# MINT
## MEMRISTIVE NEUROMORPHICS FOR SMART INTERNET OF THINGS


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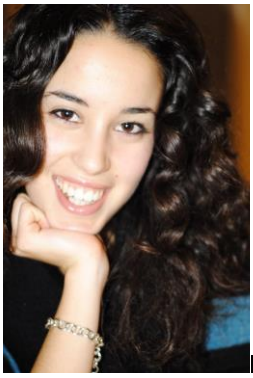
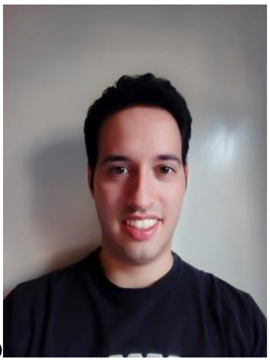
**Diletta Milana,** Computer Science and Engineering, Politecnico di Milano

**Luca Nanni,** Computer Science and Engineering, Politecnico di Milano

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# Project description

At present the analysis of massive amounts of data is generally performed in the cloud by remotely accessing large computing resources. Cloud computing is however plagued by security limitations, lack of flexibility and excessive costs. In addition, conventional digital hardware has inherent difficulties in processing unstructured and multimedia data (video, audio, etc.), which instead are straightforwardly recognized and elaborated by the human brain. Power consumption is also a huge concern for data processing, especially for Internet of Things (IoT) applications which rely on energy scavenging for distributed sensing. These problems may be addressed by embedded intelligence, such as low-power neuromorphic circuits, aimed at real-time screening and pre-processing of data before they are transmitted to the cloud. In the last years, one of the main innovations in the field of electronic circuits consisted in the discovery of the memristor. This device is able to store information through a variable resistance, which can be modulated by specific input voltages. The variability of the resistance state which allow this component to assume values in a continuum range is of great potential with respect to current transistor based digital memories simply characterized by only two resistance state. Due to this peculiarity, the memristors have the potential to increase considerably the circuit density and are great candidates to replace the transistor in the for the future of digital memories. Furthermore, the large range of possible resistance states makes the memristor a very plastic device. Thanks to this plasticity property it can be used for building pattern classifiers.

The MINT project aims at evaluate and compare the usage of the memristor technology with respect to more classical electronic devices in the context of pattern recognition problems. In particular, a specific case study has been analyzed: the detection and classification of Arrhythmia patterns from ECG data. The arrhythmia case has been selected since it is a widespread disease indeed about 14 million of people in USA, a prevalence of 5% are affected by it. Part of the project focused on the understanding of the current trends of the IoT health market and of the possible product concepts applicable to this kind of health problem. The team developed a business model specific for the selected case study and gathered data from the different stakeholders. A final assessment selected the best product concept on the basis of the user requirements and the feasibility study previously conducted on the memristive technology, which was conducted as follows.
First of all a model of a memristor-based pattern classifier has been developed. This model has been tested on the MIT-BIH dataset of labeled arrhythmia patterns. Its performances has been compared to the one obtained by using a different device, BrainCard, which is a pattern recognition board for IoT applications developed by General Vision. The result of the comparison led to the design of a device targeting the arrhythmia classification problem.

# Tasks and skills

In order to tackle the complexity of the project we decided to split the work between different subgroups.

The ***Laboratory and experiments group*** focused on the practical and experimental study of the memristive technology and other embedded solutions. The members of this group were **Luca Nanni** and **Gianluca Papa**.

The ***Business and market analysis group*** analyzed the IoT market and the selected application market in order to understand the main actors, their needs and extract the main requirements. The members of this group were **Paolo Ludovico Razzoli** and **Flavio Giobergia**.

Finally, the ***Theory and simulation group*** focused initially on the theoretical study of the memristor and on the machine learning and pattern recognition problems and later it designed a set of simulations in order to experiment the recognition capabilities of the memristive technology using a mathematical model. The members of this group were **Diletta Milana** and **Antonio Picano**.

