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EDUARDO DE MÔNACO MAGALHÃES

PiezoPioggia: Energy Harvesting with Raindrops

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Research report presented to the scientific apprenticeship program "Cientista Aprendiz" (Apprentice Scientist), from Colégio Dante Alighieri, to conclude the school year.

Area of research: Electrical Engineering

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Abstract

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This project wishes to study and analyze the possibility of generating clean and accessible energy with the plain impact of droplets in the ground. Therefore, it was necessary to use piezoelectric devices in order to convert the kinetic energy of each droplet into electric energy throughout piezoelectric energy harvesting processes, (PEH). Piezoelectricity is a method of clean and sustainable energy generation, developed and explored by several scientists worldwide. Thus, while studying the proprieties of those devices, the project evaluates the present situation of electricity harvesting in Brazil, the benefits of piezoelectric technology and the possibilities it presents to economy and society.
Throughout the development the project builds itself upon mathematical equations and experimental results, analyzing the deformation and generated tensions of piezos. Brand new data on the behavior of rain, as well as about the potential it presents for PEH are highlighted throughout the research, reinforcing the value of such process as a sustainable energy generation method alongside with its investment potential, both from governmental and private institutions. The project also deeply characterizes the piezoelectric device studied, diving deeply in its characteristics and evaluating the deformation of the device and treating the data sets with statistical analysis methods, in order to improve the precision of the data presented. All in all, the opportunities of piezoelectric energy harvesting in the rain, *nella pioggia*, shall be discussed profoundly throughout the project.

Keywords: Piezoelectricity, Rainfall, Energy Harvesting

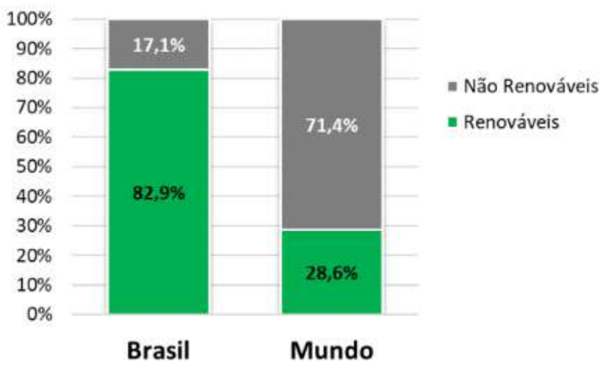
Contents

1 Introduction

Nowadays, financial and energetic efficiency matters are becoming more and more important, and, therefore, methods for their implementation and the means that directly make such implementation possible are much needed (ARHUN *et al.*, 2019). And, as it is necessary to promote mechanisms for raising capacity for effective climate change-related planning and management (SDG 13.b), substantially increasing the share of renewable energy in the global energy mix (SDG 7.2) is essential (OSBORN; CUTTER; ULLAH, 2015).

Viewing these topics from the Brazilian scene, the Latin American nation is a pioneer in sustainable energy harvesting. By 2020, 82.9% percent of all the electricity generated nationwide came from renewable sources, 60 percentage points above the relatively low international average. However, in the international average, only 28,6% of the generated electricity comes from renewable sources, much less than the Brazilian values. (EPE, 2022).

Figure 1 – Brazilian electric mix vs. world average.



Source: Elaborated by ⟨https://dante.pro/epeenergymix⟩.

However, non renewable energy harvesting techniques are still responsible, in the Brazilian energy mix as whole, for around 203,7106 toe. This is 70,8106 toe more than renewable energy sources (toe: tonne of oil equivalent - measurement energy used by the Brazilian government for the national energy mix). Nevertheless, it is important to state that the energy mix covers each and every energy use, including automobiles, stoves, ovens, heating systems, etc. Yet, analyzing the Brazilian energy mix, it is possible to see recently, since 2017, a large growth in the tonnes of oil equivalent produced by non renewable sources, reaching the largest gap from renewable energy in the last 20 years.

Aware of this situation, the Brazilian government is launching several campaigns. Among them, "Brazil World Leader of Energy Transition - Giant by thine own Nature", was established by the Ministry of Mines and Energy in 2024. The campaign focus on the

"Fuel of the Future", the development of new bio-fuels in order to retire fossil fuels in the country.

