Environmental Monitoring based on Wireless Sensor Network via Mobile Phone

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Abstract - **Preventive conservation of artwork is a vital issue for museums. Therefore, it is fundamental to continuously monitor its environment. To accomplish this, the WISE-MUSE project proposes the use of Wireless Sensor Networks (WSNs) for monitoring and automatically control museums' environment and structural health. The deployment of a Wireless Sensor Network can help to implement these measurements continuously, in a real-time basis, and in a much easier and cheaper way than when using traditional measuring equipments and procedures. Nevertheless, continuous monitoring implies that the persons in charge for the museum must be immediately informed of any abnormal value detected in its environment. Thus, this contribution arises: the development of a new mobile application that allows users to continuously monitor the environment and be aware of any undesirable changes that may occur**.

Keywords-wireless sensor networks; mobile applications; environmental monitoring; preventive artwork conservation.

I. INTRODUCTION

Controlling some of the major causes of deterioration and damage of artwork in a museum environment avoids or reduces the need for invasive conservation treatment and ensures that artwork is protected. Therefore, preventive conservation of art in museums is of extreme importance.

Preventive conservation is achieved mainly by controlling the indoor environment, especially temperature, humidity, and light levels. However, environmental monitoring and control in this type of buildings must respect some specific requirements due to esthetical reasons, like minimizing the visual impact caused by the installation of monitoring systems. Besides, the current economic situation requires the choice of a cheap solution.

The deployment of a Wireless Sensor Network (WSN) in a museum can help to implement these measurements automatically and continuously. This solution is much cheaper and easier to install than traditional measuring equipment. Besides, the major advantage of using WSNs in this type of environment is causing very little visual impact due to the small size of sensor nodes, and an extremely important aspect in the context of a museum: being wireless.

Considering these requirements, the WISE-MUSE project [1, 2] was created with the purpose of employing WSNs for monitoring the environment and structural health of museums, and automatically control relevant environmental parameters. The importance of this project, obviously besides monitoring the environment of the museum, is to study and to demonstrate some practical aspects of WSNs, since most of the applications have not been tested in real WSNs.

The WISE-MUSE project is an on-going project that was initially developed for a contemporary art museum that is located on the premises of Fortaleza São Tiago, a fortress located in Madeira Island. Currently, this project has been extended to Madeira Whale Museum, also located in the island.

In this paper, an emphasis will be given to the WISE-MUSE mobile application, which is an important contribution of the WISE-MUSE project that was not planned from the beginning. This contribution came up to meet the needs that have arisen throughout the course of this project.

The WISE-MUSE mobile application was developed to meet the concerns of those responsible for the museum to be always informed about abnormal environmental parameters, when they are not on the premises of the museum. The WISE-MUSE mobile application is developed for Android and iPhone mobile platforms and allows an easy and flexible way to remotely monitor the museum environment.

This paper is organized as follows. Section 2 briefly describes some of the most important aspects of the WISE-MUSE project. In Section 3, an emphasis will be given to the WISE-MUSE mobile monitoring application designed to monitor a WSN through either Android or iPhone mobile platforms. Section 4 describes related work and provides a comparison with the WISE-MUSE mobile application. Section 5 summarizes the most important conclusions, whereas Section 6 points out some directions for future work.

II. THE WISE-MUSE PROJECT: APPLYING WSNS TO MUSEUMS' ENVIRONMENTAL MONITORING

The main goal of the WISE-MUSE project is to create a WSN for monitoring and automatically controlling the most critical environmental parameters of interest to a museum,

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which are humidity, temperature, and light, in museums (exposition rooms and storage rooms).