Follows a more detailed description of the team members:

- **Flavio Giobergia** Computer Engineer specializing in data science. After getting an initial understanding of the memristive technology, Flavio tried to bridge the gap between the technical and the business sides of the project. Along with Paolo, he took care of the market analysis, concept definition and business model ideation.
- **Diletta Milana** Computer Scientist and Engineer specializing in Artificial Intelligence and Machine Learning, currently focusing on Deep Learning. Diletta analyzed the state of the art for arrhythmia detection and implemented the software simulations of the memristive network
- **Luca Nanni**: computer scientist and engineer with a specialization in artificial intelligence and machine learning. He worked at the implementation of the arrhythmia detection algorithm on the Braincard and at the laboratory analysis of the memristor.
- **Gianluca Papa** automation and control engineer specialized in modelling and control theory. He worked in the laboratory for the characterization of the memristive device and analyzed the current used algorithm for the arrhythmia detection.
- **Antonio Picano:** physics engineer specialized in condensed matter physics. He worked in the laboratory for the characterization of the memristive device together with Luca and Gianluca, and on simulations together with Diletta.
- **Paolo Ludovico Razzoli:** management engineer specialized in international economics. He worked on the business model side of the proposed application together with Flavio after a comprehensive research on IoT trends in healthcare.

# Abstract

This project focus on the evaluation of the memristive technology applied to a specific pattern recognition problem. In particular, we selected as pattern recognition problem the arrhythmia detection and we compared the memristive technology performance with the currently used one based on classical technology.

The memristor is a newly discovered electronic component that can be used for building complex neuromorphic chips for pattern recognition and anomaly detection. Memristor-based neural networks are low power when compared to other kinds of hardware networks. On top of that, they allow for on-the-spot processing of data, without relying on cloud computing. This makes them a perfect tool to be used inside embedded systems and in particular in the context of the Internet of Things. While this

technology is unlikely to replace – at least in the near future – clusters of computers dedicated to the recognition task, the limited power consumption of this hardware-only technology makes it an appetible candidate when the context imposes constraints on this regard. The identified solution to the arrhythmia detection problem makes use of this peculiar feature of the memristors.

The project has been aimed at analyzing the feasibility of the application of this technology for neuromorphic purposes, highlighting strengths and weaknesses of such an approach when compared to other existing technologies.

# Understanding the problem

The *memristor* is the fourth fundamental circuit element, after the *resistor,* the *capacitor* and the *inductor.* Its peculiarity is that it has a resistance that depends upon an internal state and, in particular, on how much electric charge has flowed in what direction through it in the past: the device remembers its history. When the power supply is turned off, the memristor remembers its most recent resistance until it is switched on again. Because of this, it is suitable for the emulation of synapses: this is why it finds its natural application in *neuromorphic computing* (as well as in *non-volatile memory* applications). Additionally, memristors are characterized by a low power consumption: this is ideal for cases where devices collect large amounts of data and need to process them, as is the case with the Internet of Things.

The ever-growing data generated by IoT devices needs to be processed in order to extract meaningful value: doing so locally significantly cuts delays, power consumption and data transferred. This is of particular importance in the wearable sector, where devices are required to have a long battery life and cannot be always connected.

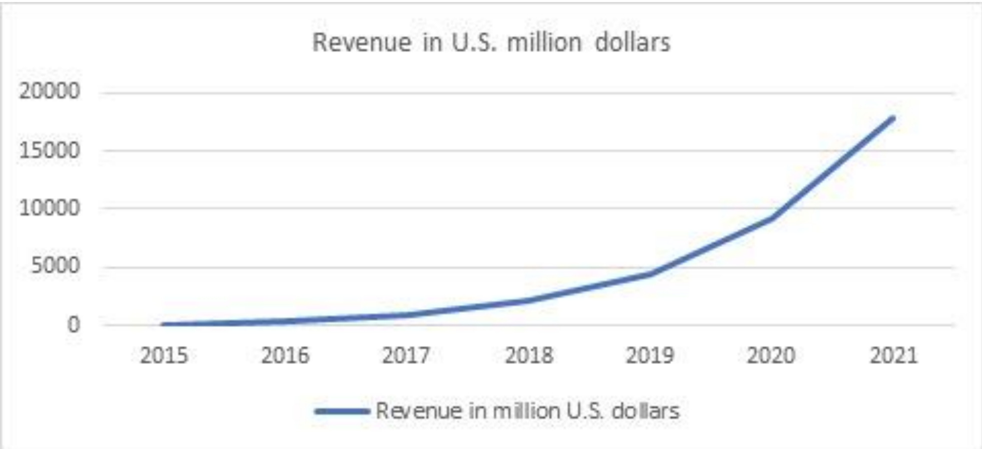


***Figure 1*** *Expected revenue of the wearable market in the next years*

The wearable market has experienced a huge growth in recent years, and is expected to do so exponentially in the years to come. One of the most important applications of this technology can be found in the health sector: vital parameters can now be tracked 24/7 with small, non-invasive devices. While today's technology already provides satisfactory results, the final consumers are unhappy with some of the problems imposed by the technological limits – first and foremost the short battery life available. Despite that, the state of the art is being redefined by new, more advanced technologies such as the memristive one. This, as explained, will allow for smaller, more performant devices.

