

Research Article

Design and Implementation of the Prevention System of Molds Growth Using Wireless Sensor Networks

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Due to the advances in memory and processing capacity of embedded systems, wireless communications, and size of the devices, many researchers are growing more and more interested in wireless sensor networks (WSN). WSN have a large number of nodes with a sensor board, and wireless communication board, and have been applied to many fields. Summer is the season when much personal and property damage arises from various natural disasters such as the heat being reminiscent of subtropical climate and flooding from heavy rain due to global warming. This unusual temperature affects our lives much besides causing natural disasters. Recently, many problems have occurred with respect to hygiene and beauty of view especially due to growing of various molds in the residential environment. In the heat of summer, the damages from molds become serious due to the effect of temperature and humidity according to seasonal characteristics. In this paper, we build a wireless sensor network with some sensors such as temperature and humidity. And then we design and implement the prevention system of molds growth which can predict and prevent molds production in indoor environment.

1. Introduction

Ubiquitous sensor networks (USN) is a technology that allows you to manage wirelessly environmental information such as temperature, light, acceleration, and CO₂. This information is collected from sensor nodes which are attached to the surrounding objects [1, 2]. At the present time, due to the advances in memory and processing capacity of embedded systems, wireless communications, and size of the devices, many researchers are growing more and more interested in wireless sensor networks. In WSN, sensor nodes have a wireless transmission capability and can constitute a large network. So, WSN have been applied to many fields. Sensor nodes can measure and gather a variety of information from the environment such as temperature, humidity, light, and motion. Data gathered by sensor nodes is transmitted to a sink node for further processing [3–6].

WSN have a large number of sensor nodes with a sensor board and wireless communication board. Environmental information collected from these sensor nodes is used to determine how environmental condition is. WSN can also take part in the development of safe living environments for

people and are useful to monitoring of life style, traffic, health, environmental pollution, and so forth [7–10].

Recently, unusual temperature affects our lives much besides causing natural disasters. As a result, many problems have occurred with useful respect to hygiene and beauty of view due to growing of various molds in the residential environment. It is highly probable for the mold to grow in some places as the places keep a certain temperature and contain constant humidity.

In this paper, we build up a wireless sensor network with sensor nodes attached to the sensor boards being placed in the toilet, bathroom, shower room, and laundry room, which detect and collect environmental information such as temperature and humidity and send them to the management system installed in the central server. And sensors to collect temperature and humidity data are placed to monitor environmental condition of these areas of control. A sensor network is built up to transmit the environmental information to management system through placed sensors.

The remainder of this paper is organized as follows. In Section 2, we overview some of the recent researches and books related to mold. In Section 3, we describe the design

of the prevention system of molds growth. In Section 4, we present the implementation of our system. Finally, Section 5 concludes this paper.

2. Related Works

Summer is the season when much personal and property damage arises from various natural disasters such as the heat being reminiscent of subtropical climate and flooding from heavy rain due to global warming. This unusual temperature affects our lives much besides causing natural disasters. Recently, many problems have occurred with respect to hygiene and beauty of view especially due to growing of various molds in the residential environment. In the heat of summer, the damages from mold become serious due to the effect of temperature and humidity according to seasonal characteristics. The kinds of mold growing in the general residential environment reach about 300. Mold may grow better in the bad conditions than viruses or yeast in general. That is, it may grow in the place with lower moisture, of wider pH and temperature range, and higher sucrose concentration, comparing with viruses or yeast. But it needs longer time than viruses or yeast to begin growing. In this chapter, we describe the factors to affect the growth of microorganism.

2.1. Factors to Affect the Growth of Microorganism. For propagation of microorganism, external supply of nutrients is necessary. However, the supply of nutrients is abundant, microorganism may not grow where external environmental condition is unfavorable for it. Especially, as many factors such as temperature, moisture, and light affect the growth of microorganism, it may grow only when proper external environmental condition is maintained. The growth of microorganism is affected much by various environmental factors. The environmental factors around microorganism may promote or hinder the growth of microorganism. The factors affecting the growth of microorganism may be classified into two categories: physical factors and chemical factors. Physical factors comprise temperature, osmotic pressure, light, and, and so forth, and chemical factors comprise nutrient, pH, oxygen, and so forth [11, 12].

