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A Simple and Robust Intelligent Environment Monitoring System for Special Purpose Medical Laboratories

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***Abstract* – Controlling the environment is a critical component of quality assurance in laboratories. That is because in many cases the environmental condition can severely alter the quality of results. In other cases, having complex systems operating in a non-compliant environment can lead to malfunctions or decreased life-span of those systems. This is exactly the case of large medical or molecular biology or laboratories. Typically, most available commercial solutions are comprised of a set of sensors and a system logic which decides to override and reprogram the maintenance systems to return to desired conditions. This article introduces a simple and robust intelligent system with a feedback loop for monitoring and alerting in the scenario the environment parameters get out of range. Besides continuous display, visual and sound alerts, the system is equipped with the possibility of sending SMS-notifications to a given set of phone numbers (remotely located human administrators) with delivery of current environmental out of range parameter values. Threshold values can be easily redefined since the system has a separate initialized file containing all the configurable parameters and scenarios.**

Keywords – quality assurance, microcontroller, uncertainty estimation, SMS, environment control, medical laboratory

I. INTRODUCTION

The current advent of mobile solutions generated by myriad of devices, together with their accessibility, made the development of intelligent control systems a ubiquitous presence. The widespread of the INTERNET lead to the following statement: there is no use for mobile solutions if the information cannot be accessed anytime, anywhere [1]. Currently, there is an ongoing development of control systems (some of them cost-effective and miniaturized) for a myriad of industrial, scientific and also daily applications. Paper [1] discusses the implementation of automated control systems within a large company (ABB Sweden). The reviews emphasize the main benefits of automated solutions: human operators spend less and less time in dangerous / toxic environment, therefore the needs of advanced protective gear becomes less of a challenge in several scenarios. Also, real-time access to relevant information and / or the ability to run various analyses based on that information is a major advantage compared to classical on-the-spot data collection. While the information is available almost everywhere there is communication, there are certain risks that need to be addressed, the main one being security. Paper [1] suggests there needs to be a balance between the security level (important in many applications, e.g. nuclear power plants) and availability of information. Rapid development of software features with the addition of dedicated hardware ensures a robust and independent development. The article mentions the extensive use of environmental sensors, gyroscopes, accelerometers used by the ABB control systems. The article foresees the use of augmented reality by ABB engineers for machines maintenance driven by the fact that continuous updates will trigger request of new features. A bio-inspired environmental platform is described in [2]. The monitoring system is able to move in aquatic (marine) environment, record data from sensors but also execute tasks. The field of application is also toxic environment (i.e. marine oil spill accidents). The central processing unit is implemented on a PIC microcontroller, components connected via joints which are actuated by Faulhaber micromotors. The navigation is done via a GPS-system. The device was reported to follow a mission-path and record data, both in simulation scenario (pool) and real-life scenario (Lake Geneva). Paper [3] describes a mobile control system for soil moisture monitoring for grape vineyards, almond and olive trees. The implemented system consists of 12 sensing locations. The communication between the sensor systems and central unit is done via 868 MHz band. The central unit is controlled by a low-power PIC microcontroller while the power supply is given by solar panels and rechargeable batteries. The entire network covers an area of 10 km x 10 km and the entire system can be considered as fault-tolerant since there are several sensing units. Study [4] presents a monitoring system for agricultural areas where fresh water is used 70% for this purpose. The system consists of 16 sensing units and collects information about rainfall, temperature and wind. The information is sent via ZigBee network to a central unit. A web-based application displays the information on a map in a meaningful way for the human operator. That is because each sensing unit is equipped with a GPS locator. The central unit is implemented on a MSP430F2274 microcontroller. Depending on the environmental parameters, the irrigation algorithm decides when and how long to start the irrigation process. All this information is stored in a cloud database such that backward data inspection can be done. The system was found to increase irrigation efficiency, therefore water savings. Paper [5] presented a similar system but based on a different microcontroller (ATmega 128L) connected to a star network-topology. A remote monitoring system with display on an Android smartphone is presented in [6]. A camera automatically starts recording when a light sensor detects lights on and data is transmitted via ZigBee wireless network to a smartphone for display. Since the power system is connected to the microcontroller, the user can also switch off the lights remotely via the smartphone app. A monitoring system for tomato hydroponics cultures is described in [7], [12]. It is known that tomato cultures require a lot of care from the irrigation point of view. The system implemented in this paper decreases the need for labor work and increases the quality of crops. Also, the system is cost effective. The communication protocol uses the 400 MHz band since the propagation radio propagation is better even in high humidity environments. The system estimates the amount of hydroponic liquid based on the information coming from sensors deployed in the crops. The amount of hydroponic liquid is determined based on evotranspiration which is derived from vapor pressure deficit and relative light intensity. The latter information is read by the sensors. Based on the computational result, the actuators which are controlled by the processing unit feed the hydroponic liquid. Even though conceptually simple, in order to produce high-quality crops, the liquid has to be supplied delicately, in the right amounts (in the range of mm) and in real-time. The evaluation of this system generated its implementation in greenhouses in Japan. Paper [8] introduces a monitoring system for fruits' cold storage. The sensors send temperature data to a modem and the information is available to the human operator via the internet. The system uses a general purpose 8051 microcontroller. The information provided by the sensors is also stored in a Google cloud database. Another application of mobile control systems is in the field of home appliances of people suffering from a medical condition (e.g. Alzheimer's disease, deafness, etc). Paper [9] presents such a system which is primarily meant to improve the quality of life. The system is comprised of an Android mobile device, a GSM network and a home information center. This center implemented in a PIC microcontroller receives information from the door bell, and light sensors. An SMS is generated to the smartphone which alerts the user interface such that the human operator can decide accordingly. Opening the door, switching on / off the lightning is done in a similar fashion by an automated SMS which triggers the home information center to perform the required task. A similar application is implemented in [10], [13], [15] where multiple home appliances are centrally operated from a smartphone (e.g. curtains, light intensity level, fans, etc). Also, the system is equipped with gas sensors in order to enhance safety. The mobile control systems can also be applied in media with high traffic. Paper [11] describes a monitoring system operating in subway stations in order to control the fan output and orientation. This is critical especially in confined spaces where pollution elements can easily accumulate. The system consists of humidity / temperature, gas sensors and a central control unit. The positioning of fans was arranged such that the quality of air was best at all levels (platform, waiting halls and tunnel entrance). Study [14] introduces a sophisticated monitoring system mounted on the wing of drones (UAV) in order to early identify and prevent icing which can pose a serious threat to the aircraft safety. The high precision sensors (icing) transfer the information to the control system which can decides whether it is safe to continue the flight or immediately land.