# Exploring the opportunities

After conducting the research on memristor technology and the market of health devices in the context of IoT technology we have deeply explored the universe of health monitoring devices. This enabled us to understand what is currently available and the state of the art of detection technologies in the field of arrhythmia and what will be their future development. The result of our analysis pointed out that, the future generation of healthcare wearable devices will be characterized by very general devices able to capture and autonomously elaborate significant wide range of data without the need of any human input. This trends towards the autonomous functioning will be mainly based on the newest developed neural network based arrhythmia detection algorithm. This new approach leverages the autonomous extraction of relevant features from the data and it has been proven to be significantly more accurate than the hand-crafted feature extraction methods. What is required for this algorithm to work is a specific hardware architecture.

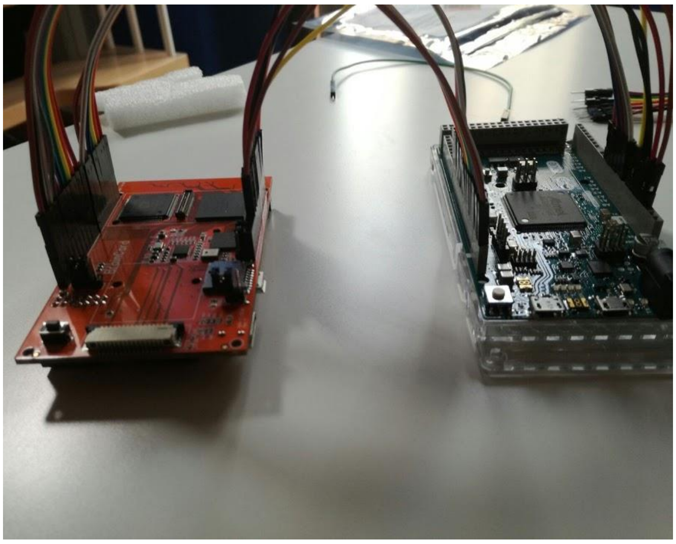

***Figure 2*** *Setup of the BrainCard experiments using an Arduino board as controller*

In order to identify the best architecture, we have compared two different technologies; the memristor based and the best option available on the market. For what concerns the memristor, we have defined a model that allowed us to exploit its strengths and weaknesses in terms of performance, size and consumption. For what concerns the C-MOS based architecture, we have not only realized and analyzed a software model but also work with a real physical device. To do that we got in touch with the General Vision a Californian company specialized in neuromorphic devices. This provided us with its most advanced pattern recognition chip called BrainCard.

The main components of the Braincard are the FPGA and the CM1K chip. The CM1K is a fully parallel silicon neural network composed by 1024 neurons which can store and process information simultaneously. The neurons can be trained either in real time or offline by providing them with learning examples without the need of any programming code. Indeed, it is enough to provide the Neuromem chip with a high quality labelled training data and it will do the rest.

# Generating a solution

The first step for testing these two technologies consisted in the definition of a common training set. This was retrieved from the MIT-BIH Arrhythmia Database. The MIT dataset is composed by ECG signals. Each ECG signal has been labelled by cardiologists depending on the kind of arrhythmia it showed.

As far as the Braincard is concerned, we needed to establish a communication channel. This, has been accomplished thanks to Arduino, controlled using a specific Python library. Once established, the communication has been used to pass the preprocessed data directly to the embedded system which, after training, was able to extract the features useful for the arrhythmia detection.

The memristive technology has only been tested via simulation. Specifically, we implemented a simple memristive-based neural network (NN), a MultiLayer Perceptron (MLP) using Tensorflow. The behavior of the single memristor inside the NN model was designed to be as close to the one observed and reported during the laboratory experiment as possible.

