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Protect the Storing Paper Documents Using PICBASIC Microcontroller Board

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حماية المستندات الورقية المخزنة باستخدام لوحة المتحكم الدقيق PICBASIC

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Abstract:
Paper is one of the most important materials used to save information due to its simplicity of use and low cost, even today and development of the digital technologies, paper documents are still irreplaceable in storing and backing up information. However, paper as a material is still vulnerable to environmental hazards and fires which may lead to its deterioration. The main factors that affect paper deterioration, specifically in the study region in Sabratha/Libya are: sun rays, temperature, humidity, and dust, the objective of this study is to design a control system that provides the proper environment for paper document storing by monitoring and detect the deterioration factors. The control system of this research is consisting of PICBASIC Microcontroller board and a specific set of sensors such as LM35 for temperature, HIH-4000 to sense the humidity, NORPS-2 to detect the light intensity, MQ-7 for smoke and harmful gases, and the actuators which are the number of solid-state relays and contactors to control the doors, windows, ventilation fans, and air conditions, the system also use the LCD to display the level of deterioration factors.

Keywords: Microcontrollers; PICBASIC; Sensors; Environmental Conditions.

الملخص
يعد الورق من أهم المواد المستخدمة لحفظ المعلومات بسبب بساطته في الاستخدام وانخفاض تكلفته نسبياً، وحتى يومنا هذا ومع تطور التقنيات الرقمية، لا تزال المستندات الورقية لا يمكن الاستغناء عنها في تخزين المعلومات وعمل نسخ احتياطية منها. ومع ذلك، فإن الورق كمادة يكون عرضة للمخاطر البيئية والحرائق التي قد تؤدي إلى تلفه. إن العوامل الرئيسية التي تساهم في تلف الورق وتحديداً في منطقة الدراسة في صبراتة/ليبيا هي: أشعة الشمس، ودرجة الحرارة، والرطوبة، والغبار، والهدف من هذه الدراسة هو تصميم نظام تحكم يوفر البيئة المناسبة لتخزين المستندات الورقية عن طريق مراقبة وكشف عوامل التدهور. يتكون نظام التحكم في هذا البحث من لوحة PICBASIC Microcontroller ومجموعة محددة من المستشعرات مثل LM35 لدرجة الحرارة، HIH-4000 لاستشعار الرطوبة، NORPS-2 للكشف عن مدى شدة الضوء، MQ-7 للدخان والغازات الضارة، بالإضافة الى المشغلات وهي عبارة عن عدد من المرحلات الالكترونية والقواطع للتحكم في الأبواب والنوافذ ومراوح التهوية وتكييف الهواء، كما تم في البحث استخدام شاشة LCD لعرض مستوى عوامل التدهور.

الكلمات المفتاحية: المتحكمات الدقيقة؛ لوحة PICBASIC؛ المجسات؛ الظروف البيئية.

1. Introduction

When designing Archives and Record Storage facilities, several critical systems must be taken into account to ensure the preservation and protection of the materials stored within. Key among these systems are HVAC (Heating, Ventilation, and Air Conditioning), fire alarm, and fire suppression systems. To fully integrate these functions and maintain comprehensive oversight, an advanced monitoring and control system is required. This is generally referred to as a control system, which allows for the seamless coordination of environmental and safety mechanisms. In recent years, the rapid pace of technological advancements, particularly in the realm of internet connectivity, has profoundly impacted both industrial and educational sectors. Industry 4.0, the so-called fourth industrial revolution, has driven the digital transformation of industrial processes, with digitalization now being a cornerstone of modern operations across various industries [1].

Understanding and regulating the environmental conditions within archives and libraries is critical for the long-term preservation of collections. Effective environmental management helps optimize resource allocation while ensuring that preservation strategies are appropriately tailored to the specific needs of each collection. In this context, the study presented in this paper details the design of a system aimed at maintaining optimal environmental conditions within the archives at the Faculty of Engineering in Sabratha, employing a microcontroller-based approach. Microcontrollers are highly efficient in executing tasks such as reading sensor data and implementing control algorithms. However, it is important to acknowledge that these devices operate in a digital domain, whereas the real world functions in an analog, continuous manner. To bridge this gap, microcontrollers rely on two fundamental processes: digital-to-analog conversion (DAC) to translate binary data into actual output voltages, and analog-to-digital conversion (ADC) to convert real-world analog signals into digital data that the microcontroller can process [2].

Typically, microcontrollers are utilized in real-time control systems where rapid response is required to modify outputs based on changing input conditions. In simpler applications, assembly language is often used to maximize execution speed and minimize memory usage. However, for more complex systems, higher-level programming languages are necessary to enhance functionality and efficiency. PIC microcontrollers, for instance, are often programmed in languages such as C or BASIC, which offer a balance between ease of learning and control over system architecture. These higher-level languages, being more akin to human-readable syntax, are easier to understand than assembly language and do not require intimate knowledge of the underlying microcontroller architecture [3]. This paper explores the implementation of these systems, detailing the critical role that microcontrollers and associated control systems play in maintaining environmental stability, ensuring the preservation of vital documents and records over time.

2. Material and methods

2.1 Environmental Factors Influencing the Deterioration of Paper Documents

Libya’s climate, influenced by both the Mediterranean and desert regions, poses significant challenges to the preservation of paper documents. The extremes of the desert climate result in fluctuating temperature and relative humidity, as well as exposure to light, and gaseous and particulate contaminants. Proper control of these environmental factors, especially temperature and humidity, is essential for the long-term preservation of archival and library collections. The following are the most critical environmental factors influencing the deterioration of paper documents:

2.1.1 Temperature

Temperature refers to the measurement of the average kinetic energy of the molecules within an object or system, typically measured with a thermometer. Lowering the temperature can slow down chemical reactions in paper and ink, thereby reducing the rate of degradation. For the preservation of books and documents, cold storage, which involves maintaining low temperatures and humidity, is a key strategy. Ideally, temperatures near or even below the freezing point are recommended for long-term preservation [5].

