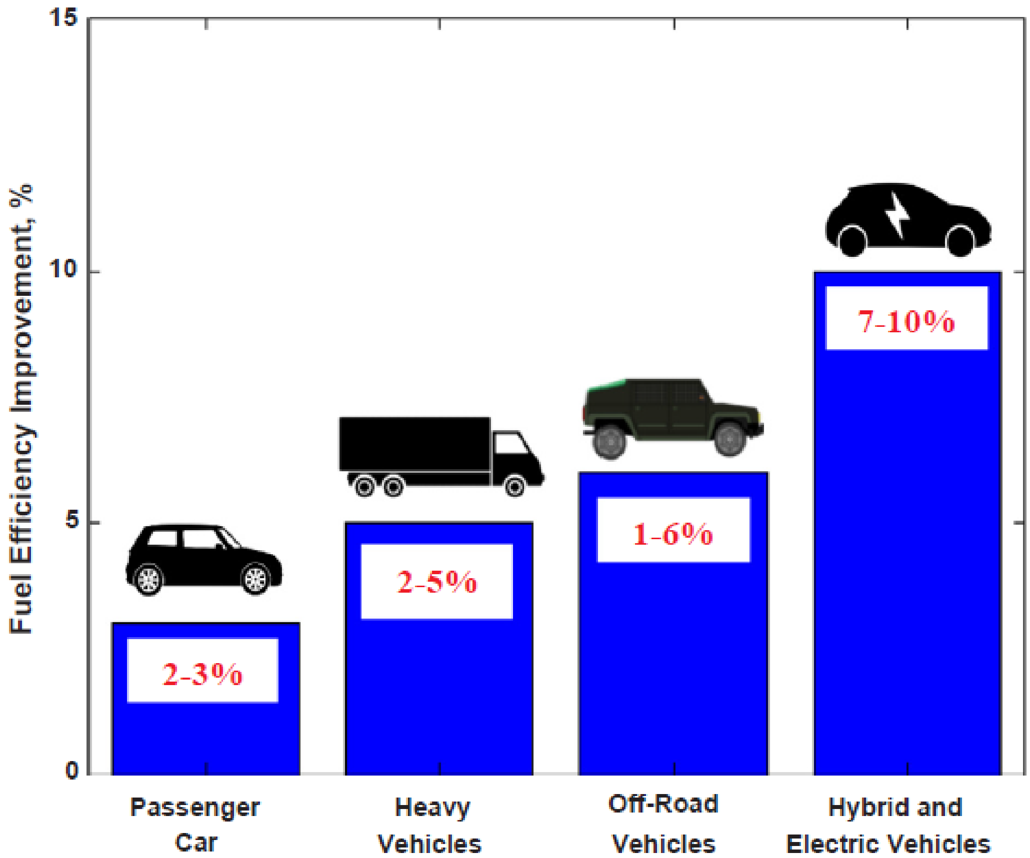

Figure 2. Fuel Efficiency improvement using Power Harvesting Mechanism

Based on a review of the literature, a fairly broad range, from 46 to 7500W, represents the potential energy of the harvestable power for various vehicle types and operational scenarios. The findings for a real drive cycle on a real field may differ from the laboratory and theoretical collected energy outputs in some way. This can be because actual operational conditions for a vehicle while driving normally differ from the testing assumptions and settings.

Reducing the vehicle energy losses is necessary for improving fuel economy, reducing emissions, and supplying other systems with the saved energy like active suspension. The vehicle consumes about 20–30% of the fuel energy in the car moving on roads. Considering the vehicle energy balance, suspension energy dissipation regrettably is not clearly quantified out of the fuel consumption, but it is only considered in the rolling resistance ranging from 3 to 12% of the fuel energy consumption. Nevertheless, in a world where energy becomes rare and expensive, even the small quantities of such otherwise dissipated energy are worth of being harvested such as the energy lost in car suspension. According to the predicted power results, the energy dissipation from the vehicle damper was predicted for various road profiles and vehicle velocities. Under city driving velocities, each damper in the vehicle dissipated energy with an average rate of 20W while a 35W under highway velocities was dissipated per absorber. Thus, as for the whole vehicle, the average dissipated power was predicted to be 80W and 140W at city and highway velocities, respectively, because of the high-speed effect corresponding to the highway roads.

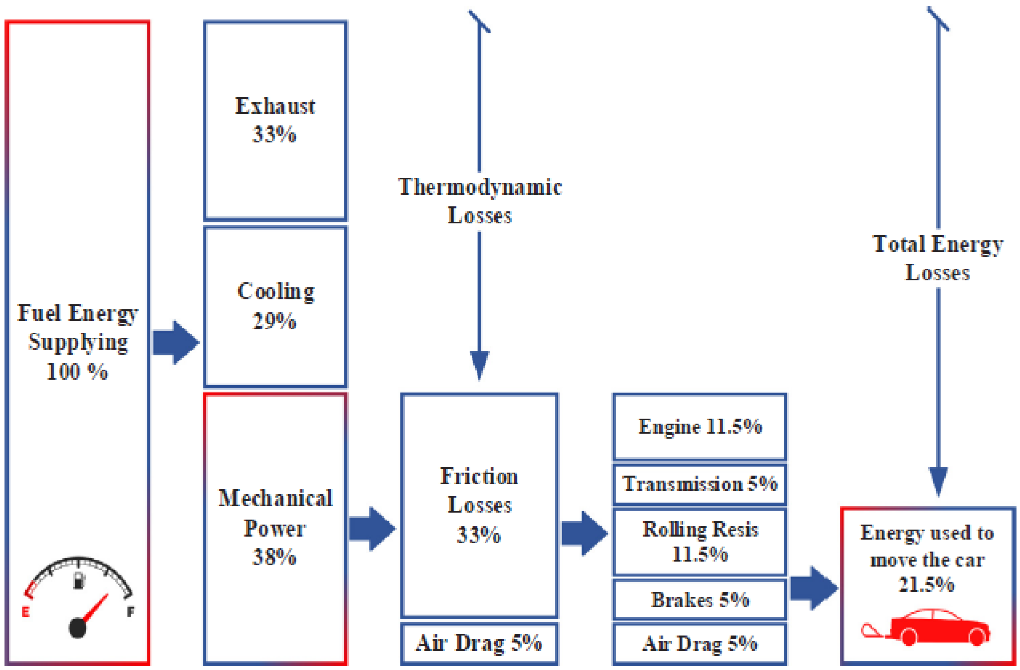

Figure 3. Energy Losses in Vehicle

Linear energy harvesters have a set of voice coils moving in an array of magnetic fields, which can produce electricity and a back electromotive force (EMF). Their energy-harvesting efficiency is generally high, but damping is too small. For instance, the linear energy-harvesting shock absorber proposed in [7] can achieve 70% - 78% mechanical efficiency, but it can only provide a damping of 940 Ns/m under a short circuit condition, even not sufficient for a compact-sized passenger car. To overcome low-damping drawbacks, bidirectional rotary energy harvesters have been proposed, which utilize some mechanisms, such as ball screws [8-10], rack and pinions [11] or other motion conversion mechanisms [12], to transfer reciprocating linear vibration into bidirectional rotation of rotary generators to produce electricity. By converting low-speed linear motion into high-speed rotation, the damping of bidirectional rotary energy harvesters is significantly increased. However, the irregular oscillation of the motion transmission mechanism in bidirectional rotary energy harvesters causes numerous problems such as low efficiency and bad vibration performance. For example, the bidirectional rotary energy-harvesting shock absorber investigated in [11] has a suitable damping range of 1800Ns/m – 8000Ns/m, but it also has large backlash which leads to a relatively low mechanical efficiency of 33% - 56%.

The rotary electromagnetic harvester used different mechanism for linear to rotary transmission including rack and pinion mechanism, ball screw mechanism and hydraulic transmission based electromagnetic rotary energy harvesting damper. Among them rack and pinion based electromagnetic rotary energy harvester damper gives the highest energy conversion efficiency.

2.1. Ball-Screw Electromagnetic Energy Harvester:

Three components make up the electromagnetic damper model employed in this study: a DC motor, a ball-screw, and a nut. The ball-screw and nut design convert the linear motions of the damping system brought on by environmental vibrations into rotating motion. The motor's rotational motion causes a voltage, which creates a current, which is then stored as electrical energy in an electric double layer capacitor. The ball screw and nut are used in back-driven mode, which means that irregular suspension vibrations cause the nut to reciprocate at low speed, driving the screw to rotate in both directions at fast speed. In the ball-screw case, the nut can travel along the linear guide. Simulations carried out showed that the average regenerated and absorbed energy during a period of 20 seconds were 31.63 W and 55.39 W, respectively. This gave an efficiency of 36 %.

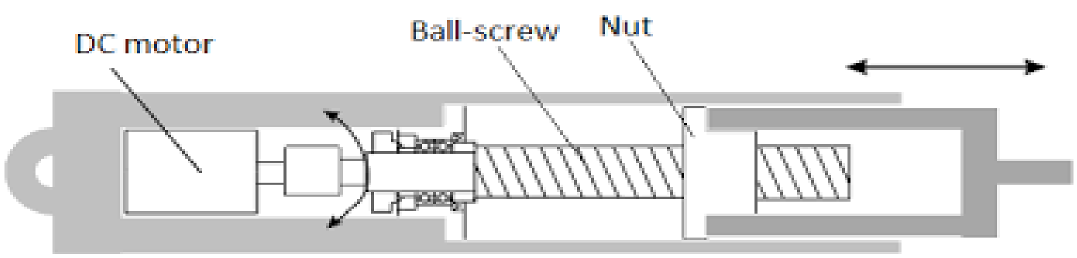

Figure 4. Ball Screw Electromagnetic Energy Harvester

2.2. Rack & Pinion Electromagnetic Energy Harvester:

In rack and pinion type arrangement to convert linear to rotary transmissions, rack is connected parallel to the shock. The linear vibrational motion of shock is also experienced by the rack, and it also move linearly to and fro. The pinion attached with the rack will rotate as the rack move linearly. This will give rotation motion to the shaft of the generator. Simulation results show that the rack-pinion energy harvester had a peak power of 67.5 W and an average power of 19.2 W with a total energy conversion efficiency of up to 56 %. This shows that the rack and pinion type arrangement have the maximum energy conversion efficiency as compared to other mechanisms.

