Research Proposal

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Title: Triboelectric nanogenerators as self-powered sensors for human-machine interfaces

Abstract

Triboelectric nanogenerators (TENGs) are a relatively new and underexplored mechanical energy harvesting solution. Through contact electrification and electrostatic induction between two materials that get into contact, electrical energy can be generated. The magnitude of the generated electrical signal depends on critical parameters. By tuning these parameters, motion, structural and material parameters, the output of TENGs can be optimised. This change in output with the change in these parameters means TENGs can also be used as sensing platform, for example as pressure or stress and strain sensors.

My research will be at the junction of three areas: model recognition and data analysis and developing TENG-based sensors. Graphene-based wearable (plastic and textile TENGs) have been developed . I will investigate methods to introduce analytical models which fully explains the working principles and output behaviour of such TENGs with changing critical parameters. This will enable the use of these wearable TENGs not only as energy harvesting solutions, but also as sensors for several applications, namely for human-machine interfaces and augmented reality applications.

Introduction

Powering the next generation electronic devices, in particular, the sensors and actuators that need to be mobile and ubiquitous, is a key challenge the world is facing today. Firstly, these device networks contain large numbers of complex circuit elements which could be located remotely. Therefore, the use of individual power units for each system and their replacement or recharging becomes a challenge. Many such devices demand flexibility and stretchable mobile designs to be efficiently integrated into everyday objects without impairing their functionalities. Furthermore, the energy supply systems should ensure the safety of the users, in terms of their chemical and physical compositions and output power characteristics. Moreover, the rapid growth in world population has caused an increased energy demand, along with ever increasing fossil fuel consumption threatens non-reversible climate changes. Therefore, the success of future electronic technologies largely depends on the construction of autonomous self-powered energy supplies, which depend on renewable energy sources available in the surrounding.

Triboelectric energy harvesting has been shown to contain unique advantages over other energy scavenging technologies [1]. TENGs can be constructed using commonly found low-cost materials, through simple fabrication processes. The fabrication techniques currently used for TENGs can be easily scaled up into large area applications. Typically, TENGs generate high output voltages and their output power is relatively high compared to other energy harvesting technologies, specially at low frequencies (typically <10 Hz) associated with ambient mechanical energy sources. Furthermore, TENG-based sensors have shown high sensitivity and accuracy in pressure, position and motion sensing applications due to their operational nature. This opens up the way to explore the use of TENGs for human-machine interface.

Graphene-based wearable TENGs based on plastics and fabrics have been demonstrated at Exeter by Dr Ana Neves and Prof Monica Craciun [2,3]. These devices, being wearable, have the potential to generate electrical energy from human motion, if worn by a user

The Problem

Despite the significant advancements in the demonstrated applications, there are a number of issues that need to be resolved to enable TENGs in becoming a reliable and efficient energy harvesting technology. For sensing applications, significant improvements need to be made on the understanding of working principles and the output trends of TENGs. The conventional theoretical models elucidating the output behaviour of TENGs explicitly depend on circuit model approximations constructed using parallel-plate capacitors. These models do not fully describe the electric field and electrical output behaviour of the TENG devices. Consequently, the accurate output prediction and optimisation of TENGs are impaired, restricting the precise design and construction of energy harvesters. Therefore, an accurate analytical model which fully describes the working principles and output behaviour of TENGs is essential in designing and constructing more efficient TENGs.

A number of material and structural parameters affect the output characteristics of TENGs. The effect of each parameter on TENG output behaviour needs to be carefully analysed theoretically and experimentally, in order to construct an optimised TENG design. However, contradictory views exist in literature, about the effect of different structural and material parameters and their limitations with regards to triboelectric energy harvesting. The need for a systematic study consisting of accurate theoretical modelling with extensive experimental verification to clarify the effect of structural and material parameters on TENG outputs, has been highlighted. TENGs by nature, produce intermittent power outputs corresponding to contact-separation or sliding movements of constituent triboelectric surfaces. As a result, providing a continuous uninterrupted power supply is challenging. Finally, TENGs are inherently high impedance devices, which makes the extraction and transmission of their outputs to power typical electronics devices (which are normally low impedance) less efficient, due to lack of load matching.

As a self-powered sensing technology, TENGs can be widely distributed in every corner of the environment for collecting various types of mechanical signals in real time, from skin [4] to wave energy [5]. These signals have to be collected and transmitted for real-time sensing and monitoring. Wireless transmission of such signals will further widen the application of such devices, for instance, in human-machine interface applications (e.g. haptic signals for augmented reality, to remotely control a device, etc.). Combined with artificial intelligence, TENG-based big data analytics could be developed as a new branch of self-powered systems to automatically analyse the collected data and provide scientific guidance. Based on TENG-based big data analytics, smart sensing systems can be built for a wide range of fields, such as environment monitoring, healthcare, sports, safety, and more. This new branch will greatly expand the TENG application range for the Internet of things (IoT) [6]. Additionally, the sensing accuracy of TENGs is usually neglected at the current research stage of TENG-based self-powered sensing systems. With the rapid development of the self-powered sensing field, the sensing accuracy of TENG will be vitally important in the process of its commercialization, which can be improved by structural design, material modification, and power management. In addition, signal processing circuits can also be used for improving the sensing accuracy.