2.1.2 Relative Humidity

Relative Humidity (RH) is defined as the percentage ratio of the amount of water vapor present in the air compared to the maximum amount the air could hold at the same temperature and pressure. When air reaches 100% relative humidity, condensation occurs. Higher temperatures enable the air to hold more moisture, whereas cooling the air reduces its moisture capacity, increasing RH. For archival materials, low RH is preferred as paper tends to absorb moisture when moved from a cool, dry environment to a warm, humid one, and releases moisture when transferred from a warm, humid environment to a cooler, drier one. This process can cause dimensional changes in the paper, such as swelling and shrinking of cellulose fibers, which may lead to mechanical stress and deterioration [5].

2.1.3 Sunlight

Light, a form of electromagnetic radiation, spans a spectrum from radio waves to gamma rays. It accelerates the degradation of library and archival materials by weakening and embrittling cellulose fibers. Prolonged exposure to light causes paper to bleach, yellow, or darken and can lead to fading or color changes in media, dyes, and inks. This results in the loss of legibility and the visual quality of documents, photographs, artworks, and book bindings. Even brief exposure to light can cause irreversible damage, which accumulates over time [6].

2.1.4 Air Quality and Pollutants

Airborne pollutants play a significant role in the deterioration of paper and archival materials. Pollutants can be classified into two major categories: gaseous and particulate. Gaseous pollutants, such as sulfur dioxide, nitrogen oxides, peroxides, and ozone, catalyze chemical reactions that result in the formation of acids within materials. This is particularly harmful to paper and leather, leading to discoloration, brittleness, and weakening. Particulates, including soot, can abrade, soil, and disfigure archival materials, further exacerbating their deterioration [5].

2.1.5 Fire

Fire is a chemical reaction that requires four elements to exist: heat, fuel, oxygen, and a chain reaction. While combustion processes are complex, fire generally occurs when a material rapidly oxidizes, producing heat and flame. To extinguish a fire, one can remove any of the four essential elements. Heat can be absorbed by applying a substance like water, fuel can be removed (though this is often impractical), and oxygen can be displaced by using inert gases such as carbon dioxide (CO2), nitrogen, or steam. For paper fires, the CO2 method is particularly effective as it suffocates the fire without damaging the materials [7].

2.2 Microcontrollers and Sensors

Microcontrollers have played a pivotal role in the evolution of embedded systems since their inception. Even when Intel introduced its first microprocessor, the 4004, in 1971, there was already a demand for microcontrollers. The contemporary TMS1802 from Texas Instruments was designed for calculators and later adapted for use in cash registers, watches, and measuring instruments. The TMS1000, introduced in 1974, was one of the earliest examples of a true microcontroller, integrating RAM, ROM, and I/O on a single chip, though it was initially labeled a microcomputer. The first widely adopted microcontrollers were the Intel 8048, commonly used in PC keyboards, and its successor, the Intel 8051. Similarly, the Motorola 68HCxx series gained popularity across various applications. Today, microcontroller production numbers are in the billions, and they are embedded in numerous devices we use daily, from household appliances like microwaves and washing machines to mobile phones, automobiles, aerospace systems, and industrial automation processes [8].

2.2.1 Microcontroller Components

A microcontroller contains all the necessary components for standalone operation and is specifically designed for monitoring and control tasks. In addition to the central processor, it includes memory, various interface controllers, timers, an interrupt controller, and general-purpose I/O pins that allow direct interaction with its environment. Moreover, microcontrollers have bit-level operations that enable manipulation of individual bits within a byte without affecting the other bits, which is crucial for precise control tasks [8]. Microcontrollers serve as the backbone of numerous real-time control systems, making them indispensable for applications that demand fast and reliable responses to changing inputs.

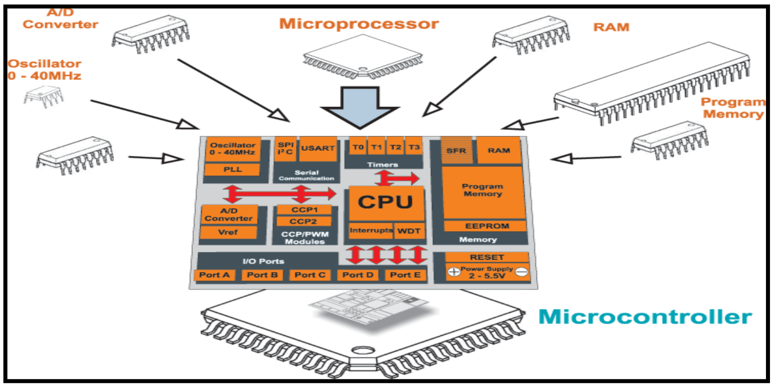


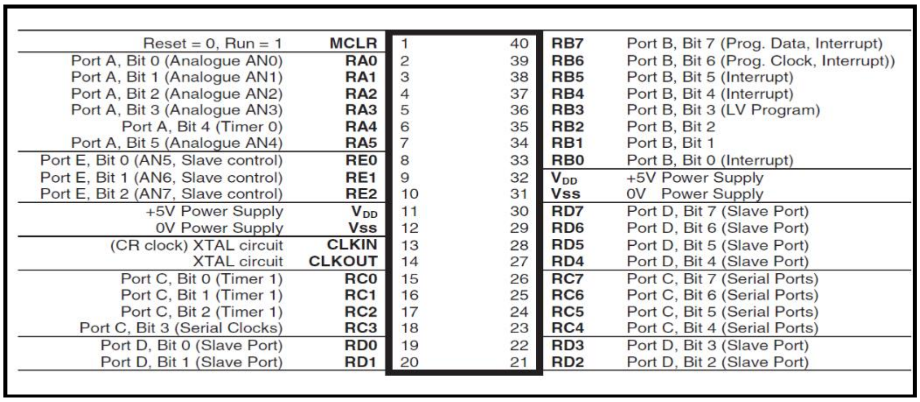
Figure 1: Microcontroller components.

