Project Title: *Modernizing photovoltaic textiles for scalability and wearable applications*

Principal Investigator: *Joseph Paradiso, MIT*

Co-investigators: *Ana Baptista, FCT NOVA*

AO/FO: *Anna Spector, Senior Financial Officer*

Proposal Research Area: *Digital Transformation in Manufacturing, Sustainable Cities*

Grant Period: *09/2023 – 09/2024*

Total Budget Requested: *US$ 100,000*

Grant renewal application: *No*

Layperson's Description: Solar power can be harnessed in new ways such as in bags, cloths, curtains, tents, sails, or construction tarps. However, existing research for photovoltaic textiles is either too expensive or not scalable. We propose to leverage inkjet printing to enable the fabrication of large textile photovoltaic surfaces affordably. This can modernize Portuguese textile manufacturing and promote sustainability. We outline the steps involved in our solution and our plan to collaborate with academia and industry in Portugal. This project can make Portugal a hub for high-tech innovation and revolutionize human-computer interfaces such as self-powered smart sensing gloves for Augmented/Virtual Reality.

Fig. 1: illustrating the potential of printed textile solar panels, from left to right: An inkjet textile printer, a construction wrapping tarp, a greenhouse, and a smart glove.

1. Abstract

Thanks to photovoltaic (PV) textiles, solar power can be harnessed in new ways such as in bags, cloths, curtains, tents, sails, or construction tarps. However, the existing options for PV cells are either too expensive or not scalable. Using inkjet printing, an affordable and widely used technique in the textile industry, we can fabricate PV cells on large textile surfaces. It would contribute to modernize Portuguese textile manufacturing and promote sustainability, or even eco-tourism. In this proposal, we outline the steps involved in our solution and how we plan to collaborate with academia and industry in Portugal to make this a reality. Ultimately, this project can participate in making Portugal a hub for high-tech innovation and revolutionize human-computer interfaces such as self powered smart sensing gloves for Augmented/Virtual Reality (AR / VR).

2. Project Objective

For this project, the teams of Pr. Paradiso (MIT) and Dr. Baptista (NOVA FCT) will work closely together to investigate how to create solar powered textile interfaces at a scalable level, and apply their research findings in the context of self powered wearables.
Pr. Paradiso has been working on energy harvesting since the 90's [1, 2] and has access to fabrication facilities that can enable the exploration of scalable production for large quantities of PV textiles.

Mass manufactured flexible PV panels can be integrated in a bulky manner but they are not visually appealing so they were not adopted by the general public. Research has been working on the problem, but there is still no scalable and affordable solution [3-6], so we are proposing a solution with a widely accessible technique: inkjet printing. However, this will require an effort of replication of multiple approaches (Perovskites, DSSC, etc), characterization, simplification, and adaptation for scalability.

Dr. Baptista brings such application domain expertise, i.e, she is a Senior Researcher in Materials Science and Engineering, her research focuses on the development of innovative smart textiles based on biocompatible polymers with multifunctional properties envisaging their application in energy conversion systems and medical devices. This proposal will impact her research in electronic textiles, specifically for energy harvesting and storage devices. The findings will complement her ongoing research within the scope of the All-FIBRE project funded by the FCT (Portuguese Foundation for Science and Technology - ref: PTDC/CTM-CTM/1571/2020).

Overall, this proposal aims at developing a novel inkjet printing process that can deposit PV materials onto textiles with high precision, reproducibility, and efficiency. For such purpose, the following objectives are identified:

1. Optimize the inkjet printing process parameters, such as ink composition, printing speed, and drying conditions, to achieve high-quality PV textiles with good electrical properties and mechanical stability.
2. Investigate the compatibility of different textile materials with the inkjet printing process and identify the best-suited materials for PV textiles.

3. Characterize the performance of the PV textiles, including their power conversion efficiency, durability, and resistance to environmental factors such as light, moisture, and temperature.
4. Develop scalable manufacturing processes for producing PV textiles using inkjet printing, and evaluate their economic feasibility and environmental impact.
5. Explore potential applications for the PV textiles, such as wearable electronics, smart textiles, and building-integrated PVs, and assess their market potential and customer needs.
6. Collaborate with industry partners to ensure the successful commercialization of the PV textiles and facilitate their adoption in various sectors.

2.1 Why?

Solar textiles offer several advantages over conventional solar panels, including flexibility, lightweight and cost-effectiveness. PV textiles are highly flexible enabling them to be woven, knitted, or printed onto a variety of fabrics, envisaging a wide range of applications including bags, cloths, curtains, tents, sails, construction, and tourism. Due to their lightweight, PV textiles are also an ideal solution for portable devices and to be used in remote locations where traditional solar panels are not practical.