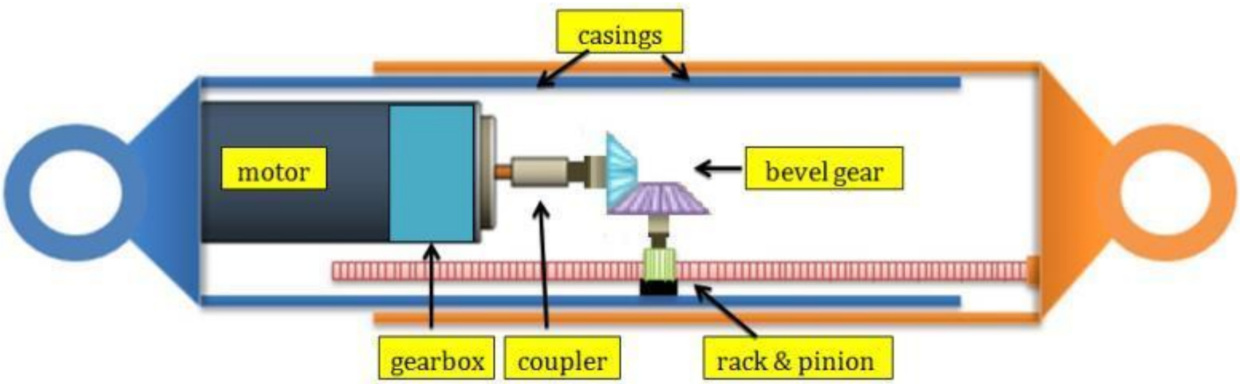

Figure 5. Rack & Pinion Electromagnetic Energy Harvester

2.3. Hydraulic Electromagnetic Regenerative Damper:

Both the ball-screw and rack-pinion mechanism, when used in energy regenerative shock absorbers, causes the rotational direction of the generator to constantly change depending on if the shock absorber is compressing or expanding. This constant change of rotational direction has a negative effect on the generator and can be the cause for failure in the long term. The generator in this system is put in motion by a hydraulic fluid and has a constant rotational direction regardless of if it is exposed to a compression or expansion. This system utilizes the fluid pressure for the conversion of kinetic energy into electric. The experiment showed that the system only recovered 16.5 % of the vibrational energy it was exposed to. Even though this system's fundamental purpose was to reduce the energy loss in the generator from the constant change of rotational energy, the report showed that 21.1 % of the energy was lost in the hydraulic motor and the generator.

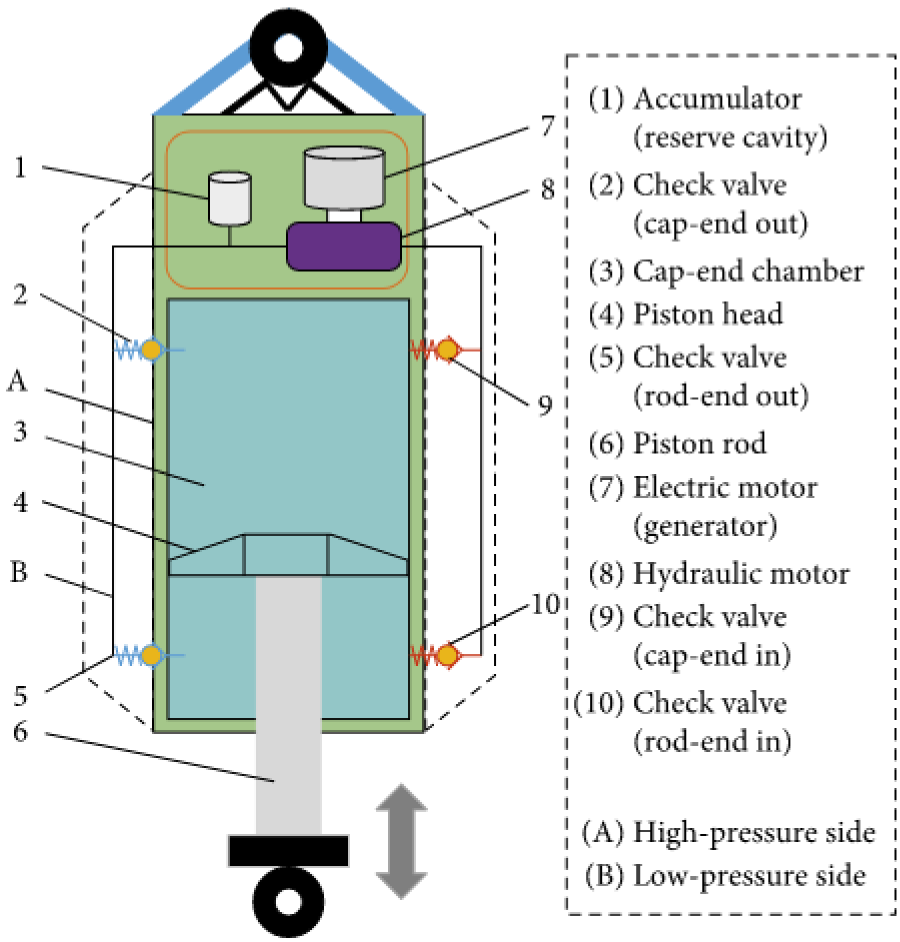

Figure 6. Hydraulic Electromagnetic Regenerative Damper

2.4. COMPARISON OF DIFFERENT METHODS:

Compared to the rack-pinion mechanism, the ball-screw mechanism can significantly reduce backlash before the MMR, resulting in higher energy-harvesting efficiency. Also, by using the ball-screw mechanism, an enclosed lubricated MMR gear transmission system can be designed, which increases the transmission durability and efficiency. The mechanical friction force of the ball screw mechanism is larger than that of the rack-pinion design due to additional friction induced by the ball screw and the high-speed rotational MMR gearbox. The rack and pinion have the highest energy conversion efficiency and give better result under high amplitude vibrations as compared to the ball screw mechanism. The remaining system that should be compared with rack and pinion is hydraulic based regeneration system. The advantage of using hydraulic based system is that with the change in linear motion, the rotation direction of the generator doesn't change. As the rack and pinion mechanism used solid metal parts for energy transformation so it is more prone to damage under sudden bumps which exerted large external forces as compared to hydraulics where fluid is used for the energy transformation fluid itself is damping the forces. Although the hydraulic system is more robust than the ball-screw it is shown to be less energy efficient due to an extensive loss of energy largely caused by friction between the fluid and the surrounding container. Compared to the 16.5 percent power regeneration efficiency of the hydraulic system the rack and pinion energy harvester with its 56 % is clearly dominant.

No.	Energy-Harvesting Technology	Linear-Rotary Motion Transmission	Harvestable Power Range (W)	Conversion Efficiency (%)
1.	Rotary electromagnetic energy-harvesting dampers (indirect-drive based electromagnetic harvesters)	Rack-Pinion Based Mechanism	20–250	30–70%
		Ball-Screw Based Mechanism	25–290	20–65%
		Hydraulic Based Mechanism	30–350	10–40%
2.	Linear electromagnetic energy-harvesting dampers (direct-drive based electromagnetic harvesters)	–	25–300	20–50%

Figure 7. Comparison of Rotary & Linear Electromagnetic Energy Harvesting Dampers

3. DESIGN METHODOLOGY

When a vehicle moves on a road it is always subjected to excitation because of the irregularities on the road, acceleration forces, braking forces and inertia forces on a curved track which causes discomfort to the driver and passengers of a car. Suspension systems are primarily utilized to absorb any type of road shocks caused by poor roads, holes, and bumps, hence providing vehicle stability. They provide consistent contact, comfort, and control, maximizing friction between the tires and the road surface in any sort of motion. The tires, tire air, springs, shock absorbers, and auxiliaries of a basic suspension system work together to absorb the energy of vertically accelerated wheels, letting the frame and body of a vehicle to remain undisturbed while gripping the road and isolating vibrations. A shock absorber is a mechanical or hydraulic device which is designed in a manner which smoothens out or damps out any sudden shock or impulse by converting the Kinetic Energy in the form of Heat Energy and then dissipating it. This energy is usually wasted in the form of heat. Springs alone cannot be used in suspension as they oscillate harmonically for a long time with a very small change in amplitude. Shock absorbers use viscous fluid which dampens the vibrations amplitude and ultimately become zero over a very small interval of time.

When someone drives a car, it experiences vibrations because of the road conditions which causes discomfort and to reduce those vibrations we use shock absorbers which result in the waste of energy. If we somehow reuse that waste energy it would be enough to use that potential energy as a sustainable source of energy. Energy harvester is the device to recycle mechanical vibration, both reducing its secondary pollution to the environment and reusing the wasted energy.

3.1. Principle of Mechanism:

Major concept of Regenerative Electromagnetic Shock Absorbers lies within the conversion of the kinetic energy obtained from the linear motion of the casings of the Magnetic Shock Absorber, to useful energy. The conversion of this linear motion to a rotational motion, and then harnessing this rotational energy with the help of an electrical generator is the main objective. To obtain rotational motion from linear motion, a system of gears known as the rack and pinion is used. This rotational motion is then given to the electrical generator and the electricity obtained is stored in a battery reservoir. This electricity can then be channelized and be used for multiple purposes.

Importantly, it is the Dampers linear motion that plays a major role in the process of electricity regeneration. The initiation of the process is done by the linear up and down motion of the shock absorber. This linear up and down motion is converted to rotational motion with the help of a rack and pinion gear system. This system can be used to convert mechanical energy into electromagnetic energy through a rack and pinion mechanism, and the electromagnetic energy is stored by energy storage elements, which can reduce vibration and recover excess energy.

3.2. Rack & Pinion:

It is a set of gears used to convert linear motion to rotational motion. The linear gear bar is known as the rack, and it engages teeth with a circular gear known as the Pinion. The linear gear called rack is attached parallel to the shock absorber. When a vehicle excites vertically because of the irregularity in road conditions, shock moves linearly to and fro to dampen the vibrations. As the rack is attached parallel to the shock absorber so it moves linearly too with the shock. The tooth of the rack meshes with the tooth of pinion, which is a circular gear, and rotates the pinion in the direction depending on the direction of motion of rack. So, when the rack moves longitudinally with the motion of shock, the pinion rotates.

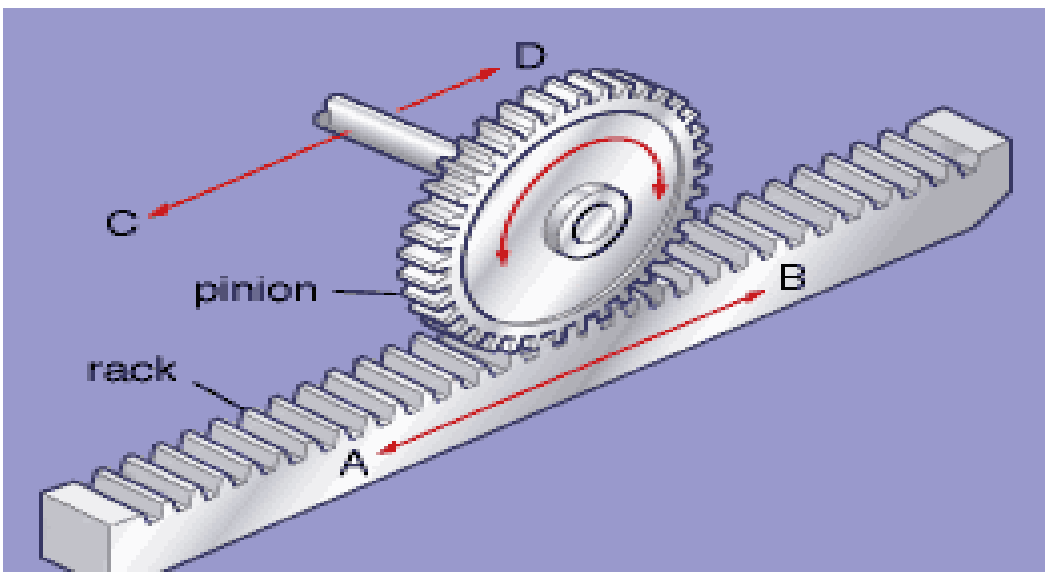

Figure 8. Rack & Pinion Mechanism

When travelling on a highway or a fine quality road where the road irregularities are not much then the amplitude of vibrations is quite low and of the order of few millimeters. In such cases the linear vibration of the rack is very small. It requires a small gear ratio of rack and pinion so that even for a small linear movement of the rack, we get more rotations of the pinion which directly rotate the shaft of the generator.