2.2.2 PIC16F877A Microcontroller

Microcontrollers are available in a variety of types and can be classified according to several criteria, including bus-width, memory configuration, instruction set, architecture, and manufacturer. One of the most widely used microcontrollers is the PIC16F877A, a member of the PIC family, which is known for its versatility and ease of use. The PIC16F877A comes in a 40-pin Dual In-line Package (DIP), with its functions distributed across the pins. One of its key advantages is that each pin is typically assigned only two or three functions, which simplifies the task of determining the appropriate function for each pin. The PIC16F877A is equipped with a set of built-in serial communication ports, allowing for efficient data transfer between the microcontroller and other devices. Additionally, it features analog inputs, which enable the measurement of various real-world signals, such as temperature. This capability makes it particularly useful in embedded systems that require the interfacing of digital and analog components. While microcontrollers differ in their specific designs and features, the fundamental operation of all standard microcontroller types is similar. As a result, an in-depth understanding of the operation of the PIC16F877A provides a solid foundation for grasping the functions and operations of other microcontroller models [9].

2.2.3 PIC16F877 Architecture

The PIC16F877, illustrated in Figure 2, is a 40-pin, 8-bit CMOS (Complementary Metal-Oxide Semiconductor) FLASH microcontroller developed by Microchip. It is built on a high-performance RISC (Reduced Instruction Set Computing) CPU architecture, which is notable for its simplicity and efficiency. The PIC16F877 uses a minimal set of 35 single-word instructions, which streamlines processing. Following the RISC architecture, most of these instructions execute in a single instruction cycle, with the exception of program branches that require two cycles. Therefore, the microcontroller operates at three selectable clock speeds: 4 MHz, 8 MHz, or 20 MHz. With a 20 MHz oscillator, each instruction cycle requires four clock cycles, which translates to an instruction execution time of 0.2 microseconds (µs). This allows for efficient and rapid data processing, making it suitable for time-critical embedded applications. In this direction, the microcontroller features two types of data memory: a 368-byte RAM (Random Access Memory) for temporary data storage and a 256-byte EEPROM (Electrically Erasable Programmable Read-Only Memory) for storing non-volatile data. These memory types ensure flexibility in managing both dynamic and persistent data in various applications.



Reset = 0, Run = 1	**MCLR**	1	40	**RB7**	Port B, Bit 7 (Prog. Data, Interrupt)
Port A, Bit 0 (Analogue AN0)	**RA0**	2	39	**RB6**	Port B, Bit 6 (Prog. Clock, Interrupt))
Port A, Bit 1 (Analogue AN1)	**RA1**	3	38	**RB5**	Port B, Bit 5 (Interrupt)
Port A, Bit 2 (Analogue AN2)	**RA2**	4	37	**RB4**	Port B, Bit 4 (Interrupt)
Port A, Bit 3 (Analogue AN3)	**RA3**	5	36	**RB3**	Port B, Bit 3 (LV Program)
Port A, Bit 4 (Timer 0)	**RA4**	6	35	**RB2**	Port B, Bit 2
Port A, Bit 5 (Analogue AN4)	**RA5**	7	34	**RB1**	Port B, Bit 1
Port E, Bit 0 (AN5, Slave control)	**RE0**	8	33	**RB0**	Port B, Bit 0 (Interrupt)
Port E, Bit 1 (AN6, Slave control)	**RE1**	9	32	**V_{DD}**	+5V Power Supply
Port E, Bit 2 (AN7, Slave control)	**RE2**	10	31	**Vss**	0V Power Supply
+5V Power Supply	**V_{DD}**	11	30	**RD7**	Port D, Bit 7 (Slave Port)
0V Power Supply	**Vss**	12	29	**RD6**	Port D, Bit 6 (Slave Port)
(CR clock) XTAL circuit	**CLKIN**	13	28	**RD5**	Port D, Bit 5 (Slave Port)
XTAL circuit	**CLKOUT**	14	27	**RD4**	Port D, Bit 4 (Slave Port)
Port C, Bit 0 (Timer 1)	**RC0**	15	26	**RC7**	Port C, Bit 7 (Serial Ports)
Port C, Bit 1 (Timer 1)	**RC1**	16	25	**RC6**	Port C, Bit 6 (Serial Ports)
Port C, Bit 2 (Timer 1)	**RC2**	17	24	**RC5**	Port C, Bit 5 (Serial Ports)
Port C, Bit 3 (Serial Clocks)	**RC3**	18	23	**RC4**	Port C, Bit 4 (Serial Ports)
Port D, Bit 0 (Slave Port)	**RD0**	19	22	**RD3**	Port D, Bit 3 (Slave Port)
Port D, Bit 1 (Slave Port)	**RD1**	20	21	**RD2**	Port D, Bit 2 (Slave Port)

Figure 2: The PIC16f877A Pin-Out.

2.2.4 IC Temperature sensors

There is a wide variety of temperature sensor ICs (Integrated Circuits) available that are designed to address the broadest range of temperature monitoring challenges. These silicon-based temperature sensors offer unique operational characteristics, including a wide temperature range, typically from -55°C to +150°C. This allows them to be suitable for a variety of industrial, environmental, and consumer applications where accurate temperature monitoring is crucial. Moreover, one of the primary advantages of temperature sensor ICs lies in their integrated functionality. As integrated circuits, these sensors can incorporate extensive signal processing circuitry within the same package, thereby eliminating the need for external compensation circuits typically required by other types of temperature sensors. This design simplicity allows for more efficient and compact systems. Temperature sensor ICs are available in two main types: analog and digital. Analog temperature sensors typically output either a voltage or a current that is proportional to the sensed temperature. These analog outputs can be fed into other circuits for further processing. Some analog sensors also include voltage comparators, which provide alert functions when a certain temperature threshold is exceeded.

On the other hand, digital temperature sensor ICs are designed to interface directly with microprocessor-based systems. They combine analog-sensing circuitry with digital input/output and control registers, making them ideal for applications where the temperature must be monitored and controlled via a microcontroller or microprocessor system. With this context, the temperature sensor illustrated in Figure 3 has three terminals and requires a maximum supply voltage of 5.5v. This type of sensor operates based on the principle that its resistance varies with temperature. As the temperature changes, the material inside the sensor alters its resistance, which is then measured by the circuit. The circuit calculates the temperature based on this resistance change. An increase in voltage corresponds to an increase in temperature. Because these sensors can be directly connected to microprocessor inputs, they offer reliable and efficient communication with microprocessors, making them well-suited for real-time temperature monitoring in various embedded applications [10].