(1) Temperature. The growth of microorganism is influenced by temperature. Reviewing the relation between the growth rate of microorganism and temperature, growth rate changes according to temperature as shown in Figure 1.

There are the temperature at which the growth rate is fastest (B) and the temperature at which the microorganism does not grow (A, C). That is, microorganism does not grow at the temperature up to point A, the growth rate keeps increasing as temperature increases from point A until point B and the growth rate would be max at point B. After that, the growth rate drops rapidly from point B until point C, and the microorganism does not grow over the temperature of point C. As microorganism could not grow below point A, point A is minimum temperature of growth. Microorganism could not grow because permeability of cell membrane and enzyme activity in the cell reduce as temperature goes down,

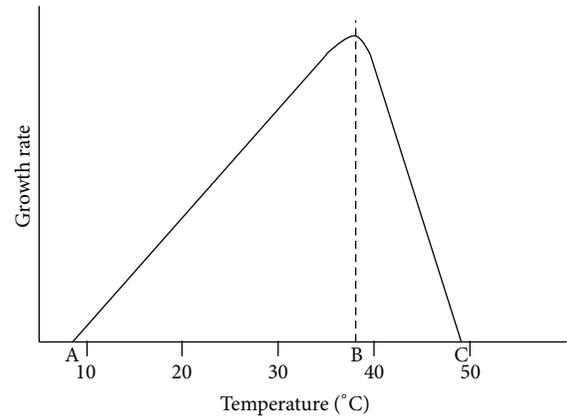


FIGURE 1: Growth rate of microorganism according to temperature.

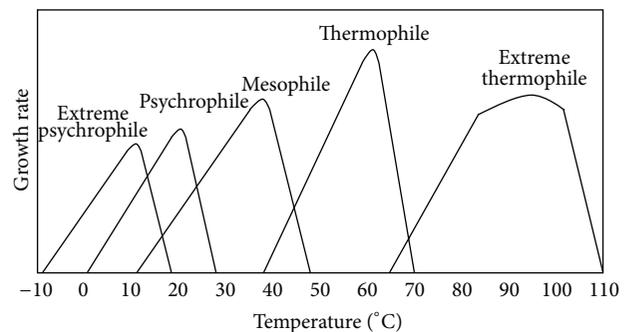


FIGURE 2: Range of growth of microorganism according to temperature.

so that nutrition is not being taken well and metabolism does not work correctly. The growth rate becomes fast from point A because enzyme activity increases, and fluidity of cell membrane goes well as the temperature goes up.

The growth rate keeps increasing gradually like this as the temperature goes up until the point at which the growth rate is the fastest, which is called optimum temperature. At this point, the enzyme reaction rate is max. In many cases, the optimum temperature for all of the microorganism is not one point, but a wide range of temperature like 37~45°C and the maximum temperature and minimum temperature are also affected by surrounding environment. Through Figure 1, it can be noted that there is a range of temperature in which microorganism could survive, and that it could not live out of certain temperature range. Microorganism is classified into extreme psychrophile, psychrophile, mesophile, thermophile, and extreme thermophile according to optimum temperature of growth as shown in Figure 2. In general, the temperature range in which microorganism could grow is wide from subzero up to more than 100°C as shown in Table 1.

In this paper, we want to make research on black mold, the scientific name of which is *Aspergillus niger*. As black mold belongs to mesophile, we know that its optimum temperature of growth is in the range of 28~43°C. Mesophile, which is the most common microorganisms in the nature, likes the temperature of around 37°C that is similar to human or

TABLE 1: Classification of microorganism and temperature range of growth.

Classification	Minimum temp.	Optimum temp.	Maximum temp.
Extreme psychrophile	-10	10~15	20
Psychrophile	-10	20~30	42
Mesophile	5	28~43	52
Thermophile	30	50~65	70
Extreme thermophile	65	80~90	100

warm-blooded animal body temperature. The most number of this microorganism are found in the temperate regions, and it is also found in the soil and water in the tropical region [13–16].

