HEALTH CARE APPLICATIONS OF ENERGY HARVESTING TECHNIQUES FOR IMPLANTABLE AND WEARABLE ELECTRONICS

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Abstract
If specific biological signals can be precisely monitored, implantable and wearable electronic devices have the potential to enhance the quality of life as well as the life expectancy of a large number of people who suffer from chronic illnesses. It is now possible, as a result of developments in packaging and nanofabrication, to embed a variety of microelectronic and micromechanical sensors (such as gyroscopes, accelerometers, and image sensors) into a small area on a flexible substrate for a relatively low cost. This is made possible by the fact that it is now possible to do so. We analyse the benefits, drawbacks, and likely directions that each approach will go in the future. The idea of generating power for implanted devices by the collection of energy from natural sources and the motion of the human body has recently received new significance. The collection of kinetic, electromagnetic, thermal, and infrared radiant energy are the topics of discussion in this overview. A wide range of biocompatible materials, such as piezoelectric and triboelectric nanogenerators, biofuel cells, and environmental sources, may be used to carry out harvesting procedures. As is the case with all of the techniques for putting biocompatible harvesters into action, some of them have a low rate of power consumption, while others vary according to the device and the location where they are implanted. In this overview, we explore the integration of harvesters into implantable devices, analyse the various materials and approaches, and investigate how new and better circuits will aid generators in maintaining the functionality of medical devices.

Keywords: wearable, electronic, devices, biocompatible, electromagnetic, radiant energy

INTRODUCTION

Energy harvesting devices are able to do this by directly converting the energy that is present in their surroundings into electric energy. As of right now, implanted biomedical devices get their power from a few of cables; this configuration may put patients at risk for skin infections, pain, and other potential dangers. At the moment, implantable biomedical devices get their power from batteries that are placed within the body. Batteries, on the other hand, have a constant energy density, a finite lifespan, chemical side effects, and a massive bulk. As a result, researchers have devised a variety of techniques to gather energy for use in implanted devices. Conventional electronic equipment have a shorter lifespan yet provide less comfort and safety compared to those powered by energy obtained from the environment.
When it comes to providing electricity, implanted medical devices have a significant limitation, despite the fact that these devices may be quite dependable and, in most cases,

have only minimal difficulties. Batteries are the only source of energy that can keep implantable medical devices functioning properly. These devices mostly consist of electronic circuits. Nevertheless, batteries lose their capacity with time, and in this particular instance, their replacement will need some kind of surgical procedure. In addition, the goal of almost all implanted devices is to take up as little space as possible and to be as unnoticeable as possible to the patient at all times. With the technology that is available today, this goal is plausible, but it is made difficult because of the limited power storage capacity of the batteries; as a result, there is an urgent need to find ways to harvest power for the batteries from the human body or its internal surroundings.

The fixed nature of these batteries, on the other hand, makes it more difficult for electronic equipment to adapt to changing circumstances. Batteries only have a finite lifespan, which violates the ideals of sustainable development, and there is also the possibility that they may pollute the environment. As a direct consequence of this, a significant amount of work has been put into the investigation of fresh renewable energy sources that are also kind to the environment. Technology that can power itself offers a solution to the problem of providing a sustainable energy source for portable and wearable electronics. The term "self-powered technology" refers to a gadget that can continue to function without the need for an external energy source by powering itself via the process of harvesting energy from the surrounding environment. The concept of self-powered technology is predicated on the efficient gathering of a variety of sources of energy present in the working environment. Smart textiles make it possible to integrate wearable medical devices (WMDs) into clothing, such as gowns, so that vital signs and electrocardiogram (ECG) signals may be recorded. Because of factors such as I the prevalence of chronic diseases, (ii) the increase in the number of elderly people, (iii) the ability to enable easy accessibility to the personal health record, (iv) the ability to monitor health conditions in real time, and (v) the cost-effectiveness of portable medical devices, the demand for their incorporation into healthcare is rapidly increasing. In addition, the widespread usage of IWM devices has been made possible by recent developments in integrated circuits, sensor technologies, and enhanced interfacing of biology and electronics.