II. ARTICLE CONTRIBUTION

The contribution of this work can be seen at different levels: firstly the application field - molecular biology labs where environmental conditions can easily alter the quality of results. In these labs, the environmental conditions can change fast given the increased heat output of machines operating in the lab and also the fact that usually these labs are located in confined spaces. Secondly, this paper uses an Atmel microcontroller (ATmega328P) which is connected to high performances sensors. Thirdly, the system uses a layer-based system (depending on severity of alert): light, display, audio and SMS. All the necessary information is transmitted via GSM communication to a preset number. Also, the uncertainty estimation is in detailed evaluated.

III. MATERIALS AND METHODS

The proposed system is based on ATmega328P microcontroller (Atmel, USA) featuring the parameters in Table 1.

Table 1. ATmega328P parameters.

CPU	8-bit
Flash memory	32 kB

E2PROM	1 kB
Operating Frequency	20 MHz
I/O Pins	26
No. of channels	16

The sensor system contains a digital humidity-temperature sensor SHT 75 (Sensirion, Switzerland) having the pinout in Table 2.

Table 2. SHT 75 pinout.

Pin 1	SCK	9
Pin 2	VCC	VCC
Pin 3	GND	GND
Pin 4	DATA	8

The communication is done via standard RS-233 protocol. The GSM – GPRS communication board (Quectel Wireless, China) is connected to the serial port of the ATmega328P microcontroller. The sound alert device is connected to the digital pin 11 while the light alert is connected to the digital pin 10.

The 2 x 16 LCD display (from Xiamon Amotec, China) is connected as presented in Table 3.

Table 3. LCD display connections.

