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# Smart Classroom Study Design for Analysing the Effect of Environmental Conditions on Students' Comfort

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**Abstract.** This paper presents a work in progress study focusing on evaluating the environmental conditions and its influence on students' academic performance. The motivation is to find link between the environmental factors such as temperature, humidity, indoor air quality, lightning and the sense of comfort of individual students measured by the specific body movements. The paper elaborates on the sensor network architecture and the movement identification as well as on the multi-factor study design. The results of this study will be used to design a smart classroom that would control for identified influencing factors in order to improve students' comfort and provide for better academic performance.

**Keywords.** Smart classroom, environmental conditions, test anxiety, study design.

## 1. Introduction

Taking exam is a critical activity in every students' life. The exam result is the measure of student competences and success. However, the exam result is not only influenced by attained knowledge but also by the environment in which the exam is taken [27]. The evidence suggests that the student's performance is effected by environmental factors such temperature, noise, lighting, indoor air quality, decoration, etc. [17]. Automating control of these factors might be beneficial to enhance students' attention during a lecture or performance during a test.

This paper presents a work in progress study focusing on evaluating the environmental conditions and its influence on students' comfort during lecture or exam. The motivation is to find a link between the environmental factors such as temperature, humidity, indoor air quality, lightning and the sense of comfort of individual students measured by the body movements. The link will further be analysed in respect to exam scores. The results of this study will be used to design a smart classroom that would control for the identified influencing factors in order to improve students' comfort and provide for better academic performance. Similar study has been conducted by Uzelac et al. [25] but they measured the attention by students' self-evaluation. In this study, instead of self-evaluating the attention, the comfort will be measured as little body movements while the students are seated during a lecture or test. The body movements will be sensed using accelerometers in seats. The paper will expand on the study design scenario, on the sensor network architecture and on the students' motion sensing.

## 2. Review of the literature

There is an extensive body of research studying the effect of various factors on human behaviour. Research, for example, indicates that noise is a pervasive source of stress and even low to moderate intensity could degraded performance [11]. Appropriate lightning and artificial illumination may have under specific conditions positive effect on cognitive abilities such as long-term memory and problem-solving tasks [12; 22]. Also, poor ventilation might affect human performance. It has been found that higher concentration of $CO_2$ has detrimental effect on decision making [20]. Thermal comfort is regarded as a dominant factor influencing overall satisfaction with indoor environment [5]. In office environments the productivity is believed to decrease if the temperature was above 25 °C [9]. Sometimes, the environment with lower temperatures that reduce the thermal comfort are reported to increase performance in activities requiring attention [23]. There are also studies focusing on combined effect of the environmental factors such as temperature, lightning and acoustics [16].

The application of smart technology in order to improve working environment is also thoroughly researched. The current proliferation of sensors and the advancements in data processing enabled the real workspace to be blended with a virtual one. In the context of learning smart technology is deployed in various scenarios. These scenarios include instruction enhancements, classroom environment adaptation, lesson management automation, energy saving, etc. Khalfallah [10] for example utilized web camera and analysed facial expression in order to promote understanding. Yang [26] suggested how to integrate new devices into the smart classroom infrastructure without complex configuration so that students can download materials and make notes using their preferred devices and applications. Aguilar [1] deployed agent communities to define sets of agents with their characteristics, roles, functionalities in a smart classroom environment. Koutraki [13] applied ontology and rule based system in a classroom assistant that recognizes classroom activities and adjust the environment accordingly. Shen [21] equipped the classroom with near field communication (NFC) technology to automate attendance management, locate students and provide real-time student feedback. Similarly, Kim [8] utilized radio-frequency identification (RFID) to implement smart display system that identifies students and presents individualized timetables, announcements, lecture plans, and similar information. Luansheng [15] introduced electric power line communication bus in campus building in order to control classroom illumination and save energy. There are also attempts to evaluate the smart classroom environment. Huang [7] developed a framework to evaluate smart classroom environment that focuses on behaviour, technology and physical environment. Li [14] elaborated smart classroom inventory based on identified features. They propose to use several scales such as physical design, flexibility, technology use, learning data, etc. to assess the effectiveness of a smart classroom environment.

The study presented in this paper fits into the classroom environment adaptation. The major difference from the listed studies is that the attention is focused not only on analysing effects of individual factors but also on investigating the interactions among the identified factors.