The rack and pinion are attached externally to the case of the shock absorber because of the two reasons:

- The first reason is that because of the movement of the rack and pinion it is prone to breakdown in different components and that would damage the shock absorber if placed internally. Moreover because of the wear and tear of the moving system, we can replace it easily without disturbing the shock absorber.
- Secondly to avoid the wear and corrosion of rack and pinion assembly we can provide lubrication to it, so if placed externally it would not interfere with the shock absorber assembly.

3.3. Generator:

A generator is a device that converts mechanical energy into electrical energy. It works on the principle of Faraday's Law of electromagnetic induction which says that whenever magnetic lines of force passing through a closed-circuit change, a current is induced in it. The electromotive force EMF or voltage is generated in a current-carrying conductor that cuts a uniform magnetic field. When a conductor rotates in a static magnetic field, it experienced a change in magnetic flux and EMF induced in it. The armature rotates between the poles of magnet and in perpendicular direction to the magnetic field, so the flux changes continuously. As a result, alternating current flows through galvanometer and the slip rings. The rack moves parallel to the shock absorber as it experiences the vibration. Then rack rotates the pinion with both the teeth of rack and pinion meshes each other. The pinion is connected with the shaft of the generator. So, any rotational movement of the pinion will force the shaft of the generator to move as well. As a result, the rotation of the shaft of the galvanometer will generate electricity.

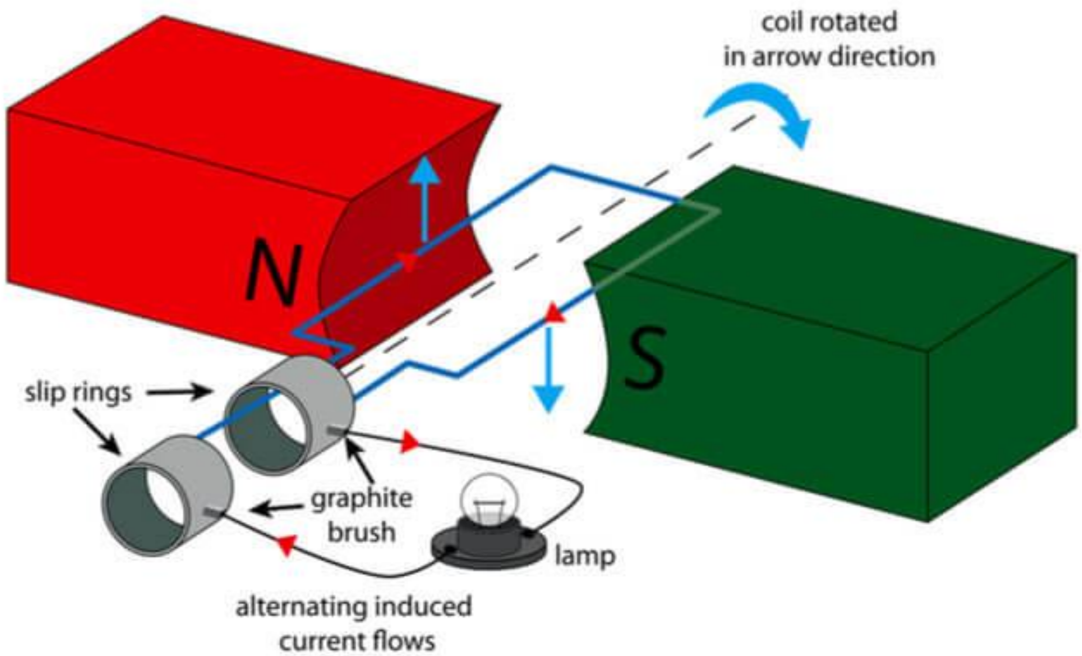

Figure 9. Generator & it's Working Mechanism

3.4. Mechanical Motion Rectifier:

With the excitation of the vehicle from the road bumps, rack moves with shock absorber in both upwards and downward direction. This upward and downward movement of the rack will cause the pinion to rotate in both clockwise and anticlockwise direction. This bidirectional movement of the pinion will also rotate the shaft of the generator in both directions. To convert this bidirectional motion of the pinion into unidirectional motion of the shaft we used a mechanism called the mechanical motion rectifier. The key component of motion rectifier is one-way rollers that transmits rotation only in one direction and divide the motion in two different routes. When the central shaft rotates in clockwise direction, the one-way clutch #1 is engaged, and the bevel gear #1 embedded with clutch #1 rotates and drives the bevel gear #3 to work. Meanwhile, the other clutch #2 is open, and the bevel gear #2 fixed on it does not output any power to the small bevel gear #3. The working principle is vice versa when the central shaft rotates in reverse direction. By using the mechanical motion rectifier, loss of energy is reduced as the energy can be harvested in both the directions which otherwise would go waste in one of the directions and hence is useful to improve energy utilization. Moreover, a stable current can be produced by rotating the shaft in single direction. The disadvantage of using mechanical motion rectifier is that whatever little amount of energy is taking from the suspension system, part of it will be used in rotating the gears of the MMR which will result in decrease power output.

Generator is used to produce continuously alternating current in which the direction of current changes alternately. The purpose of the thesis is to store the energy in the battery to use it later for other purposes or to use that current directly to supply to electrical devices like air conditioner, radio, ECU etc. All of these devices used DC current or to store the current in battery we need to convert the alternating current (A.C) into direct current (D.C). For this purpose, we use rectifier that is an electrical device that converts alternating current (AC), which frequently changes its order, to direct current (DC), which streams in only single order.

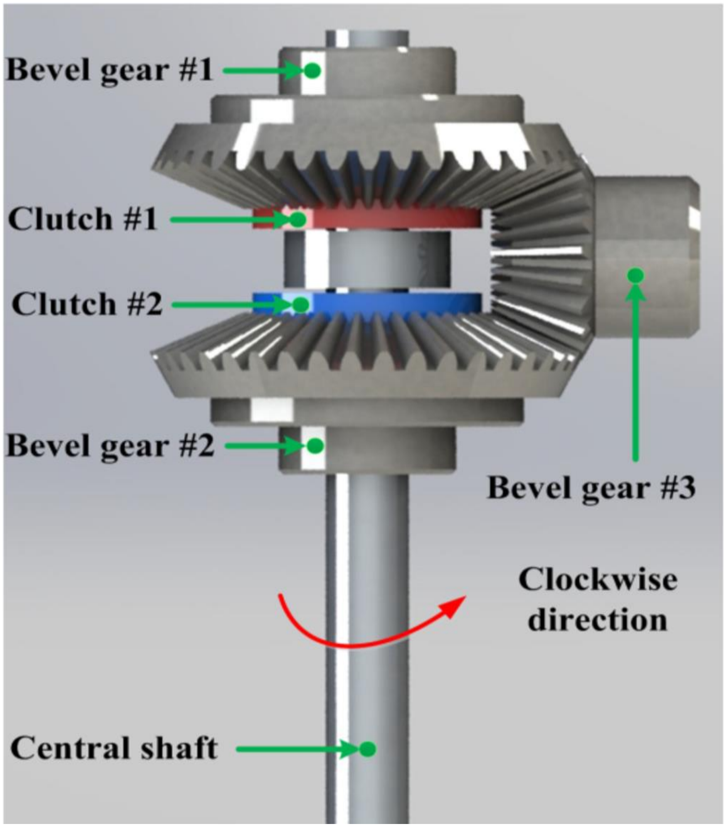

Figure 10. Mechanical Motion Rectifier

3.5. Working Flowchart:

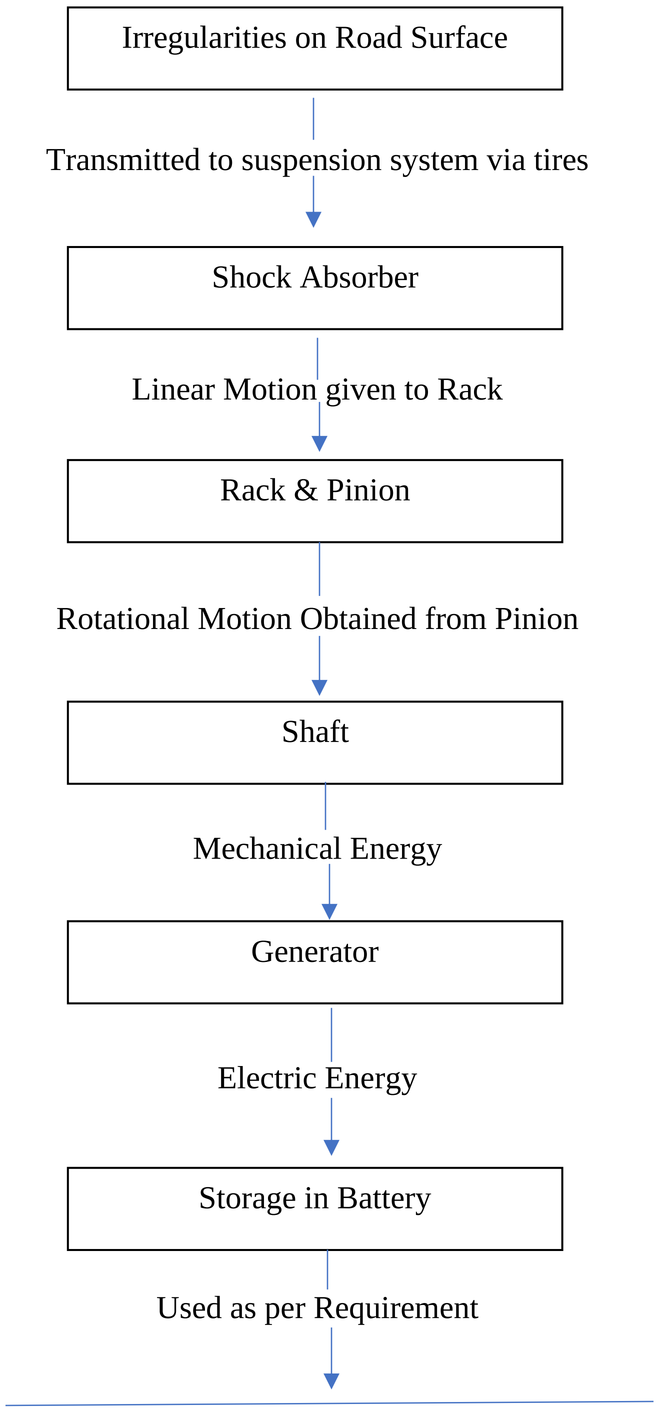

Figure 11. Flowchart of Mechanism Working

The overall system consists of a different component including suspension system, rack and pinion, generator, rectifier, and battery. The vibrations that were experienced by the vehicle will absorbed by the suspension system. Because of the irregularities on the road, motion of wheel will cause the suspension to compress and expand giving it a reciprocating motion. This reciprocating motion will transfer to the rack, which is connected parallel to the shock, which in turn will rotate the pinion having teeth meshed with the rack. The pinion will then rotate the shaft of the generator which will produce the AC current. The rectifier will convert this AC current to DC which will then store in the battery to use it as per requirement.