RS LCD	Pin 5
E LCD	Pin 4
DB4 LCD	Pin 3
DB5 LCD	Pin 2
DB6 LCD	Pin 1
DB7 LCD	Pin 0

The entire programming is done in ANSI C. Fig. 1 below presents the control system.

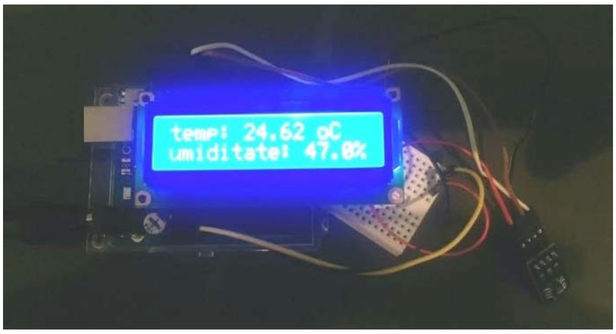

Fig. 1. Environment control system based on ATmega328 microcontroller

Given the environment in the special purpose medical laboratories the temperature and humidity can quickly (matter of tens of minutes) increase due to the high heat output from machinery (mainly high-throughput of medical analyzers in case of genetic laboratories or scanning machinery in case of nuclear medicine scanners). Many of these machines have a heat output greater than 30,000 BTU / h and usually a room houses more than one unit. The sensor is to be mounted on a side-wall at 1 m height to increase the reliability of measurement. The flow-chart in Fig. 2 describes the functionality of the system.

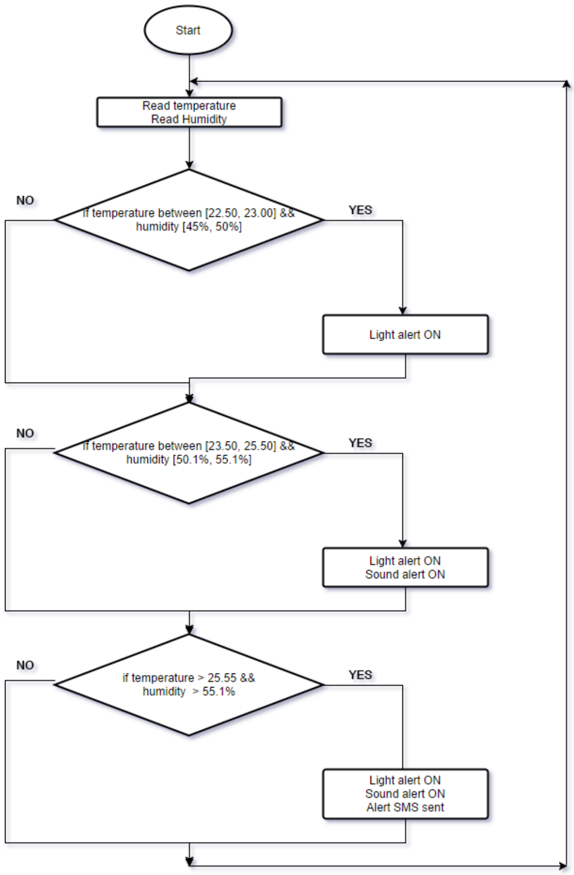

Fig. 2. System flow-chart

IV. RESULTS

The first step was to calculate the extended uncertainty for the sensory system. For this purpose, it was used the formulae introduced in [16]. The system was tested in several work scenarios: no workload, after 1 h of full workload, 2 h of full workload, 5 h after switching on the cooling systems, 2 h after switching off the cooling systems. Table 4 and Table 5 present the data obtained for humidity and temperature, at a time-step of 1 min for a time-frame of 30 min. In all the cases, the measurement uncertainty was found to be 0.0022 C while in case of humidity it was found to be below 0.008%. For each, the measurement uncertainty was computed. In the 2nd step, the entire system was also evaluated for the time-periods mentioned above.

V. DISCUSSION

In this paper, a new environmental control system was introduced with an application to special purpose medical laboratories where strict environment control is critical.