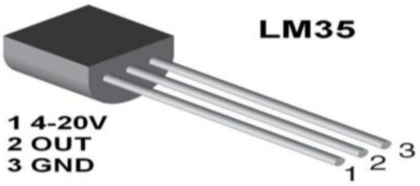


Figure 3: LM35 IC temperature sensor.

IC temperature sensors can be classified based on both the input source and the output signaling method, allowing for diverse applications in temperature monitoring and control. The input source typically refers to the temperature measured at the IC’s own package, as the sensor monitors its internal temperature. However, certain configurations allow for specialized measurements. For example, some temperature sensors incorporate an on-chip heater, which elevates the package temperature above ambient levels, enabling the detection of airflow or other environmental changes. Additionally, diode-connected transistors can be used to measure remote temperatures, allowing the sensor to monitor external locations away from the IC package.

2.2.5 Humidity sensors

Humidity sensors are critical components in modern data acquisition systems, playing an essential role in both environmental monitoring and the control of industrial processes. In the context of the big data era, these sensors provide indispensable real-time data, helping to optimize human living environments and monitor industrial production with precision. The importance of humidity sensors is particularly evident in applications where controlling moisture levels is crucial, such as in HVAC systems, agricultural monitoring, and various manufacturing processes [12]. Research on Relative Humidity (RH) sensors frequently focuses on the materials used, which can be either organic or inorganic, and their fabrication techniques. Common materials include porous ceramics (semiconductors), polymers, ceramic/polymer composites, and electrolytes. These materials are chosen based on their conductivity properties and their ability to accurately detect humidity levels. The development of these sensors relies heavily on the conduction mechanisms within the materials and the fabrication technologies employed, which determine the sensor's sensitivity, accuracy, and durability.

The HIH-4000 Series Humidity Sensors, as depicted in Figure 4, are designed specifically for high-volume Original Equipment Manufacturer (OEM) applications. These sensors provide a linear voltage output, enabling direct integration with controllers or other devices, making them highly versatile for various applications. With a typical current draw of only 200 µA, the HIH-4000 Series is particularly well-suited for low-power, battery-operated systems, where minimizing power consumption is critical. Moreover, the tight sensor interchangeability in this series helps reduce or even eliminate the need for OEM production calibration, thereby reducing manufacturing costs [13], [14].

Figure 4: HIH4000 Relative humidity sensor.

This series delivers instrumentation-quality RH sensing performance in a cost-effective, solderable Single In-line Package (SIP). The sensor is available in two lead spacing configurations, further enhancing its adaptability for different applications. At the core of the HIH-4000 Series is a laser-trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning, ensuring high accuracy and reliability. The multilayer construction of the sensing element also provides strong resistance to environmental hazards such as moisture, dust, dirt, oils, and other common industrial chemicals, making it a robust choice for various demanding environments [13], [14].

2.2.6 Light sensors

Photoresistors, also commonly referred to as light-dependent resistors (LDRs) or photocells, are semiconducting devices that exhibit variable resistance based on the intensity of light they are exposed to, as illustrated in Figure 5. The core principle behind photoresistors is the behavior of the semiconductor material when exposed to light. When light strikes the surface of a photoresistor, the energy from the light's radiation is absorbed by the material. This absorbed energy excites electrons, causing them to move from the valence band to the conduction band of the semiconductor. As more electrons populate the conduction band, the material's ability to conduct electricity increases, thereby lowering its resistance. In other words, increased light exposure leads to a significant decrease in resistance.

Figure 5: LDR light dependent resistance sensor.

In complete darkness, the photoresistor exhibits its maximum resistance, often close to 100%, meaning it allows very little current to pass through. Conversely, as light intensity rises, the resistance decreases, allowing more current to flow through the device. This characteristic makes photoresistors ideal for applications that require light sensing or light-controlled functionality, such as automatic lighting systems, light meters, and other light-sensitive devices [15].

2.2.7 Carbon Monoxide sensors

Carbon monoxide (CO) detectors are essential safety devices that generate an electrical signal when they detect a specific concentration of carbon monoxide over a period of time. These sensors are widely employed in both residential and industrial settings, as well as in automotive applications, to detect and prevent the accumulation of toxic carbon monoxide gas. Given the dangers associated with CO exposure, reliable detection is critical. There are various types of carbon monoxide sensors available, each with different sensing technologies to address specific environments and detection needs.

One common type of CO sensor is the MQ-7 gas sensor, as depicted in Figure 6. This sensor consists of several components, including a micro–Aluminum Oxide (Al2O3) ceramic tube, a Tin Dioxide (SnO2) sensitive layer, measuring electrodes, and a heater, all housed within a casing made from plastic and stainless-steel mesh. The Tin Dioxide (SnO2) layer serves as the active sensing material, as it reacts to the presence of carbon monoxide by altering its electrical resistance. The integrated heater creates the appropriate operating conditions by ensuring that the sensitive components are maintained at the required temperature.

Figure 6: MQ7 Carbon monoxide sensor.

The combination of these elements enables the MQ-7 to detect carbon monoxide in the surrounding environment with high sensitivity. The sensor provides a direct electrical signal output corresponding to the CO concentration, which can then be interpreted by the connected system to trigger an alarm or safety response when dangerous levels of carbon monoxide are detected. Due to its robust construction and sensitivity, the MQ-7 is commonly used in a variety of gas detection systems, providing an effective and cost-efficient solution for carbon monoxide monitoring.

2.3. Experimental design

The work presented here employed a constructive design research approach, where insights were obtained through a blend of field studies, iterative design explorations, and a solid theoretical foundation derived from existing literature. This methodology allowed for a practical and theory-informed exploration of the design process. The initial step in designing the archive storage environment was to select a real-world environment as a sample and troubleshoot ideas through practical applications. The goal was to develop suitable conditions for storing paper documents by designing a control system capable of mitigating the key factors that affect the quality of storage. These factors include temperature, relative humidity, sunlight, harmful gases, and fire. The case study focused on the Sabratha Faculty of Engineering (SFE), specifically the archive used by the Department of Study and Exams for storing important documents such as exam papers and student results. This real-world application served as a reference point, ensuring that the design work remained grounded in a setting where it could eventually be implemented. The second step involved the creation of a system to mitigate the hazards affecting the archive environment. To do this effectively, it was necessary to develop a sequence of operational steps (the system algorithm) that the control system would follow before moving on to its implementation. This systematic approach ensured that the design addressed the environmental challenges specific to archive storage and laid the groundwork for an applicable and functional solution.

