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Comparaison of solar cell photocurrent by solar tracker using an Arduino card and the machine learning algorithm

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ABSTRACT

The purpose of this study is to analyze the realization of a solar tracker based on the Arduino card, and on the other hand, to discuss the prediction of future solar cell photo-current generated by the machine learning algorithm. Firstly, the system creats the photocurrent I_{ph} based on programming in Arduino software the movement of the solar panel at predefined time intervals (between sunrise and sunset) in accordance with the path of the sun during the day, so as to keep the active surface of the panel perpendicular to the solar radiation. Finally, we discuss the prediction of solar cell photo-current generated by the machine learning algorithm. The result shows that the random forest algorithm is more accurate compared to the K-Nearest Neighbors, decision tree algorithms based on the RMSE statistical indicator.

Keywords: ***Arduino card, Solar tracker, Photovoltaic cell, Servomotor, Solar energy, Artificial intelligence.***

I. Introduction

Global demand for renewable energy sources and energy consumption, particularly in developing nations, have continuously increased. The exploitation of renewable energies has developed considerably in the world in recent decades [1].
Photovoltaic (PV) energy systems are always a necessary topic and the capacity and development of renewable energy technologies has also increased due to significant cost reduction and has reached parity in some markets. PV modules work with the direct conversion of light to electrical energy. Sunlight is a necessary and effective ingredient. They work with maximum efficiency when incident light is perpendicular to their cells. Therefore, the energy efficiency of these systems depends on the degree of use and conversion of solar radiation [2,3]. There are two ways to maximize the rate of useful energy: by optimizing the conversion and degree of absorption, and increasing the incident radiation rate by employing mechanical steering systems. These systems called solar trackers or trackers solar. Solar trackers are designed and built to optimize the power efficiency of PV modules by ensuring that they are tilted towards the sun at all times during the day. Multi-system solar trackers have been used for a wide application including: photovoltaic solar cells, solar concentrators and telescopes [4].
In this work, we present a general information on an artificial intelligence, its history, its applications, and trends, as well as its advantages and disadvantages. Then, we describe the photovoltaic systems, semiconductors, the *p-n* junction, and solar cells; the photovoltaic effect and their operating principles; the different types of cells and their electrical characteristics.
Finally, and as an application of artificial intelligence on photovoltaic cells is devoted to the design and construction of a solar tracker based on the Arduino UNO card and the connection of the components with the Arduino program.

II. Artificial Intelligence

The word intelligence is derived from the Latin intelligenta, which in turn comes from the word inteligere. This term is composed of other terms: intus ("between") and legere ("to choose"). Artificial intelligence (AI) is the term used to describe systems or machines that imitate human intelligence in order to perform functions and can develop as a result of obtained data through iteration. Artificial intelligence is less about a specific format or purpose and more about the method and capacity to think deeply and evaluate facts. Although the idea of high-performance, human-like robots taking over the world is associated with AI, this is not the intention of this technology. It seeks to greatly enhance human potential and contributions. The AI is, then, artificial. It can arouse dread, because in our representations, it induces the loss of control of the human in favor of the machine. Additionally, robots employing AI become totally independent thanks to the various degrees of machine learning, including those established by Yann Le Cun, who won the Turing Prize in 2019. These levels include supervised, unsupervised, deep, and reinforcement learning [5].

In deep learning – deep learning – human intervention is becoming rarer to the point that the machine is gaining independence. Hence the maddening vision of a world entirely under the control of machines and where the human would become only an object. AI has become a catch-all term for applications that perform complex tasks that previously required human intervention, such as communicating with customers online or playing chess. The term is often used interchangeably with the areas that make up AI such as machine learning and deep learning. There are, however, differences. For example, machine learning focuses on creating systems that learn or improve their performance based on the data they process. It is important to note that while all of machine learning relies on AI, AI is not limited to machine learning.

The central principle of AI is to replicate, and then surpass, the perception and reactions of human beings in the real world. This approach quickly becomes the cornerstone of innovation. Using various forms of machine learning that identify patterns in data to generate predictions. Artificial intelligence attempts to reproduce human cognitive processes in order to perform "intelligent" actions. It is like "the construction of computer programs that engage in tasks that are currently done more satisfactorily by human beings because they require high-level mental processes such as perceptual learning, organization memory and critical reasoning.

