SUPERIOT project
Newsletter #2
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- *Developing sustainable conductive inks at NOVA*
- *Substrate testing for printed electronics at INESC TEC*
- *Standardising DNNs compression evaluation at University of Bristol*

https://superiot.eu

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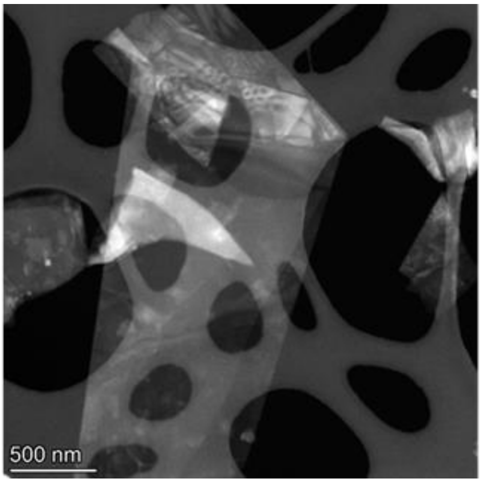
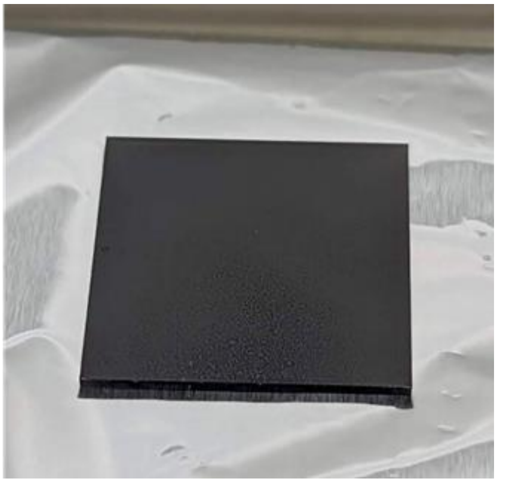
Solution-based methods for conductive inks

The SUPERIOT project aims to develop fully printed and hybrid demonstrators that combine both optical and RF communication strategies. To achieve these ambitious goals, a great deal of effort is being put into the development of sustainable printed electronics components. NOVA University of Lisbon, through its Faculty of Science and Technology (FCT), and in particular the Advanced Functional Materials for Micro and Nanotechnologies (AFMMN), will contribute to SUPERIOT with its expertise in materials development and characterisation, and printing technologies for sustainable microfabrication of components and devices.

NOVA is exploring solution-based methods for the formulation of sustainable low environmental impact nanomaterial-based inks for printing and coating thin film devices (see figure). One approach uses liquid phase exfoliation for graphene processing in dihydrolevoglucosenone (cyrene). This solvent is seen as a promising alternative to the toxic ones commonly used, as it is derived from biomass processing waste and has no identified environmental risks. Another approach is the synthesis of metal oxides by sol-gel with a focus on the solution combustion synthesis method. Work on this methodology continues progress made in a previous EU project, SUPERSMART, in which NOVA studied the implementation of sustainable inks to produce diodes at pilot scale in collaboration with VTT.





Left: graphene ink in cyrene. Centre: representative TEM micrograph of a graphene flake. Right: spray-coated conductive graphene electrode.

The developed inks, based on graphene and other materials of interest, will be used chiefly for the development of micro-supercapacitors (MSC). These energy storage components will work along with organic photovoltaic (OPV) harvesters (developed by VTT) for reconfigurable internet of things (RIoT) optical-radio concept nodes. Graphene will be used as both the current collector and active material, thus simplifying the fabrication process. In addition, printing and coating technologies allow the MSC fabrication on the same substrate as the OPV. Finally, the use of a carbon-based material in combination with sustainable solvents is expected to significantly reduce the environmental impact of device fabrication.

For the node concept and demonstrators, NOVA will also develop other devices including UV sensors based on ZnO nanostructures, memristors for storing signals and diodes for rectifying signals.

The proposed devices will be fabricated on sustainable and low impact substrates. NOVA has already shown the feasibility of device development on both paper and cork. In recent work, the use of other substrates that ensure transparency, flexibility and compatibility with microelectronic fabrication processes were also demonstrated using polymers like parylene, PET and polyamide. This in-house manufacturing know-how will be directly applied in SUPERIOT and its aim of technological sustainable microfabrication.

NOVA has a printing lab composed of diverse printers (inkjet - Dimatix, flexographic and screen printing; 3D extrusion high precision printing - XTPL), and coating techniques (spin, spray, blade and dip coating systems). A new inkjet printer Dimatix DMP-2850 was acquired through the SUPERIOT project (see below).

Dimatix materials inkjet printer DMP-2850.

NOVA has a long tradition of sustainable component development and device microfabrication. The ongoing project *Green nAno diMensional Based Inks for energy sTorage applications* (GAMBIT), funded by the Portuguese Foundation for Science and Technology, is devoted to the development of 2D material-based environmentally sustainable inks. More recently, under Portugal's Recovery and Resilience plan, NOVA has received substantial funding for infrastructure development and requalification.

