Introduction

It is known that cold air holds less water than warmer air, and therefore the humidity of homes across Ontario tends to drop during the winter months. Low levels of humidity have detrimental impacts on household health and wellbeing. Numerous kinds of bacteria and viruses thrive once the relative humidity drops below 40%. Illness could spread and/or people in the household could get infected. Low household humidity levels also lead to dehydration, causing dry skin and eyes. Those who have sensitive skin are especially vulnerable to dehydration [1].

The elderly specifically are susceptible to low household humidity levels. With age, one's skin, eyes, and respiratory system become more sensitive to extremely high or low levels of humidity. The same goes for their immune systems, senior citizens have more major respiratory problems such as asthma, which worsens from low humidity. Just as importantly, the elderly do not necessarily know when the humidity level is too low as they lose their sense of tactition naturally with age: "...the elderly group had difficulty in feeling dryness in the nasal mucous membrane despite being easily affected by low humidity" [2].

Therefore, our primary customers are the approximately 75,860 elderly citizens (demographic attribute) who reside in the Waterloo region in Canada (geographic attribute), that are retired (economic attribute) [3].

Proposal

Our proposed product is a “smart” humidifier that regulates the humidity of a room. We will use the TM32F401RE microcontroller as the main component in our design. The system regularly checks the humidity level and turns the humidifier on if the humidity level drops below 40% and turns the humidifier off once the humidity level reaches 60%. In other words, the system maintains the humidity level between 40% and 60%.

Competitive Landscape

1. Technological and economic: Government incentives and rebates for energy-efficient home appliances encourage new homes to include energy-efficient solutions, including integrated humidity control systems. These incentives aim to reduce energy consumption and greenhouse gas emissions by promoting the use of energy-efficient humidifiers and HVAC systems. This system adequately regulates the humidity in homes that have it. However, this kind of system can only be easily implemented in new homes that are being built. Shall a client request to have this system installed in their existing home, the cost would be much higher since a complete upgrade of the entire HVAC system would be required [4].
2. Social: Public health education campaigns, such as those run by government health agencies and HVAC companies, are a social solution to address the challenges associated with indoor humidity control. These campaigns aim to educate the public about the importance of maintaining optimal indoor humidity levels for health and well-being [5]. They provide guidelines on humidity control and raise awareness about the risks of low or high humidity, often persuading people to regulate their household humidity [6]. However, a limitation of this approach is that it relies on individual compliance and awareness, which may vary among the population.
3. Technological: Smart humidifiers with built-in humidity regulation are an advanced technological solution designed to address the challenges associated with maintaining optimal indoor humidity levels. These devices incorporate sensors and automated control systems to continuously monitor and adjust humidity levels within a specified range. They power on if the humidity level drops too low, and power off once the desired humidity level is reached. However, the initial cost of smart humidifiers with built-in humidity regulation features can often be higher compared to conventional humidifiers, which do not have these automation capabilities [7].