## 3. Study aims and design

The study will be conducted at the premises of the Faculty of Informatics and Management, University of Hradec Kralove. A medium size lecture hall with 63 seats in a theatre style will be equipped with a set of sensors to account for factors influencing the classroom environment. The study aims to answer the research question that focuses on whether there is a statistically significant effect of environmental conditions to students' anxiety and exam scores. The impact of environmental conditions on students' scores has already been studied for example in [6] and reviewed for example in [17]. However, it needs to be confirmed that these diverse conditions could be simulated for the purposes of this study. The environmental conditions will include the following factors: temperature, humidity, light, noise and $CO_2$ level. These factors will represent independent variables. The dependent variable will be the students' discomfort or anxiety. The level of discomfort or anxiety will be measured as the number of student's repeated movements. These repeated students' movements will be identified using the accelerometer. Each independent factor will be considered in two levels high and low. The full factorial study design would require $2^5 = 32$ runs. Performing the study in such extend would require too many students and would be beyond resource limitation. Therefore, the fraction factorial study design will be used. A fraction factorial study design enables to focus on an adequately chosen fraction of factor combinations in a full factorial study design [3]. In particular, the study would follow the quarter factorial design $2^{5-2} = 8$ runs. The penalty for performing just a quarter of runs is that there will be confounding factors that is in some cases the unique contribution of each factor would not be possible to determine. Assuming the factors are denoted as ABCDE, the generators in $2^{5-2}$ are ±D=AB and ±E=AC. The defining relationship in this design is then I=ABE=ACE=BCDE. Using the defining relationship it is possible to determine all the confounding factors. The $2^{5-2}$ is a resolution III design it means that the shortest word in the defining relationship is of length 3. That is the main effect will be confounded with second order interactions. In regard to confounding factors, the factor A should be assigned to less important factor. This is because the main effect of A factor is confounded with two second order interactions. Also, the main effects of other factors are confounded with second order interactions of the A factor. Therefore, it is desirable that the interactions with A are rare and have low impact on the estimated dependent variable. If these second order interactions are assumed to have zero effect then the effect could be attributed purely to the given factor as main effect. In the presented study the A factor will be the humidity. Humidity is believed to be just an auxiliary factor. It is also believed that there is almost no interaction with the other factors. The Table 1 shows the factor with notation and confounding interactions.

**Table 1.** Factors and confounding interactions.

| Notation | Factor | Confounding interactions |
|---|---|---|
| A | Humidity | Temperature * Noise; Light * $CO_2$ Level |
| B | Temperature | Humidity * Noise |
| C | Light | Humidity * $CO_2$ Level |
| D | Noise | Humidity * Temperature |
| E | $CO_2$ Level | Humidity * Light |

Based on the previous considerations the runs will be designed with respect to 5 factors and 2 levels. The quarter factorial design with 8 runs will be extend with another run with two center point runs i.e. runs in which all factors will have centre values given their value range. The designated runs are shown in Table 2. The plus sign in the Table 2 refers to the high level of a given factor and the minus sign refers to the low level of a given factor. The zero represent the central value of a given factor.

**Table 2.** Designated runs and factor levels. High level (+). Low level (-).

| No. | A Humidity | B Temperature | C Light | D Noise | E $CO_2$ Level |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | + | + | + | + | + |
| 3 | - | + | + | - | - |
| 4 | + | - | + | - | + |
| 5 | - | - | + | + | - |
| 6 | + | + | - | + | - |
| 7 | - | + | - | - | + |
| 8 | + | - | - | - | - |
| 9 | - | - | - | + | + |
| 10 | 0 | 0 | 0 | 0 | 0 |

The runs will be also randomized to avoid possible influence of extraneous factors except the center point runs. The center point runs will be scheduled as first and last runs.

## 4. Participants

The study will focus on young psychologically healthy university students aged up to 25 years. The participants will be recruited among the students of the Faculty of Informatics and Management, University of Hradec Králové. During the recruitment procedure the information about the study will be announced and potential participants will be listed. The runs will be performed during the lectures of selected courses. Therefore, for the student to be eligible he/she has to be enrolled in these courses. Further, they have to be enrolled for the first time, since the level of anxiety might be different in repeated enrolments. Similarly, students cannot take that exam before i.e. students that failed previously will not be further eligible for the study. Eligible volunteers will be given further information asked for informed consent. Students, however, will be blinded to distinctions of different environmental conditions. The reason is to avoid placebo like effect in which participant behave the way they are expected to in regard to the group they are in. Thus, students will be randomly assigned to the designed runs. Runs will be scheduled during the period of one month. It is assumed that there will be approximately 20 students in each run. Given, there are 10 runs approximately 200 students will participate in the study.

## 5. Sensor network architecture

The proposed sensor network architecture is based on heterogeneous hierarchical arrangement. The hierarchical structure organizes network nodes into grids, trees or clusters [2; 18]. The nodes in a cluster communicate with a special node denoted as cluster head. The cluster head directs data to the base station also called sink [4]. The sensors will be deterministically placed at the appropriate locations in the lecture hall. In a heterogeneous network there are various nodes with different roles and therefore the suggested network architecture has been split into three layers. The Figure 1 shows the proposed sensor network architecture.