(2) *Humidity*. As more than 75% of an organism is water, water is essential to the survival of all organisms. The water necessary for the growth of microorganism can be explained with the concept of water activity. If we dry food or add solutes to food, the moisture that microorganism could utilize reduces. The availability of the moisture can be conveniently shown by indicating the water vapor pressure of the food with equilibrium relative humidity (ERH). That is, a food has a vapor pressure (P_0) unique to the food at a certain temperature. When the food is placed in the atmosphere of a certain water vapor pressure (P_1), the moisture in the food evaporates if $P_0 < P_1$, and the moisture in the atmosphere is absorbed into the food if $P_0 = P_1$. When food is left in the atmosphere, it absorbs moisture or evaporates to become moisture equilibrium with surrounding atmosphere. Equilibrium relative humidity is relative humidity of the vapor pressure of atmosphere when at a certain temperature, that is, when the vapor pressure of atmosphere is in equilibrium relation with vapor pressure a food (P_0). The relation between equilibrium relative humidity and water activity (A_w) is as follows [17, 18]:

$$\begin{aligned}
 A_w &= (\text{Vapor pressure of food (solution)}) \\
 &\quad \times (\text{Vapor pressure of pure water} \\
 &\quad \text{at the same temperature})^{-1} \\
 &= \frac{P}{P_0} = \frac{\text{ERH}}{100}.
 \end{aligned} \tag{1}$$

Water activity of pure water is 1.0. When a food is completely dried, showing no vapor pressure, the water activity of it is 0. In other words, equilibrium relative humidity is same as 100 times of water activity. Depending on the kinds of microorganism, the water activity range in which the microorganism may grow is different. Most of the viruses found in the food grow well as the water activity comes near to 1. That is, they grow fast in the condition that sufficient nutrients is contained. As the lowest limit of water activity is known to be 0.61, no microorganism can grow in the food of below 0.61 of water activity. Therefore, any deterioration

under this condition should not be microbiological one, but only chemical one.

(3) *Light*. The lights affecting microorganism are ionizing radiation, ultraviolet light, microwave ant, and so forth. Besides special microorganisms that obtain energy through photosynthesis, most of the microorganisms usually do not need light. As ultraviolet light in the sunlight gives harm to the growth of microorganism, it can be said that microorganism may grow well in the darker places rather than in the bright places. But a little light is necessary for sporulation of mold. The sporocarp faces toward light and matured spores are discharged to the direction of light.

2.2. *Factors to Affect the Growth of Mold*. As described before, microorganism may not grow where external environmental condition is unfavorable for it. In this paper, we use humidity, temperature, and lights as the factors that affect the growth of the mold in order to prevent the occurrence of mold. They can be easily measured by a sensor.

(1) *Humidity*. Moisture is essential to the growth of mold. Moisture in the mold body acts as menstruum for crystalline structure in the cell and involves in maintaining osmotic pressure, becoming a dispersive media of colloid. If there is no moisture, a hypha loses moisture through vaporization, cells plasmolyze, and die. That is, drying is an important condition to prevent the growth of mold. Moisture can be measured by the humidity.

(2) *Temperature*. Mold is mesophilic with proper growth temperature being 25~30°C, but the temperature range for its growth is wide from minimum (-10~-5) to maximum 50°C depending on the strain. The growth temperature of mold, however, varies depending on the various conditions such as light, oxygen, and moisture of the environment.

(3) *Light*. Just like other microorganisms, visible light of 400~800 micrometer is harmful to mold. In the meantime, ultraviolet ray, X-ray, and γ -ray act to sterilize mold and cause modification of mold.

Therefore, the rainy season with continuing humid climate and high temperature provides the best environment for growing of mold. Mold exists in various forms such as spore and so forth and in the air and soil, and it grows well in the rainy season when temperature is 25°C~30°C and relative humidity is 60~80% or higher. Therefore, if the relative humidity is kept under 60%, the growth of mold may usually be prevented.

3. System Platform

In this paper we build a wireless sensor network with some sensors such as temperature and humidity. By using this wireless sensor network we can predict and prevent molds growth in indoor environment. In this section, we design the prevention control system of molds growth using wireless sensor networks.