Requirement Specification

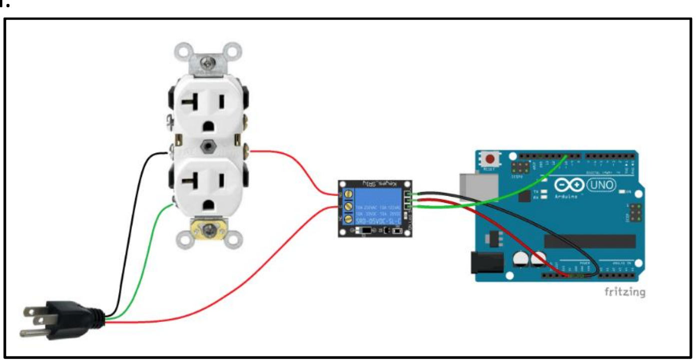
1. Humidity control range

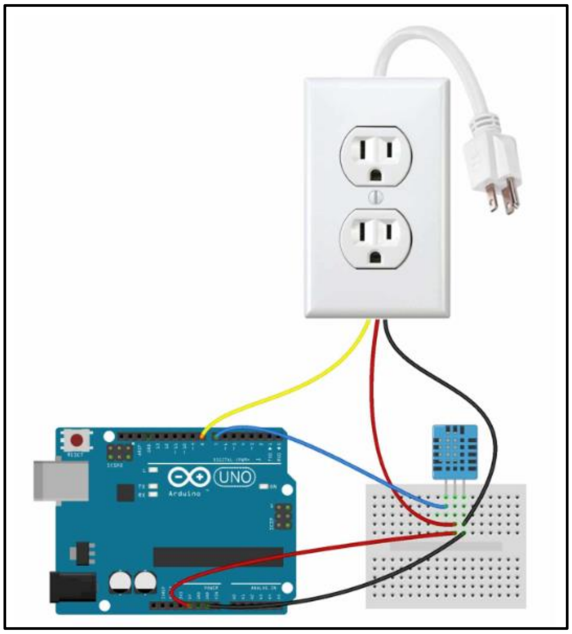
- The smart humidifier shall maintain the indoor relative humidity within the range of 40% to 60%.
- Units: Percentage (%)

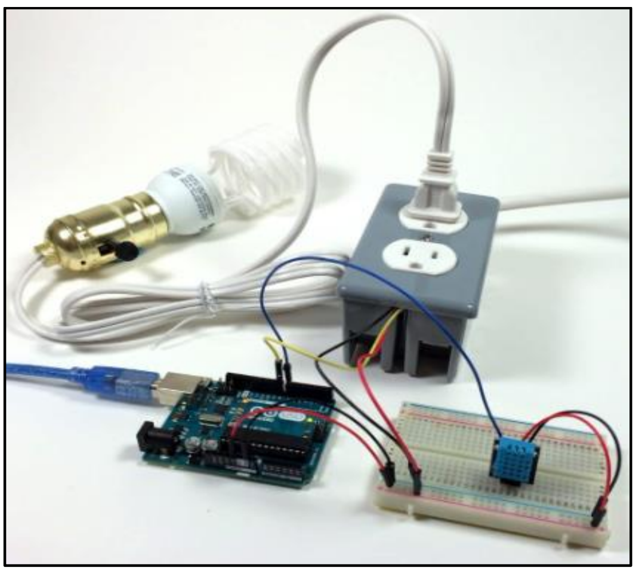
2. Humidity sensor accuracy
    - The humidity sensor used in the system shall have an accuracy of ±2% relative humidity.
    - Units: Percentage (%)
3. Response time
    - The smart humidifier shall activate or deactivate within 5 minutes of the detected humidity falling below or exceeding the specified range, respectively.
    - Units: Minutes (min)
4. Power consumption
    - The smart humidifier shall consume no more than 50 watts of power during operation.
    - Units: Watts (W)
5. Maintenance interval
    - The system shall operate effectively for a minimum of 6 months without the need for maintenance, including sensor calibration or component cleaning.
    - Units: Months

Design

These schematics outline our idea for the humidifier, one of the diagrams showcases the connections of our wires of the 5V relay and the other shows the connections with the DHT11 sensor [8].

- As observed in this diagram, the microcontroller is connected to the 5V relay, which is connected to the outlet. Based on based on the humidity measured by the DHT11 sensor, the relay will open and close the circuit, meaning it will supply electricity to the power outlet. The relay and the outlet will then be placed in the outlet box which will be covered, as shown in the next diagram.
    - 

- This diagram also showcases our connections with the DHT11 sensor. We use a breadboard to centralize the connections with the sensor, relay, and microcontroller. All that is left is to plug in the humidifier and based on the humidity threshold set for the DHT11 sensor, the humidifier will turn on and off. After the design is built, our project will look like the picture below:
    - 

- In place of the lightbulb will be the humidifier, and in place of the Arduino will be the STM32401RE microcontroller.
    - 

Scientific/Mathematical Principles

1. Clausius-Clapeyron relation

- The Clausius-Clapeyron relation states that as the temperature of air increases, the air can hold more water vapor, and as the temperature decreases, the air can hold less water vapor. In other words, warmer air has a higher capacity for holding moisture (water vapor) than colder air. As temperature increases, the air's capacity to hold water vapor also increases.
- If a room has a fixed amount of water vapor and the temperature rises, the air's relative humidity decreases. This is because the air can now hold more moisture, making the existing moisture content a smaller fraction of the air's total capacity.
- Conversely, as temperature decreases, the air's capacity to hold water vapor decreases. If the air's temperature decreases while the moisture content remains the same, the relative humidity of the air increases. This is because the air's capacity to hold moisture has decreased, so the existing moisture content represents a larger fraction of the air's total capacity [9].
- We use this principle as our main exigence for this product; during the winter, household humidity levels drop due to colder temperatures. We can understand why this process occurs because of the Clausius-Clapeyron relation. Therefore, we are optimizing our product for use in winter months.