This initiative is an example of the policies Brazil is adopting, covering financial aids, actions and partnerships in order to bring countless investment opportunities to Brazil, creating new jobs, bringing income, economical growth and sustainability (ENERGIA, 2024). It is possible to see, as a consequence, that the government is open to invest in clean energy harvesting technologies.

Figure 2 – Energy production from the Brazilian energy mix 2001-2022.

Source: Elaborated by ⟨https://dante.pro/figure2/⟩.

Figure 3 – Energy Transition campaign logo.

Source: Elaborated by ⟨https://dante.pro/campaign⟩.

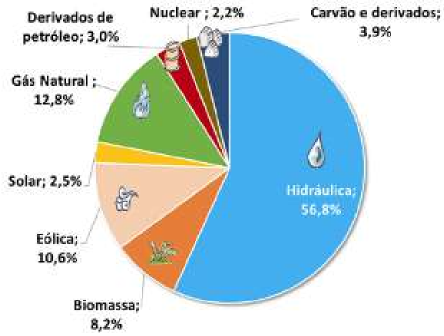
Even though most of the national electric mix is generated from renewable sources, this value should (and must) grow in order to achieve the goals UN's 2030 Agenda set, mainly SDGs 7 and 13. Therefore, it is necessary to explore every renewable natural resource to ensure access to affordable, reliable, sustainable and modern energy for all (OSBORN; CUTTER; ULLAH, 2015).

All in all, it is possible to notice several gaps and improvement areas in the energy harvesting sector in order to accomplish the United Nations Sustainable Development Goals. It is imperative, thus, to fulfill those hiatus and provide sustainably those 20% of the mix the sooner the better, in order to adequately fight the climate emergency.

Per consequence, the scientific field has been searching for several solutions for energy generation issues, converting and harvesting it in a more sustainable and economical way. Some researches proposed the use of kinetic energy harvesting devices throughout the application of piezoelectric crystals (ARHUN *et al.*, 2019). This method, using piezoelectric devices, might be very helpful on solving the energetic issues of Brazil. Nowadays, there are already several projects work on the possibility of floors and pavements covered with piezo ceramics/crystals for clean energy harvesting, using the kinetic energy of people walking/dancing, for instance. However, the number of projects which dive onto the possibility of piezoelectric energy harvesting without steps or vibrating motors is significantly smaller.

According to Ilyas and Swingler (2015), the Piezoelectric Energy Harvesting (PEH) techniques might be used to capture movement, vibration and acoustic resonance, converting it into electric energy. Thus, following Ilyas and Swingler (2015) line of thought aforementioned, it is possible to harvest energy from the impact of droplets in a PEH system replicating experimentally the rain and developing a rainfall model for simulation.

Figure 4 – Detailed view on the Brazilian electric mix.



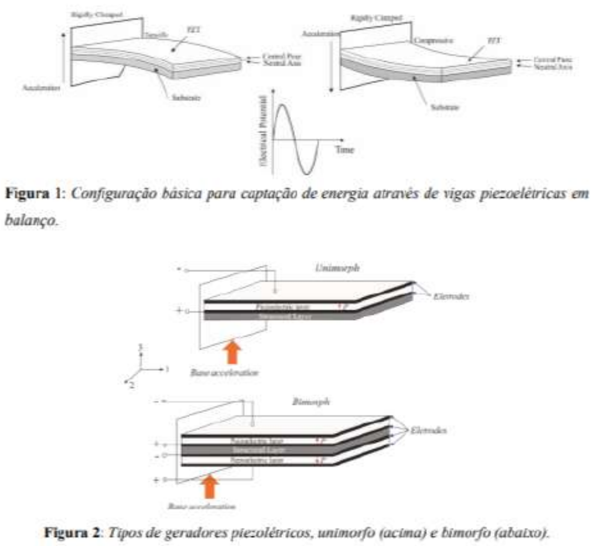
Source: Elaborated by ⟨https://dante.pro/epeenergymix⟩.

Piezoelectric materials are those who possess the homonymous property that allows them to generate energy from pressure. Piezos are capable of transforming a physically applied pressure "x" into an electric tension peak "y".

Therefore, they are used in countless circumstances that require a higher precision on detecting or describing a vibration or pressure. Thus, there is a niche yet to be scientifically explored, since there are not many studies, especially with deeper research and prototyping, that analyze energy generation with piezoelectric materials and the kinetic energy of rain.