The system is hardware-wise simple yet robust with multiple features (e.g. automatic SMS sending, alert levels). Supplementary, the alert levels can be easily be programmed to other values given that these are input values defined in a special external configuration file. Interestingly, the sensory system performed well but it is noticeable that with the temperature - humidity increase, also the measurement uncertainty increased. However, given the fact that the cooling systems go off as soon as the alert is raised, this effect can be labeled as side-effect. In any case, the increase in uncertainty is minimal.

Table 4. Temperature data obtained for different work scenarios.

Set 1	Set 2	Set 3	Set 4	Set 5
23.03	25.33	28.36	21.35	23.83
23.01	25.34	28.37	21.36	23.82
23.01	25.33	28.36	21.34	23.84
23.02	25.32	28.36	21.35	23.85
23.02	25.32	28.35	21.35	23.84
23.03	25.32	28.36	21.34	23.84
23.02	25.33	28.36	21.35	23.84
23.02	25.32	28.34	21.34	23.83
23.04	25.31	28.35	21.34	23.85
23.04	25.31	28.35	21.35	23.86
23.04	25.33	28.35	21.33	23.84
23.04	25.31	28.36	21.35	23.84
23.05	25.33	28.37	21.35	23.85
23.04	25.33	28.36	21.34	23.84
23.04	25.33	28.37	21.34	23.85
23.04	25.33	28.35	21.35	23.84
23.03	25.33	28.35	21.35	23.84
23.04	25.32	28.37	21.33	23.85
23.04	25.32	28.37	21.34	23.85
23.04	25.33	28.36	21.35	23.85
23.04	25.31	28.36	21.35	23.87
23.04	25.32	28.36	21.34	23.86
23.05	25.31	28.36	21.35	23.85
23.05	25.59	28.36	21.34	23.86
23.05	25.59	28.37	21.35	23.85
23.04	25.6	28.36	21.35	23.86
23.04	25.59	28.36	21.35	23.85
23.04	25.59	28.36	21.35	23.87
23.04	25.59	28.36	21.34	23.87
23.03	25.6	28.35	21.36	23.88
		Measurement Uncertainty		
0.00202	0.02124	0.00139	0.00132	0.00241

VI. CONCLUSION

The proposed system was found to be robust and easy to use in a special purpose medical laboratory (a nuclear medicine laboratory and a genetic lab). The system is easily portable and configurable. It can also be further interfaced with HVAC systems via the free USB port attached to the board. Also, the system can be reprogrammed according to other application needs. The system fully benefits of the GSM features being able to send SMS messages to predefined recipients containing important information. Also, via the same GSM features, the system could also be programmed to receive commands via SMS messages sent by specially designated users.

Table 5. Humidity data obtained for different work scenarios.

Set 1	Set 2	Set 3	Set 4	Set 5
51.82	51.95	51.57	63.24	48.63
51.83	51.93	51.55	63.21	48.61
51.99	51.8	51.64	63.08	48.73
52.12	51.8	56.27	63.08	48.79
52.18	51.9	56.24	63.18	48.73
52.12	51.93	56.33	63.21	48.64
51.83	51.86	56.3	63.14	48.7
51.77	51.8	56.33	63.08	48.57
51.86	51.86	56.27	63.14	48.51
51.96	51.77	56.3	63.05	48.45
51.93	51.58	56.27	62.86	48.35
51.8	51.67	56.3	62.95	48.16
51.61	51.67	56.52	62.95	48.03
51.64	51.8	56.81	63.08	48.03
51.8	52.59	56.65	63.87	48.29
51.71	53.19	56.49	64.47	48.51
51.71	53.19	56.46	64.47	48.79
51.67	52.88	56.43	64.16	49.05
51.58	52.63	56.49	63.91	48.92
51.58	52.56	56.62	63.84	48.7
51.8	52.56	56.52	63.84	48.61
51.93	52.44	56.49	63.72	48.76
51.96	52.37	56.49	63.65	48.73
51.93	52.37	56.42	63.65	48.57
51.74	52.25	56.17	63.53	48.48
51.55	52.09	56.11	63.37	48.57
51.61	51.9	56.39	63.18	48.73
51.71	51.74	56.46	63.02	48.89
51.74	51.71	56.36	62.99	48.89
51.61	51.61	56.3	62.89	48.99
		Measurement Uncertainty		
0.03098	0.08383	0.26944	0.08381	0.04631

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