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Proposal for an IoT System for the Monitoring and Analysis of Ultraviolet Radiation

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Abstract

According to the World Health Organization (WHO), one of the main factors contributing to skin cancer is ultraviolet (UV) radiation from the sun.Considering the above, it is necessary to develop systems that allow not only the capture and monitoring of UV radiation, but also the application of automatic learning models, in order to facilitate the clear identification of the distribution of radiation intensity with respect to the reference radiation levels proposed by the WHO.Thus, in this paper we propose as a contribution the development of an IoT system for the monitoring and analysis of UV radiation levels, which is articulated in the four layers of the conventional IoT architecture (capture, storage, analysis and visualization).The proposed IoT system aims to serve as a reference for the development of studies about the potential risk of UV radiation at different latitudes.

Keywords: Internet of things,IoT system, skin cancer, radiation level, ultraviolet radiation.

I. INTRODUCTION

One of the technological concepts that has grown rapidly in recent years thanks to its great potential within the commercial and consumer sector has been the Internet of Things (IoT)[1].IoT can be defined as the connection of physical objects or devices in an open network, which has the ability to self-manage, share information, data and resources, react and act on situations and changes in the environment[2], [3]. On the other hand, according to ITU-T, IoT can be understood as a global infrastructure for the information society that enables the deployment of advanced services through the interconnection of physical and virtual objects through the use of interoperable information and communication technologies[4]–[6].

From the advantages provided in terms of real-time monitoring and analysis of variables of interest, IoT has been deployed in various application contexts such as: health, industry, tourism, environment, transportation, among others, allowing the progressive construction of the so-called smart cities[7]–[9].In the particular case of monitoring environmental variables, the use of IoT systems contributes to identifying environmental impacts in different contexts, with a view to making decisions related to improving people's quality of life[10]–[12].

In this sense, one of the environmental variables of interest that affects living organisms and the atmosphere is ultraviolet radiation (UV)[13]. Thus, in the health area, UV radiation is considered one of the main factors that affect the development of skin cancer[14]. Thus, according to the World Health Organization (WHO), a marked increase in the incidence of skin cancer in fair-skinned populations around the world is strongly associated with excessive exposure to ultraviolet radiation from the sun[15].Taking into account the influence of radiation on skin cancer, the WHO, the United Nations Environment Programme, and the World Meteorological Organization, proposed an index of UV radiation, which has 5 levels: low, moderate, high, very high, extreme[15]–[17].

Based on the above and considering the importance of UV radiation in the context of health, it is necessary to build systems that not only allow the capture of UV radiation from the sun, as commercial devices do, but also the storage and analysis, in order to conduct studies for the analysis of the impact of radiation at different latitudes.According to the above, in this paper we propose as a contribution the development of an IoT System for the monitoring and analysis of ultraviolet (UV) radiation, which is framed within the conventional four-layer IoT architecture: capture, storage, analysis and visualization[18], [19]. In the capture layer, using free hardware sensors, the values associated with UV radiation levels are obtained periodically.Within the storage layer, the values are stored in a local database or in the cloud using a session id and a timestamp.In the analysis layer it is possible to obtain the data from a given capture session in order to perform analyses based on descriptive statistics, as well as to apply supervised and/or unsupervised learning models.Finally, in the visualization layer it is possible to visualize the values of the radiation levels in real time, as well as the results of the application of statistical analysis and the results of the application of machine learning algorithms.

The proposed system was implemented through the use of free hardware and software tools, in such a way that it intends to serve as a reference for the construction of IoT systems for the monitoring and analysis of environmental variables in different latitudes.El resto del artículo está organizado de la siguiente forma: en la sección 2 se presenta la metodología considerada para el desarrollo de este trabajo.Section 3 presents the results derived from the present research, which include the architecture of the IoT system, the prototype derived from the architecture and a case study through which it was possible to verify the functionality of the system.Finally, Section 4 shows the conclusions and future work derived from this research.

II. METHODOLOGY

For the development of this research, 4 methodological phases were defined: exploration and selection of technologies, definition of the architectural views of the IoT system, construction of the system prototype and finally a case study (see Fig. 1).