Nowadays, science works with natural piezoelectric materials and artificial ones, such as piezoceramics and piezopolymers, laboratorially developed during the 1950s. As previously mentioned, PEH techniques have been bringing attention to itself

Figure 5 – Observations on the piezo by Perlingeiro, Pimenta and Silva (2016).



Source: Elaborated by Perlingeiro, Pimenta and Silva (2016) as new, non-pollutant way of energy harvesting (PERLINGEIRO; PIMENTA; SILVA, 2016). As the figures show, when the piezo is left like a cantilever structure, a concept to be discussed further on, its deformation capacity is increased, polarizing the crystal.

The piezo used throughout the development of this project, represented on Fig. 6, is different from the commercially accessible piezo. It is, therefore, a laboratorial device.

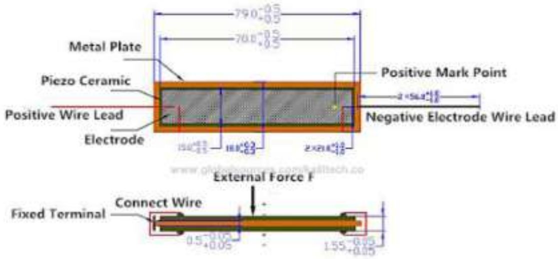
Nevertheless, similar devices are available online in retail, specially in business to business sales. One of those devices are being sold by Hong Kong-based *GlobalSources*. This product is similar to the one used in the tests.

Figure 6 – Piezoelectric device used in the experiment.

Source: Personal collection.

Rain, on the other hand, offers countless possibilities of exploring its renewable energy harvesting potential.

Figure 7 – Piezoelectric device avaiable at *GlobalSources*.



Source: *GlobalSources* - https://dante.pro/globalsources

Brazil, a South American tropical nation, is, mostly, inserted in the Tropics, or Torrid Zone, with a predominant Equatorial climate and large volumes of rains, frequent throughout almost all the national territory. Those characteristics are more notable when analyzing the North Region of Brazil, as the following graphic, from the Amazon rain forest-inserted city of *Manaus*, shows. *Manaus* is the state capital of *Amazonas* (*AM*), one of the largest Brazilian states by area. The state is almost fully inside in the rain forest, from where its name is inherited. As a wet and humid jungle, the Amazon was chosen to exemplify the potential rain can offer, and the *Manauara* metropolis shows exactly how tropical Brazil can be.

Observing *Manaus* as an example, it is possible to notice more than 100 mm of rain for three quarters of the year. All this rainfall, frequent and sometimes interrupted, already supplies the hydroelectric plant of *Balbina*, in the *Uatumã* river, and several others in the Amazon river region.

Yet, due to the challenges of building wiring and electric harvesting facilities in the middle of the dense Amazon Rain forest, there are little to no alternative renewable energy sources throughout the aforementioned North Region. The climate is not helpful neither for establishing solar energy, due to the mist, fog, steam and high trees, nor for wind power turbines, due to the weak multi directional winds. Those environmental factors, added to the constant rains, are visible in a great part of the Brazilian territory, except for certain dry regions, such as parts of the *Cerrado* plains and savannas, or the semi-arid *Caatinga*. Yet, even southern states, such as *São Paulo*, deal with heavy and frequent rains. Thus, with an special attention the Amazonian region, the use of energy harvesting systems related to Brazilian high pluviometric rates is largely beneficial. The Brazilian Federal Government understands that bringing investments for renewable energy generation and harvesting, increasing their participation in the national energy mix as a primary part of its environmental agenda.

Figure 8 – Climograph of *Manaus*, AM, Brazil.

Source: Elaborated by ⟨https://dante.pro/climatogramme⟩.

Therefore, there is not a better moment to work on renewable energy harvesting in Brazil. Financially speaking, the Brazilian government is open to invest in projects and offer several tax benefits for those who plan to work on clean energy, from micro generators to industrial scale. (SILVA, 2023). In addition, foreign investment in renewable energy is growing exponentially as well, as countless initiatives throughout the globe rise in favor of the sustainable energy goals of the 2030 Agenda. The need for new renewable alternative energy sources is something constantly under the spotlights of the international community as a whole, facing the new politics, at national and international level, willing to protect the environment.