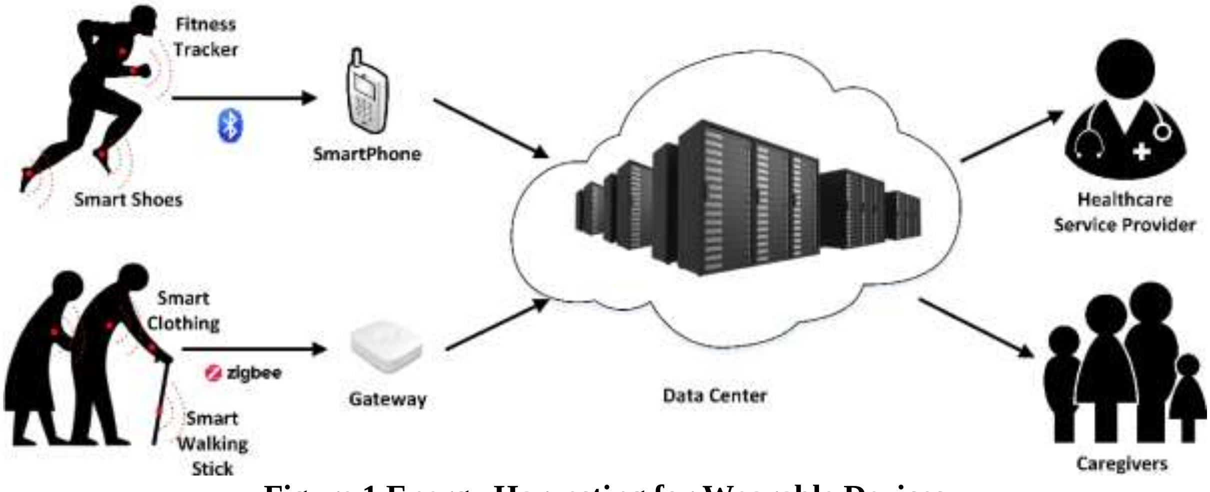

Figure 1 Energy Harvesting for Wearable Devices

Scavenging energy from the surrounding environment is an effective method for addressing the issue of lack of power in wireless sensors. Infrared radiant energy, thermal energy (including solar–thermal and geothermal gradients of temperature, as well as combustion), kinetic energy (including wind, waves, gravity, vibration, and body motion), wireless transfer energy, and RF radiation energy are examples of the types of energies that can be reclaimed (inductive and capacitive coupling). It has been shown that collecting energy from human or natural sources may be a viable alternative. Several researchers have discovered potential remedies that might be helpful and included in a review study. Therefore, a number of studies have provided reviews that only focus on one type of energy harvesting for biomedical implanted devices, such as kinetic energy from body motion, vibration, piezoelectric material, or wireless transfer energy, or using thermal and solar energy from the environment sources as given in. These reviews can be found in a number of different places online. As technology advances, particularly in the field of biomedicine, implanted devices are getting more advanced, both in terms of their level of efficiency and the dimensions of their physical makeup. In the present time, biomedical implantable devices play an essential role in a number of medical aspects including diagnosis and therapy. These devices are able to monitor a variety of illnesses by using highly effective circuit designs, biocompatible materials, and high resolution biosensors. Defibrillators, pacemakers, medication pumps, cochlear implants, and stimulators are some examples of the subcutaneous devices that are included in the category of biomedical implantable devices that are being discussed here. To provide an additional instance of the effect of implanted devices, let us examine individuals who suffer from an irregular heartbeat (also known as arrhythmia) and are required to be monitored and evaluated on a consistent basis.

Those who suffer from arrhythmia but have a pacemaker implanted in their chests may lead lives that are otherwise typical. Moreover, nonimplant able gadgets that are widely accessible on the market, such as watches and rings that aid in the monitoring aspect, may give an incredible amount of support with the previously described biomedical devices. In recent years, portable and wearable electronic devices have been in a stage of rapid development. Personalized electronic devices such as smart watches and smart glasses have sprung up, bringing much convenience to people's lives. At the same time, with the promotion of flexible electronic technology, big data technology and artificial intelligence technology, portable and wearable electronic devices have shown the development trend of flexibility, integration, and personalization.

