Risk Identification in a Smart Monitoring System Used to Preserve Artefacts Based on Textile Materials

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Abstract. Exhibited textile-materials-based artefacts can be affected by the environmental conditions. A smart monitoring system that commands an adaptive automatic environment control system is proposed for indoor exhibition spaces containing various textile artefacts. All exhibited objects are monitored by many multi-sensor nodes containing temperature, relative humidity and light sensors. Data collected periodically from the entire sensor network is stored in a database and statistically processed in order to identify and classify the environment risk. Risk consequences are analyzed depending on the risk class and the smart system commands different control measures in order to stabilize the indoor environment conditions to the recommended values and prevent material degradation.

1. Introduction
Textile-based exhibited artefacts can be affected by the environmental conditions like temperature, relative humidity, light intensity variations or pollutants. Textile materials are extremely vulnerable to the climate changes therefore a lot of researchers are focused on the environment monitoring and control in museums where old artefacts are exhibited.

According to Abdel-Kareem [1] in most cases, textile-material based artefacts are stored and exhibited in very poor environmental conditions. Environmental monitoring and control is essential in order to preserve the textile artefacts but the problem is not permanently solved even if there are a lot of concerns for it.

Peralta et al. [2] present some components of the WISE-MUSE project designed by their team in order to monitor and control the environmental parameters. These component parts are intended to control the temperature and relative humidity of the environment using the air-conditioning and dehumidifying systems. The Wireless Sensor Network (WSN) architecture with a new sensor-node type and the communication system are described. Measures of the transmitted signal level are made in order to establish the limits of the sensing areas in the monitored space.

Stable environment parameters must be ensured in museums in order to preserve the artworks, according to Martens [3]. In its thesis, the author quantifies the climate risks based on the measured and simulated values of temperature and relative humidity in an indoor space. Risk assessment non-statistical predictive formulae are proposed and applied on four object types (books, furniture pieces, panel paintings and wooden sculptures) in a Dutch museum. The response time of each object type is established by a long-term monitoring process and it is used to estimate the museum climate risks.

Simić et al. [4] design and present a sensor-based environment monitoring system for indoor spaces. Temperature, relative humidity and light level are measured using a WSN. Data are collected
and transmitted to a PC in order to be stored in a SQL database. Data is visualised in a Windows application. E-mail and phone alarms are sent in critical cases.

ASHRAE (American Society for Heating, Refrigerating and Air-Conditioning Engineers) standards for indoor air-quality are applied aiming to ensure the optimal climate in museums and other exhibition spaces. Many versions of ASHRAE standards [5] were developed over time.

In UK, the same concern for maintaining stable environmental conditions in museums exists, in particular for textile artefacts for whose preservation guides have been edited [6].

The smart system used to monitor the textile-material-based artefacts is described in section 2. Section 3 presents the method used to process gathered data and to identify the environmental risk. Experimental results including some measured value, processed data and environmental parameter evolution graphs are exposed in section 4. Finally, conclusions and references are presented.

2. Smart monitoring system of textile artefacts

The proposed smart monitoring system commands the environment control system for indoor exhibition or storing spaces containing textile artefacts like old pieces of clothing, carpets, tapestry etc. The materials used for these items can be various such as hemp, linen, silk, satin, canvas, wool or jute [7].

The monitoring system is composed by a wireless sensor network [8], a communication system and a processing unit. The entire system can be characterized as an adaptive automatic control system.

All the exhibited objects are monitored by many multi-sensor nodes placed around each artefact, on the upper, middle and lower sides of it, depending on the shape of the object.

Each node contains temperature, relative humidity and light sensors. Arduino boards with DHT-11 sensors, a resistive divider composed from a Light dependent resistor (LDR) and a 10k Ohms resistor and Li-ion batteries are used to implement the sensor node prototype (Figure 1 and Figure 2).

![Image 1](Sensor node)

![Image 2](Prototype image)

A set of data is collected from each sensor-node for each environmental parameter: temperature, relative humidity and light intensity.

The sensor nodes are grouped in clusters. It can be one-object cluster or a multiple-object cluster. The grouping of sensor nodes is made based on the distance between them. In each cluster, one sensor node works as a master node called cluster head. The cluster head collects data from all inside sensors monitoring one exhibited object and wirelessly sends it to the access point (AP) installed in the monitored room. All information get by the sensors are sent to the central communication node via the communication network of the museum in order to be stored and processed (Figure 3). In our prototype network, the central communication node and the processing unit are both located in the network server.

The table presented in Figure 4 includes some measured values from 6 sensors. These two nodes are placed in separated clusters.
Figure 3. Two-dimensional schematic representation of a monitored space.

Sensors number 1, 2 and 3 compose the first sensor node, represented by cluster 4 (Figure 3) while sensors number 4, 5 and 6 compose the second sensor node, represented by cluster 6 (Figure 3).