All in all, it is possible to see that the best exploration of climate factors allows mankind to work for a prosperous future. Brazil generates around 2.5% of its energy from solar harvesting (EPE, 2022). Rain, however, only has its energetic potential explored to fill the reservoirs of the national network of Hydroelectric Plants. And, in this constant search for ways to suppress the national energetic demand, would the truthful potential of rain being left behind? Isn't there anything else yet to be done with water and its energy? This project works on answering those questions.

2 Defining the Problem and Presenting its Solution

2.1 Defining the Problem

Considering all of this, this project seeks to solve the following problem: Is it possible to harvest electricity throughout the piezoelectric kinetic-electric conversion with good cost benefit?

2.2 Solving the Problem

Analyzing the capability of exploring the kinetic energy of rain, a great range of options inside the world of piezoelectric opens up. As a material, the piezo offers countless possibilities of study and exploration, usually forgotten. Piezoelectric devices are easy-to-access in the market, constantly available in retail. Yet, it is important to state that the piezos used during the development of this project are different from the commercially accessible ones, due to its scientific and laboratory purposes. Therefore, this equipment shall be introduced and characterized later on. Nevertheless, the piezoelectric properties do not alter.

In addition, countless projects willing to harvest energy from the rain, through different machinery such as the TENG, or triboelectric nanogenerators, recently developed (LI *et al.*, 2023). The TENGs were introduced to the scientific world in 2012, by Zhong Ling Wang, and explored in several researches conducted by him and colleagues, such as Wang (2020). The nanogenerators are new and potential-full renewable energy harvesting methods and, maybe, would be the natural choice for this project, such as it was for Li *et al.* (2023) and other projects. However, the major issue with the use of TENGs in this project is its availability. One of the main ideas in this project is to develop a financially accessible way to harvest energy, and TENGs are still restricted to the scientific field. Therefore, the use of TENGs would, sadly, go against the principle of accessibility, nullifying the cost benefit as well. Other projects researched the use o piezoelectric materials in floors, willing to generate electricity from converting the steps (ARHUN *et al.*, 2019). It is rare, however, to find projects working on the hypothesis of joining the rain impact from Chinese-led studies and the universally explored piezoelectric properties.

Working on the hypothesis that it will be possible to efficiently harvest electricity with the piezos and the raindrops, the benefits would be enormous. From the environmental approach, it would be the development of a new, non pollutant and renewable source, capable of complementing the Brazilian and the international electricity generation mix. Economically speaking, a new alternative source would receive investments not only from Federal initiatives, but also from the private entrepreneurship, opening the path to establish this new technology as an individual-level harvesting system that the common citizen can have at his home. In the current wave of environmentally conscious *Eco Friendly* research, the projects who receive the spotlights of science and engineering are those of alternate energy harvesting sources, such as this one.

All in all, the issues of this methods orbit around two **main** topics:

1. Will the raindrops offer enough kinetic energy to trigger the piezoelectric properties?
2. Will the cost-benefit of the operation be viable for retail?

The answers to those primary questions will be developed in the experimental phase.

3 Methodology

This research follows, when analyzing its approach, a quantitative methodology, providing measurements and modeling of the phenomena observed at each stage of the research. As for its nature, it is applied research, as it seeks to generate knowledge for practical application, in resolving specific issues. Given its experimental nature, this research aims to explain the factors that generate a certain phenomenon (GERHARDT; SILVEIRA, 2009).

The methodology, when observing the procedures, will be divided in phases described below:

1st Phase - Study of mathematical models to predict the kinetic energy of a raindrop, analyzing the characteristics of the piezo;

2nd Phase - Schematics and circuit design

3rd Phase - Prototype development

4th Phase - Take note and analyze the results

3.1 Methodology for statistical and data analysis

In order to correctly analyze the data collected throughout the experimental phases 2, 3 and 4, statistical processes will be conducted, offering more precision and trustfulness to the data sets. As a consequence, the equations and methods offered by Lee, In and Lee (2015) shall be used as the basis of this methodology.

Therefore, the first step to be taken is to calculate the mean, which shall be represented by

$$\mu = \sum_{i=1}^{n} \frac{\alpha_i}{n} \quad , \tag{1}$$

considering that,

$$\sum_{i=1}^{n} x_i = x_1 + x_2 + x_3 + ... + x_n \quad . \tag{2}$$

In those equations μ stands for the mean, which is the result of the summation $\sum_{n}^{i=1} x_i$, Eq. (2), divided by n, the number of terms involved in the summation.