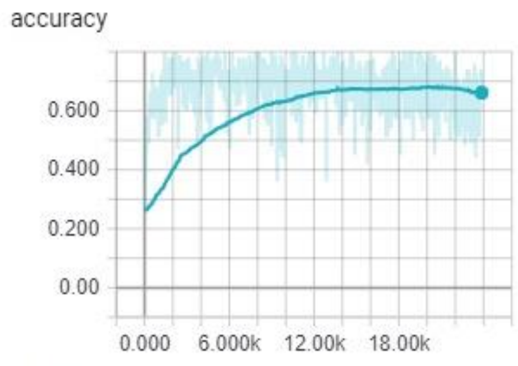


*__Figure 3__ Accuracy as a function of the training iterations for the memristive network simulation using TensorFlow*

After the training and testing phases the performance of the two devices have been compared. The results showed that the Braincard performs better when compared to the memristive-based model, which showed promising nonetheless.


*__Figure 4__ Confusion matrix of the arrhythmia classification problem using BrainCard*

Furthermore, the two systems have been compared both in terms of power consumption and size. For the Braincard, these two pieces of information have been retrieved from the available datasheet. As for the memristive chip, the values have been obtained by considering both the size of the neural network and the average resistance values measured during the testing. The results showed that the memristive chip size is 100 times smaller than the Braincard, while the power consumption is reduced by a factor of ten. Overall, the reduced size of the chip and the overall power consumption resulting from the testing simulation balance the comparison with Braincard.

Given this superiority of the memristor when compared to other CMOS-based technologies, and given the promising results on the arrhythmia dataset, the next logical step is that of building a concept for a suitable device. In particular, the low power consumption and the chance of locally processing the data were found to be particularly suitable for a wearable device, and further design-centered considerations lead to the definition of a bracelet as the ideal product. Leveraging the information collected from potential customers, different features and characteristics have been further refined.

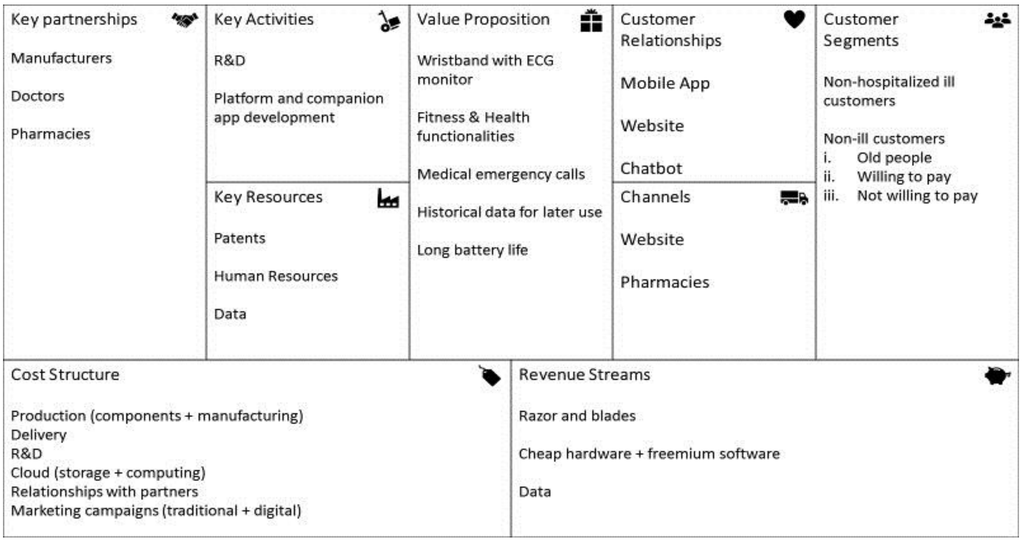


***Figure 5*** *Business model generated after the requirement analysis of the arrhythmia detection case study*

The business model for this product has then been laid out, with the bracelet as the core product. Considering that, based on the data collected and differently from what was previously thought, most potential customers embrace the idea of a cloud-aided service, additional Internet-enabled functionalities have been taken into account as a side, optional offering. While the basic arrhythmia detection feature of the bracelet has been thought as being able to work completely offline, the entirety of the collected data can be optionally stored and processed, thus offering an added value (e.g. evolution of the condition through time, or historical health information for future check-ups) for those customers interested.

# Main Bibliographic References


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# TAGS

Memristive technology,
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General Vision,
CNR