The provision of an adequate energy source is a significant barrier to the flexible and integrated deployment of portable and wearable electronic devices. Batteries that can be swapped out are the most prevalent kind of power supply used in modern electronics. Precision medicine makes it possible to provide patient-centred treatment that is also flexible, portable, and less expensive than traditional clinical decision support systems. The precise measurements of a person's physiological characteristics help to identify the individual's present state of health and provide support for the clinical decision-making process undertaken by medical experts. Implantable and wearable medical (IWM) devices are an essential component of nursing, the monitoring of physical activity, rehabilitation, clinical early identification of illnesses, and monitoring of the course of diseases. IWM devices are beneficial in the evaluation of both a service member's physical and mental status, in addition to their widespread use in precision medicine. For instance, the human heartbeat may be derived from the blood flow in the cardiovascular system and measured using wearable photoplethysmography (PPG) sensors.

LITERATURE REVIEW

M. Fahim (2022): Wearable technology provides a significant amount of untapped potential for the development of patient-centred medical applications. Our way of life is altered as a result of the information it provides about our physical activities, the monitoring of our sleep, and the rhythms of our pulse. In this article, we discuss a novel approach to oral healthcare that notifies consumers when it is time to brush their teeth and focuses on the concept of prevention rather than treatment. It is built on an accelerometer that is worn on the wrist and has two components: first, a computationally lightweight feature extractor, and second, a strong feed-forward neural network to identify the activity of cleaning teeth. The performance of the model is evaluated using the standard performance metric known as F1 - score (i.e., 98%), which demonstrates the applicability of the model to a situation that occurs in the actual world. The trained model may take up residence inside the smartwatch and be worn on the wrist as a wearable device. If the user missed the toothbrush action, it would send tailored alerts to the user's device. In addition, it reminds users to replace their toothbrush every three months, which helps reduce the mental load associated with this task. Clinical Significance: The findings of this study may assist people in preserving their dental health by using smartwatches as a wearable device.

A. Kassem (2021): Because of the proliferation of wireless technologies and the shrinking of electronic sensors, the development of equipment that can be worn to monitor a person's health has made significant strides forward in recent years. The utilisation of active health monitoring devices connected to the Internet of Things (IoT) to follow patients and athletes as they go about their normal daily activities has the potential to revolutionise the future of healthcare services. Applications in the medical field such as remote monitoring, biofeedback, and telemedicine are helping to construct a whole new system for managing both the quality and expenses of healthcare. Our effort intends to produce a low-cost, high-quality wearable smart gadget that can serve several purposes and monitor the health care of patients with heart disease as well as athletes who are interested in fitness. Within the scope of this article, we will explore our suggested system in three distinct stages. In the first stage of development, we make use of a Raspberry Pi as an open-source microcontroller in conjunction with a Healthy hat, which acts as a conduit between the Raspberry Pi and the Healthy-connected biomedical sensors that measure a variety of parameters (temperature, ECG, pulse, oximetry, etc.). In this phase, we also use a Healthy hat. Our experiment began with 15 distinct participants, all of whom varied in terms of their gender, age, and degree of physical fitness. We positioned the planned wearable device and collected data on each subject's readings while they were seated, walking, and running. In the second phase, our device will be linked to an open-source Internet of Things dashboard. This will allow the data to be displayed on an interactive Internet of Things dashboard, which physicians will be able to access remotely. Additionally, new action rules will be implemented, which will send alerts to both patients and physicians in the event of a problem. In the third phase, we developed and tested a Fuzzy Logic system. This system takes as inputs the data collected from the experiments on the accelerometer, gyroscope, heart rate, and blood oxygen level, and it outputs the physical state (resting, walking, or running) that helps determine the patient's or athlete's health status. The data inputs come from the experiments on the accelerometer, gyroscope, heart rate, and blood oxygen level. The results that were obtained from the application of the proposed method demonstrate that it is possible to perform effective remote health status monitoring of test subjects in real-time through the IoT dashboard, as well as the identification of anomalies in their health status. Furthermore, the proposed Fuzzy Logic system design was found to be effective in the detection of physical motion mode.