A. *Machine learning*

Machine Learning or automatic learning is a scientific field, and more specifically a subcategory of artificial intelligence. It consists of letting algorithms discover "patterns", namely recurring patterns, in data sets. This data can be numbers, words, images, statistics…Machine learning can use any data that can be digitally stored as input. Algorithms discover patterns in this data, which helps them learn and get better at a particular activity. In summary, machine learning algorithms automatically learn to perform a task or make predictions from data and improve their performance over time. Once trained, the algorithm will be able to find patterns in new data [6].

B. *Deep Neural Network*

Artificial Neural Network is a hardware and / or software computer system whose operation is modeled on that of the neurons of the human brain. This is a variety of Deep Learning technology, which itself is part of the artificial intelligence subcategory of Machine Learning [5].

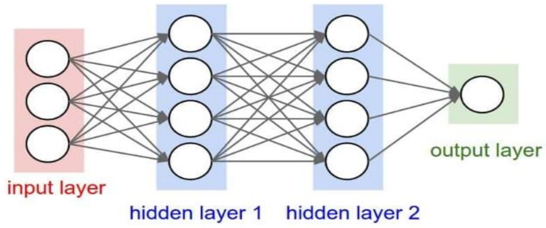

Figure 1. Artificial Neural Network function.

A neural network, as shown in figure 1, typically relies on numerous processors running in parallel and arranged into tiers. Similar to how human optic nerves analyze visual signals, the first third of the brain receives. Unprocessed information inputs. Subsequently, each third party receives the information outputs of the previous third party. The same process is found in humans, when neurons receive signals from neurons close to the optic nerve. The last third, on the other hand, produces the results of the system. Through an algorithm, the artificial neural network allows the computer to learn from new data. The computer with the neural network learns to perform a task by analyzing examples to practice.

a) *Decision tree*

The decision tree creates regression or classification models in the form of a tree structure. It decomposes a dataset into progressively smaller subsets while creating a decision tree in relation to each subset.The output result is a tree with leaf nodes and decision nodes [7].

b) *Random Forest*

Random forest is a supervised machine learning algorithm that is frequently employed in classification and regression problems. On various samples, it constructs decision trees and, in the case of regression, uses their majority vote for classification and average in case of regression. This is a general procedure that can be used to reduce variance for algorithms that have high variance, usually decision trees [8].

The basic steps in applying the random forest algorithm are as follows:

1. Pick N random nodes from the dataset.
2. Build a decision tree based on these N nodes.
3. Choose the number of trees you want in your algorithm and repeat steps 1 and 2.
4. In case of a regression problem, for a new node, each tree in the forest predicts a value for Y (output). The final value can be calculated by taking the average of all the values predicted by all the trees in forest.

C. *K-Nearest Neighbors Regression*

The K-Nearest Neighbors (K-NN) algorithm is a supervised learning method. It can be used for both classification and regression. Calculating the average of the K nearest neighbors' numerical target is an easy way to implement K-NN regression. An alternative method makes use of the K nearest neighbors' inverse distance-weighted average. The same distance functions are used in KNN regression as in KNN classification [9].

Euclidean:

$$\sqrt{\sum_{i=1}^{k}(x_i - y_i)^2} \quad (1)$$

Manhattan:

$$\sum_{i=1}^{k}|x_i - y_i| \quad (2)$$

Minkowski:

$$\left(\sum_{i=1}^{k}(|x_i - y_i|)^q\right)^{\frac{1}{q}} \quad (3)$$

III. PHOTOVOLAIC ENERGY

A. *Photovoltaic solar cell*

Photovoltaic energy comes from the direct transformation of part of the solar radiation into electrical energy. This energy conversion is carried out through a so-called photovoltaic cell based on a physical phenomenon called the photovoltaic effect, which consists of producing an electromotive force when the surface of this cell is exposed to light [10]. The photovoltaic cell is made of semiconductor materials, which are capable of transforming the energy provided by the sun into an electrical charge, therefore into electricity because the sunlight excites the electrons of these materials.

B. *Principle functioning of PV solar cell*

The photovoltaic effect used in solar cells permits directly converting the light energy of the sun's rays into electricity through the production and transport in a semiconductor material of positive and negative electric charges under the effect of light.