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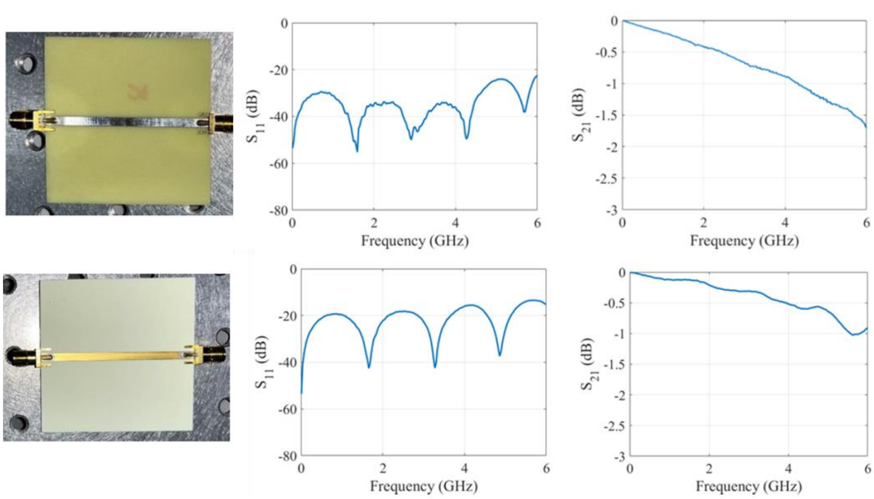
Testing substrates for sustainable printed electronics

INESCTEC



The SUPERIOT team at INESC TEC has been testing a variety of candidate sustainable substrate materials and conductive inks for IoT node implementation using printed electronics. The first method considered is represented in the images shown on the left.

Reference copper transmission on lines on FR4 and Rogers RO4350B substrates.

This method consists in the use of microstrip transmission lines for the extraction of substrate and conductive ink properties from measured S-parameters.

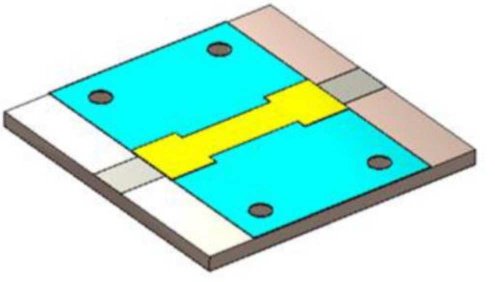
The tested substrates were:

- Polyester/polyimide films (flexible substrates)
- FR4
- Rogers RO4350B.

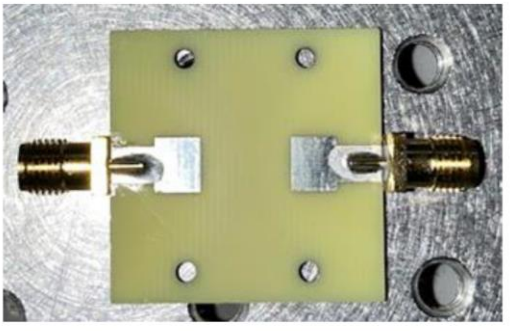
The second method considered uses a capacitively coupling technique for RF excitation of materials assembled on a second substrate. For example:

- Base FR4 substrate connected with SMA connectors
- PET substrate on top, containing the material under test

The next step planned at INESC TEC is to follow up this work applying ink samples in both methods and gather results on the most promising approaches.



Structure of the test fixture: design (above) and fabricated structure (below).



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On standardising DNNs compression evaluation

University of BRISTOL

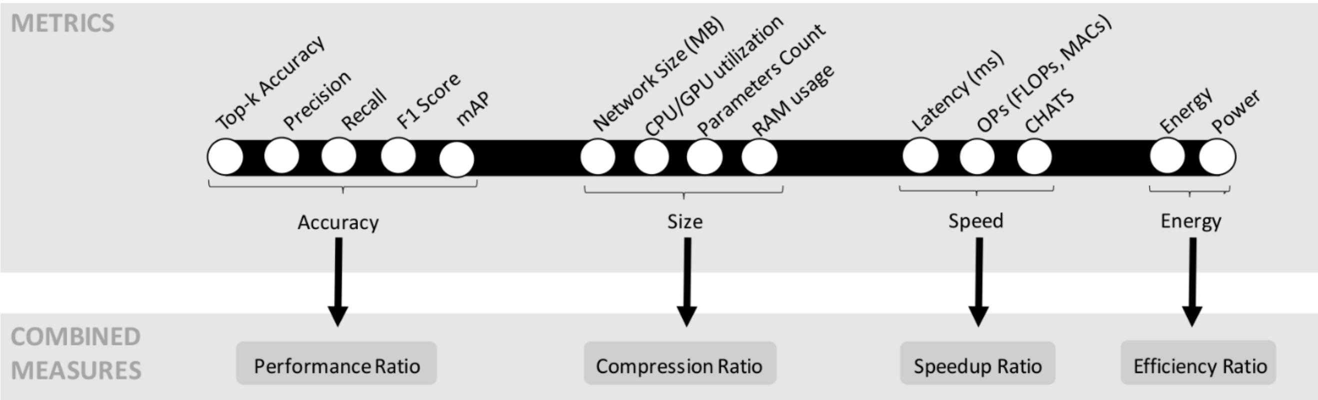
There is a lot of ongoing research effort into developing different techniques for the compression of deep neural networks (DNNs). Neural network compression refers to the process of reducing the size and computational complexity of a DNN while trying to retain its performance. This allows for the deployment of more efficient models in resource-constrained environments, *e.g.* edge devices, and so is highly relevant to SUPERIOT.

