Internet of Things and Cyber Physical Systems

ECE 510

Project Proposal

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Project Abstract

The project aims to develop a connected device that converts untapped energy from mechanical to electrical. This project is an extension of the smart home or smart grid automated system. The device is fit at locations with prevalent mechanical energy, i.e., in this case, doors are used as tools that can be harnessed for their unused energy or rotary motion. Every time a door opens or closes, the device attached to the hinge captures the thrust via a motor, translates that to electrical energy, and stores it in an inductor or capacitor in this scenario. The purpose is to plug this into the grid and, thus, analyze the efficiency of the user's electrical usage in the long run.

Problem Statement

The way we connect with our surroundings has been completely transformed by the introduction of Internet of Things (IoT) technology into our daily life. The development of devices that transform mechanical energy into electrical energy is a promising breakthrough in this field. Through the revolutionary process of catching and utilizing energy that would otherwise be wasted, smart home and smart grid systems are enhanced. This paper explores the specifics of this gadget, including its operation, immediate uses, and possible long-term advantages.

Device Functionality

The suggested gadget is made to be fastened to door hinges in order to collect the mechanical energy released when a door opens or closes. The following steps are involved in the fundamental operation:

1. **Energy gather**: A little motor fastened to the hinge uses the motion of the door to gather kinetic energy.
2. **Energy Conversion**: This mechanical energy is transformed into electrical energy by the motor.
3. **Energy Storage**: An energy storage device, like an inductor or a capacitor, is used to store the electrical energy that has been produced.
4. **Energy Utilisation**: By feeding the stored energy into the smart grid, you can increase the system's overall energy efficiency.

Immediate Applications

This technology's immediate applications are transformational and practical, especially when considering smart homes and smart grids.

- **Energy Efficiency**: This device improves a home's overall energy efficiency by catching energy that would otherwise go unused. Little but frequent motions, like opening and closing doors, can add up to be quite a bit of energy.
- **Sustainability**: By lowering dependency on conventional energy sources, this innovation fosters sustainability. The total demand on the electrical system is decreased by each ounce of energy that is captured and used.
- **Integration with Smart Homes**: The gadget may be easily included into already-existing smart home networks, giving homeowners access to connected apps that track energy production and consumption. Users can make educated decisions about their energy consumption by using this integration, which gives them access to real-time data on their energy efficiency.

Potential Applications

This technology's possible uses go far beyond its first installation in households.

- **Commercial and Public Buildings**: These kinds of gadgets could be quite helpful in high-traffic locations like retail malls, schools, and office buildings. These areas have a lot of doors, which means there is a lot of mechanical energy there that can be used.
- **Public Infrastructure**: By adding these gadgets to public spaces like lifts, airport gates and tube doors, cities may create a greener urban environment by integrating them into their energy grids.
- **Wearable Technology**: The concepts of this technology may be modified for wearable electronics, such as knees and elbows, which might be powered by joint motion to power personal electronics.
- **Remote & Off-Grid Locations**: These gadgets can offer a vital backup energy source in places where conventional power sources are hard to come by or unstable. This is especially important in underdeveloped countries or isolated scientific research facilities.

Long Term Prospects

The development of this technology has a great deal of potential for a more efficient and sustainable energy supply in the future. The adoption of these devices is projected to rise as they become more affordable and efficient, opening up new applications and having greater effects. Potential developments in the future could be:

- **Enhanced Energy Storage**: The quantity of energy that can be harvested and stored can be increased by advancements in energy storage technology, such as more effective capacitors or sophisticated battery systems.
- **Micro-Grid Applications**: These devices can be included into micro-grid systems, together with other renewable energy sources, to offer robust and sustainable localised energy solutions.
- **Extension of the Internet of Things (IoT)**: As IoT technology advances, more devices will be networked together, resulting in an energy ecosystem that is more responsive and dynamic. Better energy distribution and management will be made possible by this.