After calculating the mean/average, it is important to observe that, in a data set, the average is a plain simplification of the real scenario. Therefore, in the need for precision, analyzing the dispersion rate of each data and parameter of the function is primary. Per consequence, it will be necessary to evaluate the standard deviation of data. Such information can be determined by the following equation:

$$\sigma = \sqrt{\sum_{i=1}^{n} \frac{(\alpha_i - \mu)^2}{n}} \ , \tag{3}$$

where the standard deviation, (σ), is determined by the square root of the square difference of the mean, Eq. (1), from the data set values (α) times the summation, Eq. (2), divided by the number of data points (n) (LEE; IN; LEE, 2015).

Alongside calculating the deviation and variance of the data, it is important to consider the error taxes in each data. Therefore, propagating the error is primary. In order to do so, it is necessary to assume that

$$\sigma_x = \sqrt{\frac{1}{N^2} \sum_{i=1}^{n} \sigma_i^2} \ , \tag{4}$$

considering that,

$$\sum_{i=1}^{n} = x_1^2 + x_2^2 + x_3^2 + ... + x_i^2 \ , \tag{5}$$

where σ_i is the error associated to the i measure, $\sum_{i=1}^{n} \sigma_i^2$ is the sum of the square of the errors, Eq. (5), and N^2 is the square number of samples in the data set (TAYLOR, 1980).

In addition, the use of regression in the analysis of the data set is another valuable technique to be considered by the project. Regression is the process that allows to transform dispersed points in a graphic into an uniform function. The most known type of regression is linear regression, expressed by

$$I = \alpha + \beta + \epsilon \ , \tag{6}$$

where α is a constant, β is the variation of a certain measure throughout time, ϵ is the action of external factors, an error tax (SYKES, 1993).

However, it is more interesting for the project to study a non-linear regression form, considering that it is necessary to deal with the wave-like movement of the piezoelectric device, rather than a linear or constant growth. Therefore, the function used in the analysis of the deformation was,

$$F(x) = Ae^{Et} \sin(Bt + C) + D \ , \tag{7}$$

where A is the initial amplitude of the wave, E is the dumping rate of the wave, t is time, B is the angular velocity of the wave, C is the wave phase and D is an independent term (DOUGLAS; WOLFGANG; ROBERT, 2017).

4 First phase - Preliminary mathematics

In the literature, it is possible to notice countless projects exploring the wonderful world of rainfall and its possibilities, including those related to electricity. Countless equations are presented, since older ones, which allow calculations on the Universal Soil Loss Equation (USLE) (WISCHMEIER; SMITH, 1978), to the modern complete data, developed throughout the last fifty years from the legacy of such primary algebraic discoveries such as the USLE. Among those newer researches, a mathematical model created to predict and calculate the raindrop speed in order to develop a rainfall simulator stands out. This model, developed by Boxel *et al.* (1997) introduces the following equation for the terminal velocity of rain, in m/s,

$$V_t = \frac{\rho_w g d^2}{18\mu} \ , \tag{8}$$

where V_t is the terminal velocity of the raindrop in m/s, ρ_w is the density of water ($1 \times 10^3 kg/m^3$), g is the gravitational acceleration ($9.8 m/s^2$), d is the diameter of the droplet (in this case, $d = 7 \times 10^{-4} m$) and μ is the dynamic viscosity of air ($1.8 \times 10^{-5} N \cdot s/m^2, or\, 1.8 \times 10^{-5} P \cdot s$).

Following Eq. (8), all the values were based on an average sized droplet, of around $0.7mm$ of diameter and a mass of $5 \times 10^{-5} kg$ (BOXEL *et al.*, 1997). A dimensional analysis, dealing with the different units in the equation, assures that the terminal velocity shall be achieved in the International System (SI) unit for speed, meters per second (m/s). Therefore, when applying the droplet aforementioned in Eq. (8), it was possible to calculate its speed: $14.8 m/s$, or $53.8 km/h$. This value is the first proof of the pioneer approach of this project, as it opened the path to measuring the kinetic energy of a single droplet.