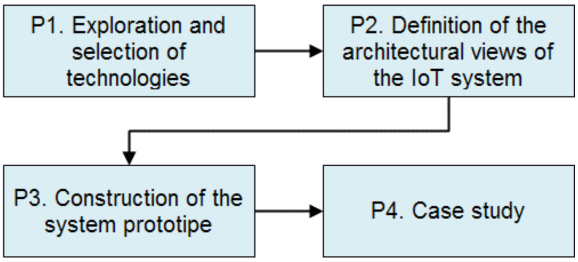

Fig. 1. Methodologyconsidered

In phase 1 of the methodology, a set of free hardware and software tools and technologies were chosen for the monitoring and analysis of ultraviolet radiation levels.In phase 2, the IoT system architecture was designed, which consists of two views (functional and implementation) and four layers (capture, storage, analysis and visualization), taking into account the conventional IoT architecture.The functional view defines the processes associated with the four layers of the architecture, while the implementation view includes the tools and technologies that enable the implementation of the processes defined in the functional view.In phase 3, based on the architecture defined in phase 2, a prototype of the IoT system is implemented.In this way, the IoT system in the capture layer through the use of a UV radiation sensor periodically obtains the radiation levels, which are stored in a non-relational, local or cloud database within the storage layer. From the radiation level data stored in the database, machine-learning methods are applied in the analysis layer, in order to determine the distribution of the data with respect to the radiation reference levels defined by the WHO.On the other hand, in the visualization layer, it is possible to follow graphically and in real time, the data captured by the sensors, as well as to visualize the results of the application of the machine learning models.Finally, in phase 4, a case study is developed in the city of Popayán-Colombia, making use of the implemented IoT system.

III. RESULTS AND DISCUSSION

In this section, the results obtained through this research are presented, which includes the specification of the views of the system architecture, the description of the prototype of the implemented IoT system and the case study developed from the latter.

Before presenting the above results, it is worth mentioning that for the design of the architecture and implementation of the IoT system for monitoring and analysis of UV radiation, the UV radiation index (UVI) defined by the World Health Organization was taken into consideration, whose 5 levels are shown in Table 1.These levels were taken into account for the application of the analysis models on the data captured by the system, in order to determine the distribution of the data around these ranges.

Table 1. Ultravioletradiationindex

Level	Range
Low	1-2
Moderate	3-5
High	6-7
Very High	8-10
Extreme	11+

III.I IoT System Architecture

The architecture of the IoT system for UV radiation monitoring and analysis consists of the functional and implementation views, each of which includes 4 layers: capture, storage, analysis and visualization, taking into account the conventional IoT architecture[19], [20]. Thus, Fig. 2 presents the functional view of the proposed IoT system, which includes the different processes that the system developed in each of the four layers of the architecture.