Market Availability

The following are some of the existing available concepts that work towards harnessing untapped energy:

1. **Piezoelectric Materials for Bicycle Lane Lighting Systems**: The use of piezoelectric materials to transform mechanical energy from bicycle traffic into electrical energy to power bicycle lane lighting systems is explored in this work by Jettanasen et al. The bicycle pressure is used by the system to generate electricity. It uses mechanical energy from routine tasks and transforms it into electrical energy, just like this project does. But instead of employing a motor

and hinge mechanism, it applies itself in a different context—cycling lanes—and uses piezoelectric materials instead of door movements.[1]

2. **MIT's Vibrational Energy Harvester**: A microelectromechanical system (MEMS) that produces power from low-frequency vibrations has been created by researchers at MIT. The purpose of this penny-sized device is to power wireless sensors without requiring frequent battery replacements. While this gadget and our idea both convert mechanical energy into electrical energy, the MIT device—unlike the door motions in this project—specifically targets low-frequency vibrations from buildings like bridges.[2]
3. **WITT Energy Converter**: The WITT (Whatever Input to Torsion Transfer) gadget transforms chaotic motion energy into electrical energy by capturing its energy. It can catch movement in any direction and is made to capture wave energy in marine situations. It transforms mechanical motion into electrical energy in a manner akin to this project's idea, but it can handle more intricate and multidirectional movements than the single-directional door movements in this project. In addition, the WITT gadget is employed in a different setting with an emphasis on maritime uses.[2]
4. **Zinc Oxide-Based Nano-Generators**: KAIST researchers have created nano-generators that use zinc oxide to transform mechanical energy—such as vibration, sound, and movement—into electrical energy. Usually, wearable and portable electronics use these technologies. They transform mechanical energy into electrical energy, just like this project's idea, but they're designed for different uses, such environmental sensors and wearable technology, not door movements.[2]
5. **Mechanical Energy Conversion Device Patents**: In the patent No. 11171544, "Mechanical energy harvesting system for converting kinetic energy of a user having a trunk and limb portions into electricity," a system comprising a driving device, a rotating shaft device, and a base seat unit with two seat bodies is described. The driving device consists of a gearbox unit and a minimum of one driving unit. The rotating shaft is driven by the second seat body's movement in relation to the first, producing rotational kinetic energy that is then transformed into electrical energy. Unlike devices that record door movement energy, this one records human movements when the user is seated.[3]

[1] (Jettanasen, Songsukthawan, & Ngaopitakkul, 2022)
[2] (Lindsay, 2016)
[3] (United States Patent No. US 11,171,544, 2021)

Tools, components and Software

Hardware Components

1. **Generator**: One essential part in the process of converting mechanical energy from door motions into electrical energy is the DC motor, often known as the generator. The motor's shaft revolves in response to movement of the door, producing power using electromagnetic induction. For effective energy conversion, choosing a motor with the proper characteristics (such as voltage, current, and torque) is crucial. These motors are ideal for retrofitting existing doors because they are small and simple to incorporate into the hinge mechanism. The motor makes sure that there is always an electrical energy source available for the smart grid system to store and use by harnessing the energy from each door movement.

2. **Inductor or Capacitor**: For the purpose of storing the electrical energy produced by the motor, inductors and capacitors are necessary. The capacity of capacitors in particular to quickly store and release energy makes them ideal for this use. They offer a reliable and effective method of controlling the sporadic energy produced by door motions. It is essential to select capacitors with the right voltage and capacitance values to make sure they can withstand the energy produced without running the risk of overloading. These storage components are essential to the smart grid system's continuous energy supply, which enables effective energy management and utilisation.

3. **Energy Management IC**: This integrated circuit controls the amount of electrical energy that travels from the motor to the grid and storage device. By controlling the voltage and current levels, avoiding overcharging, and optimising the energy conversion efficiency, it guarantees the best possible energy harvesting. Maximum power point tracking (MPPT), a function of advanced integrated circuits (ICs), modifies the operating point of a motor to optimise energy output. This part is essential to keeping the energy harvesting system stable and effective, which allows it to work seamlessly with the smart grid and supply consistent energy.

4. **Microcontroller**: Coordinating the several parts and analysing sensor data, the microcontroller acts as the brains of the energy harvesting system. It keeps an eye on how the doors move, regulates the motor and storage units, and oversees the smart grid communication. Well-known microcontrollers with a variety of functions that can be programmed to match project requirements include Arduino and ESP8266. They offer the processing power required to put

control algorithms and data processing into practice, guaranteeing the energy harvesting system operates well.

5. **Sensors**: Sensors are essential for tracking door motions and giving the microcontroller data in real time. While motion sensors, such as accelerometers, can identify the speed and direction of movement, position sensors, such as hall effect sensors, can measure the angle and movement of the door precisely. By giving precise information about the motion of the door, these sensors enable accurate energy capture and help the microcontroller optimise the energy conversion process. Consistent energy generation and optimising the efficiency of the energy harvesting system depend on accurate and dependable sensors.