The function of a battery in a vehicle is just to supply the necessary current to the starter motor and the ignition system while cranking to start the engine. It also supplies additional current when the demand is higher than the alternator can supply and acts as an electrical reservoir. So, in vehicles battery act as an electrical storage device to start the ignition. All electrical components of a car when it's in a running condition are drive by the alternator. The alternator charges the battery and supply the current to all electrical devices as well. The alternator is run by the engine and take power by the crankshaft of the engine, so it reduces the fuel efficiency of the vehicle as fuel is used to run the engine and engine in turn is used to run the alternator. The consumption of alternator is found to be almost 4% of the total consumption. The rotation of the engine drives the alternator, forcing electrical energy (current) into a battery, where it's stored as chemical energy. The chemical energy of the battery is then changed back to electrical energy when it supplies current to the starter motor and accessories. The cycle repeats itself as the engine's mechanical energy again drives the alternator to recharge the battery so it can supply more current to the starter when needed. As in this research, the aim is to generate power from the suspension and store it in the battery for further usage. By providing the regenerative power to the battery we can increase the fuel efficiency of a vehicle as the work of the alternator would be reduced which was taking 4% of the consumption. We can also provide the regenerative power directly to some electrical appliance like air conditioner which consumes most of the energy from the alternator. As we are storing power in the battery for further usage so it will be more efficient if the mechanism is used in electric vehicles. The price of EVs is significantly higher than traditional vehicles. The primary reason for high prices is the high cost of vehicle batteries. Electric vehicles run entirely by the battery and as we supply the regenerative power to the battery so it would not require much charging and will be more efficient if used alone without regenerative mechanism.

4. DATA ACQUISITION

Most of the research previously done on this topic is on theoretical methods of how to device a mechanism that harvest power from the excitation or vibration of the shock absorber because of the road irregularities. So, researchers proposed different methods and mechanisms to harvest power either by linear electromagnetic harvesters or by using rotary electromagnetic harvesters. The work being done on it was mostly theoretical summary of how those mechanism work and draw power from the suspension system. Most of the calculations were done just by assuming different variables and equations that gives the power output ranging from tens to hundreds of watts. Some have also done simulations and analysis using different mechanisms and different simulations software to get to know the real amount of power extracted from the suspension system using that mechanism. But we can't get to know the real power being extracted until we apply the real-life data taken from the road in real time to the mechanism being used. Lab experiments were also done in the past on the mechanism being used to harvest power by applying it the vibrations of constant amplitude either by hand or by motor. As the amplitude of vibrations experienced by the vehicle is not constant and it damped down over time and the amplitude of vibration experienced by the vehicle every time it passed through some bump or irregular surface is not constant so that lab experiment also does not work out. It just gives the idea that some power could be extracted by using that mechanism from suspension but could not give the exact or near amount of power being generated.

In this research we will acquire data from the real time driving vehicle of how large the amplitude of the vibrations will be when a vehicle is running on a particular road at some constant speed for some interval of time. We will take three different sets of data for different road conditions like for highway, city road and rough road. We will also see the effect on the vibrations experienced by the vehicle by varying the speed of the vehicle. So, we have two variables here, speed and road conditions, and by varying both we will see their effect on the amplitude of vibrations. These data of vibrations amplitude, that we acquire from the real time driven vehicle excited by the real road conditions, will then apply on the mechanism of rack and pinion that we used along with the generator using pneumatic actuator on the testing rig. By applying the actual data on the testing rig we will calculate how much power we can regenerate from the reciprocating movement of the shock absorber when acted by the irregularities of the road surface.

4.1. Data Acquisition Setup:

As the vehicle passes over an uneven road surface there is a relative motion of individual wheels. The shock absorber compresses and expand until the vibrations damped over time.

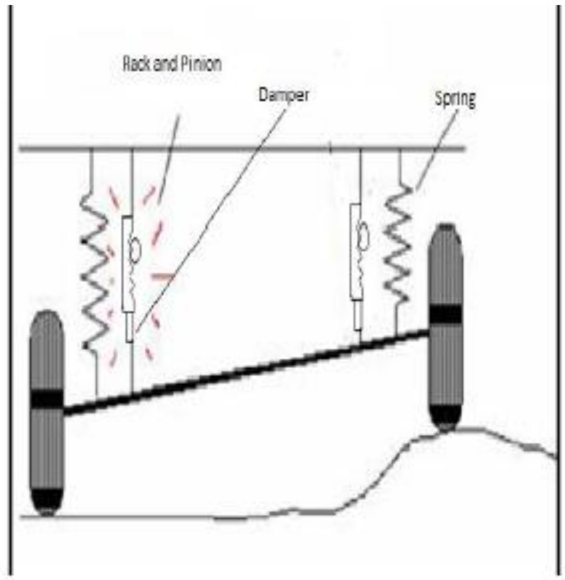

Figure 12. Independent suspension system

So, we need a sensor that sense the relative motion between the axle and body of a car as the car experienced a bump or some irregularity on a road surface. We need to find the vibration amplitude or the displacement of the vibrations so the sensor must be of the type that is used for sensing the displacement. There are many sensors of different interface that are used to find the distance or displacement having different properties. Since we have certain requirement of precision, vibration frequency and range of displacement that must be fulfilled so we select the sensor accordingly. We also need some device that we can interface with the sensor to store the data. For this purpose, we will use Arduino that will be connected with the sensor and a laptop to store the displacement data into the laptop in excel file. We have performed this experiment on the motorcycle as we didn't have the equipment in the lab to apply the force equivalent to the weight of the vehicle. Motorcycle, on the other hand, are not too heavy and by using pneumatic actuator we will easily be able to apply the force equivalent to the motorcycle. First of all, we need to find out the sensor that fulfilled all our requirements of precision, frequency and range to be used in data acquisition.

4.2. Accelerometer Sensor (ADXL345):

It is a sensor that measures the acceleration or vibrations of any body, object, or structure while in rest or motion. The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it. Since the charge is proportional to the force, and the mass is a constant, then the charge is also proportional to the acceleration. There are two types of acceleration forces, static and dynamic forces. Static forces are those which are being applied to some object constantly like a gravitational force. Dynamic forces are those forces that are applied to the moving object at changing rates like vibrations. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. It measures the acceleration in all 3-axis x, y, and z. Accelerometer sensors have different types but the one we used was ADXL345. It fulfilled our requirement of precision, frequency, and range but the problem was that it gives the vibration data in units of acceleration. The data we want to acquire from the suspension system is the vibration amplitude and it should be in units of displacement. By using an accelerometer, we will have the data in the acceleration terms and to convert it again into displacement is a time-consuming process. Moreover, the other issue with the accelerometer sensor is an error in the data while a vehicle is moving down or up the slope. The accelerometer sensor counts the slope in the vibration amplitude as it is not a coordinate acceleration. Because of these two problems with the accelerometer sensor, we cannot use it for our data acquisition as it would make the data incorrect.

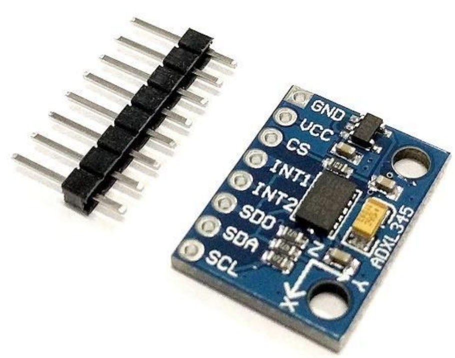

Figure 13. Accelerometer Sensor

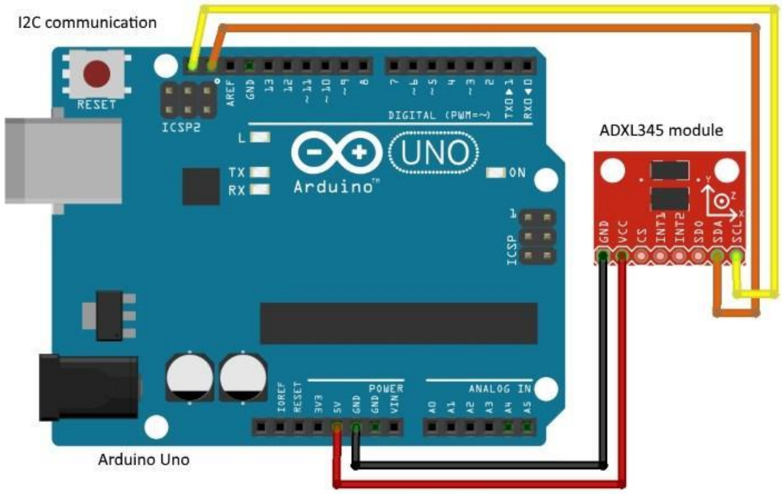

Figure 14. Arduino Connection with Accelerometer

4.3. Capacitor Sensor (E2K-C):

It is a type of sensor that is used to detect solid or liquid targets without having physical contact with them. To detect these targets, capacitive sensors emit an electrical field from the sensing end of the sensor. Any target that can disrupt this electrical field can be detected by a capacitive sensor. This type of sensor is used for very precise data measurement with a frequency of 10Hz. It is useful for small range detection purposes. The sensing distance of the E2K-C, however, will vary with the electrical characteristics of the object, such as the conductance and inductance of the object and the maximum sensing distance of the E2K-C will be obtained if the object is made of grounded metal. The sensing range of this type of sensor is 3mm to 20mm which is less than our requirement, so this type of sensor is not best for data acquisition in our case.

Figure 15. Capacitor Sensor

4.4. IR Distance Sensor GP2Y0A02YK0F:

It is an IR sensor that is used for accurate distance measurements. It worked by sending the infrared which bounces off the object. The analogue voltage that is returned determines how close the nearest object is. The closer it is, the higher the voltage is returned. The variety of the reflectivity of the object, the environmental temperature, and the operating duration are not influenced easily to the distance detection because of adopting the triangulation method. It is available in a number of different distance measuring ranges as per the requirement of short-range detection applications or long-range distance measuring applications. As per our requirement, the distance range best fit for our purpose was 10-150cm. It fulfills our requirement of distance measuring range and required frequency as well, but the precision requirement is not fulfilled. This type of sensor gives the reading in units of centimetres while our precision requirement is in millimetres. As the vibrations experienced by the vehicle running on the road are not so large that we measured it in centimetres, so this type of sensor also did not best for our scenario. Another disadvantage of using it is when the detector is exposed to the direct light from the sun, tungsten lamp and so on, there are cases that it cannot measure the distance exactly.