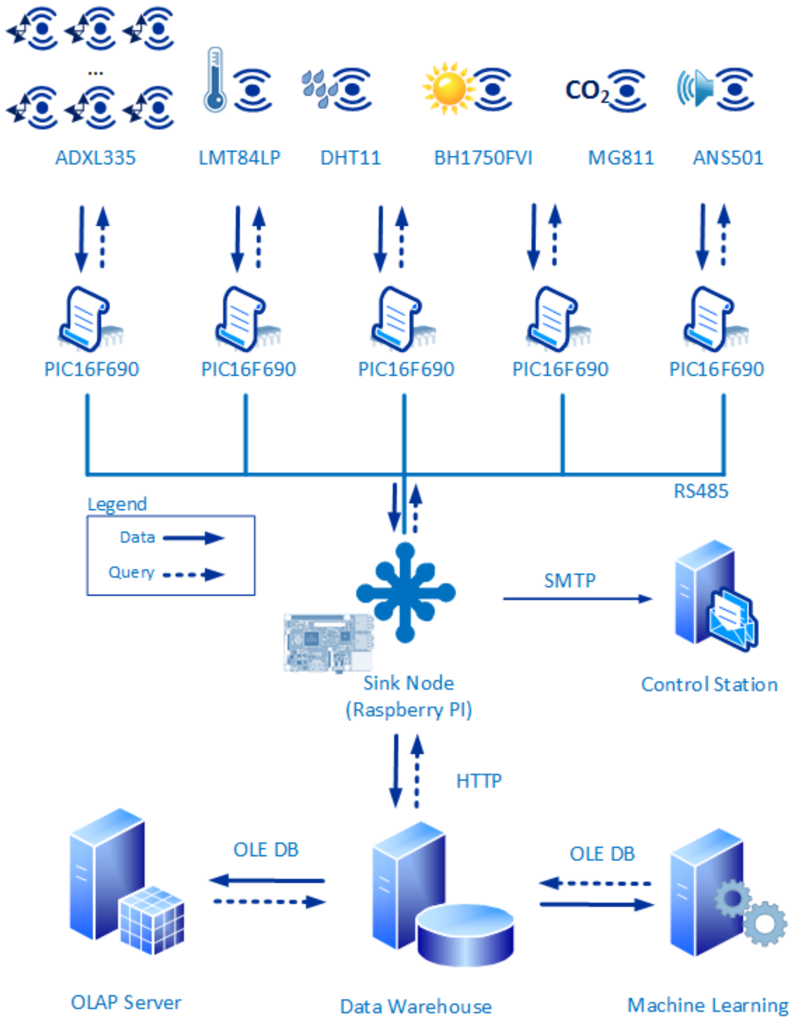


**Figure 1.** Sensor network architecture.

The first layer is responsible for capturing the sensor generated data. The layer includes individual sensors and microcontrollers. The sensors measures the above stated factors (temperature, humidity, light, noise and $CO_2$ level). In particular, sensors used in this study will be as follows:

- 63x ADXL335 accelerometers
- 2x LMT84LP thermometers
- 1x DHT11 humidity sensors
- 1x BH1750FVI light sensor
- 1x MG811 $CO_2$ sensor
- 1x ANS501 sound sensor

The sensors nodes will be connected to cluster heads represented by PIC16F690 microcontroller. The microcontroller will be programmed to query sensors and fetch data in given time intervals. The time interval will differ based on the sensor type. The shortest time interval will be set to accelerometer sensors in order to identify even little movements. If necessary the microcontroller will buffer sensor data before passing it to the sink node. No other data aggregation will be performed at this level. Each PIC16F690 could control up to 3 sensors. Therefore, there will be 21 microchips to control 63 accelerometers. The other sensors will require another 2 microchips. In total there will be 69 sensor nodes and 23 cluster heads. The sensor nodes and cluster heads (microcontrollers) will be hard wired.

The second layer will be represented by a sink node and will be responsible for fusing data from cluster heads. The sink node will consist of Raspberry PI like Advanced RISC Machine (ARM) computer. The sink node will query cluster heads in a sequential manner and will fetch the data. The data received from all sensors will be timestamped and written to specified flat files. The flat files will be organized according the time when the data were recorded. The data files will be made available for download through traditional HTTP (Hypertext Transfer Protocol). The sink node and the cluster heads will be connected using the RS485 communication standard. The basic RS485 enables to connect up to 32 devices. In case one of the cluster heads will stop responding the sink node will send a node failure notification to the control station as a standard mail message. The clusters will be independent so the failure of one cluster will not influence the performance of other clusters. There is, however, no redundancies among clusters, so if a cluster fails the data will not be available until the cluster will be up again.