Network Tools

1. **Wi-Fi Module**: This module allows communication between the energy harvesting equipment and the smart grid as well as a connection to the home network. Because of their powerful connectivity characteristics and ease of integration, modules such as ESP8266 and ESP32 are commonly employed. Through a web interface or mobile app, users can remotely monitor and manage the gadget thanks to their wireless communication capabilities. In order to enable a smooth integration of the energy harvesting device into the home automation system, the Wi-Fi module makes sure that it can send data to the smart grid and receive updates.

2. **Network Interface Controller (NIC)**: The NIC enables dependable connectivity between the local network and the energy harvesting equipment. It guarantees that the device's data is effectively transferred to the smart grid and home automation platform. For the energy harvesting system to be monitored and controlled in real time, a solid connection, data packet handling, and network protocol management are all provided by the NIC. The NIC is essential to the integration of the device into the larger network architecture because it guarantees stable connectivity.

3. **Gateway**: By bridging the gap between the smart grid and the local network, the gateway device gathers data from the energy harvesting device and processes it for additional analysis. By serving as a middleman, it guarantees safe and effective data transfer between the home network and outside services. Advanced security mechanisms are frequently included in gateways to safeguard data integrity and stop illegal access. The gateway controls the data flow, ensuring that the energy harvesting equipment functions properly within the smart grid ecosystem and offering useful insights into energy generation and consumption.

Application Software(s)

1. **Home Automation Platform**: A home automation platform offers an intuitive user interface for system management and monitoring while integrating the energy harvesting gadget into the smart home ecosystem. Devices and protocols of all kinds are supported by platforms like OpenHAB and Home Assistant, which makes integration easy. They include notifications, automation scripts, and dashboards so that users can track the effectiveness of the energy harvesting system and optimise energy utilisation. These platforms improve the device's functionality and usability, which facilitates user interaction and system benefits.

2. **Data Analytics Software**: By processing the information gathered by the energy harvesting system, data analytics software produces insights regarding energy efficiency and consumption. MATLAB and Python modules such as Pandas and NumPy are capable of pattern analysis, trend identification, and energy-use optimisation recommendations. Through the use of data analytics, users may enhance the overall efficiency of their smart home system and make more educated decisions by gaining a deeper understanding of their energy generation and consumption. This programme is necessary to convert unprocessed data into meaningful insights.

3. **Mobile App**: Using a mobile app, users may conveniently monitor and control the energy harvesting gadget from a distance. The app, which was created with the help of tools like Android Studio and Xcode, can deliver notifications, show data in real time, and let users change settings. The software improves the energy harvesting system's usability and accessibility by providing a user-friendly smartphone interface. It makes it simpler for users to operate and optimise the system from any location by ensuring that they can remain informed about the energy they generate and use.

Price of Components

SL No.	Components/Tools/ Software	Estimated Price	Source
1	Generator	$79	Portescap Athlonix series DC brushed motor
2	Inductor/Capacitor	$5.99 to $7.49	Digikey and Mouser Electronics offer a variety of inductors and capacitors
3	Energy Management IC	$12.34	Texas Instruments BQ25570 Ultra Low-Power Harvester Power Management IC from Digikey
4	Microcontroller (ESP 32)	$4.90	Amazon and Adafruit
5	Sensors (Motion and Door)	$10.99	Amazon and SparkFun
6	Wi-Fi Module (ESP 8266)	$6.50	Adafruit and Amazon
7	Network Interface Controller (NIC)	$14.99	Amazon and Newegg
8	Gateway (Raspberry Pi 4)	$45	Official Raspberry Pi Store and Amazon
9	Home Automation Platform	Free	Home Assistant website
10	Data Analytics Software	Free	Grafana website
11	Mobile App	Free	Blynk website and app stores
Total Estimated Cost		**$177.20**	

Description of Technical Content

Hardware Components

1. *Generator (DC Motor as Generator)*

- **Function**: Produces electrical energy from the door's rotating action.
- **Specification**: A brushed DC motor from the Portescap Athlonix line, renowned for producing DC voltage (Portescap)[4] with dependability and efficiency.
- **Selection Criteria**: Selected for its low resistance and suitable back EMF constant, which guarantee steady performance in generator mode.