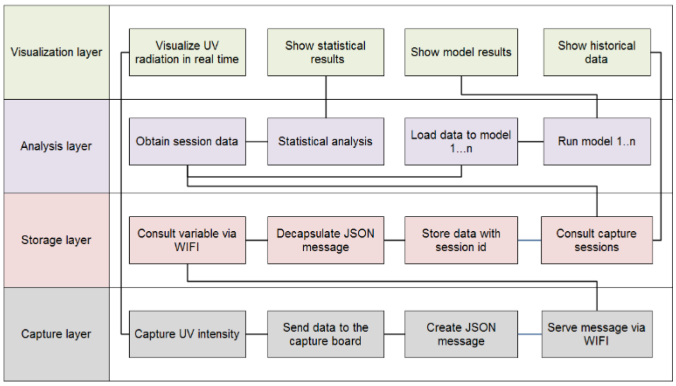

Fig. 2. Functional view of the architecture

In the first instance within the capture layer and through the use of a UV radiation sensor compatible with an arduino board, the values of the intensity of UV radiation are obtained, so that once captured, these are sent to the arduino capture board.On the free hardware arduino board, JSON messages are created with the UV radiation intensity data, which are served via WIFI in response to HTTP requests made from the storage layer.To comply with the above functionalities, the selected arduino board must have the ability to implement a mini web server.In the storage layer, periodic HTTP requests are made to the capture board via WIFI, in order to obtain JSON messages with the UV radiation intensity values.As JSON messages are received, these are de-encapsulated to obtain the intensity values, which are stored in a database either locally or in the cloud making use of a session id and a timestamp.Similarly, in the capture layer, it is possible to use different methods to consult the data captured in the different sessions from the analysis and visualization layers.On the other hand, in the analysis layer, it is possible to obtain the data stored in the different sessions, in order to perform an analysis based on descriptive statistics, as well as to load the data to different machine learning models, for their subsequent execution and validation.Machine learning models make it possible to describe more clearly the distribution of the data captured in the sessions with respect to the ranges defined in Table 1.Finally, in the visualization layer, it is possible to monitor graphically the variation of UV radiation over time, as well as to visualize the results of the application of descriptive statistics and machine learning models.Likewise, in this layer, it is also possible to visualize the results of consultations to the history of capture sessions.

In Fig. 3 it is possible to visualize the implementation view of the IoT system architecture, which includes the technologies that allow the fulfillment of the different processes that are presented in the functional view.

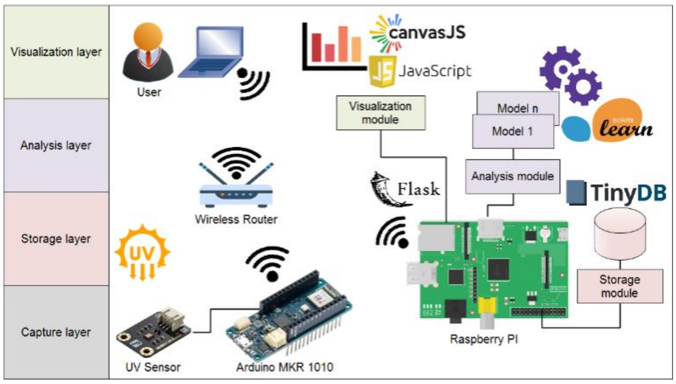

Fig. 3. Implementation view of the architecture

As shown in the implementation view presented in Fig. 3, the proposed IoT system was built using a web application, in which the capture, storage and analysis layers belong to the backend, while the visualization layer corresponds to the frontend.

Continuing with the above, in the capture layer the DFROBOT ML8511 UV radiation sensor is located outdoors and is responsible for capturing the UV radiation intensity to send it to an Arduino MKR 1010 board, which has support for WIFI connectivity and allows the implementation of a mini web server that listens for HTTP requests.Once the board obtains the ultraviolet radiation intensity values, it generates a JSON message with these values and serves them to the backend of the web application, which has been deployed on a Raspberry PI board and has been implemented using the Python Flask micro framework.Thus, on the Rapsberry PI board, once the JSON messages are obtained via WIFI, the radiation values are de-encapsulated and stored by means of a session id and a time stamp in the non-relational database TinyDB, using the storage module of the storage layer.The TinyDB database stores the information of the sessions in a plain text file type JSON, allowing portability to the system. Additionally, the storage module has implemented different methods that allow consulting from the other layers of the architecture, the data of the sessions stored in the TinyDB database.From the data stored in the capture sessions, through the backend analysis module, it is possible to apply machine learning models and specifically unsupervised learning or clustering models based on the K-Means algorithm. This algorithm obtains as a result a determined number of clusters with an associated centroid, in such a way that it allows determining the way in which the data are distributed with respect to the UV radiation levels in Table 1.For this purpose, the analysis module of the analysis layer makes use of Python's scikit-learn library, which has a set of methods that enable the design and implementation of supervised and unsupervised learning models.Finally, from the frontend visualization module, it is possible through javascript and the JQuery library to consult the history of the captured data and the results of the application of the analysis models on a specific capture session.Likewise, in the visualization layer, the variation of UV radiation is presented graphically and in real time, making use of the CanvasJSJavascript library.The results presented in the visualization layer are useful for conducting studies to assess the potential impact of ultraviolet radiation on humans at different latitudes.

III.IIImplemented IoT System

Based on the different processes in the functional view and the technologies selected in the implementation view that fulfill the functionality of those processes, a prototype IoT system for monitoring and analyzing UV radiation levels was developed, whose main web interface is presented in Fig. 4.