Specifically, we aim to target human-machine interface applications of these graphene-based TENG sensors. TENGs have been shown to have the potential to be used has haptic sensors for augmented reality applications [7]. In this project we will explore this type of application by integrating wearable TENGs in smart-glove-type of applications, endowing the TENGs with wireless communications, gathering and analysing the data generated for the purpose of controlling objects with the hands. This finds applications in health rehabilitation [8,9].

Method

1. TENGs will be fabricated using different types of graphene (e.g. graphene nanoplatelets dispersed in water and spray coated onto textile substrates) and copper electrodes. As triboelectric layers, polymers such as polydimethylsiloxane (PDMS) and fabrics such as nylon and polyester will be used. This will be mostly done by experienced Graphene Engineering lab users and I will learn from them, as I have limited experience in this area.

2. The above-mentioned TENGs will be characterised in terms of voltage, current and power using an existing test rig that is capable of applying repeated motions vertically and horizontally at the surface of the TENGs, with signals registered with source meters and multimeters connected to a computer. My prior experience in electronics will be important for this.

3. The TENG signals will also be explored using an artificial hand to mimic the use as smart gloves. Again, my background in electronic engineering will be fundamental for this.

4. The data generated will be as follows:

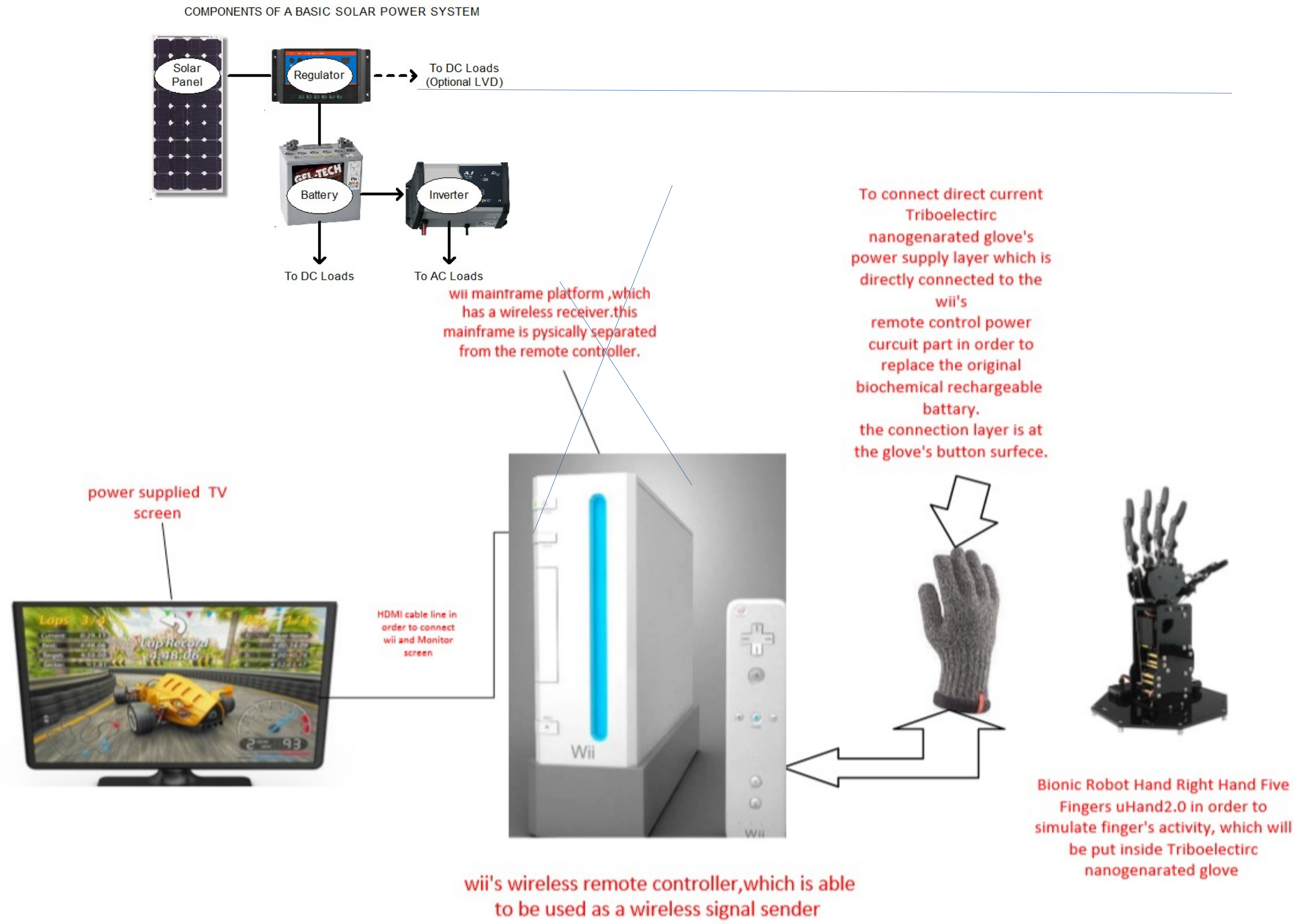
Data analysis

outdoor temperature,humidity,useage of sunlight,voltage,coupling current, bionical robot hand speed,Vehicle Engine temperature,PC rotation speed,