The solar cell is a large-area *p-n* junction photodiode that generates an electrical signal without the aid of an auxiliary power source. When the photons from the sun strike the cell, some are reflected and others are transmitted or absorbed in the solar cell. Only the absorbed photons participate in the photoelectric effect. Photovoltaic conversion involves three physical phenomena, intimately linked and simultaneous.
-The absorption of light in the material,
-The transfer of energy from photons to electrical charges,
- Collection of charges.

It is therefore clear that the materials constituting a solar cell must have specific optical and electrical properties to allow photovoltaic conversion. An electric field capable of dissociating the formed electron-hole pairs is required. The *p-n* junction is most often used for this. The incident photons generate electron-hole pairs in the N-and P-type regions and in the space charge region. Generated electron-hole pairs behave differently depending on the region:

- In the N and P zones, the minority carriers are diffuse. What reaches the space charge zone is propelled by the electric field towards the P zone (for the holes) and the N zone (for the electrons), where they will be in the majority. This transport of charge carriers generates a diffusion photocurrent.
- In the space charge region, the photo electron-hole pairs generated will be driven by the electric field towards the N region (electrons) and the P region (holes).
- This displacement of the carrier photo gives rise to a current photo. These two contributions together result in a total current I_{ph}. It is a stream of minority carriers. It is proportional to the light intensity [11].

C. *Description of system components*

In this section, we present the procedure for making our solar tracker based on the Arduino card. The electronic device includes a servo motor and an Arduino UNO microcontroller control circuit. To keep the solar panel's active surface perpendicular to the sun's rays, the orientation mechanism is based on programming the Arduino software to move the solar panel at predetermined time intervals (between sunrise and sunset) (zero incidence angle) [12].

a) Arduino board

Arduino is a platform for prototyping interactive objects for creative use consisting of an electronic card and a programming environment, this hardware and software environment allows the user to formulate his projects by direct experimentation with the many resources available online. Arduino projects can be autonomous, as they can communicate with other software installed on the computer such as Flash, Processing or MaxMPS, Matlab). These cards are made based on a simple input/output interface and a development environment close to the language.

b) Servo Motor

A servomotor is a system for rotating an object. It consists of the following elements: An electric motor, which provides input movement. A reducer, which slows down the speed of rotation and increases the "force" of the motor (we speak of torque). A spreader bar, on which we recover the movement of the servomotor. A potentiometer that determines the angle traveled by the rudder [13].

c) LDR Sensor

A photoresistor is an electronic component whose resistivity varies according to the amount of incident light. It can also be called a light-dependent resistor (LDR). The materials used in photoresistors are most often compounds from columns II-VI of the periodic table of elements. For use in the visible range and at low cost, cadmium sulphide (CdS) or cadmium selenide (CdSe) are most often used. For uses in the infrared, lead sulphide (PbS) is used. The main use of the photo resistor is the measurement of light intensity (camera, counting, alarm system, etc.) and therefore presence detection. Presence detectors are available under two different principles. A first detecting the increase in flow induced by the presence of a body in the field (mainly infrared sensors), the second detecting the decrease in flow induced by the shadow of the body present in the field of the sensor which is more limited than the infrared one (detection in the visible and more directional LDR sensor).

d) USB Cable

The USB cable allows both to power an Arduino project, to program the card (via Arduino IDE) but also to use the Serial Monitor.

e) Arduino Program

The Arduino software is an integrated development space (IDE) that allows us to write, compile, and send code on the printed circuit of the same name. The main functions of the Arduino software are:

- be able to write and compile programs for the Arduino board.
- connect with the Arduino board to transfer the programs to it.
- communicate with the Arduino board.

The Arduino UNO is a programmable card, it can be programmed with Arduino software, and the Arduino programs have three parts:

- Declaration of global variables and constants;
- Setup() function: executed when the program starts or when the Reset button is pressed;
- Loop() function: loop executed endlessly (well everything while the Arduino is powered).

IV. RESULTS AND DISCUSSION

After describing the hardware component of our system, we arrived to the most crucial part of the actual implementation of the solar tracker system.

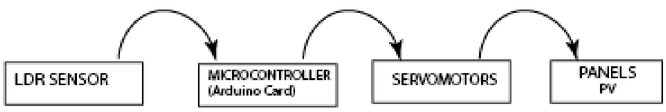

Figure 2. Diagram of the system hardware components.