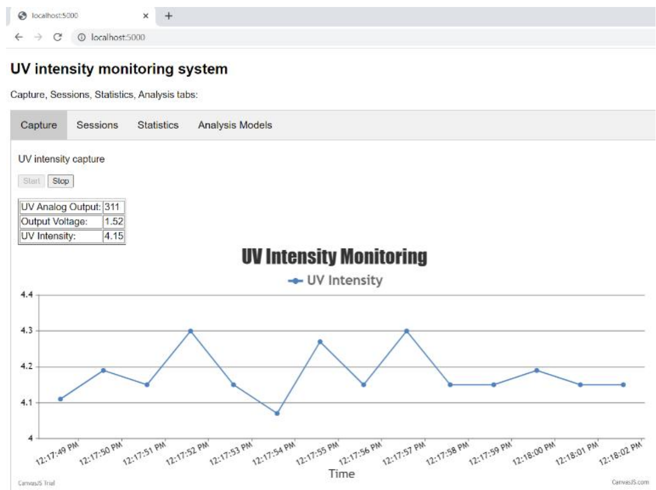

Fig. 4. Main interface of the IoT system

As shown in Fig. 4, the IoT system interface consists of four tabs: "Capture", "Sessions", "Statistics" and "Analysis Models".Within the "Capture" tab, by pressing the "Start" button, HTTP requests are made periodically to the capture board and the UV radiation sensor, so that once the JSON response messages are obtained in the backend, the radiation intensity values are de-encapsulated and stored with a session id and a time stamp in the TinyDB database, after which these values are presented in real time numerically and graphically in the "Capture" tab using the CanvasJS library.On the other hand, Fig. 5 shows the graphical interface of the "Sessions" tab, where it is possible to consult the UV radiation values associated with a given capture session by selecting the session id and pressing the "Consult" button.

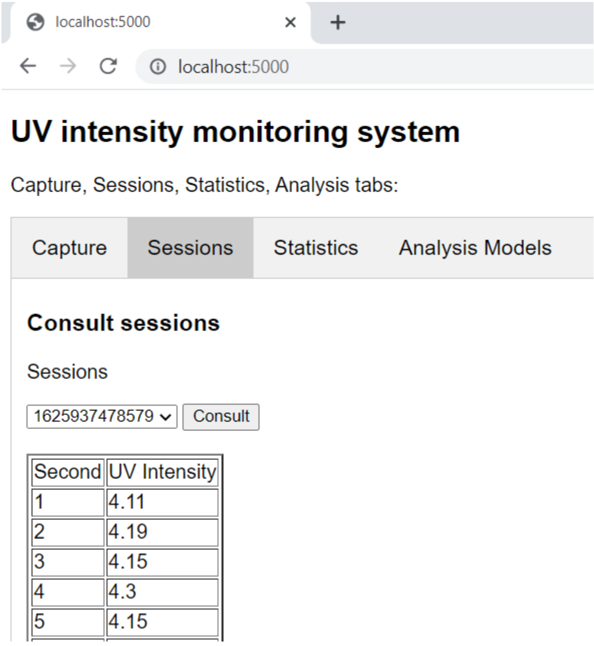

Fig. 5. Tab "Sessions" of the IoT system

Similarly, Fig. 6 shows the graphical interface of the "Statistics" tab, which allows to perform an analysis based on descriptive statistics on the data associated with a specific capture session. In this way, by selecting a session id and pressing the "Consult" button, it is possible to obtain the number of captures, the average, the standard deviation, the maximum value and the minimum value for the data of the selected session.Thus, as an example, Fig. 5 shows that for the capture session with id: 1625937478579, the number of captures performed was 282, the average radiation intensity was 4.1585 mW/cm^2, the standard deviation of the values was 0.068, the minimum value was 3.88 mW/cm^2 and the maximum value was 4.38 mW/cm^2.