Nevertheless, pollutants are also of major concern for museum managers due to their influence in the degradation of artworks; therefore, this project also involves the monitoring pollutants, namely CO and CO_2. Thus, the major goal of the WISE-MUSE project can be divided into several sub-goals, which comprise:

- To create a WSN for monitoring the most critical environmental parameters in museums (both in exposition and storage rooms).
- To monitor pollutants as they are also a major concern for museum managers.
- To give users and museum' managers the possibility of consulting the collected data in real-time, via different data formats (e.g., graphs, tables, colour gradients, etc.), and consulting the historical reports whenever needed.
- To analyze data in order to verify its compliance with the art conservation rules. If a significant variation (below or above the required levels) on at least one of the measured parameters occurs, an alert has to be automatically sent to the user through a mobile phone (SMS) or e-mail, in order to increase the efficiency of this environmental monitoring system.
- To control the environmental conditions through the automatic control of the air conditioning and dehumidifying systems of the museum.
- To visualize data integrated in a 3D representation of the building.
- To remotely monitor the state of the emergency doors of the museums, giving their managers and security personnel more awareness of their state, and avoiding their displacement to examine the state of each door.
- To implement low-cost devices for monitoring and controlling environmental parameters, as well as the state of emergency doors.

So, this project proposes an environmental monitoring solution that involves installing only one network, using nodes that have the ability to monitor several parameters at the same time. In the context of the WISE-MUSE project, new wireless sensor nodes [1, 2] were developed. These new nodes are smaller and cheaper than the nodes used in other solutions, like the ones used by Spinwave [3]. Besides, the concepts encompassed in WISE-MUSE project are appropriate to be applied either in historic or new buildings. These factors are the basis for making the solution proposed by the WISE-MUSE project more suitable to the environmental monitoring of buildings.

The WISE-MUSE project offers several advantages in relation to other approaches, namely: i) visualizing sensors' data using either a web-based platform or a mobile phone; ii) changing sensors' parameters through the platform; iii) creating and manipulating collaborative sessions using the WISE-MANager tool [4]; and, finally, it allows to monitor the state of the WSN through the awareness tool or the WISE-MANager tool [4]. Another advantage is that, using the same visualization platform; it is also possible to monitor the state of the emergency doors and the environment of cold chambers of the museum [5].

The WISE-MUSE project was validated in two real scenarios: i) Museum of Contemporary Art of Funchal and; ii) Madeira Whale Museum. These scenarios were chosen to reinforce the validation since they have completely different characteristics. The Contemporary Art Museum of Funchal, situated in the city of Funchal, on the island of Madeira, Portugal. Fortaleza São Tiago is an irregular-shaped fortress from the 17th century, which today houses the Museum of Contemporary Art of Funchal). On the other hand, Madeira Whale Museum is a recently built museum located in a small fishing village, on Madeira Island. The museum focuses on the whale hunting activities that were part of many fishermen's lives for several decades and houses several types artifacts, like 3D models of whales, objects made of whale bones, etc.

III. THE WISE-MUSE MOBILE APPLICATION.

To complement the monitoring platform already developed and installed in the museum, a mobile application for the environmental monitoring of museums was developed. With this application, the managers of the museum can see data anytime and wherever they are, they can receive notifications of unwanted situations even when they are not in the museum.

This application was implemented in Android, and later it will be extended to the iPhone platform. The reason for using these platforms is because these Operating Systems (OS) are the most widely used nowadays. This application will allow the visualization of data produced by a WSN installed in the Whale Museum. This application will also display in a user-friendly interface data captured by the sensor nodes installed in the exhibition rooms, in cold chambers and the emergency doors, through graphs and maps. The historic data collected can also be found in tables.

Thus, the monitoring system will allow to:

- Observe the state and the most important environmental monitoring information, monitoring of emergency doors and cold chambers;
- Consult the historic of sensed data;
- Visualize data from environmental monitoring, monitoring of emergency doors and cold chambers, through graphs and maps, thereby making it more noticeable;
- Visualize environmental parameters (humidity, light, temperature, CO2 and CO) collected both in exhibition rooms and cold chambers;
- Generate notifications in order to alert the user of a parameter whose value is not within the desired levels.

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This application will display the measurements received by wireless sensors, in a fast and reliable way, so that as soon as a problem is detected, those in charge for the museum are informed about it, being able to act in time and solve the problem, preventing major damage.

Use cases detail the functional requirements of the application, thus giving a clear idea of the different activities that users can perform, when using the application.

The most important use cases used for this application can be seen in Figure 1, in which the behavior of two important stakeholders can be seen; these are the client (person responsible for constant monitoring of data from the museum), and WSN coordinator or gateway (system responsible for sending the data required for monitoring).