The system aims to orient the sensors in real time towards the sun and to place the panel in an optimal position in relation to the incidence of solar radiation (perpendicular to the radiation if possible), because throughout the day and the year, the position of the sun varies constantly and in a different way according to the altitude and the azimuth (from east to west, as the day progresses, in height according to the season and the progress of the day). The principle consists of noticing that the light received by the photoresistors is identical as soon as the sensor is oriented along the axis of the light. It is therefore necessary to measure the light received by each photo-resistor by measuring the voltage at their terminals. This measurement is carried out by connecting *pin* ports 0 to 3 of the Arduino card. The program then compares these voltages by ordering the servomotors to rotate in the direction of the photo-resistors that receive the high light. After having simulated and tested the operation of each component individually, we finally arrive at the final simulation, which includes them in a single circuit.

The microcontroller board was pre-programmed with the solar time algorithm. The azimuth angle and elevation angle at solar noon, which are utilized to orient PV modules as shown in Figure 3, were used in the solar time method.

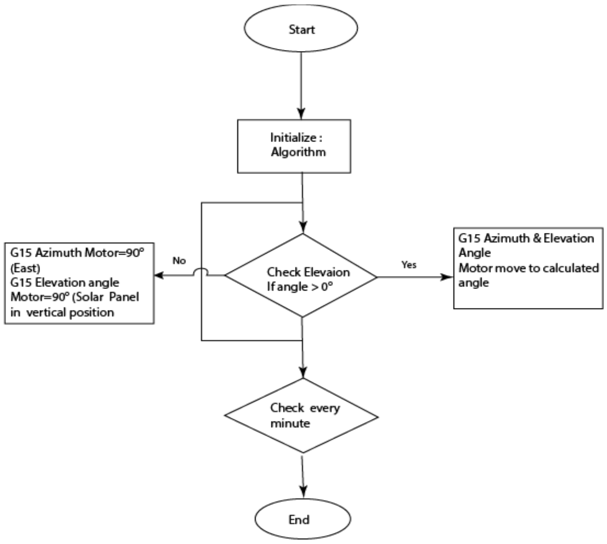

Figure 3. Flowchart for the solar tracker.

A tracking device was used in the simulation of the experiment to have the solar panel follow the sun.The experiment will be conducted close to the main campus of the Sultan Moulay Slimane University in Beni Mellal, which is located at latitude 32.20 and longitude 6.20. The results of the experiment are shown in Figure 4.

In practice, we obtain the photocurrent I_{ph} delivred by the solar tracker listed in the table 1.

TABLE 1. EXPERIMENTAL DATASET OF THE SOLAR CELL PHOTOCURRENT I_{PH}.

N°	1	2	3	4	5	6	7
I_{ph} (mA)	9	17.4	24.6	31.6	37.8	45.1	51

N°	8	9	10	11	12	13	14
I_{ph} (mA)	31.5	31.7	32.2	33.4	33.9	35.7	36.1

To predict these values of the photocurrent, we use the machine learning algorithm such as the Decision tree and the Random Forest. This study presents the prediction of photo-current using different algorithms such as, KNN, decision tree, and random forest based on data of photocurrent I_{ph} delivered by the solar cell. The results are presented in the following figures.

Figure 5 presents the prediction of Iph treated by decision tree which gives a good contribution between the real values and the predicted values; this algorithm evokes valid values for RSME.