Using the widespread Kinetic Energy equation, Eq. (9),

$$E_c = \frac{mv^2}{2} \ , \tag{9}$$

it is possible to determine the energy of the impact of a droplet in the ground: $5.5 \times 10^{-3} J$. This value is new and unpredicted in the largely broadcasted scientific world. Van Boxel predicts that Eq.(8) might present an error to droplets larger than 0.1mm, due to other external factors such as turbulence (BOXEL *et al.*, 1997). Yet, even as an ideal model, the value achieved is a new landmark, and those distortions shall be analyzed further on.

However, it is fundamental to consider the high frequency of droplets falling per squared meter per second, increasing the possibilities of energy harvesting. Portilho (2009) shows that around 2×10^{-5} raindrops fall per m^2/h, or 5.5×10 droplets per m^2/s. Therefore, considering

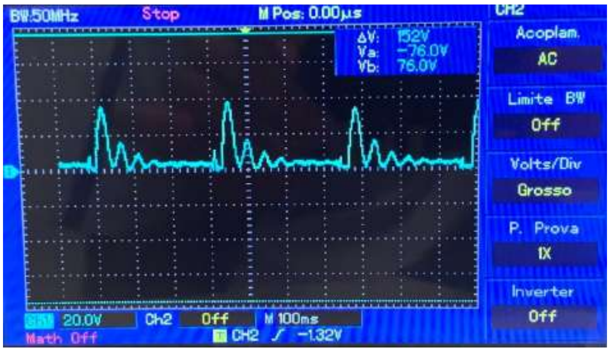
$$E_c t = n \cdot E_c \ , \tag{10}$$

where $E_c t$ is the total kinetic energy of the droplets in a certain period, n is the number of droplets falling in this period and E_c is the individual energy of each droplet, calculated in Eq. (9), it is possible to measure the impact of droplets, in a square meter during a second, which is up to $3.02 \times 10^{-1} J/m^2/s$, $3.02 \times 10^{-1} W/m^2$ or $302 mW$.

5 Partial Results

After the mathematical process, some tests on the characterization of the piezo were conducted. Initially, an early testing procedure led to the construction of a basic circuit, connecting the piezo to a LED and repeatedly touching the device, while the led lighted up with each touch. Later on, the piezo was welded to an oscilloscope and the tests were repeated, reaching tension peaks of up to 40 volts.

Figure 9 – Initial footage of the oscilloscope

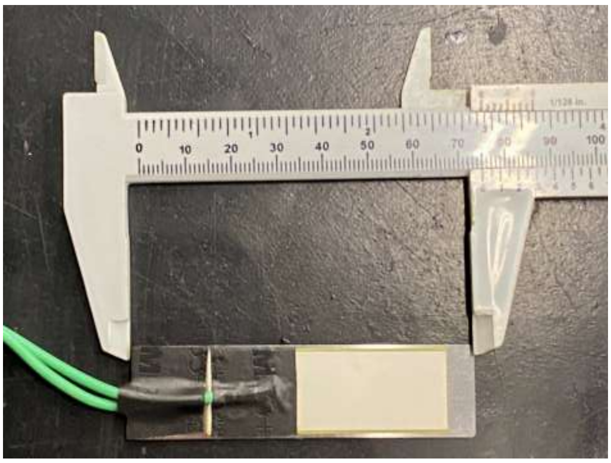


Source: Personal Collection

After those tests, it was easy to observe how inefficient it was to use welding methods with the wires and piezo. Throughout the experiments, the weld failed repeatedly, proving the necessity of new approaches to ensure a good connection. Therefore, different methods were studied in order to better connect the piezoelectric device to the circuit. After several tests, it was possible to see the benefits in the use of an electrical liquid tape, as well as standard electrical tape. The liquid electrical tape, commercially retailed in Brazil as *Fita Isolante Líquida*, is a product developed by *Permatex*. Its objective is to improve electric isolation within small areas where the use of standard tape is difficult.

The product is mostly sold by one brand in Brazil, *Quimatic Tapmatic*, a national subsidiary of the Swiss-American group *Tapmatic*. This system, using both the liquid and standard tape, offered excellent results when analyzed.