2.4. Control peripherals

The fluctuation of temperature in the archive is measured using the LM35 IC temperature sensor, which provides precise readings of temperature variations. Similarly, changes in relative humidity are detected by the HIH4000 humidity sensor, while variations in light density within the archive are monitored by a Light Dependent Resistor (LDR). For detecting the presence of fire and harmful gases, the MQ-7 gas sensor is employed, which is particularly sensitive to carbon monoxide (CO). All these sensor outputs are sent as input signals to the microcontroller, which serves as the central processing unit for the system. When the temperature or humidity levels exceed the required thresholds, the system activates air conditioning to restore optimal conditions. Additionally, after a fire is detected, the system uses the air conditioning system to help clear smoke from the environment. In the prototype, a low-voltage fan is used to simulate the air conditioning unit, showcasing the system's capability to manage environmental controls.

In the event of a fire, the system triggers CO2 valves to release CO2 gas into the archive to suppress the fire. In the prototype, a lamp is used to simulate the opening of the CO2 valves. Furthermore, the system includes an alarm mechanism that alerts personnel to the presence of a fire. A beeper, specifically the PBM-R5, is utilized to simulate the sound of the fire alarm, ensuring timely notification of potential hazards. This integrated control system efficiently monitors and responds to environmental fluctuations in the archive, ensuring that critical conditions such as temperature, humidity, and fire hazards are addressed in real time to protect sensitive documents.

2.5. Control algorithm

To effectively monitor and control the various environmental factors that impact the preservation of paper documents, these factors were organized according to their level of threat. For instance, a fire presents a significantly higher risk compared to fluctuations in relative humidity. This classification not only prioritized each factor based on its potential to cause damage but also considered whether a specific factor could influence others. A clear example of this interdependency is the relationship between illumination levels and temperature. When sunlight enters the archive, it can cause a misreading of the ambient room temperature, as direct sunlight can artificially raise localized temperatures. Therefore, illumination was given a higher priority level than temperature, ensuring that light levels were regulated first to avoid inaccurate temperature readings.

This prioritization was particularly important in scenarios where multiple threats occurred simultaneously, exposing the paper to more than one irregularity. In such cases, it was critical to assess whether the mechanisms used to manage these threats could work in tandem or might conflict. For example, certain actions, such as activating ventilation systems and CO2 fire suppression, could be incompatible. Operating both mechanisms simultaneously could potentially damage both the paper documents and the equipment. Thus, the system had to be designed to avoid these risks by prioritizing the most pressing threat while managing other conditions accordingly. The findings from this study demonstrated that controlling uncontrolled air flow, by shutting down mechanical ventilation systems such as air conditioning units, was effective in managing all the environmental factors affecting the paper documents. Moreover, the control system proved capable of containing fires while maintaining overall environmental stability within the archive. This strategic approach to threat prioritization and factor interdependencies allowed for a more effective protection and preservation of sensitive archival materials.

2.5.1 Fire and / or smoke stage

The results of the present study indicate that the system's fire containment mechanism is activated only when a significant increase in gas concentration, specifically carbon monoxide (CO), is detected in the room. This detection, made by the MQ-7 gas sensor, serves as confirmation of a fire. Upon receiving this critical reading, the microcontroller initiates a sequence of actions aimed at containing the fire. One of the primary responses is to prevent uncontrolled airflow, as it could exacerbate the fire by providing a fresh supply of oxygen (O_2), which is one of the key elements needed for combustion. To avoid further fueling the fire mechanical ventilation systems such as air conditioning units are temporarily halted, effectively containing the oxygen supply within the room. This is a crucial step in the fire containment strategy, as uncontrolled ventilation could lead to the rapid spread of the fire.

Once the immediate fire threat is addressed, the system then employs the air conditioning system to clear smoke from the room. This helps to ensure that any residual smoke, which could obscure visibility or cause damage, is effectively removed from the archive environment. The system will remain in this emergency containment mode until the smoke detector provides a reading that indicates a return to normal gas concentration levels, confirming that the fire has been extinguished and there is no further threat. Only at this point will the microcontroller signal the system to exit the fire containment stage, resuming regular environmental control operations. This staged, conditional response ensures a safe and efficient method for managing fire hazards without causing additional damage to archival materials.

2.5.2 Light Stage

Since exposure to light—whether natural (sunlight) or artificial—can adversely affect the integrity of stored paper documents, the system is designed to react promptly to both sources. When excessive light is detected, the system automatically triggers the closing of windows to block sunlight. Additionally, an alarm is sounded to alert operators, allowing them to investigate and address the issue of artificial lighting or other potential problems. This protective mechanism ensures that sensitive documents are shielded from harmful light exposure, which can cause degradation over time, such as fading of ink or weakening of paper fibers. Once the system confirms that the windows have been successfully closed, it will exit the light-management stage. However, if the system detects smoke in the room while responding to the light issue, it will prioritize the fire containment protocols, overriding the light protection mechanism, as fire presents a more immediate threat to the safety of the archive. This ensures that the system effectively manages multiple environmental hazards, prioritizing the most urgent risk.

2.5.3 Temperature and humidity stage

The results of the study demonstrated that the system enters this stage when either temperature or relative humidity exceeds the recommended values for optimal archival storage. In this stage, the air conditioning system is activated to lower both the temperature and humidity levels until they return to the recommended range. During this process, the system continues to monitor all other environmental factors, ensuring that no additional threats, such as fire or gas leaks, arise. The system is designed to exit this temperature and humidity regulation stage when the temperature and humidity have been restored to safe levels. However, if a higher-level threat, such as the detection of fire or gas, is identified while the air conditioning is running, the system will prioritize addressing the more urgent issue and override the current process. This real-time monitoring and threat prioritization allow the system to maintain a balanced and controlled environment for storing sensitive documents. The entire process is illustrated in the flow graph, as shown in Figure 7, which provides a visual representation of how the system responds to various environmental factors in a step-by-step manner.