A. Benjamin Joseph (2022): The proposed effort has as its goal the prevention of substantial impacts caused by COVID 19, including fatal illness, by the early diagnosis and treatment made feasible by an integrated intelligent health care system. The study that is being suggested utilises Wearable Internet of Things (WIoT) technology, which is based on Ensemble Bayes Deep Learning Neural Network (DNN) technology, in order to establish an integrated health care system with improved early detection capabilities. The following are some of the reasons why this work is being done: I The pandemic of Covid 19 has seriously impacted 219 nations all over the globe, out of which crores of individuals have been infected in India. (ii) There is a lack of knowledge on the illness, and the health care support system in India is inadequate. (iii) The death rate in India owing to COVID 19 is 5.1 per 100,000 people. Using the most recent developments in integrated intelligent technologies, the work that has been presented intends to solve the problems that have arisen as a result of COVID 19. The suggested approach would be implemented throughout the nation to stop the spread of COVID 19 and the deaths that are caused by it in both rural and urban regions. Using the most recent advances in Internet of Things (IoT) technology that are powered by artificial intelligence, the system is able to identify asymptotic individuals who are infected at an early stage, before the sickness progresses. The system collects data from the people smart rings, which is then processed using a pre-processing algorithm. The data that has been processed is then classified using a deep learning neural network as either normal people or disease-infected people in an edge computing environment. Finally, the data that has been processed is stored in the cloud and interfaced to an application server. The infected person receives notifications on their mobile device about their current health status and the locations of nearby medical institutions that are equipped to treat COVID 19, among other things, from the information that is retrieved via the application server.

G. Yang (2019): In recent years, there have been significant developments in the areas of stretchy and flexible electronics, functional nanomaterials, and micro and nano manufacturing. The development of sensors that can be worn has been sped up as a result of these advancements. Wearable sensors offer significant application possibilities in the future generation of personal devices for the treatment of chronic diseases because to their exceptional flexibility, stretchability, durability, and sensitivity. Wearable sensors that are flexible and stretchy play a vital role in providing chronic illness care systems with the capacity to monitor biological signals over the long term and in real time. These signals have a strong connection to the chronic illnesses that are present in the human body, such as the heart rate, wrist/neck pulse, blood pressure, body temperature, and information about biofluids. The monitoring of these signals via the use of wearable sensors offers a practical and non-invasive method for the diagnosis and monitoring of chronic diseases and health conditions. This article provides an overview of the ways in which wearable sensors may be used to the treatment of chronic diseases. In addition, this analysis makes use of a detailed assessment of needs for flexibility and stretchability, as well as ways of augmentation based on nanotechnology. In addition, the most current developments in wearable sensors, such as pressure, strain, electrophysiological, electrochemical, temperature, and multifunctional sensors, are discussed in this article. In conclusion, a discussion is had about the opening research problems as well as the future directions of flexible and stretchy sensors.

L. -W. Chang z(2021): With the purpose of developing a personal health monitoring system based on a mirror, this research blends non-contact measures and wearable sensors. We ask for permission from the user before using the Google Fit REST API to access his or her activity history. This includes the number of steps taken, the number of calories burnt, the heart rate, and the amount of sleep. The user is thus able to simply and quickly comprehend the behaviour of the past by way of a bar chart that displays all of the physiological data that has been collected and shown on the monitor.

METHODOLOGY

These sensors were introduced. In 2010, researchers Paulo & Gaspar and in 2011, researchers offered an excellent analysis of a power harvester that used the motion of the human body to power biomedical sensor nodes. This study offers a comprehensive analysis of the research that has been conducted about the topic of energy harvesting for biomedical implants. The purpose of this review is to discuss and classify all of the different types of energy harvesting that are used in wireless telemetry bio-devices and biomedical implanted devices. This will allow for the development of appropriate solutions to the challenges and problems that are currently being faced. Implantable biomedical devices may be classified into two types. The first type includes devices powered by energy harvested from the human body and covered by secondary forest.