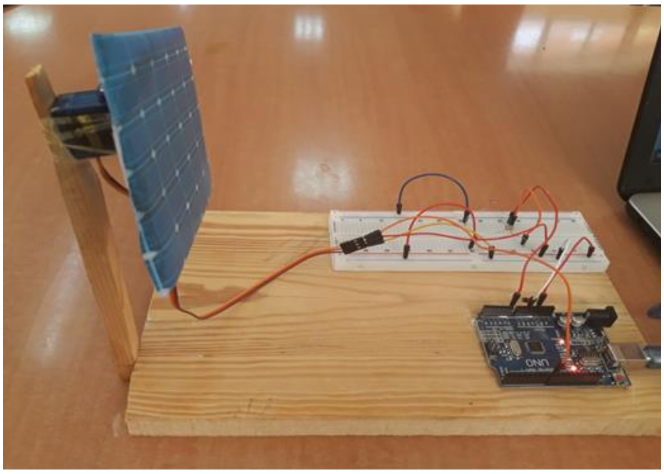

Figure 4. Solar tracker experiment

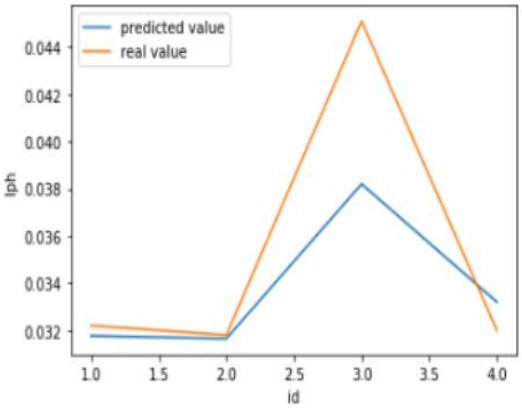

Figure 5. Prediction of I_{ph} by the decision tree.

Figure 6 shows the predicted values given by the random test which are very close to the actual values. This result offers important information namely that the linear regression algorithm is reliable in the prediction of the photo-current values since it presents a low RSME, as it presented in fig 8.

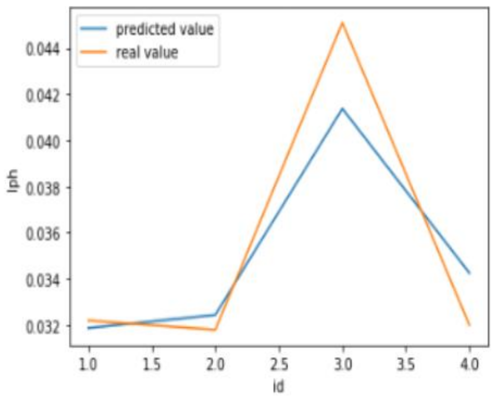

Figure 6. Prediction of I_{ph} by the random forest.

In figure 7, the evaluated values of photocurent given by the K-NN algorithm which is reliable in the first observations, up to node number 30 in which it has a large difference between the predicted and actual values.

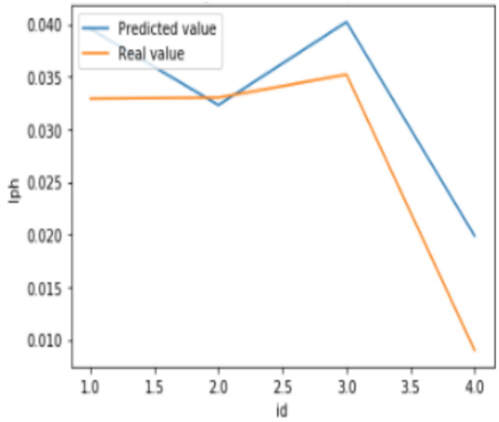

Figure 7. Prediction of Iph values by K-NN.

To compare these machine learning algorithms, the RMSE is used in fig. 8. We notice that the Random Forest algorithm is the most efficient since it gives the smallest error values as it is shown in fig. 8.

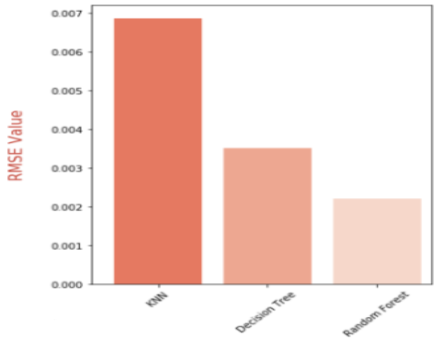

Figure 8. RMSE test obtained by the algorithms used.

V. Conclusion

This study illustrates how artificial intelligence was used to predict the values of the photovoltaic current cell I_{ph}, such as the tree decision, random forest and the K-NN algorithms. On the hand we created the photocurrent by the solar tracker using an Arduino UNO board. For this application, we have produced a photoresistor system of the 'LDR' type which are arranged so that their illumination is only identical if this system is perpendicular to the sun. The signals from the sensors are transmitted to the inputs of an 'ATmega328' type microcontroller in the "arduino" which allows the comparison of voltage levels for the control of servomotors. In addition, it allows the orientation of the panel towards the sun. The result of this study is to put into practice a technical solution that will turn a static solar panel into a mobile panel, improving its performance. Concerning the predicted values of the photocurrent, it can be concluded that the the reliable algorithm is that of forest random due to its low error values RMSE.

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