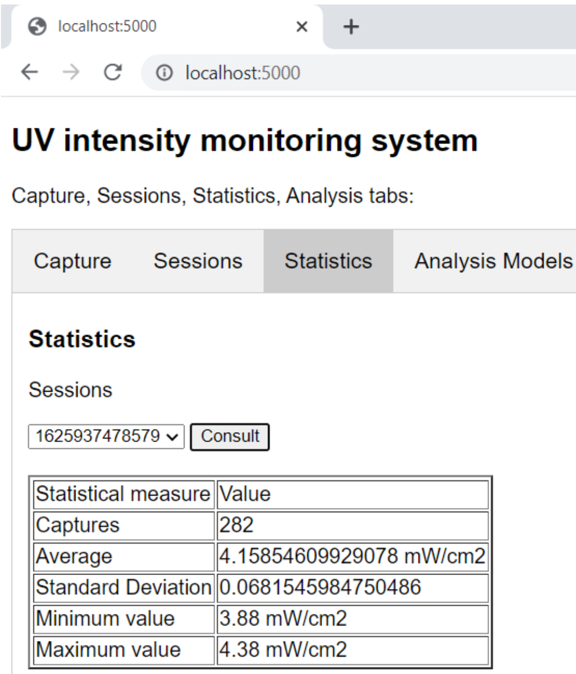

Fig. 6. Tab "Statistics" of the IoT system

Fig. 7 shows the graphical interface of the "Analysis Models" tab, in which the results of the application of the clustering models based on the K-Means algorithm on the data of a specific capture session can be visualized. De este modo, al escoger el id de una sesión específica y presionar el botón “Model” son obtenidos los resultados de la aplicación de un modelo de clustering (pre-configurado para la obtención de 2 clusters) que relaciona los valores de intensidad de la radiación UV con los niveles de referencia de la Tabla 1 (Low:0, Moderate:1, High:2,Very High:3, Extreme:4).

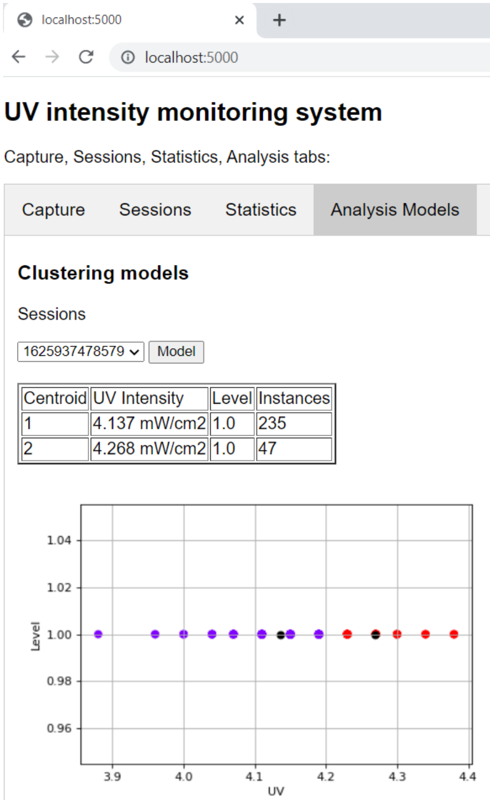

Fig. 7. Tab "Analysis Models" of the IoT system

Thus, as an example, Fig. 7 shows the results of the application of the clustering model defined on the data of the capture session with id: 1625937478579, in which a total of 282 instances were captured. It is possible to see how the K-Means algorithm obtained 2 clusters (cluster 1: purple color, cluster 2: red color), each of which has a centroid (black color), around which the data is concentrated.With respect to cluster 1, a total of 178 instances were obtained, which are distributed around C1={UV Intensity=4.119 mW/cm^2, Level=1.0}. Similarly, for cluster 2, a total of 104 instances were obtained, which are distributed around C2={ UV Intensity=4.225 mW/cm^2, Level=1.0}.The previous results show the usefulness of clustering models to better understand the way in which the data of a session are distributed with respect to the radiation levels presented in Table 1.

III.III Case Study

In order to verify the functionality of the IoT system built, a case study was developed in the city of Popayán-Colombia, in which a total of 1110 radiation intensity captures were performed on July 10, 2021 between 2 and 3 pm (see Fig. 8).