Sensors placed at higher height in the room get higher temperature and lower relative humidity values than the sensors placed in the bottom of the room. Measured light intensity value depends on the sensor position towards the light sources, natural or artificial.

Information get from each cluster is processed independently in order to make a decision regarding the control unit (e.g. air-conditioning equipment, dehumidifying device, smart glass or window blinding system) that must be started to correct some environmental parameters.

Figure 4. Some measured values (print screen).

Data collected periodically from the entire sensor network is stored in our database [9] and processed in order to identify risks based on critical events that occur regarding the environmental conditions in the exhibition space for each point-of-interest (POI) consisting one exhibited object. This
database manages monitored objects, sensors used by the monitoring system and values measured by it that are compared to specific thresholds, critical events, installed actuators and environmental control elements included in the control system. The database diagram is presented in Figure 5.

Figure 5. Database diagram.

Measured values can be read online, on the website designed by our team for the monitoring system, in order to be remotely accessed using a device connected to the Internet. The access to the web application is restricted for authorized users only. The supervisors have access to the information given by the monitoring system, anywhere and anytime, using any type of device with Internet access.

3. Environmental risk identification

The climate parameters must be monitored in order to be stable and to preserve the textile artefacts [11].

The heating regime in the exhibition space must be permanently monitored and controlled in order to keep temperatures between 10° and 20°C. In order to preserve textile artefacts, the exposure temperature must not drop below freezing. The textiles must not be placed in the vicinity of radiators and heaters too hot or dry. Air circulation around textile artefacts is also important in order to ensure a stable environment.

Textile materials absorb and release moisture from and to the air. Fast variation of relative humidity over time can cause different materials to separate. For example, painted areas can lift from the textile support when humidity changes. The textile density can be changed by high humidity. Other textile damaging processes can be caused by humidity variation. High relative humidity over 65% leads to mould outbreaks and pest infestations. Low relative humidity reduces moisture contents of textiles and the materials become brittle and dry. It is recommended to keep the relative humidity between 45% and 65%, for 90% of the time.

Light-damage on textile artefacts occurs progressively and it cannot be reversed. Therefore it is recommended to control strictly the light intensity that is correlated to the exposure time. For example, 1 hour - 5000 lux exposure is equivalent to 10 hours - 500 lux which is equivalent to 100 hours - 50 lux according to Museums Galleries Scotland.

Therefore the recommended light intensity for exhibited textile artefacts is 50 lux. In storing spaces, the light intensity can be lower but a completely dark environment is not recommended because it encourages different biological infestations by microorganisms. The environmental parameters are measured periodically by the sensors. All data collected is processed in the central node, differentiated by parameter type and POI.
This paper is not intended to do a statistic analysis of these parameters for a long time period but to identify the environmental risks in real-time. Therefore data are analysed on short time periods by processing a reduced set of values of each measured parameter.

The following variables can be calculated: the maximum and minimum values, amplitude, mean value, standard deviation, central value, variation coefficient, skewness and Kurtosis [10]. Extreme values of the environmental parameters are found by determining the maximum and the minimum value of it. These values are compared to specific thresholds in order to identify critical events.

These thresholds are established based on the recommended values of climate parameters given in the literature for textile materials.

The amplitude of a parameter is a measure of its change over a single period. It is calculated as the difference between the maximum value and the minimum one. In order to stabilize the environmental parameters and to maintain an optimal climate in the exhibition space for textile artefacts, the relative amplitude is used and it is defined by us as the difference between the average value and the optimal or a reference value of a parameter. The reference values can be a minimum allowed value, a maximum accepted one, a standard value given in literature or an experimentally deduced value regarding environmental parameters.

Depending on the relative amplitude, a risk class is identified in order to launch an environmental control protocol.

The risk classes are defined depending on the parameter type:
- temperature (T): cooling or heating risks can be identified;
- relative humidity (RH): drying or humidifying risks can be detected;
- light intensity (L): risk of light intensity rising can occur.

The risk level is expressed as low or no risk (0), moderate risk (1) or high risk (2).

The risk level of a parameter is variable because after the corresponding control unit is started, the risk level decreases. The risk level can increase if no action is commanded.

Depending on the risk level, a decision is made regarding the control action needed to correct a certain climate parameter. Different cases can occur:
1. For no risk, no action is commanded.
2. For an identified risk for only one parameter at a time, the corresponding control unit is started.
   The power of the device is dictated by the risk level: medium power for level 1 and full power for level 2.
3. A multiple decision has to be made based on the risk hierarchy when multiple risks are identified simultaneously. Composed risk classes (T-RH; T-L; RH-L; T-RH-L) must be analyzed. Risk levels are added in order to get the composed risk level. The number of simultaneous not-null risks is defined as the composed risk order. The risk associated to only one climate parameter has the order equal to 1.