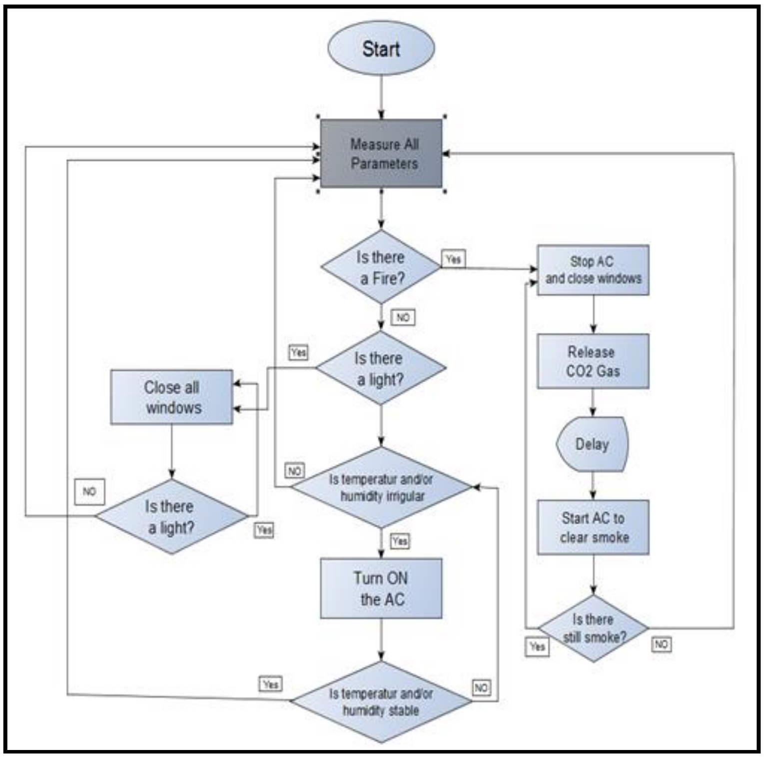


Figure 7: Algorithm flow chart.

2.6 Hardware and connections

After the system algorithm was designed, the subsequent step involved assembling the control circuit using the necessary hardware devices and electronics, all connected to the microcontroller. This step was critical to ensure the system could monitor and control the environmental conditions for paper document storage effectively. To achieve this, each sensor (such as the LM35 temperature sensor, HIH4000 humidity sensor, LDR for light detection, and MQ-7 gas sensor) and each actuator (such as the air conditioning system, CO2 valve, and alarms) were properly connected according to the design.

The circuit was set up to interface the microcontroller with these components, allowing it to process input data from the sensors and trigger the appropriate actions through the actuators. Figures 8 and 9 provide detailed circuit diagrams that illustrate the hardware setup. These diagrams depict how each sensor and actuator is integrated into the system, showing their connections to the microcontroller's input and output pins. This ensures that the system is capable of responding to environmental changes in real time, such as adjusting temperature, controlling humidity, regulating light exposure, or managing fire threats, based on the sensor data received. The proper configuration of these components is essential for the system to function reliably and maintain the integrity of the stored documents.

2.7 Control unit programming

After developing the algorithm to monitor, manipulate, and control the environmental factors affecting the paper storage process, the next step was to link the algorithm to the hardware system and define the practical functionality of the control system. This was achieved by programming the microcontroller using PICBASIC Studio—an Integrated Development Environment (IDE) specifically designed for programming PIC microcontrollers using the BASIC language. Using PICBASIC Studio, the code for the control system was written and then stored in the program memory of the microcontroller. This allowed the microcontroller to execute the algorithm in real-time, processing sensor data and controlling the actuators accordingly. PICBASIC Studio, as depicted in Figure 10, provides a user-friendly interface for writing, debugging, and uploading code to the microcontroller. The software supports a wide range of PIC microcontrollers and simplifies the process of programming by offering built-in commands and libraries tailored for microcontroller functionalities. The integration of the control algorithm with the hardware system, through the programming done in PICBASIC Studio, resulted in a fully functional system capable of maintaining the optimal storage environment for paper documents by controlling variables such as temperature, humidity, light exposure, and fire hazards [16], [17].

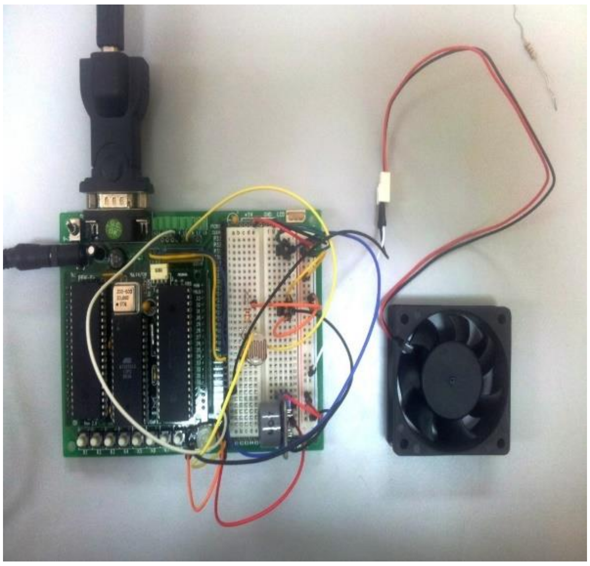


Figure 8: Designed system circuit.