The WSN coordinator will send data from the various sensors, in real-time manner, to be visualized later by the customer using this application.

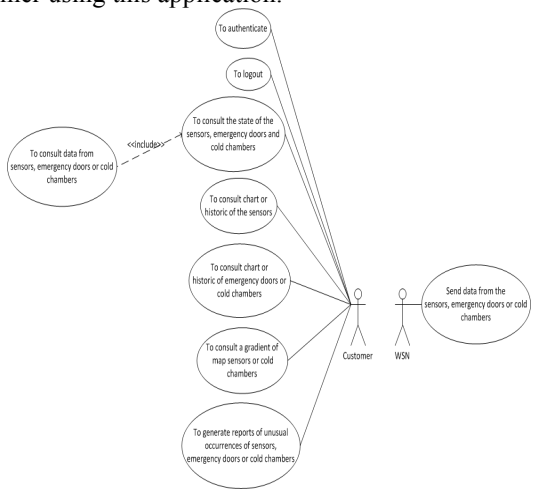

Figure 1. Use case diagram of the WISE-MUSE mobile application

Figure 2 shows the architecture of the WISE-MUSE mobile application. It follows the client-server paradigm.

It is possible to observe that there is a search service that sends the data to the database or gets data form the database, which is implemented through the PHP server, The PHP server, in turn, takes care of the communication between the mobile platform and MySQL database.

Figure 2. Client-server architecture of the WISE-MUSE mobile application

This communication is initiated by the client, which makes a request to the PHP server using the HTTP protocol. This protocol is integrated into the Android operating system. Subsequently, the server connects to the MySQL [6] database using SQL language [7]. The server encrypts data using the JSON format, which will be used by the WISE-MUSE application to obtain and process this data, showing it later on their Android device [8].

Regarding the implementation different mockups were created, in order to show the interaction between the different scenarios, as well as their presentation. A planning scenario was conducted both for the iPhone and Android platforms. In this paper, only the most important navigation scenarios of these two OS are presented.

A. Android platform

Figure 3 shows several scenarios of the Android platform. The application menu (Figure 3a) can be expanded to view some of its options; the menu can be saved after choosing what to visualize, thus allowing optimizing the size of the screen for the presentation of information. Then, it is possible to see the information (Figure 3b) and state (Figure 3c) about the most important sensors, emergency doors and cold chambers, allowing to choose the floor where the different sensors to be visualized are located. The application also allows selecting the different rooms of a previously selected floor, finishing with the visualization afterwards.

Next, the user can select to visualize data by a graph (Figure 3e) or a historic (Figure 3f), selecting different visualization criteria (Figure 3d). First, a date can be chosen; then the floor where sensors are located can be chosen (all, several or a specific floor); subsequently, all rooms may be chosen, several rooms, or only one room, from the floor which has been previously selected; similarly, the device category may be chosen, i.e. the type of device (sensors, emergency doors or cold chambers); besides, it is possible to choose whether to view all or only a few of these sensors. After choosing the sensor, it is then possible to choose the types of parameters to be displayed, the user may opt for one, all or some, among which are: temperature, humidity, light, CO2 and CO. It is also possible to display a graphic or historic with all the selected criteria.

B. iPhone platform

Regarding the iPhone platform, the application menu is always visible and the user can choose one of the options, at any time. When selecting the scenario, it remains green, allowing giving feedback to the user. In Figure 4, the user can visualize several scenarios of the iPhone platform on which data is represented in different maps (Figure 4a). First, the user has to select the type of map (Figure 4b) that user wants to observe, such as the map of temperature, humidity, light, CO2 and CO.

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Figure 3. Android Prototypes. a) Application menu. b) Viewing the state of a sensor. c) Display of data from a selected sensor. d) Graphics menu. e) Graphics display. f) Historic display.

Inside the maps, we can choose the criteria according to which data will be visualized, such as the floor, the room and the sensor, and for these last three, it is possible to choose one, all or only some. In the case of temperature map, the visualization criteria are the same; with the exception of have the possibility of choosing the type of device to be visualized (sensor or cold chambers). In any case, the presentation of data is performed using the map (Figure 4b). The user can also see the notifications (Figure 4c) of devices that are in danger or emergency, through its representation using different colors depending on the corresponding status.