The second method includes those powered by energy harvested from the environment and covered by secondary forest. All types of energy harvesting methods used in biomedical applications are presented in Figure 1, and as follows. Human activities are sources of kinetic and thermal energies. On the basis of energy harvesting technology, a variety of portable, wearable self-powered sensors for monitoring physical, chemical, and physiological information have been developed. There are two main ways to realize self-powered sensing. The first is active sensing, which uses the electrical signal itself as the sensing signal, where the output electrical signal will be affected by some external factors. Active sensing has been widely used in the monitoring of pressure81, humidity, and temperature.

Although implantable devices have dramatically increased in their efficiency as a result of their batteries having more storage capabilities and the circuits within the average implantable device consuming less power, there is still a great challenge in finding ways to harvest power back to their battery packs. Patients who use implantable devices still suffer from the fact that the batteries have to be changed, requiring potentially costly surgical interventions. To reduce the need for surgery, the harvesting technique regarding the implantable device is a potentially fruitful approach, whether to eliminate the use of batteries entirely or—in the case of recharging them—to delay the need for surgical intervention. Several harvesting methods have been presented in this review; they were nominated due to their sensible application with regard to their power output, advantages, and disadvantages with the illustration of their testing on animals and humans. Human body activities are a promising source of energy for implantable biomedical devices. Kinetic energy is a readily available energy source for both human and environment energy harvesting devices. This section briefly explains the principles of different transducers for obtaining electrical energy from kinetic energy, including piezoelectric, magnetic induction generator, and electrostatic transduction methods and as follows. The first piezoelectric effect was discovered by brothers Jacque and Pierre Curie in 1880. They found that certain materials, when subjected to mechanical strain, suffer an electrical polarization that is proportional to the applied strain. This piezoelectric effect is used to convert mechanical motion to electrical energy. Photovoltaic cells are implanted to transform sunlight energy to electrical energy.