Figure 10 – Adapted piezoelectric device, with the liquid and standard tape



Source: Personal Collection

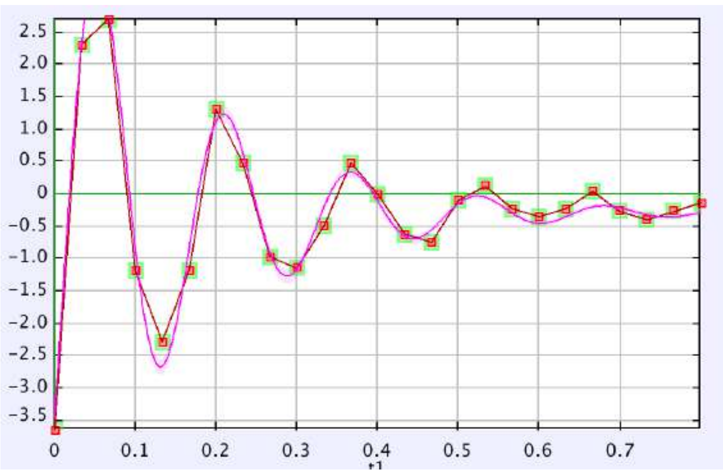
In order to be sure of such excellency, it was necessary to conduct more testing. Thus, the same procedures adopted earlier were repeated, connecting the device with the oscilloscope and lightly touching it. However, the results were much better than the welded system ones, registering peaks of up to 150 V. Using the liquid tape to "glue" the wires in the device and the standard tape to assure the system was thigh was a very positive solution, ensuring a larger energetic efficiency.

Later on, after this phase of early testing, the data collection process started. In order to do so, the piezos were left swinging on the edge of a desk, such as presented by Perlingeiro, Pimenta and Silva (2016). Then, they were lightly touched, and each swing was recorded by a cellphone's slow-motion camera.

All those video tapes recorded were uploaded and analyzed through a software called *Tracker* (https://physlets.org/tracker/). The *Tracker* system is a free-to-access software developed by a professor from the Cabrillo College that allows to mark points throughout a video and analyze them (DOUGLAS; WOLFGANG; ROBERT, 2017). With the measured deformation of the piezo, it is possible to evaluate a relation between deformation and generated tension. Therefore, throughout the aforementioned platform, it is possible to observe the real deformation of the piezo and table it.

Initially, of the 12 videos recorded, 9 were successfully analyzed. The *Tracker* system records the points marked in a spreadsheet and develop a graph from it. The graph from the point-marking process measures the movement, in centimeters, throughout time.

Figure 11 – Graph from the fourth test



Source: Personal Collection

From such graph, the system adjusts the parameters with Eq.(7), considering the position of each data in the different data sets. The results of such adjust are presented by the pink function. The use of these equations as the basis of the *Tracker* analysis allowed to evaluate the piezoelectric device's movement after each touch it received.

The Fig. 11 shows an expected behavior for the piezoelectric device, as suggested by Moreira and Grande (2021) and Perlingeiro, Pimenta and Silva (2016). Initially, the piezo is hit with a major deformation, result of the touch. As a consequence, it is possible to notice a major wave downwards of up to 3.5 cm, that leads to another significant movement of more than 2.5 cm above the standard position, all before 0.3 seconds. Afterwards, the vibration continued in the device, allowing other movements of 2.7 cm, 2.3 cm, 1.3 cm, 0.5 cm, etc until certain stabilization after 0.8 second, returning to the initial position.

Analyzing the results of the 9 successful testes provided by *Tracker*, a spreadsheet was developed to allow the calculation of the error process in each data set. Using the equations (1), (2) and (3), as presented in 3.1, it was possible to reach the following results for the five parameters of the function throughout the tests:

A = (4.77 ±0.13) cm

B = (4.30 ±0.02) Hz

C = (-4.77 ±0.15) - dimensionless

D = (-2.7 ±0.24) cm

E = (-5.63 ±0.22) Hz

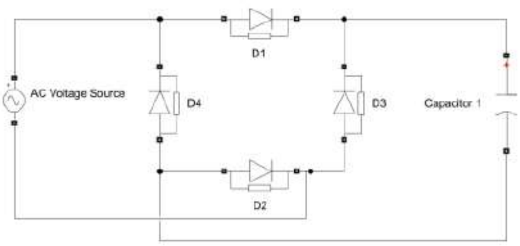
Those values are automatically established by *Tracker*, allowing the creation of the pink function in Fig. 11. The more precise the parameters are, the better Eq. (7) shall fit the real deformation.