However, the existing options for PV textiles are expensive and not scalable, which limits their widespread adoption. The proposed project seeks to develop a cost-effective and scalable solution that leverages inkjet printing technology to fabricate PV textiles. Inkjet technology will offer a high precision deposition methodology of PV materials onto textiles, enabling the use of various commercial textiles substrates, including natural and synthetic fabrics, allowing to preserve their flexibility. Additionaly, this technique can be easily integrated into existing textile production lines, enabling large-scale production and enabling the printing in different patterns, shapes, and sizes, which can be tailored to specific design requirements and aesthetic needs.

The project also aims to explore the use of self-powered sensors and machine learning to interpret the data generated by the PV textile cells, which can have significant human-computer interaction (HCI) applications, such as self powered smart gloves for gesture recognition (feasibility research: [7-9]).

2.2 Work plan

The proposed project will be executed in three steps.

<u>Step 1</u>: Replication, Characterization, and Comparisons.
The first step involves the replication of PV cells on rigid substrates using existing approaches. We will start with DIY PV fabrication techniques, such as organic/perovskite and dye-sensitized solar cells (DSSC). The PV cells will be characterized, and the most scalable approaches will be pre-selected for further development.

<u>Step 2</u>: Adapting the Process to Make it Robust and Scalable.
The second step involves adapting the PV cell fabrication process for inkjet printing technology. This process will be used to deposit the materials, mostly from Step 1, such as conductive inks, dielectric materials and the active layer (for instance P3HT:PCBM). Several layers in different configurations should be evaluated to find the

most promising structure to obtain efficient PV devices. The main idea in this step is to develop suitable inks able to be directly used in common cartridges of commercial inkjet printers. The inkjet printer must be capable of printing these inks at high resolution and with a high degree of accuracy.
For such purpose, we must evaluate formulation properties of inks made of the different materials, including those that are highly viscous or prone to clogging the printer's nozzles.
After optimization of the formulated ink, the printer should print multiple inks with different properties or printing multiple layers of ink to create a three-dimensional structure.
Finally, we will fine-tune the process for the production of large textile surfaces and make it mechanically resistant to deformation. We will also explore the use of computational fabrication techniques to enable customized devices with a specific pattern or design. If needed, we can also consider the use of silicon-based materials to encapsulate the PV textile and protect it against oxidation, mainly caused by its contact with ambient conditions, and possible water damage.

<u>Step 3</u>: New Applications.
The third step involves the use of the large textile surfaces for real-world applications, such as crafting cloths, curtains, and other textile-based products. We will also explore the fabrication of self-powered sensing eTextile devices, such as data gloves

2.3 Beyond Seed Funding

The proposed project has the potential to facilitate long-term collaboration between us and industry partners in Portugal and beyond.
We hope to explore the development of scalable battery fibers with PV capabilities, which can have significant implications for the energy and textile industries.
We also hope to disseminate the findings of the project through academic publications and conferences to contribute to the advancement of the field of 3D printing and robotics.
The proposed grant project envisions a robust collaboration between members of MIT and FCT NOVA, which will foster effective dissemination of project outcomes through various channels such as webinars, advanced and post-graduation courses. Furthermore, the project anticipates multiple research exchange visits between the two universities to strengthen the collaboration and promote knowledge sharing.

3. Collaboration with faculty, industry, and other institutions in Portugal

MIT:

- *Joe Paradiso (PI): Physics, energy harvesting and sensing*
- *Cedric Honnet (PhD student): Embedded systems and manufacturing*

Portugal faculty:

- *Ana Baptista (PI): Materials science and functional textiles*
- *Amjid Rafique (Postdoc): Nanomaterials, solar cells*

Portugal industry:

- *Started discussions with textile printing companies: versaltex.pt, portus.pt, adalberto.pt and otojal.pt.*
- *Already have collaborations with a fiber manufacturer (for next steps): inovafil.pt.*

4. Impact on Portugal

This proposal can contribute to the modernization of various sectors of the Portuguese industry, particularly textile manufacturing industry, agriculture and eco-tourism.

The use of inkjet technology to produce PV textiles is an innovative approach that can differentiate the Portuguese textile industry from competitors and enable the production of high value products. It will also enable the Portuguese textile industry to diversify its products portfolio and expand into new markets such as wearable electronics and smart textiles. The production of PV textiles can generate new revenue streams and create jobs, which can contribute to the economic growth of Portugal and the well-being of its citizens.

In agriculture, PV textiles can be integrated into agricultural textiles such as shade nets, crop covers, and greenhouses to generate electricity and enhance the efficiency and sustainability of agriculture, which can help to modernize the agriculture industry.

The use of PV textiles can differentiate eco-tourism facilities in Portugal by offering innovative and sustainable services and products. It may enable the production of sustainable energy to power eco-tourism facilities such as hotels, lodges, and campsites, reducing the reliance on fossil fuels and minimizing the environmental impact of tourism.

5. Intellectual Property

None.

6. References

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