When the user performs authentication in the application, if notifications exist, they will be shown to the user (Figure 4c), in order to alert him immediately. Nevertheless, the user may also view the notifications at any time.

IV. RELATED WORK.

When looking for other environmental monitoring works, we realize that there are some applications in either software or hardware that can monitor effectively the environmental conditions of a specific place.

The Overseer application (Network Monitoring Software) [12] monitors the environmental status of the room where a server is located, i.e., the user can monitor temperature and humidity of a data center via an EM1 monitor [13]. Alerts are sent to the user via e-mail to the mobile phone if the upper or lower limits of these parameters have been reached.

On the other hand, there are different applications which help in environmental monitoring for instance, EnviroSense [14], which is software that monitors temperature and humidity, being useful for either for agriculture, computer rooms or any area that needs monitoring. This application alerts the user by sending SMS and reports, to a mobile phone.

Among the works found that most resembles the WISE-MUSE application, we have found a surveillance monitoring system developed for the Android mobile platform [12, 14]. This system aims to address the deficiencies of security systems through WSN via the Android mobile phone, allowing the user to monitor a particular place at any time. In this work, the activity sensor was used to display data on humidity, temperature, carbon dioxide and gas concentrations, allowing shutting down or activating the air conditioning equipment, if the sensors detect abnormal data. Additionally, it indicates any unusual movement of material or people outside or inside the room. All this can be observed at the interface of the corresponding application, where data from the different sensors can also be visualized, as well as a video of the room captured by a digital camera via USB.

In the specific case of the project WISE-MUSE, an application was developed with the aim of allowing to monitor the different environmental conditions (temperature, humidity, light, CO_2 and CO) captured in a museum, thus enabling the persons responsible for the conservation of artworks in the museum to detect if the environmental parameters are outside acceptable limits, alerting the museum staff in a fast and efficient manner.

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Figure 4. iPhone Prototypes. a) Choice of different maps. b) Map view of humidity gradient. c) Display of notifications.

Other application that has some similarities to our work, is a system that allows monitoring different WSN sensor nodes (temperature and humidity) allowing the users to can visualize these parameters, and send notifications when a certain value has exceeded its limit. These sensors can be visualized by building plan, floor or sensor type; it is also possible to customize the reception of notifications from various sensors that are associated with a particular person [13].

In order not to only send notifications via SMS or email, but also to allow visualizing the data collected by the WSN at any time, the WISE-MUSE application was implemented for a mobile platform. This will ensure efficient monitoring of real-time data in order to allow better preservation of artwork.

Table 1 shows a comparison between the WISE-MUSE mobile application, the application developed by [12, 14] and a mobile application to monitor a WSN [13].

The major advantage of the WISE-MUSE mobile application is to provide complete overview of all real-time data collected by different types of sensors, emergency doors and cold chambers. It also allows visualizing data using graphs, maps and historic.

Both in the security system developed for the Android platform [12, 14] as well as in the mobile application to monitor a WSN [13], sensor data can be visualized only in real-time. That is, they do not let the users to view and analyze historic data through graphs and maps of gradients.

Another advantage of the WISE-MUSE is being possible to observe the different data from one or more sensors, emergency doors and cold chambers at a time. This is not possible with other applications. The application developed by Moreira et *al.* [13] allows selecting from various sensors, not allowing the visualization of the state of emergency doors, whereas with the security system presented in [12, 14] can only be observed data from a sensor.

Regarding the work that focus on surveillance monitoring [12, 14] it was observed that the environmental parameters are displayed on the Android application, but there is nothing to help understanding if the data are abnormal or not, which may difficult the interpretation of data. Due to this, the WISE-MUSE mobile application uses different colors to give feedback to the user and alert them if any parameter is outside the normal values. For this reason, the WISE-MUSE mobile application was designed considering different types of sensors, deployed by several floors and rooms that will need to be monitored.

The uses of cameras placed in locations to record and transmit images via a USB interface is an important advantage of the application proposed in [12, 14]. Thus, the architecture of WISE-MUSE project includes the installation of a camera-based monitoring module. Once this module is installed and integrated in the WSN network, this functionality can be added to the mobile application.