Figure 16. IR Distance Sensor

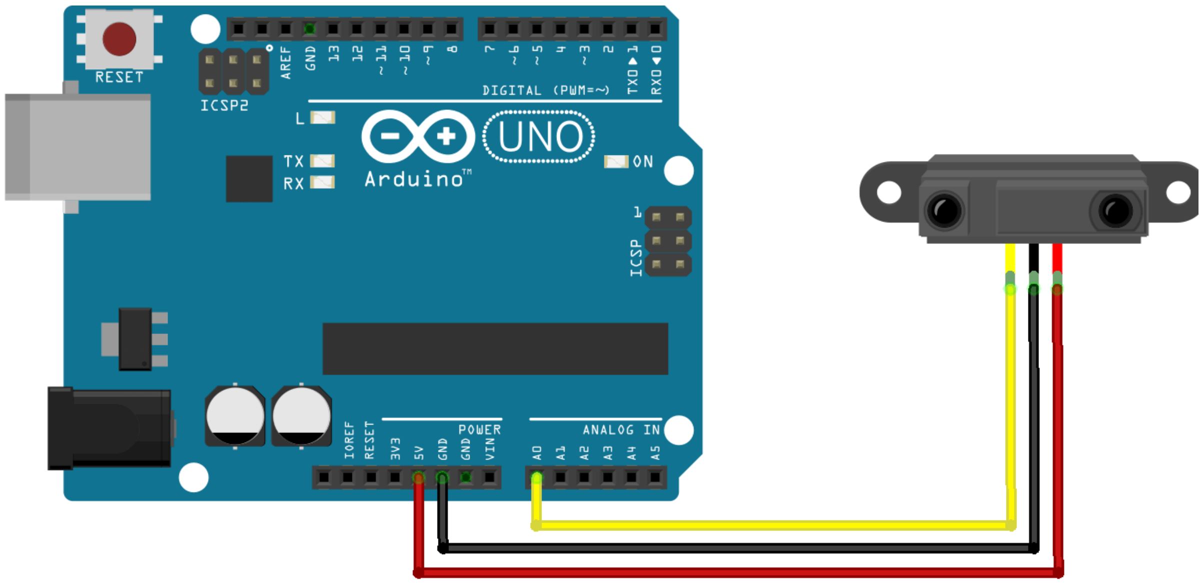

Figure 17. Connection of Arduino with IR distance Sensor

4.5. VL53L0X Sensor:

It is a distance sensor that uses the time-of-flight principle to measure the distance of the objects. It is a laser-ranging sensor. It releases the laser beam that sticks to the object and bounces back. The time taken by the laser to hit the surface of the object and reflect back to the sensor is known as the time of flight. It can even measure the distance range of the object that's surface is reflective. Unlike IR distance sensors that try to measure the amount of light bounced, the VL53L0x is much more precise and doesn't have linearity problems or 'double imaging' where you can't tell if an object is very far or very close. It can measure the target distance of up to 2 meters. As it uses a very narrow laser light source, so it is good for measuring the distance of the surfaces that are directly in front of the sensor. Depending on ambient lighting and distance, we'll get 3 to 12% ranging accuracy - better lighting and shiny surfaces will give us the best results. This sensor is best suitable for our purpose as it fulfills all our requirements of precision, which is in millimeters here, distance measuring range, and frequency range. To communicate with the microcontroller, the I2C communication protocol is provided onboard.

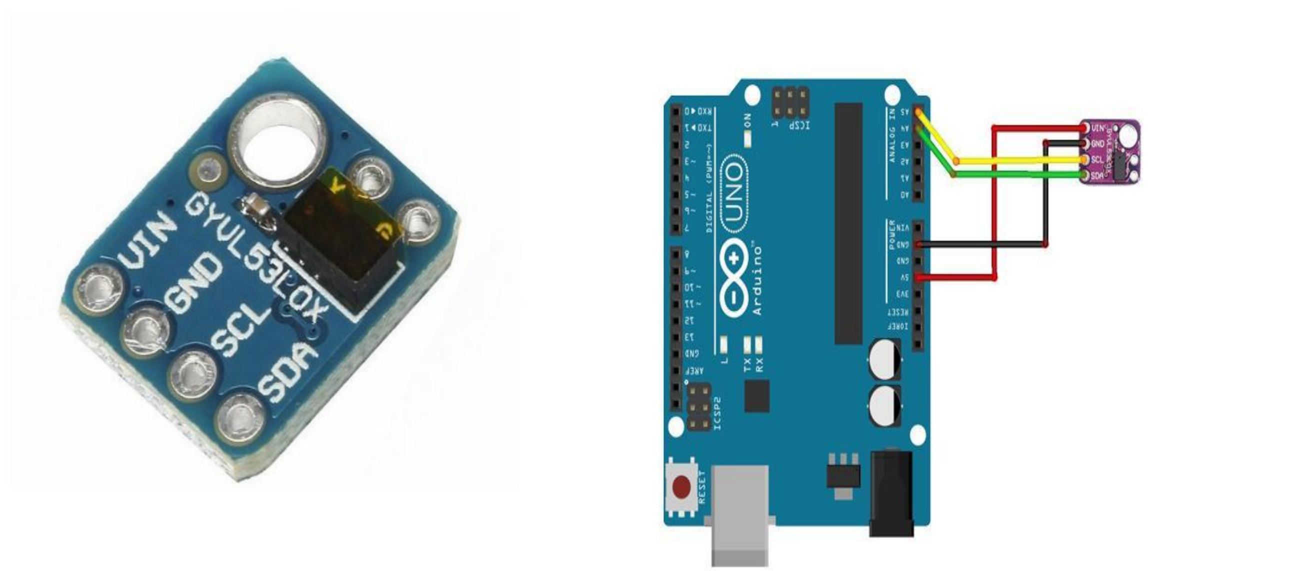

Figure 18. VL53L0X Sensor and it's connection with Arduino

4.6. Experimental Setup for Data Acquisition:

To acquire the vibrations data that the vehicle will experience while moving on the road, we add a setup on the motorcycle. The setup will sense the amplitude of the vibrations that will act on the suspension of the vehicle and by using an interface it will store the data of vibration amplitude in the laptop. This setup will consist of two metal plates, one plate will be attached to the lower end of the shock absorber which is the axle, and the second plate will be connected to the upper end of the shock absorber which is the body of the motorcycle. The lower plate that is attached to the axle will be fixed and the one attached to the body will move up and down as the shock absorber will compress and expand. VL53L0X sensor will be fixed on the lower plate. The sensor will be connected with the Arduino through connecting wires with the I2C communication protocol and the Arduino will be connected to the laptop. Now as the motorcycle moves on the road and passes over some irregular surface or bump, the shock absorber will compress and expand to dampen the vibrations. The plate attached to the upper end of the shock will also move up and down and the distance between the upper and lower plate will change. This change in distance will be noticed by the sensor attached to the lower plate. The sensor will send the data to the Arduino which will eventually save on the laptop in an excel file.

To see the effect of different road profiles on the power harvested from the regenerative suspension system, we have acquired data from three different road profiles for a specific interval of time and at a constant speed.

4.6.1. Data of Vibration Amplitude Taken from Highway:

To acquire the vibrations data experienced by the motorcycle shock, I drive it on Srinagar highway which is considered as the class A type of road, with all the experimental setup mounted on it to gather the vibrations amplitude data. The time interval for which the motorcycle is been driven is almost 30 minutes so that the acquired data is enough to apply it later to the testing rig. The maximum amplitude of vibration experienced by the motorcycle is 14mm. However, the average amplitude of vibrations on highway road was about 5mm.

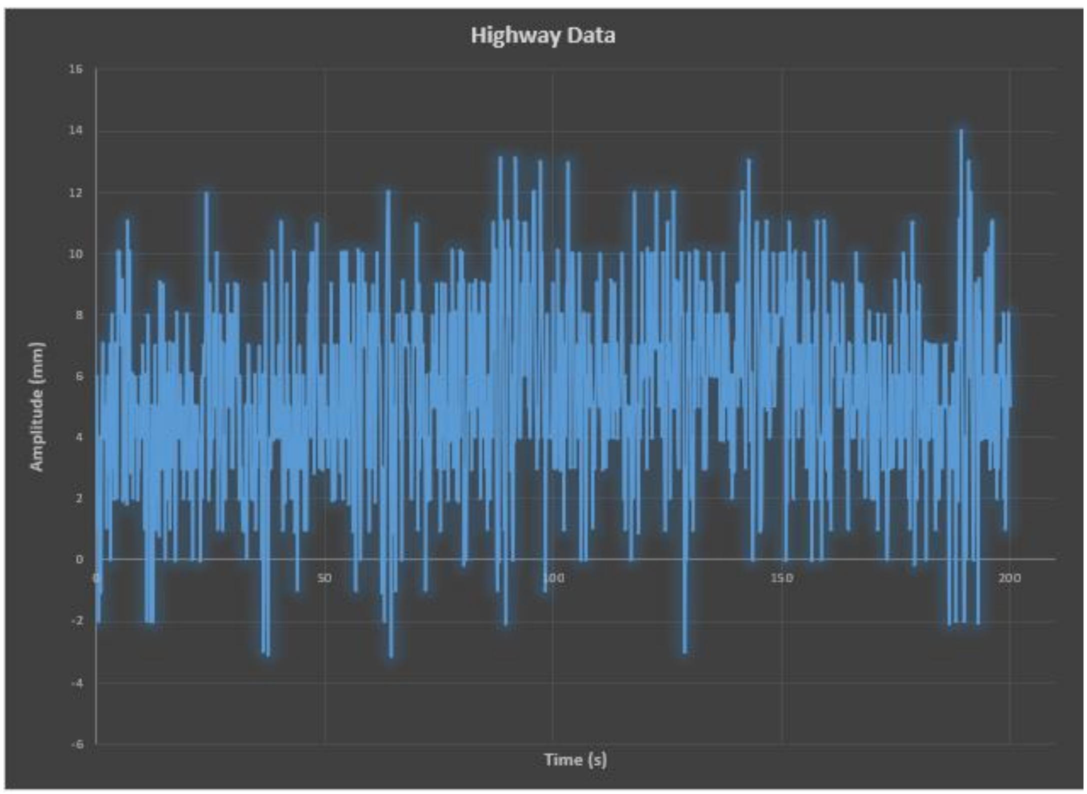

Figure 19. Graph of Highway data taken from motorcycle shock w.r.t time

4.6.2. Data of Vibration Amplitude Taken from Street Road:

The roads within the city or streets are not that fine and smooth as compared to the highway or motorway and so the irregularities are more often and hance the vibrations amplitude is greater, and speed is also slow as compared to highway. So, the maximum amplitude of vibration detected here is 17mm. The maximum amplitude of vibration is experienced where the road condition is poor and hence it's not so often. The average amplitude if vibration on street road is observed to be almost 7mm. The graph of the data of vibrations amplitude with respect to the time is shown below which is the small part of the data taken from the 30 minutes driving.

Figure 20. Graph of Vibrations Amplitude data taken from motorcycle on street road

4.6.3. Data of Vibration Amplitude Taken from Rough Road:

The conditions of roads in many villages as well as major cities of Pakistan is well below average road condition and is considered as class D of road which I termed here as rough road. Such type of roads are filled with ditches, uneven gutter holes, construction dump, absence of proper constructed road, local man-made speed breakers and so on. Because of all these irregularities the vibrations experienced here by the motorcycle's shocks is maximum. The maximum amplitude of vibrations experienced here is almost up to 20mm.