However, currently the community lacks standardised evaluation methodologies and metrics, which are key to identifying the most suitable compression technique for different applications. A recent paper by Ghobrial *et al.* [1] introduced a methodology for standardising the evaluation of DNN compression.

The methodology has four steps

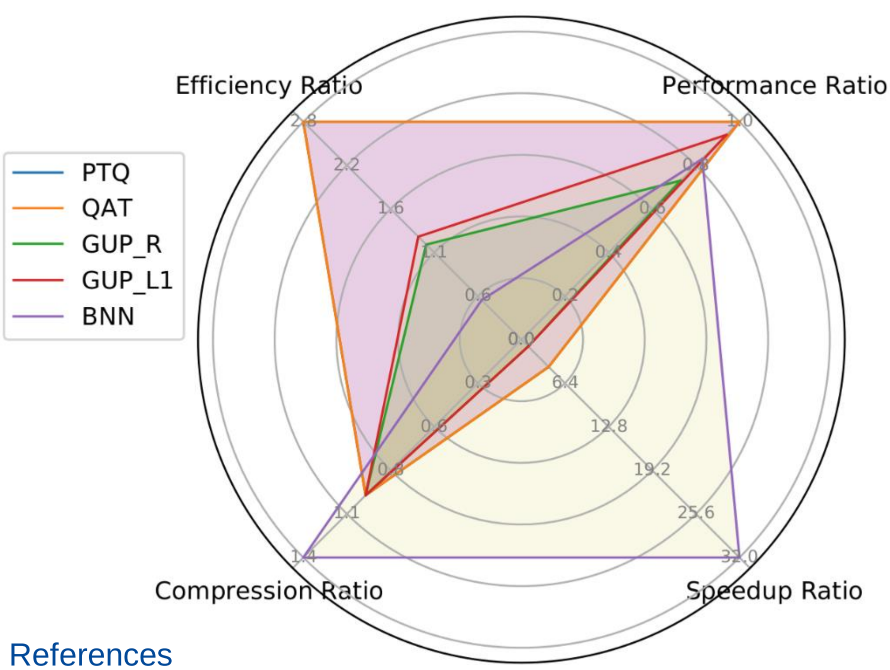
1) Select the set of metrics to be used in the evaluation between compression techniques. For this the authors provided a review of metrics and contributed some additional metrics that were necessary to fill existing gaps in evaluation. These reviewed metrics are shown in the figure on the following page.
2) Select the set of compression techniques to be evaluated.
3) Choose a set of appropriate benchmarks, these include model architecture, trained model parameters, evaluation dataset, data augmentations, the evaluation platform, operating system, and workloads running on the device.

4) The last step is visualisation, in which the authors recommend some methods to visualise the results from different compression techniques to analyse trade-offs.



Summary of evaluation metrics provided by [1]. The metrics are broken down into four categories targeting accuracy, size, speed, and energy. Using selected metrics, improvement ratios can be calculated using metrics from the combined measures.

As part of [1], Ghobrial *et al.* provided a library named NetZIP [2] that provides all the evaluation metrics that they reviewed which can be used for evaluating compression techniques using the methodology introduced in [1]. The figure below gives an example of an evaluation using NetZIP.



Left: A radar plot summarising the evaluation of a case study using the NetZIP library. The case study shows five different compression techniques applied to a ResNet18 neural network trained on ImageNet1k in PyTorch. The metrics used in calculating the improvement ratios are: Performance Ratio (mAP), Speedup Ratio (CHATS), Compression Ratio (CPU utilisation), Efficiency Ratio (Energy). Using the radar plot the trade-offs of the different compression techniques can be analysed. Three compression techniques stand out as the best candidates, depending on the application. If energy efficiency and performance are the priorities then PTQ or QAT are equally beneficial. If speed and computational utilisation take priority, then BNN would be selected.

References

[1] Abanoub Ghobrial, Dieter Balemans, Hamid Asgari, Phil Reiter and Kerstin Eder, “Evaluation Metrics for CNNs Compression,” arXiv preprint arXiv:2305.10616 (2023).

[2] Ghobrial, Abanoub. (2023). NetZIP by TSL-UOB [Computer software]. https://github.com/TSL-UOB/NetZIP

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