The third layer will serve for data exploration. The key component in the data exploration layer will be a data warehouse. The data warehouse will import data from the sink node on regular basis. The data in the flat file structure supplied by the sink node will be transformed to a star schema. The dimensions will reflect the particular sensor, location or seat and time. The data warehouse will further be extended with students' performance data (such as test score, student activity, etc.). The data warehouse will provide data for OLAP (Online Analytical Processing) presentation and machine learning processing. The data warehouse will be implemented using MS SQL Server 2014 solution and the data will be accessible through OLE DB (Object Linking and Embedding, Database).

## 6. Capturing the students' movements

In this study we attempt to relate the discomfort, anxiety and attention distraction to students' movements during a lecture or a test. Thus, the accelerometers will measure the students' movements as signs of discomfort or anxiety. The accelerometers will be mounted to each flapping seat in the lecture hall. The joint based construction of the flapping seat and the flexibility of the seat allow to measure the vibration caused by student's moves. The number and scale of the moves will reflect the level of discomfort.

The accelerometer used in this study is the ADXL335 produced by Analog Devices Corporation. The ADXL335 can measure tilt like static acceleration as well as dynamic acceleration caused by motion or vibration. The ADXL 335 has been tested as a part of the ActiGraph GT3X device for reliability. The results indicated that the accelerometer has high intra and inter-instrument reliability [19]. The ADXL 335 is a 3 axis accelerometer, however, due to fix rotation of the flapping seat only X and Y axis will change if side view of the seat is considered. To capture the student's moves the dominant force will be along the Y axis as the seat will bend up and down.

The experimental set up with a seat and attached accelerometer revealed that the sampling frequency of measuring the movements should not be less than 2 Hz. In order to identify even little trembling and shaking anxiety symptoms the accelerometer will be set to 10 Hz data gathering frequency. The accelerometer should report data in $ms^{-1}$. The particular units are however not important. Therefore, the data gathered from the accelerometer will be scaled and normalized using the following formula in Eq. (1).

$$\hat{X} = \frac{X - \mu}{\sigma} \tag{1}$$

The $\hat{X}$ is the vector of transformed values; X is the vector of the accelerometer values; μ is the mean; σ is the standard deviation. The data that are scaled and normalized have the mean value 0 and standard deviation 1. Figure 2 shows data sample of scaled and normalized accelerometer data.


**Figure 2.** Scaled and normalized accelerometer data. The roman number I and II denote movements.

The data represent a 30 second time series with two movements. There is a lean forward and back movement (I) and leg tremble (II). It could be seen that there is some noise in data i.e. even though the student is in a steady state the accelerometer reported some movements. The noise makes the repeated leg tremble movement difficult to discern. The data reported during the steady state has little differences in subsequent values. Therefore, the repeated contrasts [24] were calculated. To get positive values the calculated contrasts were squared.

$$\hat{x}_i = (x_{i+1} - x_i)^2 \qquad (2)$$

The Figure 3 shows accelerometer data with squared repeated contrasts according to the equation Eq. (2). The transformation amplifies the movements (I) and (II). The transformation also helps to distinguish the movement (I) as actually two movements lean forward and lean backward.

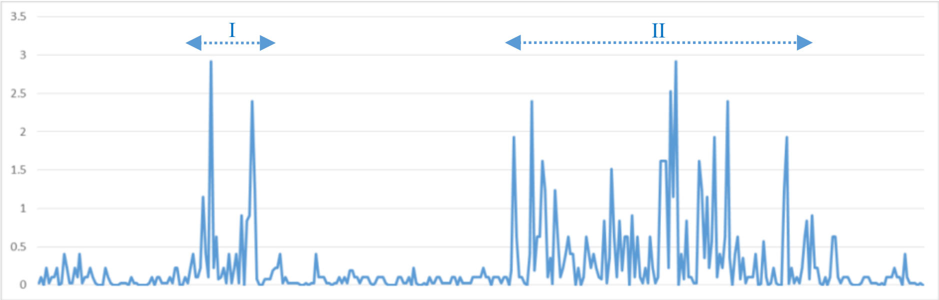


**Figure 3.** Accelerometer data with squared repeated contrasts.

## 7. Conclusion

The evidence suggests that environmental factors might influence students' performance. The concept of smart classroom introduced in this paper focuses on analysing the effect of environmental factors such temperature, humidity, light, noise and $CO_2$ level. Studying the effect of several factors would require trial with several arms. The paper elaborates on a fraction factorial study design that entails only over a quarter of runs. The paper also outlines the sensor network architecture used in the study. The proposed architecture is capable of monitoring movements of over 60 students. Finally, the paper discusses the way how specific movements are identified based on gathered data. It is assumed that the study presented in this paper could provide new insights on how students' performance is effected by environmental factors. The presented study is a prerequisite to research on optimizing the automated control of selected environmental factors in order to improve the students' academic performance.

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