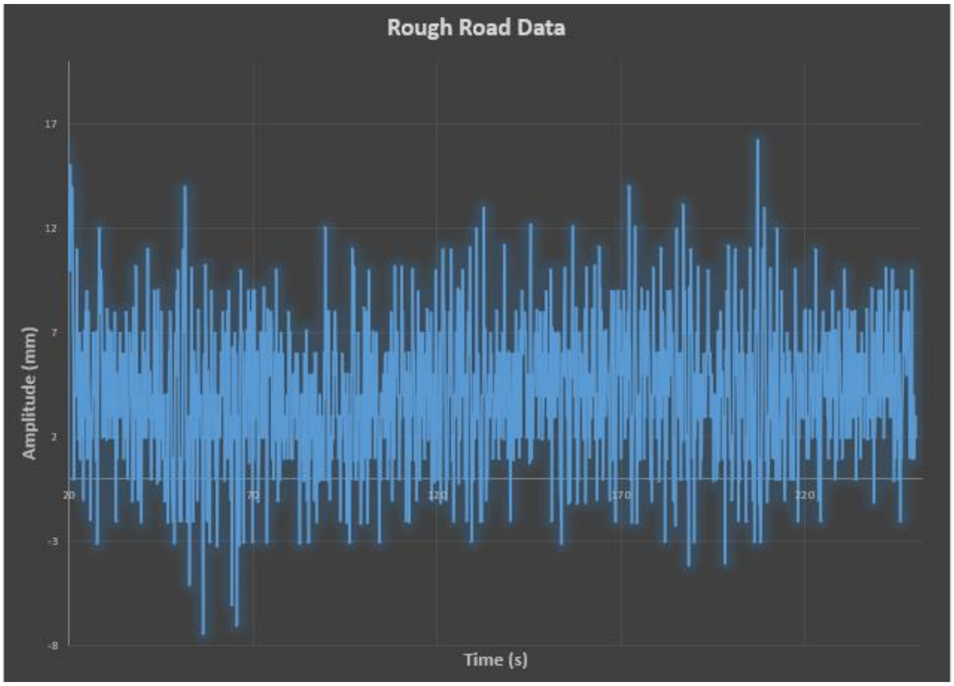

Figure 21. Graph of vibrations amplitude taken from motorcycle on rough road conditions

Properties	Highway	Street	Rough Road
Driving Speed (Km/h)	50	40	30
Driving Time (min)	30	20	30
Maximum Amplitude (mm)	16	21	33
Average Amplitude (mm)	6.13	6.52	7.04

Table 1. Comparison of Vibration Amplitude Data on different road conditions

5. Design of Mechanism

The mechanism used here in the research for the converting linear motion of the shock absorber to the rotating motion is rack and pinion. Rack will be connected in parallel with the shock absorber so that it will experience the same to and fro vibrations as the shock absorber is experiencing while moving through irregularities on the road. The rack is then connected to the pinion gear having meshed teeth to each other so the vertical vibrations of the rack would be converted to the rotating motion. This pinion gear is then connected with the shaft of the generator so the pinion rotation will be given to the shaft of generator that will then produce power.

The data that we acquired from the road on different conditions shows that the minimum average amplitude of vibration experienced by the shock is almost 6mm. Now we have to design the rack and pinion gear so that the minimum amplitude will give the required motion to the generator to produce power rather than to generate noise. The generator that we are using have the specification of 12 volts DC and the minimum RPM requirement is 50 RPM below which it will produce noise. So, the calculation of the design for rack and pinion gear is as calculated below.

- Frequency of the data acquisition = 3 Hz
- Minimum average amplitude of vibration = 6mm
- Since there would be 3 complete cycles and 6 strokes of rack so the velocity of the pinion will be

$$v = 6 \times 6 = 36mm/s$$

And according to the equation

$$v = r\omega$$

$$36 = r \times \frac{2\pi N}{60}$$

$$r = \frac{36 \times 60}{2\pi \times 50} = 6.875mm$$

The calculations shows that the radius of the pinion should be 6.875mm or less to generate the useful power and avoid noise with the min of 6mm vibration amplitude and generator of 50 RPM.

The final specification of the Pinion used are:

- Reference Diameter= 13.35 mm (less than the minimum diameter requirement of 13.75mm)
- Number of teeth= 14
- Module = 13.35/14 = 0.95

Now the rack gear should be designed in line with the specifications of the pinion gear so that they mesh accurately. For that purpose, the module of both the gear and pinion should be same.

$$Module\ of\ Rack = \frac{\frac{Distance\ between\ 10\ pitches}{10}}{\pi}$$

$$Distance\ between\ 10\ piches = 0.95 \times \pi \times 10 \approx 30mm$$

Figure 22. Manufactured Rack and Pinion

This rack and pinion should be then connected parallel to the shock absorber but should be attached externally to the case of shock absorber. The reason for it is that the rack and pinion may get wear and tear over time so to replace the mechanism without disturbing the shock absorber unit it should be attached externally. The gear ratio of the rack and pinion should be small so that even for small linear motion, pinion gets more rotation to generate more power.

6. Data Application and Testing

The main purpose of the research was to determine how much voltage and power is generated by using the mechanism purposed above in this thesis research for power harvesting from suspension system. The research previously done on this topic to calculate power was either by assuming constant vibration amplitude and applying it to the respective phenomena or by analyzing the phenomena in software to calculate its power. Both of these ways are not precise to find the power harvested by the suspension system using any mechanism as the amplitude of the vibrations experienced by the vehicle is not constant but is varying accordingly with the roughness and uneven conditions of the road. Analysis of the mechanism is one way to find the power generated but in theoretical way without considering the actual life conditions and friction that will affect to reduce the power generation in real life.

The purpose of the data acquisition was to find out exactly the varying vibrations amplitude experienced by vehicle on different road conditions. After acquiring the data, the next step is how to apply the acquired data to the testing rig containing the rack and pinion mechanism to find out the exact voltage and power harvested from the suspension system. Testing rig consists of shock absorber and our purposed mechanism of rack and pinion in parallel to each other. The shaft of DC generator is connected with the pinion which would in turn generate the voltage and power. The testing rig also consists of Pneumatic Cylinder to provide the vibration amplitude acquired from the real-life road data.

Figure 23. Testing Rig

6.1. Data Application:

To apply the data that we acquired from the road, we need some kind of automation device or mechanism as it's not possible to apply the varying amplitude from hands manually. To apply the acquired data automatically to the pneumatic cylinder, we will need following devices:

- Arduino Mega
- Arduino Uno
- SD Card Module
- MOSFET Module
- Connecting Wires (Male-to-Male & Male-to-Female)
- Power Supply
- Compressor

6.1.1. Arduino Mega:

Arduino Mega is used to apply the data acquired previously to the pneumatic cylinder using other devices connected with it as well. The need for Arduino Mega instead of Arduino Uno is because of the large data that we are required to read off the SD card. As Arduino Uno is unable to read data more than 50 or it will make the device and process slow and our data of vibrations amplitude that we acquired from the road is in thousands, so we need a large device fit for such purpose. Hence Arduino Mega is used as it have the ability to read a large number of data efficiently without consuming much time.

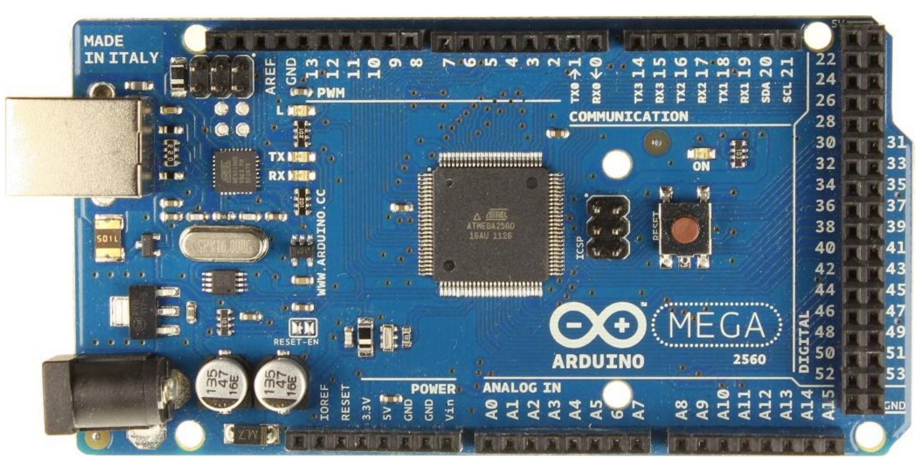

Figure 24. Arduino Mega

6.1.2. SD Card Module:

The Arduino cannot read data directly from the PC or laptop. So, to enable the Arduino to read the acquired data, we will need SD card and SD card module. First, we will transfer our data of vibrations amplitude that we acquired from different road conditions to the SD card. Now insert this SD card into the SD card module and connect it with the Arduino. We will see that the Arduino will start reading the data from the SD card and we can change the number of data we want the Arduino to read as per the requirement.

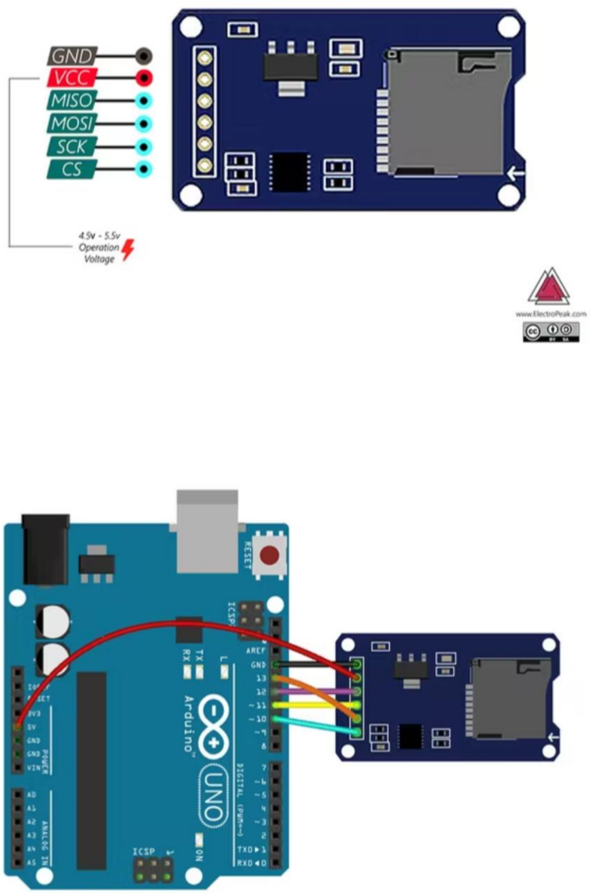

Figure 25. SD card Module & it's connection with Arduino

6.1.3. MOSFET Module:

Pneumatic cylinder needs a certain amount of voltage to operate depending upon the type of pneumatic we are using and for which operation it is being used. MOSFET is a type of field effective transistor, and it acts as an electrical switch or amplifier to control the amount of voltage and current that can be used and required for the operation. The purpose of MOSFET in this experimental setup is to control the voltage being applied to the Pneumatic cylinder so that we can control the amplitude and stoke length of the arm of the pneumatic cylinder.