2. Electric Potential

- Voltage, often referred to as electric potential, is the difference in electric potential between two points in an electrical circuit. Voltage is also measured in volts (V). Voltage is what causes electric charges to move in a circuit [10].
- In our product, the microcontroller communicated with the relay via voltage signals via one of its output pins. This signal operates at a voltage of 5V and represents digital logic levels (HIGH or LOW).
- When the relay is receives the voltage signal, by the microcontroller, it completes the electrical circuit. This, in turn, allows the flow of current from the outlet to the humidifier.

3. Feedback Control

- Feedback control is the process of continuously comparing an output with a desired setpoint and using this comparison to adjust the system's control actions. Feedback control ensures that the system remains stable and operates within desired specifications, even in the presence of variations [11].
- We will use a feedback loop to maintain the humidity of a room between 40% and 60%. Our loop is accomplished using the microcontroller, humidity sensor, relay, humidifier, and algorithm.

- The humidity sensor will be constantly updating the humidity level
- If the microcontroller receives a low humidity level from the sensor, it will turn on the humidifier
- Once the humidity sensor relays a higher humidity level, the microcontroller will cut power to the humidifier
- This will be done using the relay

Manufacturing Costs

Item	Vendor	Vendor location	Manufacturer	Manufacturer location	Item number	Cost ($)*	Other info
Breadboard	Rigidware	UW	FIND OUT		4899727	1.30	
Jumper wires	Rigidware	UW	FIND OUT	FIND OUT	4899647, 4899656, 4933082	0.15	
5V relay	Amazon	Kitchener	Huayao	China	HY002	13.99	Link
Electrical outlet box	Amazon	Kitchener	Madison electric	China	MSB1G	3.19	Link
Electrical outlet	Amazon	Kitchener	Leviton	New York	T5320-W	2.64	Link
Electrical outlet box cover	Amazon	Kitchener	Leviton	New York	00PJ8-00W	1.55	Link
NM/SE connector	Amazon	Kitchener	Sigma electric	North Carolina, USA	44694	7.57	Link
Power strip	Bought		FIND OUT	FIND OUT	-	10	
Humidifier	Bought		FIND OUT	FIND OUT	-	20	
Microcontroller	W Store		STMicroelectronics	Geneva, Switzerland	STM32F401RE	35	
Humidity sensor	Rigidware		FIND OUT	FIND OUT	4899567	15.60	

*Prices from 10/28/23

Implementation Costs

1. Safety Precautions

1. Prior to hardware installation, ensure the power supply is disconnected or turned off.
2. Keep all electrical components away from any liquids.
3. Wear proper safety gear, including safety goggles to protect eyes from any sparks or flying debris.
4. Wear gloves to prevent yourself from electrical shocks.

5. Wear anti-static wrist straps when handling the electrical components to prevent electrostatic discharges, shocks, and/or component damage.

2. Installation of the hardware components

1. Gather all the components listed in the spreadsheet above.
2. Cut the cord on the power supply and identify the neutral, hot, and ground wires.
3. Cut one of the knockout plugs from the electrical box outlet. Then instal the NM/SE connector in the cutout.
4. Strip off a few inches of the outer plastic covering of the electrical cord and feed it through the NM/SE connector
5. Cut 3-4 inches of the hot wire and strip off ¼ - ½ inch of the plastic insulation. Then insert it into the NO terminal of the relay and tighten the screw on the relay terminal to ensure the hot wire is properly secured.
6. Connect the VCC, signal, and ground wires on the relay.
7. Strip off ½ an inch of the plastic covering on the neutral and ground wires so that ½ an inch of copper is exposed.
8. Connect the hot, neutral, and ground wires from the electrical cord on to the electrical outlet. The hot black wire that is connected to the NO terminal of the relay will be screwed on to one of the gold colored screws on the hot terminal of the electrical outlet, the neutral wire from the cord will be screwed on to one of the silver colored screws on the neutral side of the outlet, and the ground wire, will be screwed on to the ground (green) screw of the outlet.
9. Connect the VCC, signal, and ground wires of the relay on to the breadboard. So that they are aligned with the humidity sensor.
10. After all of the connections are done to the outlet and humidity sensor, screw the outlet into the electrical outlet box, and attach the cover plate over the box to cover up all the connections between the relay, and outlet.
11. After the assembly of the electronics is complete, it is time to connect the humidifier into the outlet. This outlet is then connected to an outlet mounted on the wall [8].