This values shall be used in the future to allow the calculations and development of a function that relates the tension generated with the deformation of this piezo. However, while it is still not done, it is important to recognize the value of those results. It was possible to catalog the deformation of the piezoelectric device, characterizing it. The characterization is a valuable step, that shall allow the project to deal with more precise results throughout the next phases.

6 Second Phase - Schematics and circuit design

In order to factually start the prototype of this project, it is necessary to develop and design it, focusing specially on the circuit. The electric circuit must be one with rectifying capabilities. Therefore, it should be built as this one:

Figure 12 – Bridge rectifier

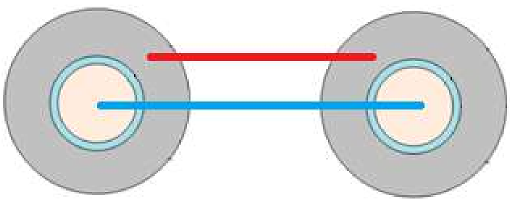


Source: Elaborated by Moreira and Grande (2021).

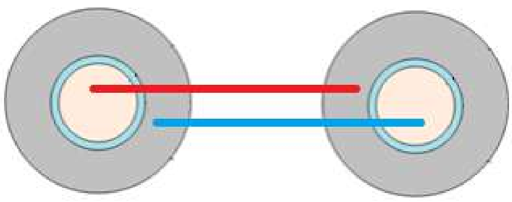
However, the circuit is not the only topic to be dealt with in this chapter. Physically dealing with the piezos is also a major issue, yet to be resolved. Therefore, initially, the project shall focus on the piezoelectric device and association methods, rather than the development of the circuit. In her research, Moreira and Grande (2021) dives into the electric conversion and association, elaborating and proposing different methods to physically deal with the piezoelectric devices.

A major point when debating such question is how to associate the different piezoelectric devices. Moreira and Grande (2021) points out that in order to increase energy harvested, it is valuable to associate the devices. Using a circular piezo as a model, her project divides between three types of association: in parallel, in series and mixed.

Figure 13 – Associations with a round-shaped piezo



(a) Piezo in parallel



(b) Piezo in series

Source: Elaborated by Moreira and Grande (2021).

Each association presents its own advantages and weaknesses. Therefore, it is important to analyze which positive aspects are more relevant to the specific goal of energy harvesting. All in all, the mixed association stands out as the most valuable one, considering that it increases both current and tension between the piezoelectric devices.

7 Final Considerations

As of this version, the project is not yet finished. Several steps still must be taken. It is necessary to relate the tensions data offered by the oscilloscope with the collected values for the deformation, in order to establish the complete function. It is primary, as well, to advance in the prototype design, developing the rectified electric circuit and associating the devices. Those fundamental steps will require more time to be developed, and, therefore, are indicated in 7.1.

Nevertheless, it is important to recognize how significant the achievements were. From the mathematical theory that allowed to calculate the groundbreaking $302mW$ of energy related to the impact of droplets in a square meter during a second to the experimental phases that characterized the piezo, this project has gone far.

At last, the opportunities of piezo-electrically generating energy with rain shall not be neglected anymore. In the tropical and rainy nation of Brazil, generating electricity *nella pioggia* is a major step for the sustainable development of the country.

7.1 Project Development Schedule

Development/Schedule	January	February	March	April	May	June
Rectified circuit	X	X	-	-	-	-
Piezoelectric association	-	X	X	-	-	-
Prototype dry testing	-	-	-	X	X	-
Prototype wet testing	-	-	-	-	X	X
Final results evaluation	-	-	-	-	-	X

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1. In addition to describing the engineering process of this research work, it would be good (also required) to present the innovation of this work. A comparison of the proposed system with existing state-of-the-art methods should be provided in the introduction so the advances, contributions, and novelty of the approach can be identified.
2. Piezo devices typically generate high voltage and low current outputs. Authors are advised to carefully consider the practical applications and implications of such power characteristics in real-world scenarios.
3. A block diagram of the system is recommended.
4. Please analyze the coverage of the GSM.
5. Please try to quantify the performance of accident detection, location capture, and alert transmission.
6. The research results include mathematics modeling (Phase I) and partial mechatronics setup (phase II); further experimental results related to energy harvesting using raindrops to the overall storyline would be good.