2. *Inductor or Capacitor*

- **Function**: Its purpose is to store the electrical energy that the motor produces.
- **Specification**: Digikey offers high-capacity capacitors that have an efficient method of storing and discharging energy (Maxon Group)[5].
- **Selection Criteria**: Capacitors were chosen because they could withstand frequent cycles of charge and discharge without experiencing a lot of wear.

3. *Energy Management IC*

- **Function**: Oversees the harvest of energy and guarantees effective power transmission and storage.
- **Specification**: The Texas Instruments BQ25570 specification combines battery management and a boost charger (Maxon Group)[5].
- **Selection criteria**: It was chosen for energy collecting applications due to its extremely low power consumption and great efficiency.

4. *Microcontroller*

- **Function**: Manages network communication, processes sensor data, and controls the system.
- **Specification**: ESP32 microcontroller with integrated Bluetooth and Wi-Fi capabilities.
- **Selection criteria**: Its integrated connectivity modules, low power consumption, and potent processing capabilities won it over.

5. *Sensors (Motion and Door Sensors)*

- **Function**: Detects door movement and initiates the process of energy collection.
- **Specification**: SparkFun motion sensors (Maxon Group)[5] are incredibly dependable and sensitive.

[4] (staff, 2021)
[5] (Kafader, Urs;, 2024)

- **Selection Criteria**: Guarantees precise door movement detection for maximum energy harvesting.

6. *Wi-Fi Module*

- **Function**: Enables wireless connection between the home automation network and the device.
- **Specification**: ESP8266 module, well-known for its simple integration and dependable Wi-Fi connectivity.
- **Selection criteria**: It was chosen because it was compatible with the ESP32 microcontroller and was reasonably priced.

7. *Network Interface Controller (NIC)*

- **Function**: Gives the device network connectivity so that it can talk to the gateway and other devices.
- **Specification**: Maxon Group[5] offers Ethernet NICs from Amazon that guarantee dependable and fast network connectivity.
- **Selection Criteria**: Ensures robust and reliable network communication.

8. *Gateway*

- **Function**: Serves as a main hub for internet and home automation platform connections.
- **Specifications**: The Raspberry Pi 4 has a lot of connectivity and computing power.
- **Selection Criteria**: Selected for its adaptability, simplicity in programming, and compatibility with a wide range of communication protocols.

Network Architecture

1. *Device Communication*

- The DC motor generator is managed by the ESP32 microprocessor, which also processes input from sensors.
- By enabling wireless connectivity, the Wi-Fi module (ESP8266) enables data transmission from the device to the gateway.

2. *Gateway Integration*

- As the gateway, the Raspberry Pi 4 gathers data from the gadget and transmits it to the home automation platform.
- The gateway manages devices, gathers data, and offers an interface to consumers through software called Home Assistant.

3. *Cloud Connectivity*

- An optional cloud service connection allows for remote control and monitoring of the gateway.

- Grafana, which can be hosted locally or in the cloud, is used for data analytics.

4. User Interface

- A user-friendly interface for controlling devices and keeping an eye on system status is offered via the Blynk mobile app.
- Through the app, users may view historical patterns, monitor real-time statistics, and receive warnings.

Software Integration

1. Home Automation Platform (Home Assistant)

- **Setup**: Home Assistant is installed on the Raspberry Pi 4 gateway and works with it to gather information and manage activities.
- **Configuration**: YAML files are used to configure sensors and devices, making setups adaptable and customisable.
- **Automation**: To maximise energy use, custom automations can be made to switch off inactive equipment when energy production is low.

2. Data Analytics (Grafana)

- **Integration**: To view the data gathered from the device, Grafana is linked to Home Assistant.
- **Dashboard**: To show important parameters like energy produced, use trends, and system efficiency, custom dashboards are made.
- **Alerts**: Users can set up alerts to be notified when there are substantial changes to their device's performance or energy usage.

3. Mobile App (Blynk)

- **Integration**: The Blynk app offers a smooth user interface by connecting via APIs to the Home Assistant platform.
- **Control**: Through the app, users may monitor real-time data, take control of the device, and receive notifications.
- **Customisation**: Depending on the user's preferences, the app interface can be tailored to show pertinent information and controls.

The system effectively gathers and controls energy through the integration of multiple hardware components, including microcontrollers, sensors, energy management ICs, generators, and capacitors. Strong connection between the device, gateway, and home automation platform is ensured by network design, monitoring, control, and analytic capabilities are provided by software integration with Home Assistant, Grafana, and Blynk. This creative method makes the project special and important because it improves the functionality of smart homes while also promoting energy efficiency.