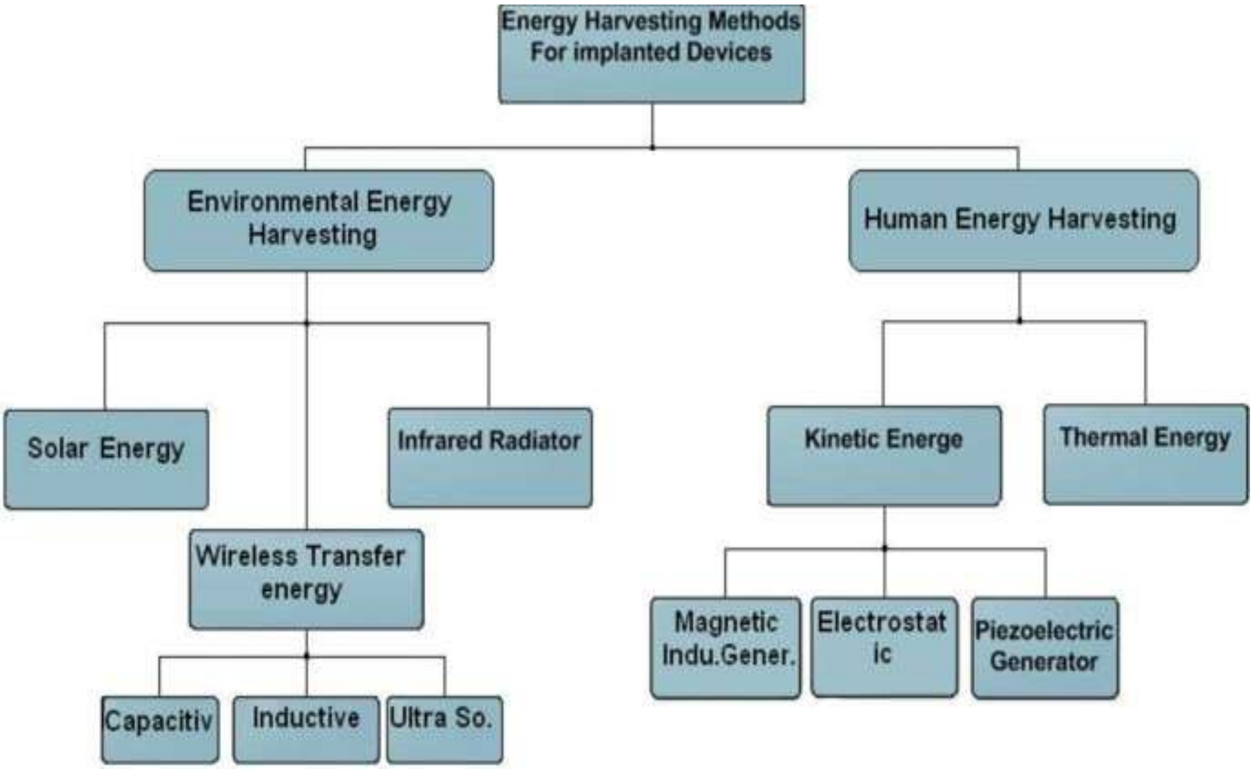

Figure 2 Energy harvesting for the implantable biomedical devices

Additionally, semiconductors are widely used to produce voltages and current as a function of optical emission by the photovoltaic effect. Inserted a photovoltaic cell set and an LED to a rabbit's eye creating a biopsied energy harvesting device powered by light with a 1.5 mW power yield. Miyake et al. in 2011 proposed a miniature assembly with a bioanode needle for accessing biofuels in a rabbit ear's artery, yielding a maximum power of 26.5 mW. Rasmussen et al. harvested energy from a disaccharide trehalose biofuel cell implanted via cuts inside its abdomen, and the generated output power density was 55 μW/cm2. Shoji et al. in 2016 examined enzymatic biofuel cells with cockroaches, which are capable of delivering a 333 μW yielded power and powering both of a light-emitting diode and a wireless temperature sensor. The technique of biochemical renewable energy involves in vivo research to generate power and was first introduced in 1974 for medical implanted devices approaches. Biofuel cells generate electricity using biocatalysts. There are infinite amounts of biofuels in living organisms that further produce microwatts of power, which cells are using in biochemical reactions to transform biochemical energy into electric energy. Zhao et al. in 2009 compared mesoporous carbons and carbon nanotube biofuel cells in the electric output efficiency, which produced a maximum power density of 38.7 μW/cm2 and 2.1 μW/cm2, respectively. Different body activities produce different levels of power. Sleeping can produce approximately 81 mW of power, whereas sprint walking and motion produce 1630 mW of power. The human body can retain temperature even when the ambient temperature changes. This property maintains the metabolic processes necessary for energy production even if the surrounding temperature is extremely cold. Therefore, the two types of energy generated by human body activities such as kinetic and thermal energy harvesting are investigated in this section.

Inductive linkages have been the subject of research attention from a number of different studies. The efficiency with which power is transferred from a system like this is determined by a number of different factors. These include the coils, which are determined by the quality factor of the coils and the coupling coefficient between two coils, as well as the geometries, shapes, sizes, alignment location, and core separation between the coils. The application determines the minimum needed data rate that must be sent between the two components of the inductive connection. High data rate transmission is necessary for devices such as endoscopic capsules, cochlear implants, and retinal implants. The number of electrodes will also play a role in determining which stimulator will be put.

As a result of its lower band ISM frequencies and greater data rate in comparison to the other ways, the inductive coupling connection is the approach that is considered to be the superior choice for powering subcutaneously implanted devices. On the other hand, the transfer efficiencies at low frequencies are often poor due to the restricted band and adverse circumstances that prevail in the majority of biological applications. For instance, the implanted coil that is used in neural recording is positioned subcutaneously, and there is very little space for the head between the cortex and the skull. Because of severe size constraints as well as biocompatibility requirements, high permeability cores, which are generally employed in a transformer to restrict the magnetic flux, are not practical due to the fact that they result in weak mutual coupling.

EXPERIMENT RESULT

Self-powered systems have a great deal of promise in applications like as energy harvesting, sensing, actuating, and human–machine interaction, and it is anticipated that they will become the primary form of electronic devices in the age of the Internet of Things. Within the scope of this examination, we will provide an in-depth introduction to the evolution of self-powered systems that are both portable and wearable. We began by developing a portable and wearable energy harvesting technology as the foundation for self-powered systems. Then, we presented the use of self-powered systems in the wearable sensing of a number of different physiological and physical markers. In addition to this, we also presented standard self-powered systems that are capable of performing actuating tasks. Two distinct categories have been established for the different kinds of implantable biomedical devices that are discussed in this research. The first category consists of electronic gadgets that get their power from the human body itself. The second technique involves rating systems that are powered by energy captured from the environment, and it has been split according to the commercial commercialization, scientific commercialization, and the prospect of selling.