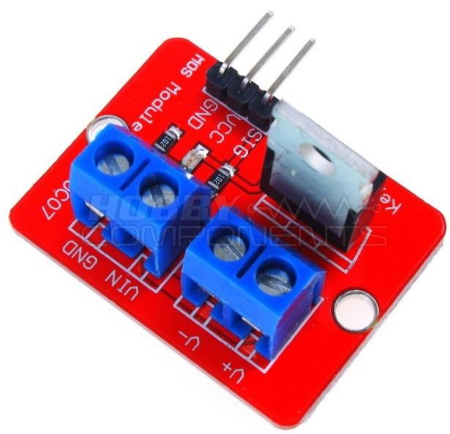

Figure 26. MOSFET Module

6.1.4. Power Supply & Compressor:

Pneumatic Cylinder needs compressed air energy to convert it into linear reciprocating motion. Pneumatic cylinder valve is used to control the movement of the piston either by automation or by the use of the single button. The compressor is used to provide the air to the pneumatic cylinder, which then convert that compressed air energy to the reciprocating linear motion of piston. Through one valve air is supplied by the compressor and the other two valves are used to provide air to the pneumatic cylinder. To push the piston forward air is supplied through the valve and then when that air moves out through the other valve, the piston moves backward.

To automate the pneumatic cylinder using Arduino, we need to provide the voltage required to operate the pneumatic which in our case is 24 volts. So, we need a power supply that can provide minimum 24 volts to the pneumatic cylinder. Here we used the 30 volts power supply that in connection with the MOSFET will provide 24 volts to the pneumatic cylinder to operate it accordingly.

Figure 27. Power Supply of 30V

Figure 28. Air Compressor

6.2. Experimental Setup:

Different devices as mentioned above in this research are connected via connecting wires in a way to apply the concerned data to the testing rig to acquire respective results. The devices are connected in a way as mentioned in the picture here.

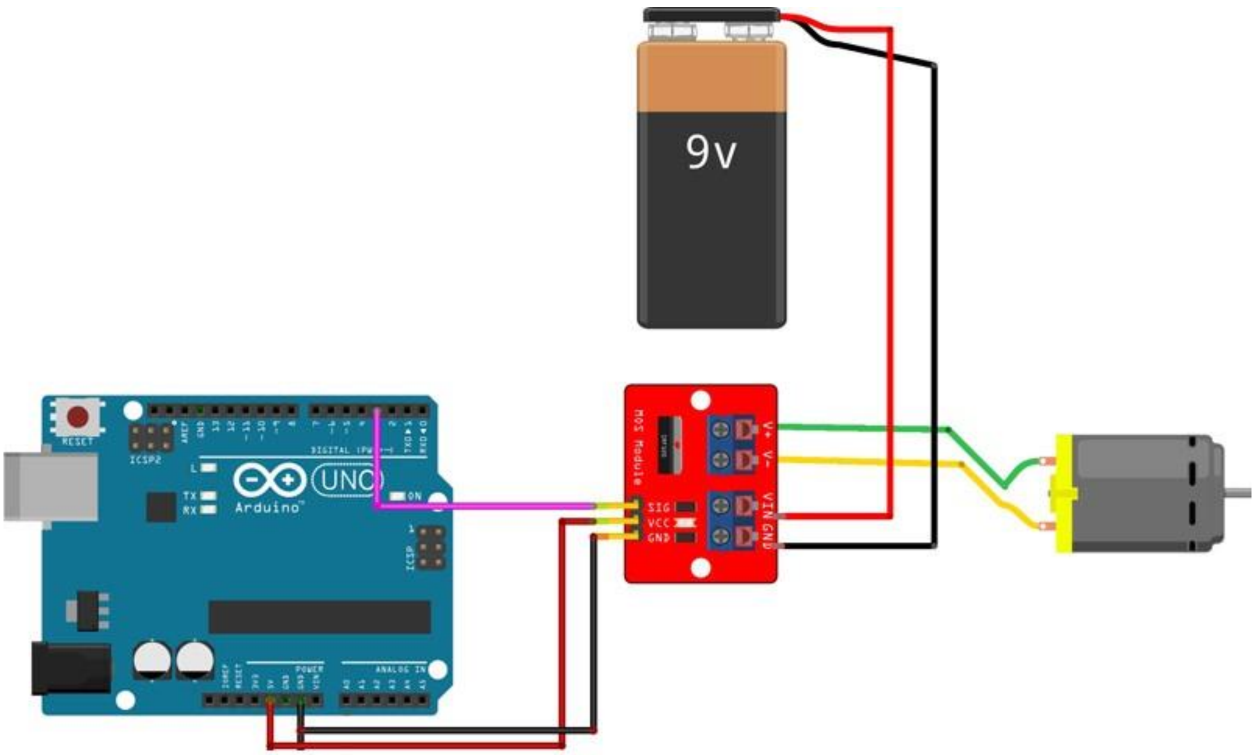

Figure 29. Wiring Diagram of Experimental Setup with Arduino

The Arduino is connected with the SD card module and MOSFET module both at the same time to read the data through SD card module and control the voltage being applied to the pneumatic cylinder with MOSFET module. The MOSFET module is connected with both the power supply and pneumatic cylinder. The power supply of 30 volt provide voltage to MOSFET which then gives the voltage to the pneumatic cylinder as per requirement to the operation conditions. The compressor provides the compressed air to the pneumatic cylinder with the required pressure necessary to operate it, which in our setup is 8 bar.

The experimental setup works in such a way that the compressor gives the compressed air to the pneumatic cylinder with the pressure of 8 bar. The Arduino reads the data through the SD card and by using the Arduino code in the Arduino software gives the required amount of data to the pneumatic cylinder. The voltage required to drive the pneumatic cylinder is provided by the power supply. So, by using this experimental setup we applied the data that we acquired from different road conditions in real life while driving the motorcycle to the testing rig.

6.3. Testing of Power Harvesting Mechanism for Power Output:

The data of the vibrations amplitude that was acquired from the road is then applied to the testing rig through the process describe above. The voltage and current generated by the generator when its shaft experienced the rotation given by the pinion is calculated from the digital multimeter first to get the roughly idea of how much voltage is being generated. The average value of the voltage being generated by the generator is around 7 volts. Since, the purpose is to charge the battery of vehicle so the voltage should be greater than 12 volts. To overcome this problem, I used the boost convertor the purpose of which is to boost the voltage according to the one's requirement which in our case is greater than 12 volts. Now to store the voltage values that are being generated instantaneously and are not constant because of the varying amplitude of the vibrations, we used Arduino. The Arduino is able to store the maximum value of up to 5 volts so the resistances of 47k and 10k ohm are used along with Arduino in the circuit as shown below.

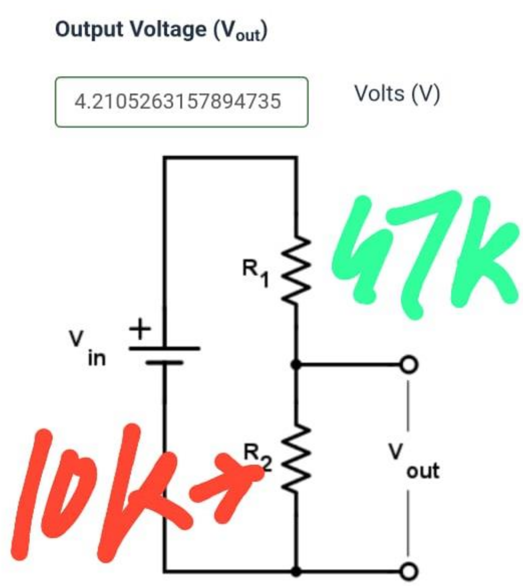

Figure 30. Voltage Divider Circuit

6.4. Voltage Generated from Vibrations on Different Road Conditions:

Just as the vibrations amplitude taken from the different road conditions, we also calculate the voltage generated from vibrations under different road conditions as well. As we have seen that the maximum amplitude of vibrations being experienced when driven on the rough road, so the voltage generated is also greatest when rough road data is being applied. Since the vibration amplitude sometime is very small and close to zero so in that case the generator did not have the specific rotation to generate power and hence in these cases the voltage or power generated will be zero and we will also see such values in the graph of the voltage versus time.

If we compare the values of voltage that is generated by applying the data acquired from the road, we will see that the maximum voltage is generated in case of rough road conditions as the irregularities and bumps in this case is large, giving more rotations to the pinion and so the shaft of the generator. Since the voltage is not constant in each case and is varying at all times so it is best to use the root mean square (RMS) value of the voltage for the accurate calculations.

Properties	Highway	Street	Rough Road
Maximum Voltage(volts)	23.427	24.339	25.614
RMS Voltage (volts)	16.125	16.356	18.042
Mean Current (Amps)	0.1	0.1	0.12

Table 2. Comparison of voltage generated by vibrations amplitude of different road conditions