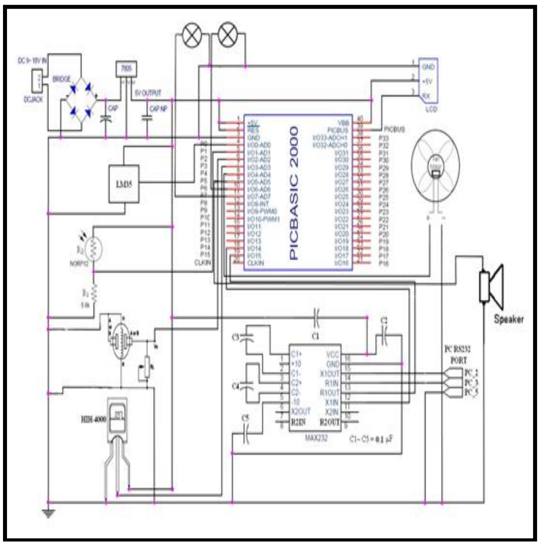
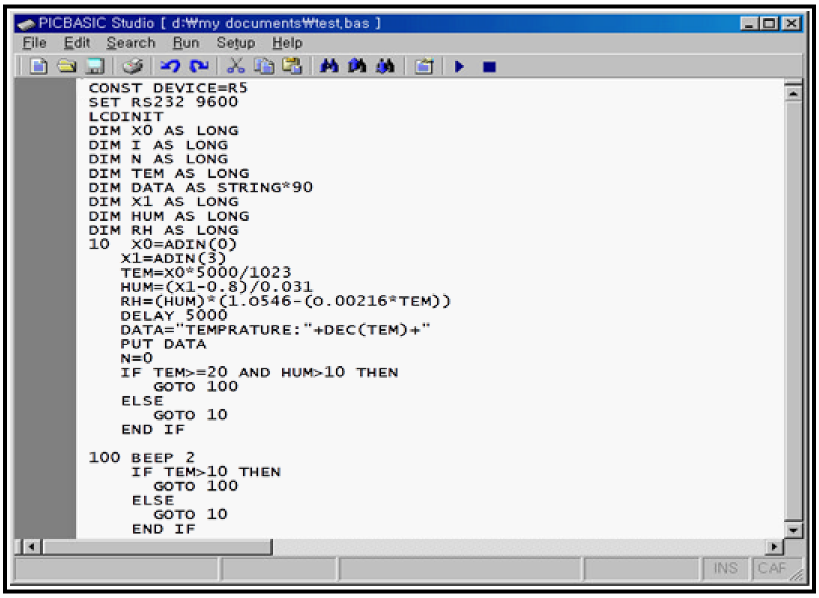


Figure 9: The system circuit diagram.



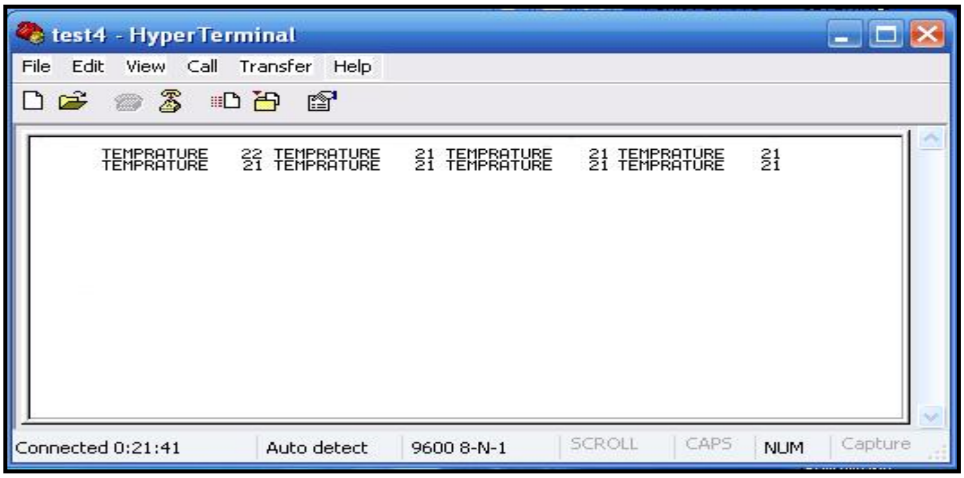
```
CONST DEVICE=R5
SET RS232 9600
LCDINIT
DIM X0 AS LONG
DIM I AS LONG
DIM N AS LONG
DIM TEM AS LONG
DIM DATA AS STRING*90
DIM X1 AS LONG
DIM HUM AS LONG
DIM RH AS LONG
10  X0=ADIN(0)
   X1=ADIN(3)
   TEM=X0*5000/1023
   HUM=(X1-0.8)/0.031
   RH=(HUM)*(1.0546-(0.00216*TEM))
   DELAY 5000
   DATA="TEMPRATURE:"+DEC(TEM)+"
   PUT DATA
   N=0
   IF TEM>=20 AND HUM>10 THEN
      GOTO 100
   ELSE
      GOTO 10
   END IF

100 BEEP 2
    IF TEM>10 THEN
      GOTO 100
    ELSE
      GOTO 10
    END IF
```

Figure 10: PICBASIC studio interface.

2.8 Monitoring

In this study, HyperTerminal is a communications and terminal emulation program that comes with the Windows operating system as in Figure 11, and used to set up a dial-up connection to another computer through the internal Modem using Telnet or to access a bulletin board service (BBS) in another computer. It can also be used to set up a connection for data transfer between a microcontroller and a computer. In this study, HyperTerminal—a communication and terminal emulation program included with the Windows operating system—was utilized to facilitate data communication between the microcontroller and a computer, as depicted in Figure 11. HyperTerminal allows for setting up dial-up connections to another computer via an internal modem using Telnet or for accessing a bulletin board service (BBS) on a remote machine. In addition to these capabilities, HyperTerminal can establish a direct serial connection between a microcontroller and a computer, enabling real-time data transfer and communication. This feature was especially useful in this study for monitoring and troubleshooting the system during the development and testing phases. By connecting the microcontroller to the computer via a serial interface, HyperTerminal made it possible to receive data outputs, issue commands, and observe system behavior, ensuring the control system was functioning correctly. The program's flexibility and ease of use made it an effective tool for interfacing with the microcontroller and ensuring seamless communication during the paper storage system's setup and operation.



```
    TEMPRATURE    22 TEMPRATURE    21 TEMPRATURE    21 TEMPRATURE    21
    TEMPRATURE    21 TEMPRATURE    21 TEMPRATURE    21 TEMPRATURE    21
```

Connected 0:21:41 | Auto detect | 9600 8-N-1

Figure 11: Hyper terminal window.

In this study, HyperTerminal was employed as a tool to test and display the environmental factors measured by the sensors, utilizing a serial connection cable as shown in Figure 12. Through this serial connection, data such as temperature, humidity, light levels, and gas concentrations were transmitted from the microcontroller to the computer, allowing real-time monitoring and troubleshooting of the system.