V. TESTS

In order to ensure that the WISE-MUSE mobile application meets all requirements and all features important to the proper monitoring of a museum, it was necessary to carry out usability tests. These tests intended to verify whether such features are implemented correctly.

Tests should be performed with the most appropriate type of users, which, in this case, are the museum's staff. They are the ones who daily deal with the concern of preserving the artworks and, thus, quickly understand the goal of the application, ensuring that it is used and tested the appropriately.

This staff was contacted and visited to conduct the tests. After the tests were carried out, they were asked to answer a short survey to help in better understanding the results of this experience and, thus the usability of the developed mobile application.

The usability tests that were conducted allowed validating the different functionalities of the application, permitting to observe how the user reacts, interacts and navigates through different application scenarios. Also, these tests allowed understanding what the users' preferences are. In addition, these tests help to observe the

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performance of users, enabling the analysis of the product's usefulness and ease of use, which allows improving the quality of the developed application.

The tests were conducted with five heads of different museums, aged between 35 and 60. This application has also been tested in the Whale Museum.

It was observed that most users easily interact with the application using all functionalities correctly, especially those who are familiar with an Android phone.

Nevertheless, the tests helped in detecting which aspects to be refined in order to improve the operation for this application, namely:

- To add the ability of zooming in and out to improve the visualization of the historic;
- To provide real-time gradient maps of the measured parameters; and;
- To increase the visibility of notifications in the users' mobile phone, to ensure that abnormal situations are quickly detected.

VI. CONCLUSION

The WISE MUSE project aims to the deployment of a WSN for automatically and continuously monitoring and control the environment of museums. The use of WSNs for environmental monitoring of a museum is, indeed, a more reliable solution. It is also less expensive than manual data collection or than a wired central monitoring system.

This project has proposed several contributions, among them the WISE-MUSE mobile application. This application allows the environmental monitoring based on wireless sensor networks via a mobile phone. Besides, it allows users to constantly check and analyze data on the monitored parameters, anytime and anywhere, enabling monitoring with more flexibility and more security, providing better visualization of all data captured by different sensors through charts, maps and historical gradients, in real-time.

One of the most important features of the proposed application is to provide a notifications' system to users, in case any parameter presents an abnormal value.

The tests carried out allow to conclude that the WISE-MUSE application fits the most important requirements of a museum, associating the efficient display of accurate measurement of environmental factors, all captured by sensors, with the ability of sending notifications, allowing preventive action in preserving the history that these works represent.

VII. FUTURE WORK

In order to make the mobile application more efficient and perceptible to the user, we intend to improve it by providing feedback about the user navigation on the application.

Similarly, we also intend to implement the zoom feature to enable enlarging or reducing the size of the table with the historic of data, so that people who want to browse data in a larger size may do so. We also intend to give the user the possibility of sorting historic data by a parameter chosen by the user, i.e., to allow the user to sort data by date, rooms, floors, or sensors, showing data in a descending or ascending order.

It is desirable that the module generating a gradient map of the environmental parameters is implemented, which will allow displaying data from a particular sensor in a more intuitive manner. This makes it possible to give a more specific idea of what is occurring, allowing the user even to check if a particular sensor needs to be moved to another location or replaced by another one.

The tests of this application were based on data collected from a small testbed installed in the laboratory. The WSN was not installed in the museum yet since the equipment for assembling the monitoring devices did not arrive in time. Thus, the application was tested with some data to permit to observe its basic operation. Therefore, one future work intention is to carry out tests with the WSN deployed in the museum.

TABLE 1. COMPARATIVE TABLE OF THE APPLICATION WISE-MUSE WITH THE SECURITY SYSTEM DEVELOPED FOR ANDROID AND A MOBILE APPLICATION TO MONITOR A WSN [12]

PARAMETERS	SECURITY SYSTEM IN ANDROID [12]	Sensor – Mobile application to monitor a WSN [13]	WISE-MUSE
Presentation of data from sensors in real-time	Yes	Yes	Yes
Presentation of data from emergency doors in real-time	No	No	Yes
Submission of data from cold chambers in real-time	No	No	Yes
Generation of graphics	No	No	Yes
Generation of data historic	No	Yes	Yes
Map view	No	No	Yes
Notification of anomalies	Yes (SMS)	Yes (SMS, E-mail)	Yes (Popup)
Presentation of a video of the monitored site	Yes	No	No
Presentation of a image of the monitored site	No	Yes	No
Visualization of all deployed sensors	No	Yes	Yes
Selection of a specific sensor to visualize	No	Yes	Yes