a smart glove with integrated triboelectric nanogenerator ,bluetooth wireless frequency.….I will be able to develop and design a (web-based /app)software platform along with visualized big data analysis interface to interpret these gathered signals and data in order to make this TENGS-based glove to work smartly,Moreover,I will also develop novel materials to analysis glove's function and more AI and augment reality possibility

5. Using the data generated to control external gear /
Below is the whole solution and bespoke software capable of gathering and interpreting this data

Door outside sunlight for enegy saving and electric-driven device preparation



software in wii: Mario Kart game

I come up with a mature project,what I have to do is to upgrade this 2D version(above) to 3D version in order to simulate them,To the end .I am making sure that they are workable in reality along with proposing a published paper.

The plan here is that I can use the TENG signals generated by a glove to interpret hand gestures to control external machinery(nintendo wii).

For example, virtual remote control car or small appliance, and extend this to VR, for example, to control a remote emergency vehicle in an inhospitable terrain where emergency personnel cannot go (e.g. war, fire, earthquake, etc).

Additionally,it is also able to be applied on physically-existing electrical remote control car systems.

As the brief instruction chart shown above.

Next step,we will have 2 options .
Firstl,we can use human hand as terminal controller left inside a smart glove with integrated triboelectric nanogenerator.

Second,we can use artificial robot hand as terminal controller left inside a smart glove with integrated triboelectric nanogenerator.

Option 2:
In this blueprint,the smart glove will be used to control a bus or emergency car remotely in reality ,apart from the car used inside software.

Research Plan

(a) Milestones and Deliverables

The project will proceed in four main phases. Each phase is composed of a number of relevant tasks and associated deliverables and milestones.

Phase 1 (Month 1 – 12), review of the state-of-the-art related to TENGs and evaluation of existing platforms used in practice.

Milestone 1 (Month 5), comprehensive review of literature and existing platforms completed.

Milestone 2 (Month 8), construction of a small-scale self-powered model testbed completed.

Milestone 3 (Month 12), evaluation of existing TENGs platforms completed.

Deliverable 1 (Month 12), a technical report on a review of the related state-of-the-art and evaluation of existing cloud management platforms.

Phase 2 (Month 13 – 28), self-powered model construction, development and evaluation.

Milestone 4 (Month 20), a preliminary analysis and evaluation of the proposed models completed.

Milestone 5 (Month 28), a comprehensive report on the evaluation of the proposed models and materials completed.

Deliverable 2 (Month 28), a software library of the developed models (this will be further refined and improved in Phase 3).

Phase 3 (Month 29 – 46), Architecture, implementation, integration, and evaluation.

Milestone 6 (Month 31), initial requirements gathering, architectural design, and choosing materials completed (this will be improved iteratively throughout Phase 3).

Milestone 7 (Month 40), implementation of framework completed (this will be continuously improved and refined in the rest of Phase 3).

Milestone 8 (Month 44), System evaluation and refinement completed.

Deliverable 3 (Month 46), A complete and functional self-powered sensor sample with associated documentation.

Phase 4 (Month 47 – 48), Industry engagement and commercialisation opportunities.

Deliverable 4 (Month 48), Dissertation report.

(b) Critical Risks

• Resource feed-in delays and unanticipated events

• Inability of architecture to meet performance requirements

• Integration difficulties are encountered

• Required functionality is discovered that is not captured in initial plan, leading to delays in other phases

• Technical difficulties are encountered during the implementation

• Mismatch between testbeds and simulation results

(c) Contingency Plans

• The project schedule allows for a 10% contingency overall. In the event of significant delay, the timeline affected by any activity will be adjusted.

• When technical difficulties are encountered during the implementation of the system, open-source alternative component(s) will be identified and evaluated.

• The research project includes staged reviews of requirements against functionality with validation by the supervisor and invited external experts from academia and/or industry.

• Develop a number of alternative approaches and investigate whether any of these could deliver an improvement to the expected metrics.

• Adopt the Agile development methodology for the design and development phases of the project. Divide workloads into micro-tasks, thus newly discovered requirements could be inserted to the project plan without incurring significant delays.

• Ensure the performance of all processes are continuously monitored by my supervisors. External reviewers will be invited to evaluate the research outcomes on a regular basis.

References:

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