Figure 12: Serial connection cable.

This setup provided a straightforward method to observe the sensor readings and ensure that the system was responding appropriately to changing conditions. Additionally, the control actions taken by the system, such as activating the air conditioning, adjusting the lighting, or triggering alarms, could also be displayed through the serial connection. This enabled a comprehensive view of how the system managed the environmental factors. For on-site monitoring without the need for a connected computer, a suitable LCD screen can be integrated into the system to display both the measured values and the control actions. This allows operators to continuously monitor critical parameters, such as temperature, humidity, and gas levels, directly on the hardware, providing an accessible and user-friendly interface for real-time data visualization and system status updates. The use of an LCD screen enhances the system's usability in practical applications where continuous environmental control is necessary.

3. Results and Discussion

Through previous studies, it has been well established that various environmental factors—such as temperature, humidity, light exposure, and gas concentrations—significantly affect the preservation of paper documents. These studies also explored the use of electronic devices like microcontrollers and sensors to measure and control these factors. Building upon this knowledge, the purpose of this study was to integrate the insights from prior research and develop a comprehensive control system using a PIC microcontroller. This system is designed to ensure a safe and stable environment for archival storage, specifically adapted to the climatic conditions of Sabratha, Libya. The results of the present study highlight the critical role that such a control and monitoring system plays in safeguarding paper documents from environmental hazards. The system was programmed to regulate and maintain the storage environment, adjusting for local weather variations in temperature, humidity, and other factors. In testing the system, several sensor readings were recorded for humidity and temperature, as detailed in Table 1.

Table 1: Readings of the designed system over 7 days.

Date	Temperature	Relative Humidity	CO Concentration
November 6 2020	21°C	45%	26
November 7 2020	19°C	55%	24
November 8 2020	20°C	57%	24
November 9 2020	22°C	61%	26
November 10 2020	18°C	48%	138 (Testing with small fire)
November 11 2020	18°C	54%	184 (Testing with larger fire)
November 12 2020	20°C	59%	25

The table 1 also presents data related to gas concentrations during fire simulations, showcasing the system's ability to detect and respond to various fire types. These findings underscore the system's effectiveness in providing a controlled environment that mitigates risks to archival materials, including both environmental fluctuations and emergency situations like fires. The system's ability to monitor and adjust to real-time environmental conditions makes it a valuable tool for preserving important documents and ensuring long-term protection from degradation. After developing an algorithm to manipulate, monitor, and control the environmental factors affecting the storage of paper documents, the next step involved integrating the algorithm with the necessary hardware. This included defining the practical function of the system, particularly how it responds to critical environmental changes. For instance, when a fire is detected in the archives, the CO2 valves are opened to release CO2 gas, suppressing the fire. In the prototype setup, a lamp was used to simulate the operation of the CO2 valves. Similarly, for light exposure, the system uses an LDR (Light Dependent Resistor) to detect excessive light levels, triggering the closing of windows and activating an alarm to notify operators of the issue. Table 1 presents the results of fire tests, including measurements of carbon monoxide (CO) concentration, temperature, and humidity as recorded by the sensors. The temperatures ranged between 18°C with a relative humidity of 48% to 54%, and 22°C with a relative humidity of 61%. During fire testing, the CO concentration increased to 138 for a small fire and 184 for a larger fire, with the ambient temperature at 18°C and relative humidity between 48% and 54%. These results demonstrate the system's capability to detect fires and environmental fluctuations, ensuring effective action in response to various threats.

The goal of this study was to design an algorithm, based on the PIC microcontroller and connected sensors, capable of controlling environmental risks—specifically temperature and relative humidity—to which paper documents in the archive are exposed. When either temperature or humidity exceeds the recommended values, the system activates the air conditioning until the levels return to acceptable ranges, while simultaneously monitoring other environmental factors. The MQ-7 gas sensor detects fire by reading elevated CO levels, prompting the microcontroller to contain the fire by activating the necessary suppression systems. The temperature sensor used in this study was selected based on the prevailing temperature conditions in the Sabratha region, as confirmed by reports such as Keysight Technologies (2012-2014) [18]. These reports emphasize the importance of selecting appropriate temperature sensors for reliable measurements. In particular, temperature ICs (Integrated Circuits) provide highly linear voltage- or current-to-temperature relationships and can deliver readings in a digital output format that can be directly processed by a microcontroller. The National Semiconductor study (2000) [10] also supports the choice of silicon temperature sensors, which operate over a wide range of -55°C to +150°C, making them suitable for various applications. Moreover, Márquez-Vera et al. (2023) [19] emphasized the importance of practical applications in software implementation. The use of virtual reality is suggested as a potential approach to enhance understanding and development of these systems, indicating that future studies could explore virtual simulations to further improve the implementation and testing of environmental control systems for archives. In summary, the results of this study demonstrate the importance of integrating sensors and microcontrollers to monitor and control environmental factors that pose risks to archived paper documents. The system provides effective and automated responses to temperature, humidity, light, and fire hazards, ensuring the preservation of valuable materials.

4. Conclusion

The design principles established in this study have broad applicability and should be transferable to various other ecosystems or educational settings, beyond just archival storage environments. One of the key findings of this research is that the PICBASIC board proves to be a highly effective platform for implementing similar non-industrial automation systems. The versatility of the PICBASIC microcontroller enables the integration of multiple sensors, such as temperature, humidity, light, and gas sensors, and allows the system to manage a wide range of actuators, including air conditioning units, CO2 valves, alarms, and other control mechanisms. This adaptability makes it suitable for various environments where automated monitoring and control are required, such as libraries, laboratories, classrooms, or even small-scale industrial settings. Additionally, the simplicity and accessibility of the PICBASIC board make it an excellent educational tool for teaching automation and control systems. It offers learners hands-on experience in programming, sensor integration, and real-time environmental monitoring, making it ideal for educational institutions looking to provide practical, project-based learning in fields like electronics, environmental science, or engineering. In summary, the findings of this study indicate that the design principles and implementation strategies used here can serve as a foundation for developing similar systems in diverse settings, leveraging the flexibility and functionality of the PICBASIC platform for both practical and educational purposes.

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