Estimated Timeline of Work and Work Distribution

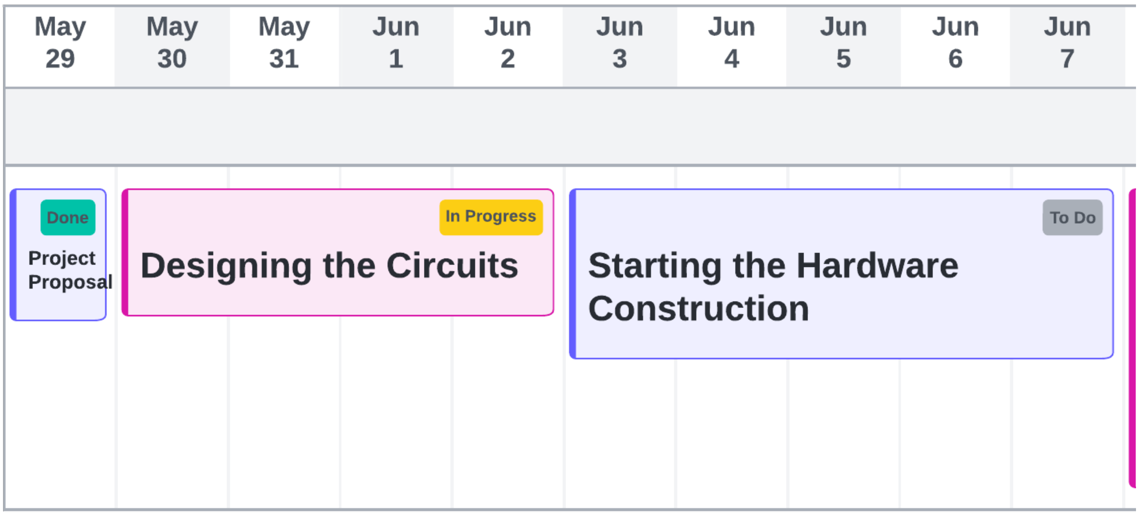

Figure 1: Estimated Timeline of Work (May 29 to June 7).

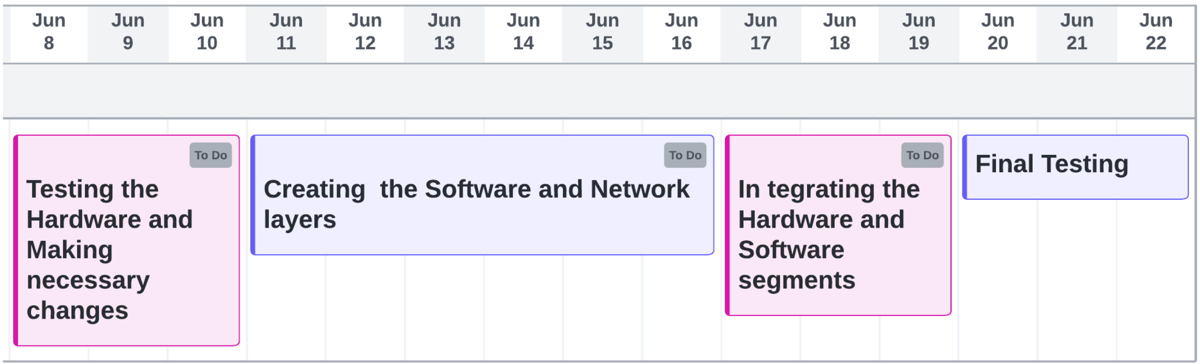

Figure 2: Estimated Timeline of Work (June 8 to June 22).

Task	Assignee
Project Proposal	Abhilash and Adnan
Designing Circuits	Adnan
Hardware Construction	Abhilash
Testing round #1	Abhilash and Adnan
Network Layer	Adnan
Software Application	Abhilash
Testing round #2	Abhilash and Adnan
Final Testing	Abhilash and Adnan

Table 1: Work Distribution

References

Jettanasen, C., Songsukthawan, P., & Ngaopitakkul, A. (2022). Conversion of Mechanical Energy to Electrical Energy Using Piezoelectric Materials for Bicycle Lane Lighting Systems. Applied Sciences, 12(14), 7237.

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