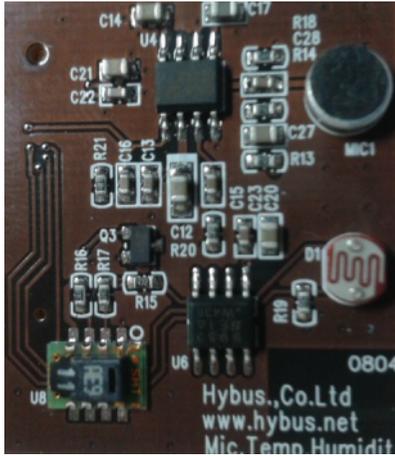
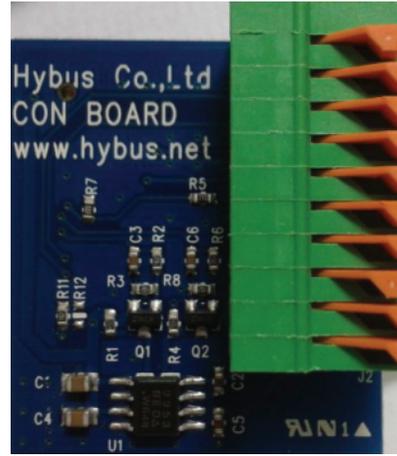


FIGURE 3: Sensor node.



(a) The front

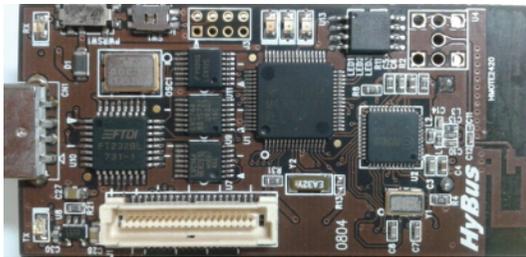
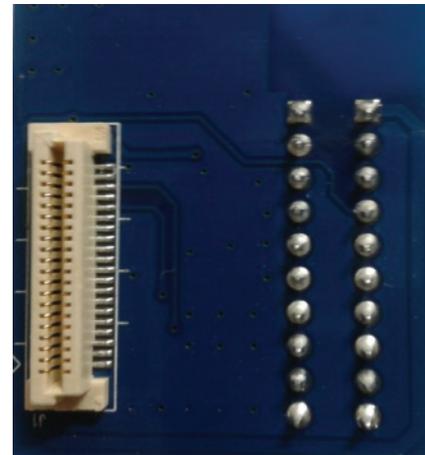


FIGURE 4: Hmote2420.



(b) The back

FIGURE 5: Signal conversion board.

The proposed prevention system of molds growth consists of three components, which are the sensor part, the server part, and the control part. The sensor part comprises wireless transmission nodes and a sink node. Wireless transmission node transmits the environmental information collected from sensor board wirelessly, and a sink node receives the information transmitted wirelessly. In the server part, an environmental information management database and a monitoring program to process this information are installed. The control part operates fan according to the value of the collected environmental information.

(1) *Sensor Part.* The sensor part forms a wireless sensor network to transmit environmental information to the sink node that is connected to the server. In this network, many sensor nodes detect temperature and humidity and wireless transmission nodes to transmit the environmental information collected from the sensor nodes wirelessly placed independently throughout the interior area of control. For this paper, general-purpose sensor nodes manufactured by Hybus Co., Ltd. are used [19]. Figure 3 shows the sensor nodes. Sensor node is attached to the wireless transmission node called Hmote2420 as shown in Figure 4.

(2) *Control Part.* Control part, which operates fan according to the collected environmental information value, consists of signal conversion board, AC board, and Mote.

Signal conversion board connected with Mote comprises 10 pins on the upper surface and 40 pins on the lower surface

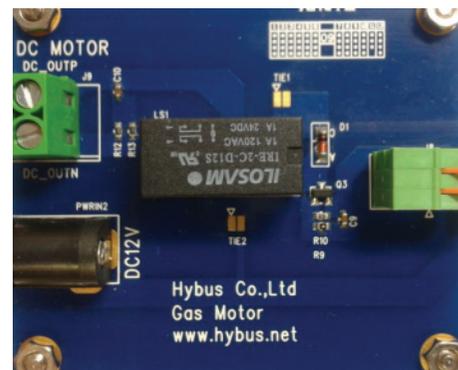


FIGURE 6: DC Board.

as shown in Figure 5. The pins on the upper surface are connected to DC board which is shown in Figure 6, and the pins on the lower surface are connected to Mote and to each port of MSP430. DC motor to rotate the fan is used under control of relay, being connected to the DC board that is

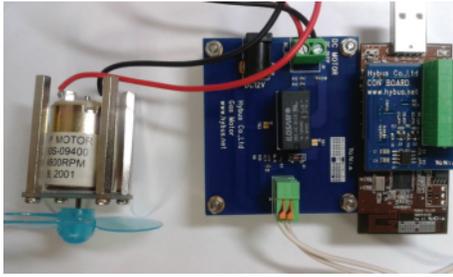


FIGURE 7: Combination of CON board, DC board, and DC motor.