In Table 1, simultaneous risk levels of heating or cooling, drying or humidifying, and light intensity rising are considered.

The energy criterion must also be considered by the decision process because it is not recommended to start all the control units in the same time. Temperature control has a higher priority than the relative humidity control that is in the same time prioritized towards the light intensity control.

A composed risk level higher than or equal to 4 is considered critical regarding the power consumption and this is recommended to be reduced by the made decision.

For order-2 composed risks, when the composed risk level is equal to 2 (e.g. for a risk level set 1-1-0), both control units are started with a medium power, but if the risk level of one parameter is equal to 2 only its corresponding control unit is started on full power, while the other control unit for the parameter having a moderate risk is started with medium power. In the critical situation when two risk levels have maximum values in the same time, the control unit of highest priority parameter is started first on full power and the second one is started only with medium power.

Order-3 risk levels are critical so the decision is made in order to reduce the power consumption.
For a composed risk of one maximum risk level and two moderate risk levels (e.g. for a risk level set 2-1-1), only two control units are started, one on full power, the other one on medium power, depending on the risk level and the parameter priority. For example, when the heating risk level is high, the humidifying risk is moderate and the light associated risk is moderate, than the air-conditioning equipment is started on full power and the dehumidifying unit is put on medium power.

For a composed risk of two maximum risk levels and one moderate risk level (e.g. for a risk level set 2-2-1), only two control units corresponding to maximum risk are started, but their starting power is dictated by the parameter priorities.

For a composed risk of three maximum risk levels (with the risk level set 2-2-2), two control units are started firstly. The decision on which control units have to be turned on and with what power level to work depends only on the parameter priorities.

### Table 1. Composed Risk Classes.

| Heating/ Cooling Risk Level | Humidifying /Drying Risk Level | Light Intensity Rising Risk Level | Composed Risk Level | Composed Risk Order |
|-----------------------------|--------------------------------|----------------------------------|---------------------|---------------------|
| 1                           | 1                              | 0                                | 2                   | 2                   |
| 2                           | 1                              | 0                                | 3                   | 2                   |
| 2                           | 2                              | 0                                | 4                   | 2                   |
| 1                           | 2                              | 0                                | 3                   | 2                   |
| 1                           | 0                              | 1                                | 2                   | 2                   |
| 2                           | 0                              | 1                                | 3                   | 2                   |
| 2                           | 0                              | 2                                | 4                   | 2                   |
| 1                           | 0                              | 2                                | 3                   | 2                   |
| 0                           | 1                              | 1                                | 2                   | 2                   |
| 0                           | 2                              | 1                                | 3                   | 2                   |
| 0                           | 2                              | 2                                | 4                   | 2                   |
| 1                           | 1                              | 2                                | 3                   | 2                   |
| 2                           | 1                              | 1                                | 3                   | 3                   |
| 2                           | 1                              | 1                                | 4                   | 3                   |
| 1                           | 2                              | 1                                | 4                   | 3                   |
| 1                           | 2                              | 2                                | 4                   | 3                   |
| 2                           | 1                              | 2                                | 4                   | 3                   |
| 2                           | 2                              | 1                                | 5                   | 3                   |
| 2                           | 2                              | 2                                | 5                   | 3                   |
| 1                           | 2                              | 2                                | 6                   | 3                   |

### 4. Experimental results and discussions

All sensors measure the environmental parameters every minute. A lot of data has to be processed so it is necessary to do a centralized data processing in the central node. Based on the analysis results, a multiple decision is made. The decision can regard the temperature, the relative humidity or the light intensity or a combination of them.

Gathered data is analysed on short time periods by processing the last 5 values of each measured climate parameter. The results are used to command the control units and to estimate the next
The variation of the environmental parameters for one sensor-node is presented below for a 12 minutes interval (Figure 6, Figure 7 and Figure 8). No action was commanded to control the environmental parameters.

**Figure 6.** Temperature Variation over 12 minutes.

**Figure 7.** Relative Humidity Variation over 12 minutes.

**Figure 8.** Light Intensity Variation over 12 minutes.
The measured values for the considered time interval are given in Table 2. Light Intensity is expressed as percentage of the maximum value.