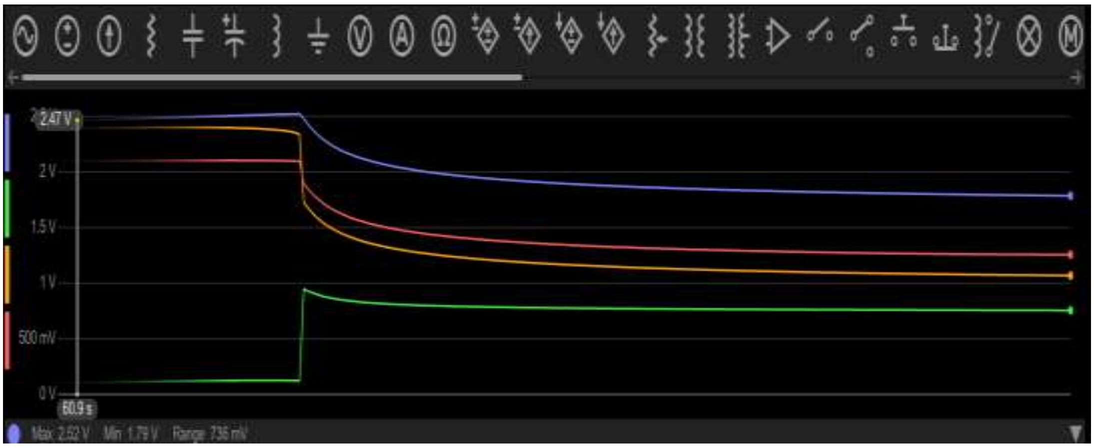

Figure 3 Energy harvesting Implantable medical devices

For commercial uses. These days, manufacturers favour one of the best techniques, which is one of the implanted devices that utilised the human energy harvesting, such as a piezoelectric generator. This is because these devices are low-cost, and there is a rising demand for them. However, in terms of the scientific foundations of marketing, we are of the opinion that the inductive coupling method is superior scientifically. At the moment, the manufacturer has plans and is conducting ongoing research in order to concentrate their efforts on making this method more suitable for commercial marketing. A photovoltaic cell in the transcutaneous site of a pig in order to gather optical energy and continuously drive a pacemaker at a rate of up to 125 beats per minute for two weeks when the animal was in the dark. Song et al. reported the presence of solar cell arrays in the transcutaneous location of a hairless mouse (Figure 4), where they were able to gather electrical power of up to 647 W. In 2018, Wu et al. produced an implanted chip that consisted of photovoltaic panels as a 256-pixel artificial subretinal. This chip was installed in the following pole of a pig's eyeball, and it was capable of producing a maximum output conversion current of up to 16.7 A. Harrison constructed a pancake coil that had an exterior coil with a diameter of 52 millimetres and a diameter of 10 millimetres for the secondary coil. This allowed for a distance of 10 millimetres. In order to provide a distance of 40 millimetres, an exterior spiral circular coil with a diameter of 44 millimetres and an implanted rectangular coil with dimensions of 15 millimetres. O'Driscoll et al developed a square inductive coupling that was powered by 915 MHz and created a distance of 15 mm; however, the problem with this coil design is that it has a very big size.