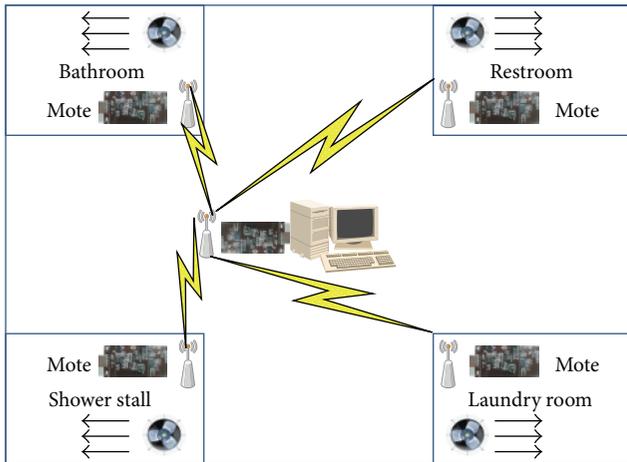


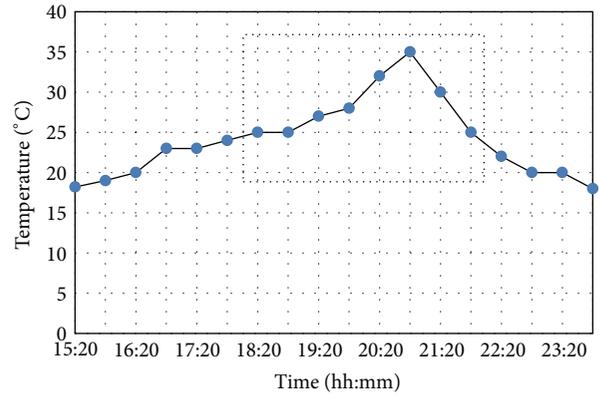
FIGURE 8: Architecture of prevention system of molds growth.

supplied with 12 V. Figure 7 is the image that Mote, signal conversion board, and DC board are connected.

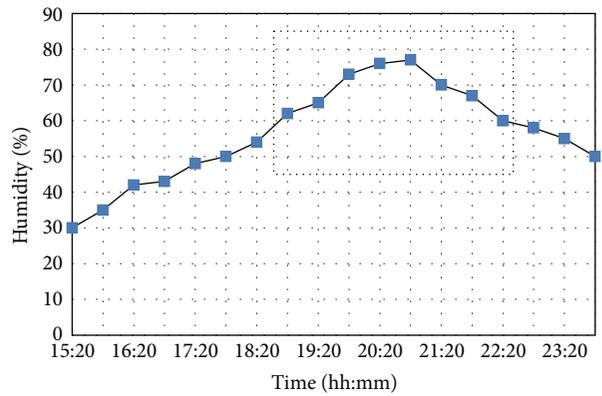
(3) *Server Part.* In the server is installed environmental information management database to process the environmental information transmitted from sensor nodes and monitoring program. The environmental information such as temperature and humidity value, which are collected from sensors installed in the interior area of control, is saved in each field of control in the environmental information management database. A program is installed to operate the fan when the environmental condition of each area of control comes to allow growth of mold.

4. System Implementation

Figure 8 shows the proposed system architecture for the prevention of molds growth. Sensor nodes are deployed in the restroom, bathroom, laundry room, and shower stall. It is highly probable for the mold to grow in these places as the places keep a certain temperature and contain constant humidity. In these places, sensors attached to sensor node detect and collect environmental information such as temperature and humidity, and then sensor node transmits this information to the management system installed in the central server.



(a) Temperature



(b) Humidity

FIGURE 9: Environmental information received from sensor node.