**Table 2. Parameters Measured Values.**

| Index | Temperature (°C) | Relative Humidity (%) | Light Intensity (%) |
|-------|------------------|-----------------------|---------------------|
| 1     | 27               | 50                    | 82                  |
| 2     | 27               | 51                    | 81                  |
| 3     | 27               | 51                    | 81                  |
| 4     | 27               | 50                    | 80                  |
| 5     | 27               | 51                    | 56                  |
| 6     | 27               | 74                    | 56                  |
| 7     | 28               | 95                    | 57                  |
| 8     | 28               | 95                    | 57                  |
| 9     | 28               | 95                    | 58                  |
| 10    | 29               | 95                    | 58                  |
| 11    | 30               | 95                    | 59                  |
| 12    | 31               | 95                    | 27                  |

The measured values are analyzed on sets of five consecutive values. In Table 3, we consider the temperature risk levels to be 1 if the relative amplitude is less than two Celsius degrees and it is equal to 2 if it has a higher value. In this case, the *heating* risk class occurs. Then in Table 4, humidifying risk is identified. The relative humidity risk level is equal to 1 if the relative amplitude is under 10 % and it is considered to be equal to 2 for higher values. Finally, in Table 5, the light intensity rising risk is analyzed. The risk level value is considered to be equal to 1 for relative amplitudes lower than 10 % and 2 for more than 10 %.

**Table 3. Temperature Processed Values (reference 26 °C) (Heating Risk).**

| Index | $T_{MAX}$ (°C) | $T_{MIN}$ (°C) | $T_{AVERAGE}$ (°C) | Relative Amplitude (°C) | Risk Level |
|-------|----------------|----------------|--------------------|-------------------------|------------|
| 5     | 27             | 27             | 27                 | 1                       | 1          |
| 6     | 27             | 27             | 27                 | 1                       | 1          |
| 7     | 28             | 27             | 27.2               | 1.2                     | 1          |
| 8     | 28             | 27             | 27.4               | 1.4                     | 1          |
| 9     | 28             | 27             | 27.6               | 1.6                     | 1          |
| 10    | 29             | 27             | 28                 | 2                       | 2          |
| 11    | 30             | 28             | 28.6               | 2.6                     | 2          |
| 12    | 31             | 28             | 29.2               | 3.2                     | 2          |

From this analysis, it result a third order combined risk because no control is done over the environment during the considered time interval.
Decision about how to control the environment must be made according to Section 3. Analytic Hierarchy Process (AHP) can be used to improve the multiple-decision process when combined environmental risks are identified [12].

**Table 4.** Relative Humidity Processed Values (reference 50 %) (Humidifying Risk).

| Index | RH\textsubscript{MAX} (%) | RH\textsubscript{MIN} (%) | RH\textsubscript{AVERAGE} (%) | Relative Amplitude (%) | Risk Level |
|-------|-----------------|-----------------|-----------------|---------------------|------------|
| 5     | 51              | 50              | 50.6            | 0.6                 | 1          |
| 6     | 74              | 50              | 55.4            | 5.4                 | 1          |
| 7     | 95              | 50              | 64.2            | 14.2                | 2          |
| 8     | 95              | 50              | 73              | 23                  | 2          |
| 9     | 95              | 51              | 82              | 32                  | 2          |
| 10    | 95              | 74              | 90.8            | 40.8                | 2          |
| 11    | 95              | 95              | 95              | 45                  | 2          |
| 12    | 95              | 95              | 95              | 45                  | 2          |

**Table 5.** Light Intensity Processed Values (reference 50 %) (Light Intensity Rising Risk).

| Index | LI\textsubscript{MAX} (%) | LI\textsubscript{MIN} (%) | LI\textsubscript{AVERAGE} (%) | Relative Amplitude (%) | Risk Level |
|-------|-----------------|-----------------|-----------------|---------------------|------------|
| 5     | 82              | 56              | 76              | 26                  | 2          |
| 6     | 81              | 56              | 70.8            | 20.8                | 2          |
| 7     | 81              | 56              | 66              | 16                  | 2          |
| 8     | 80              | 56              | 61.2            | 11.2                | 2          |
| 9     | 58              | 56              | 56.8            | 6.8                 | 1          |
| 10    | 58              | 56              | 57.2            | 7.2                 | 1          |
| 11    | 59              | 57              | 57.8            | 7.8                 | 1          |
| 12    | 59              | 27              | 51.8            | 1.8                 | 1          |

The preservation of textile artefacts or the damage of them depends on this decision process and on the environment control system efficiency.

**5. Conclusions**

Environment monitoring of the indoor spaces used to exhibit or store textile artefacts is essential for their preservation. The proposed monitoring system is able to measure environmental temperature, relative humidity and light intensity in different points using multi-sensor nodes connected into a wireless sensor network. The measured values of the parameters are stored in a dedicated database that manages the sensors from the wireless sensor network, too. These values are processed in the central node and compared to recommended reference values for textile artefacts preservation. Risk classes can be identified and the risk level can be established. According to it, control procedures have to be started in order to ensure the proper environment for the exhibited textile artefacts. Experiments were made with the implemented monitoring system and some measured and processed data are presented as an example of how the environmental risk can be identified and classified.
6. References

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