3. Software Setup

1. Download and install the STM32CubeIDE using the following link: https://www.st.com/en/development-tools/stm32cubeide.html
2. Download and install the DHT11 sensor library

4. User Manual

1. Locate the B1 button on the STM32F401RE microcontroller to reset the humidifier.

2. Using the STM32CubeIDE, set a threshold value for the desired range you want your humidity to be in. Ideally set the range between 40 and 60 percent.

3. Maintain your microcontroller by doing the following steps

- Cleaning: as dust builds up over time, it is important that you clean the components of the system

- Empty and rinse out the water container of the humidifier and use a mild detergent to clean it
- Wipe down the STM32F401RE microcontroller using a dry cloth. NEVER USE A WET CLOTH!
- Over time, the humidifier filter can become clogged due to dust, mold, bacteria, and other mineral deposits. As a result, it is less effective in moisturizing the air. Thus, it is important to clean the filter.

Risk Analysis:

1. Possible negative consequences on safety or the environment from using the design as intended
   - If the design is placed in proximity to humidity-sensitive equipment/items, these items may get humidity damage.
2. Possible negative consequences on safety or the environment from using the design incorrectly
   - Failure to follow the safety guidelines mentioned in the installation manual can lead to potentially widespread electrical damage and injury.
     i. Electrical shocks can be delivered to the customer
     ii. Major damage to the customer's electrical infrastructure can occur
     iii. The customer can get physically injured shall he/she refrain from wearing protective clothing
3. Possible negative consequences on safety or the environment from misusing the design or using in a manner that was not intended
   - Installing the design in an environment where the humidity is impossible to maintain could lead to failure of the electrical components
     i. For example, if the product is placed in a room where it is impossible for the humidity level to rise above 30% (due to extreme ventilation), the humidifier can overheat, resulting in damage to the components and a risk of fire.
4. Possible ways the design could malfunction
   - The humidity sensor can inaccurately record a room's humidity level, resulting in undesired humidity levels. The room could become damaged due to extremely high humidity.
5. Ways to avoid risks
   - Ensure the product is installed correctly, with all wiring connections performed without electrical flow
   - Place the product away from any humidity sensitive items
   - Do not place the product in a room where the humidity level is extremely hard to regulate
   - Regularly check the product for any loose connections

Energy Analysis

Test Plan

1. Humidity control range

- Test Setup: Set up the product in a controlled environment.
- Environmental Parameters: Ensure a controlled room with a starting relative humidity level outside the specified range.
- Test Inputs: Simulate changes in humidity levels to assess the smart humidifier's response.
- Measurement Standards: Continuously monitor and record the relative humidity levels.
- Pass Criteria: The smart humidifier should maintain the indoor relative humidity within the range of 40% to 60%.

2. Humidity sensor accuracy

- Test Setup: Place the humidity sensor in a controlled humidity room.
- Environmental Parameters: Maintain a stable and known humidity level in the chamber.
- Test Inputs: None, as this is a calibration test to evaluate the sensor's accuracy.
- Measurement Standards: Record and compare the humidity sensor's readings with the actual humidity levels.
- Pass Criteria: The humidity sensor readings should be within ±2% of the actual humidity levels.

3. Response time

- Test Setup: Setup the product in a controlled environment with humidity level control.
- Environmental Parameters: Simulate rapid changes in humidity levels within the desired range.
- Test Inputs: Trigger changes in humidity levels to measure the response time.
- Measurement Standards: Measure the time taken for the smart humidifier to activate or deactivate.
- Pass Criteria: The system should activate or deactivate within 5 minutes of the detected humidity falling below or exceeding the specified range.

4. Power consumption

- Test Setup: Connect the product to a power meter in a controlled environment.
- Environmental Parameters: Use a stable power supply.
- Test Inputs: Activate the smart humidifier.
- Measurement Standards: Record the power consumption during operation.
- Pass Criteria: The smart humidifier should not consume more than 50 watts of power.

5. Maintenance interval

- Test Setup: Set up the product for continuous operation in a controlled environment.
- Environmental Parameters: Maintain a stable indoor environment with fluctuating humidity levels, so that the product can regulate the humidity level as it was designed.
- Test Inputs: Continuous operation without maintenance.

- Measurement Standards: Document any maintenance or performance issues that arise during the 6-month testing period.
- Pass Criteria: The system should operate effectively for a minimum of 6 months without the need for maintenance, as specified.

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