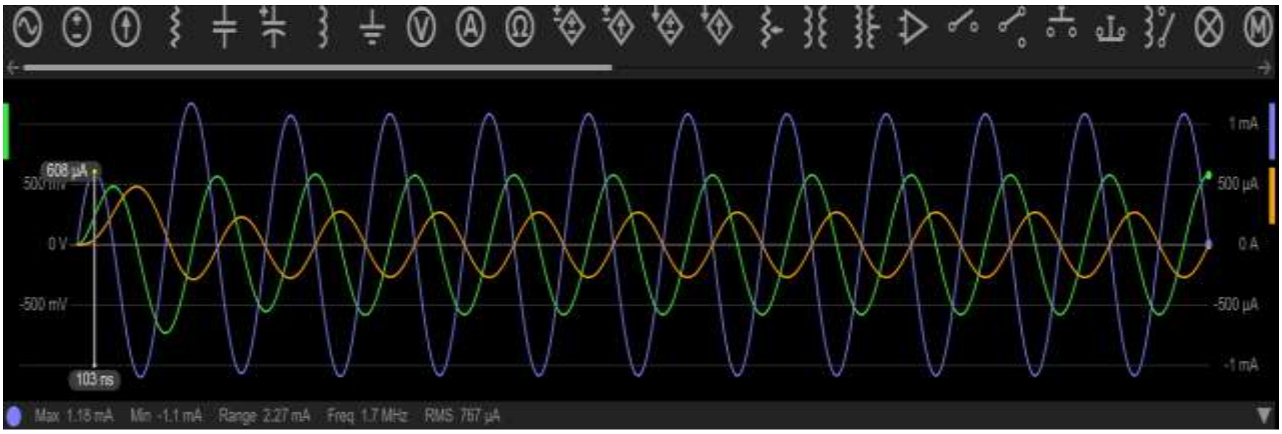

Figure 4 Energy harvesting for human wearable and implantable bio-sensors

Within the near field, the distance between the coils is much less than the wavelength. As a result, there is an increase in coupling when there is a decreased distance between the coils. The kinetic approach has the drawbacks of being rather bulky and having a limited power output. The thermal and ultrasonic technologies both emit a very low amount of energy, which prevents them from being used with some implanted devices. On the other hand, these techniques have a chance of being useful in the development of implanted biosensors in the future. While constructing implanted devices, the comfort and safety of the patients are the most crucial considerations to make. The research conducted by Hannan and colleagues examined implanted devices in terms of their power consumption, data rate, size, applications, and modulation mechanism. It is still necessary to have in-depth discussions on the power sources and energy harvesting strategies for implanted devices. As a result, all of the potential approaches of provide power to implanted devices have been outlined and discussed in this article. In the various ways of energy harvesting are outlined, along with the amount of electricity that is created and the benefits and drawbacks associated with each approach. A PENG using an implanted piezoelectric with $BaTiO_3$ to stimulate actively with endogenous ultrasonic acoustic energy the paretic muscles of a rat. Wearable devices may be located at different parts of the human body to measure and analyse human gait. The movement signal recorded by these devices are used to analyse human gait. In sports, gait analysis based on wearable sensors can be used for sport training and analysis and for the improvement of athlete performance. The ambulatory gait analysis results may determine whether or not a particular treatment is appropriate for a patient. The authors used porous polyvinylidene fluoride-trifluoro ethylene thin film to harvest the mechanical energy from the heartbeat. The maximum electrical output was 0.5 V and 43 nA under the frequency of 1 Hz. They stated that adding a proof mass of 31.6 mg on the dual-cantilever tip resulted in the power increasing by 1.82 times. Tested an Implantable Piezoelectric Generator (iPEG) on a porcine heart in vivo, with a harvested maximum output

CONCLUSION

This paper provides an overview of the many different energy collecting methods that may be used by implanted biomedical devices. All the many ways to extract energy from the motion and vibration of the human body as well as the surrounding environment are analysed and explained. These procedures are adaptable for usage in a variety of devices, including those that are portable as well as those that are implanted, such as pacemakers, cochlear implants, and implantable microsystems. The main features of the kinetic and thermoelectricity generators that are involved in the process of harvesting energy from the motion of the human body are as follows: The piezoelectric material, electrostatic generators, and magnetic induction generators that are used in kinetic harvesting are all examples. Figure 1 shows the breakdown of environmental energy harvesting that was done. There is an in-depth discussion of the properties of physical and mathematical techniques of energy harvesting, including an analysis of the benefits and drawbacks of each approach. The harvesting technique applied to the implantable device is an approach that has the potential to be fruitful in reducing the need for surgical intervention. This may be accomplished by doing away with the use of batteries entirely, or by delaying the need for surgical intervention through the process of recharging existing batteries.

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