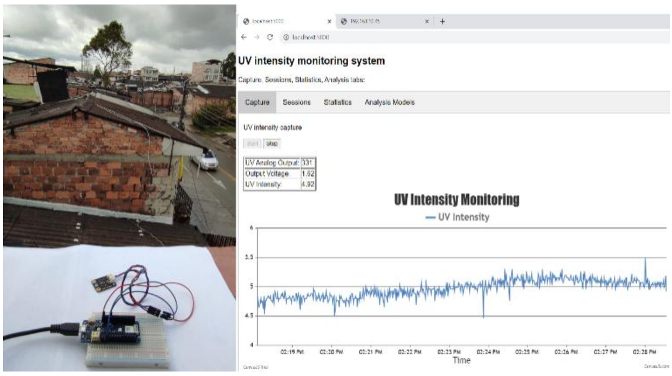

Fig. 8. Case Study

By applying descriptive statistics on the data captured in the case study, the results presented in Table 2 were obtained.Thus, it is possible to see in Table 2 that the average radiation intensity was 4,989 mW / cm^2, while the minimum value was 4.46 mW / cm^2 and the maximum value was 5.49 mW / cm^2.Likewise, it can be seen that the standard deviation of the captured values was 0.1241. Thus, it is possible to appreciate how, according to the average of the values; the intensity of radiation captured is classified in the moderate level.

Table 2. Statistical results of the case study

Statistical Measure	Value
Captures	1110
Average	4.989mW/cm^2
Standard Deviation	0.1241
Minimum value	4.46mW/cm^2
Maximum value	5.49mW/cm^2

On the other hand, by applying the clustering model with two clusters that relates the radiation intensity to the radiation level in Table 1, the results presented in Fig. 9were obtained.

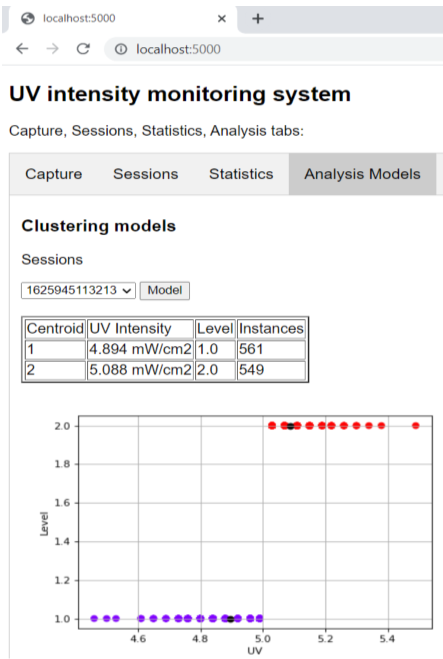

Fig. 9. Clustering model results

It can be seen from these results that centroid 1 has 561 instances, which were classified by the system at a moderate level, while centroid 2 has a total of 549 instances, which were classified by the system at a high level.In spite of the above, the intensity values captured are close to the value of 5, which is the limit value of the moderate level, keeping a certain level of agreement with the average of the values.

VI. CONCLUSIONS

In this article we proposed as a contribution the development of an IoT system for the monitoring and analysis of ultraviolet radiation generated by the sun, which is articulated within the conventional 4-layer IoT architecture (capture, storage, analysis and visualization) and is described by means of two architectural views: functional and implementation.The proposed system is intended to support the development of UV radiation analysis studies at different latitudes.

The proposed IoT system was developed using free hardware and software tools, which proved to be adequate to fulfill the requirements of each of the layers and views of the architecture considered.Thus, in the capture layer, the DFROBOT ML8511 UV radiation sensor and the MKR 1010 arduino board were used, which has the advantage of implementing web services for consulting the sensor data.In the storage layer, the non-relational database TinyDBwas used, which has the advantage of portability and the use of the JSON extensible format for storing data from the capture sessions.In the analysis layer, the advantages provided by the scikit-learn machine learning tool were used for the design, implementation and evaluation of unsupervised learning models.Finally, in the visualization layer, javascript libraries (JQuery, CanvasJS) were used for the real-time visualization of the radiation intensity and for the visualization of both statistical results and machine learning models.

The developed case study allowed to verify the usefulness of the proposed IoT system, in terms of real-time monitoring of UV radiation from the sun, as well as the application of unsupervised learning algorithms to identify the distribution of captures with respect to the levels of UV radiation defined by the World Health Organization.This allows complementing and enriching the analysis provided through the use of descriptive statistical methods.

As future work derived from the present research, it is intended to include other environmental variables to the IoT system, such as temperature and humidity, as well as to conduct a study over a long period of time in different cities in Colombia in order to identify the possible level of risk to which their inhabitants are exposed.

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