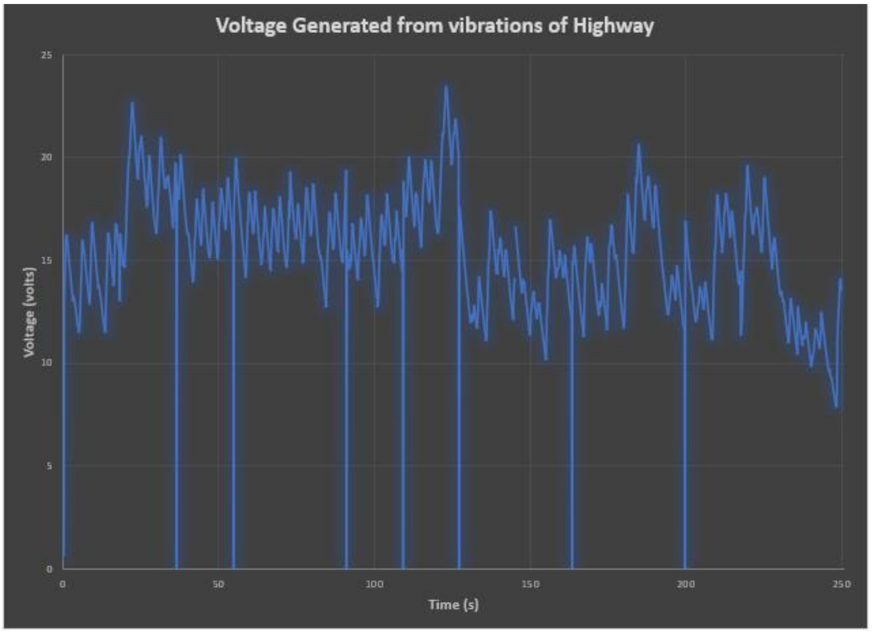

Figure 31. Voltage vs Time Graph from Highway Data

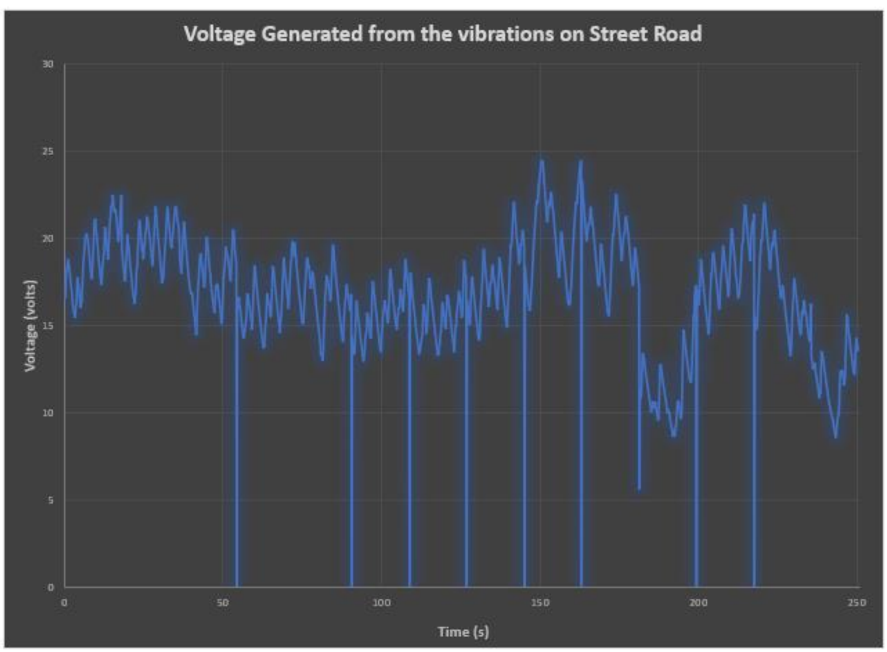

Figure 32. Voltage vs Time Graph from street road Data

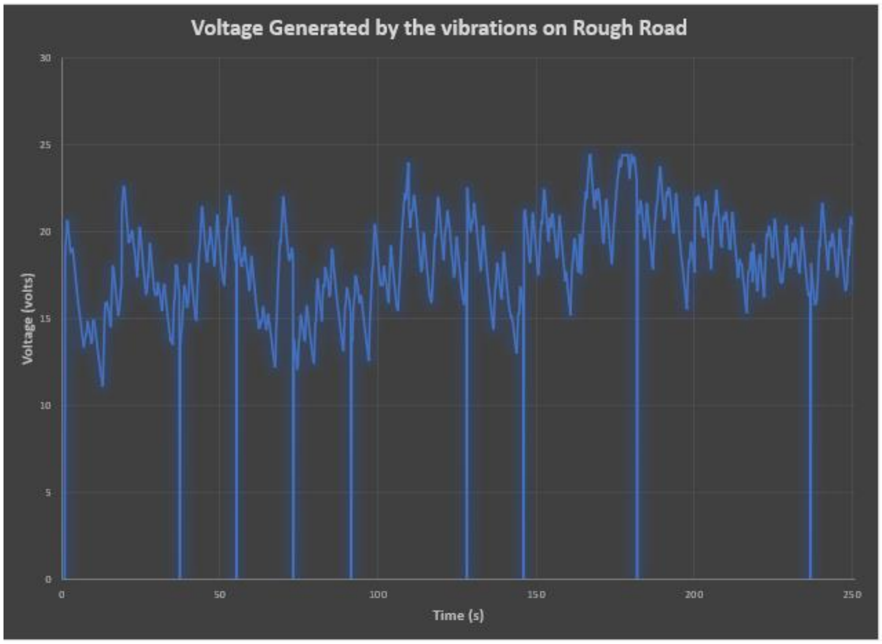

Figure 33. Voltage vs Time Graph from Rough Road Data

6.5. Power Calculation:

The calculation of power is simply done by using the formula

$$P = VI$$

Since, the frequency of data acquisition and data application is 3 Hz means there are three cycles in one second. But in one cycle there occur two strokes forward and backward and power is generated in both these strokes. So, to find the power in one second simply calculate the instantaneous power by 6. The voltage used in the calculation in power is RMS voltage as the voltage is varying continuously and the maximum power is for an instant so it's best to use the RMS voltage for accurate power calculation. The maximum power will be generated when we used the rough road data of vibrations amplitude.

	Highway	**Street**	**Rough Road**
Power Generated (Watt)	9.675	9.814	12.99

Table 3. Power Harvested by vibrations on different road conditions

7. Results & Discussions

In this research, we investigate the power potential of the suspension system that could be generated from the road irregularities. Rotary energy harvesting mechanism is designed to convert the to and fro motion of the suspension into rotary motion. Rack and pinion are used for this purpose and attached in parallel to the shock absorber externally so that the rack experienced the same linear vibrational motion and by meshing with pinion gear convert that vibration motion into rotary motion. Rack and pinion mechanism is attached externally so in case of wear and tear it could be replaced easily.

The testing that we have done on the suspension of the motorcycle by adding the power harvesting mechanism, using the real-life data that we acquired from different road conditions, shows that the power of 9.5 Watts is harvestable from single shock absorber of the motorcycle. These results proves that the vehicle suspension energy generation is very efficient to convert the vibration energy from the shock that is otherwise going as a waste to the useful energy. Currently, the batteries of the automobiles are charged by using the alternator and the alternator rotates by attaching it from the IC engine crankshaft. So, fuel is consumed to rotate the alternator and alternator is than used to charge the battery. This fuel consumption to charge the battery using alternator is found to be around 4% of the total fuel consumption.

As our results show that the power harvestable from the single shock absorber of the motorcycle is around 9.5 watts, this means that by installing the mechanism in automobiles vehicle suspension it could give us 20 watts from single shock absorber easily given the weight of the automobile is about 10 times that of the motorcycle and deflection is going to be larger than the motorcycle as well. So, by installing the mechanism on all four shock absorbers of the vehicle, it will be more than enough to charge the batter alone without taking the energy from the alternator and saving the 4% fuel consumption of the automobile.

In engine based automotives, the battery is used only to start the engine and rest of the electronic accessories are run directly by taking the energy from the alternator once the engine is on. So, we can also use the power that is being harvested to run the electronic accessories that are taking the most energy like air conditioner. The purpose mechanism can also be used in those vehicles which requires high demand of electricity like milk trucks, fire brigade trucks and other heavy compressed vehicles like that.

The regenerative system is more useful when used with the suspension system of heavy vehicles like trucks that are used to transport goods, passenger buses or military vehicles and trucks that are mostly used to drive in off-road conditions thereby experience large bumps and irregularities on road and generate more power. In upcoming electric vehicles, this system can increase the life cycle of the primary battery by providing regenerated electric power to replenish the battery while absorbing the terrain borne shocks.

The mean power that could be harvested from the suspension system of an automobile depends on the road roughness, vehicle speed and tire stiffness.

- With the increase in road roughness the vibrations are severe that rotate the pinion fast and so the shaft of the generator producing more power.
- The increase in velocity increases the power generation but on rough road with the increase in velocity the wheels may not have enough contact force with the ground. This could result is reduced road handling as the vehicle may lose control during steering and braking.
- The tire stiffness also increases the power generation. The harvestable power increase linearly with the increase in tire stiffness but it reduces the ride comfort and road handling.

The effect of the power harvesting mechanism on the stiffness of the shock absorber is that by adding the mechanism, the stiffness of the shock absorber increases by a very small amount. By testing the shock absorber of the motorcycle to see the effect of mechanism on the stiffness of the shock the results are as follow:

- Without Mechanism

Stiffness = k = 29.99940 N/mm

- With Mechanism

Stiffness = k = 30.4484 N/mm

These calculations show that by adding the mechanism along with the shock absorber to generate the power, the stiffness of shock absorber increases by a very small amount of 0.5 N/mm. So, the power harvesting mechanism will not affect the comfort and road handling of the vehicle because of the increase in the stiffness of shock absorber.

Another question that comes to mind is how to connect the power generating mechanism with the battery as it is already taking power from alternator and connected with it. There could be two possible solutions of this problem.

1. Firstly, we can either connect the battery alone with the power harvesting mechanism if it's generating enough power, which in case of automobile when using all of the four shock absorbers it will. In this way alternator will not be used to charge the battery and provide power to other electronic devices only.
2. The second solution will be to charge the battery from both alternator and power harvesting mechanism as well. This arises the question of whether we can charge a single battery from two sources or not. When we charge the battery using two chargers, there is a chance of flow of current from battery to the charging source or from one charger to the other. This is because both are providing current and voltage differently with one maybe providing slightly less than the other and as a result it will draw a large current from the other one. So, the answer to the question is it might be a good idea to supply the charging current from these many sources through a diode so as to not have current flow back into the source.

7.1. Future Recommendations:

- This research work is limited to the power that can be harvested from the single shock absorber of the motorcycle because there wasn't any motor that can apply the force equal to the weight of the automobile. The future research should focus on the design of lab experimental setup to test the mechanism on automobiles by using a suitable machine that could provide the force equal to the weight of the automobile.
- The research provides a meaningful result for the power that could be generated from single shock of the motorcycle. The future research could focus on testing the mechanism on automobile to find out the harvestable power from all of the shock absorbers of the automobile.
- The results obtained from the simulation and lab testing gives us the satisfied range of power output so the next step would be to implement the setup in automobile. The size of

the mechanism and setup to integrate it with the shock absorber in automobile is the area of future research.

- The future research could also focus on the implementation of the mechanism on different type of vehicles like passenger bus, truck, minivan, SUVs and military vehicles to find out the power range that could be harvested from these vehicles and which could give us the maximum power and most suitable to use the mechanism with it.
- The area of research is still in early stages, and one have to work in different areas of power harvesting mechanism, implementation of mechanism, to avoid wear and tear by using lubrication and practical aspect of it in electric vehicles as EVs are the future of the automobile industry.

8. APPENDIX A

DATA ACQUISITION CODE

```
#include "Adafruit_VL53L0X.h"

const byte zeroFactor = 20;    // Distance for zero factor

Adafruit_VL53L0X lox = Adafruit_VL53L0X();

bool debugInfo = false;

void setup() {

  Serial.begin(9600);

  // wait until serial port opens for native USB devices

  while (! Serial) {

    delay(1);

  }

  if (!lox.begin()) {

    Serial.println(F("Failed to boot VL53L0X"));

    while (1);

  }

}


void loop() {

  VL53L0X_RangingMeasurementData_t measure;



  lox.rangingTest(&measure, false); // pass in 'true' to get debug data printout!
```

```
  if (measure.RangeStatus != 4) {  // phase failures have incorrect data
    if (debugInfo) {
      Serial.print("Distance (mm): ");
    }
    int dist = measure.RangeMilliMeter - zeroFactor; // Substract zero factor from initial readings
    Serial.println(dist);
  } else {
    //    if (debugInfo)
    Serial.println(" out of range ");
  }

  delayMicroseconds(5);
}
```

9. APPENDIX B

ARDUINO CODE TO READ & STORE VOLTAGE

```
int R1 = 47000;     // Resistance 1 value

int R2 = 10000;     // Resistance 2 value

void setup() {

  // put your setup code here, to run once:

  pinMode(A0, INPUT); // Set analog pin as input

  Serial.begin(9600);

}


void loop() {

  // read the input on analog pin 0:

  int sensorValue = analogRead(A0);

  // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 5V):

  float voltage = sensorValue * (5.0 / 1023.0);



  // print out the value you read:

  Serial.println(voltage);

}
```

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