Sensor network is built up to transmit the environmental information to control system through placed sensors. Sensor nodes placed in the area of control periodically collect environmental information and transmit it to sink node, and the central control system connected to the sink node displays the environmental information on the screen collected from the area of control. As shown in Figure 8, the network is established by placing sensor nodes in the 4 areas of control: restroom, bathroom, shower stall, and laundry room. Each sensor node reports inside temperature, humidity monitored in the areas of control to control system through Mote, the wireless transmission node. The control system saves the environmental data, which are collected by temperature and humidity sensors in the wireless sensor network and transmitted wirelessly in the environmental information database. The control system judges whether or not the transmitted environmental data reach the expected value where mold may start growing and forecasts molds growth. And then the control system gives order to operate control part to prevent molds growth by using fan operation process.

Several experiments were performed using sensor nodes for the purpose of temperature and humidity data collection, and sensor nodes were deployed in some areas of control. Our experimental results are shown in Figure 9.

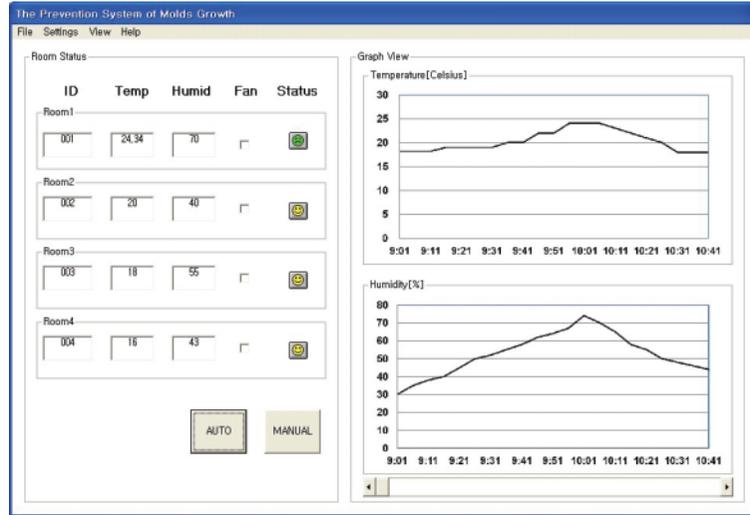


FIGURE 10: User interface of our system.

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(1) if (n->temperature >= TEMP.SET)
(2) if (n->humidity >= HUMID.SET)
(3) {
(4)   if (state_motor == 0)
(5)   {
(6)     state_motor = 1;
(7)     motor_on();
(8)   }
(9)   display();
(10) }else{
(11)   if (state_motor == 1)
(12)   {
(13)     state_motor = 0;
(14)     motor_off();
(15)   }
(16) }

```

ALGORITHM 1: Fan operation process of our system.

As shown in Figure 9, if temperature is over 20°C and humidity is over 60%, the mold growth is predicted. In this case, our system actuates fan and displays status of this area. Dotted line is a predicted range of molds growth.

Algorithm 1 shows fan operation process when the mold growth is predicted. If the collected temperature and humidity exceed setting value, fan is turned on.

In this paper, we build up a sensor network with sensor nodes attached to the sensor boards being placed in the restroom, bathroom, shower room, and laundry room, which detects and collects environmental information such as temperature, humidity. In order to manage this process, we implement the prevention system of molds growth as real applications as shown in Figure 10. When looking at the left side of the screen, the temperature of room 1 is above 24°C, and the humidity is 70%. This means that molds can grow because it exceeds 20°C temperature and 60% humidity. Therefore, to prevent molds growth, the control

system operates fan under the temperature and the humidity setting conditions, respectively. After that, if temperature and humidity in this room are less than setting value, fan is turned off.

5. Conclusions

Summer is the season when much personal and property damage arises from various natural disasters such as the heat being reminiscent of subtropical climate and flooding from heavy rain due to global warming. This unusual temperature affects our lives much besides causing natural disasters. Recently, many problems have occurred with respect to hygiene and beauty of view especially due to growing of various molds in the residential environment. In this paper, we described the prevention system of molds growth based on wireless sensor networks. To achieve this, we surveyed some of the recent researches and books related to the molds, then we knew that molds grow well in the rainy season when temperature is 25°C~30°C and relative humidity is 60~80%, or higher and molds growth may usually be prevented if the relative humidity is kept under 60%. The proposed system can predict and prevent molds growth in indoor environment.

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