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REFERENCES

[1] L. M. Rodríguez Peralta, L. M. P. L. Brito, J. P. B. F. Santos, J. F. F. Santos, C. M. M. Francisco, C. M. A. Sousa, P. M. Moraes, and F. B. Gouveia, "Environmental Monitoring Platform based on a Heterogeneous Wireless Sensor Network", Cyber Journals: Multidisciplinary Journals in Science and Technology, Journal of Selected Areas in Telecommunications (JSAT), October Edition, pp. 26- 38, ISSN: 1925-2676, 2011

[2] L.M. Rodríguez Peralta, L.M.P. Leão Brito, B.A. Teixeira Gouveia, D.J.G. Sousa, and C.S. Alves, "Automatic monitoring and control of museums' environment based on Wireless Sensor Networks", International Journal EJSE – Electronic Journal of Structural Engineering, Special Issue: Wireless Sensor Networks and Practical Applications, pp. 12 – 34, 2010, ISSN 1443-9255.

[3] Spinwave Systems, April 2009, from http://www.spinwavesystems.com/ [Retrieved: July, 2013]

[4] L. M. P. Brito, L. M. Rodríguez Peralta, F. Santos, and R. Fernandez, "Environmental Monitoring of Museums Based on Wireless Sensor Networks", Proc. 4th International Conference on Wireless and Mobile Communications (ICWMC 2008), IEEE Computer Society Press, Athens, Greece, July 27 - August 1, 2008, pp. 364- 369.

[5] L.M. Rodríguez Peralta, L.M.P. Leão Brito, and J.F.F. Santos, "Improving Users' Manipulation and Control on WSNs through Collaborative Sessions", International Journal of Knowledge and Web Intelligence (IJKWI), Special Issue on Social Media Support for Intelligent Service and Interaction, Vol. 3, No. 3, 2012, pp. 287 – 311, DOI: 10.1504/IJKWI.2012.050860.

[6] MySQL, form http://www.mysql.com/ [Retrived: July, 2013]

[7] Wikibooks, "Structured Query Language", from http://en.wikibooks.org/wiki/Structured_Query_Language/ [Retrived: July, 2013]

[8] F. Rahman, (2011) "Connection between PHP (server) and Android (Client) using HTTP and JSON", from http://fahmirahman.wordpress.com/2011/04/21/connectionbetween-php-server-and-android-client-using-http-and-json/ Retrived: July, 2013]

[9] Overseer , Overseer Network Monitoring Software, Environmental Monitoring Software, 2012, from http://www.overseer-network-monitor.com/Sensatronics-Environmental-Temperature-Monitoring-Software.aspx, [Retrieved: July, 2013]

[10] SensaTronics, "Model EM1 Environmental Monitor ", from http://www.sensatronics.com/wp-content/uploads/2013/07/SensatronicsDatasheets5-4.pdf [Retrived: July, 2013]

[11] Envirosense, EnviroSense Strategic Environmental Consultants, 2012, from http://www.envirosense.com/index.php?, [Retrieved: July, 2013]

[12] P. Heming, J. Linying, Y. Liu, and Y. Kun, "Design and Implementation of Android Phone Surveillance System", Proc. of the IEEE International Forum on Information Technology and Applications (IFITA'10), IEEE, 2012, pp. 222-225.

[13] N. Moreira, M. Venda, C. Silva, L. Marcelino, and A. Pereira, "@Sensor – Mobile Application to Monitor a WSN", 6th Iberian Conference on Information Systems and Technologies (CISTI), Leiria, Portugal, July. 2011, pp. 1 -6.

[14] H. Pang, L. Jiang, L. Yang, and K. Yue, "Research of Android Smart Phone Surveillance System", International Conference on Computer Design and Applications (iCCDA), Shenyang, China, vol. 2, June. 2010, pp. 373 – 376.

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