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A High-Precision and Low-Cost Dew Point Equipment with Fuzzy Control System

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Abstract

The control of environmental conditions in some sectors of the industry is essential since the variation of these parameters can influence the quality of the manufactured product. For this, it is necessary to use measuring equipment with high precision, and when referring to the measurement of relative humidity, the dew point meter is indispensable. The chilled mirror method for measure °Cdp is the one of the most accurate that exists in the market, but these devices typically are high cost, hampering access to small businesses. The chilled mirror method basically consists of a PID (Proportional Integral Derivative) control of the temperature of a Peltier module based on the reading of the light intensity generated from the reflection of a light source. In this context, the proposal of this work is to develop a high precision and low cost device, operating in the range of -20 to 20°Cdp, replacing the traditional PID control by a Fuzzy control system, providing better accuracy in control, thus making a viable product mainly for small and medium-sized companies. The results presented show the feasibility of the proposal of this work, obtaining 98.9% accurate readings when compared with a reference equipment, and a maximum deviation observed was of 0.02°Cdp, thus proving its precision. Another point to note is the low cost of the equipment, approximately US$ 120.00, thus reaching the proposed objective.

Keywords: Dew Point; Chilled Mirror; Absolute Air Humidity; Peltier module; Fuzzy Control System.

1. Introduction

This project proposes the development of a low-cost dew point chilled mirror equipment based on fuzzy control system.

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To this end, in this project the fuzzy controller for the Peltier module is the main challenge, since this is one of the main challenges found in the literature, since this control is very sensitive and small variations in the control generate large temperature changes. The temperature of dew point (°Cdp) is essential for measuring relative humidity and is present in many industrial processes like plastics injection, production of medicines, maintenance of large transformers, moisture measurement in pure gases, hydrocarbon and also in the reference process for measuring relative humidity, which is a parameter widely used in the most diverse segments of the industry [1,2]. Dew point is the temperature where air condensation starts as water or ice, so the air is saturated with water vapor. At any temperature there is a maximum amount of water vapor that the air can maintain. This maximum amount is called the water vapor saturation pressure [3]. In order to measure the dew point temperature, there are some techniques, from the most primitive ones, using a thermometer immersed in water inside a container and monitoring the condensation of this container by adding ice in the water to optical techniques, resonance of quartz crystals [1,3]. Due to the cost of high-precision equipment, many researches works on the development of methods for estimating the dew point value, taking into account ambient temperature and relative air humidity, for example [1,4]. There are some works in the literature that report the dew point measurement using Quartz resonance [2,5]. Despite its high precision, this system has an extremely high development cost, when compared to the chilled mirror method, and without significant gains when comparing the results of the two methods. The dew point temperature measurement by the chilled mirror method consists of the emission of a light beam on a polished metal plate (so that it reproduces the effect of a mirror) and the reception of this information (light intensity) by a receiver (phototransistor). This metallic surface is located on a Peltier module together with a temperature sensor, typically a PT100. When the temperature of the Peltier module changes, the temperature of the metal plate changes together, when chilled to dew point temperature, the condensation effect begins, disturbing the reception of the light beam. Above 0°Cdp, this humidification occurs by condensation of water contained in the air, and below 0°Cdp, an ice surface forms on the plate [2,3,5,6]. The chilled mirror measurement process is represented by Figure 1.

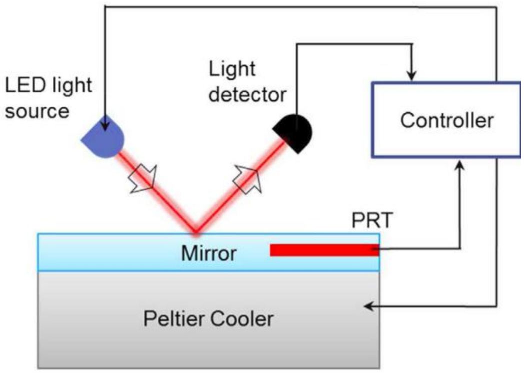

Figure 1: Dew point measurement method using a cooled mirror [5]

The control of the Peltier module temperature in this work is performed using a Fuzzy control system, replacing other controls proposed in the literature. The control of the Peltier module is one of the critical points in the development of a chilled mirror dew point meter. Some works are found in the literature for control the temperature of the Peltier module , some ones use a PID (Proportional Integral Derivative) controller for their control [7,10]. There are also some works where fuzzy self-tuning PID systems have been proposed to replace the traditional PID [10].

2. Materials and Methods

Peltier module s are modules where their operation is based on the “Peltier Effect”, which was discovered in 1834 by Jean Charles Athanase Peltier. When a current is applied, the heat moves from side to side and if the electrical poles are reversed, the chip will become a heater [11]. Also known as thermoelectric pads, Peltier modules use the theory that there is a heating or cooling effect when an electric current pass through two conductors. Due to the tension applied at the poles of two different materials, it generates a temperature difference, given this difference. Peltier cooling will cause the heat to transfer from one side to another. A typical Peltier module will contain a series of p-type and n-type semiconductor elements, grouped as pairs, which will act as dissimilar conductors. The sketch of a Peltier module is shown in Figure 2 [12,13].

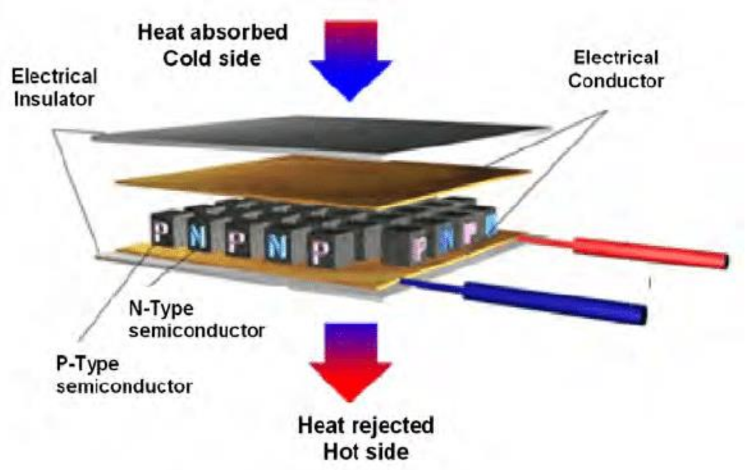

Figure 2: Sketch of a Peltier module working as refrigerator [13]

This series of elements are welded between two ceramic plates, shown by Figure 2, electrically in series and thermally in parallel. When a direct current (DC) passes through one or more pairs of elements from type-n to type-p, there is a reduction in the temperature of the joint ("cold side") resulting in an absorption of heat from the environment. This heat is transferred through the tablet by electron transport and emitted on the other side ("hot") via electrons that move from a high state to a low state. The heat pumping capacity of a chiller is proportional to the current and the number of pairs of n-type and p-type elements [13].

2.1. Peltier module characteristic

The Petier module used in this work was a model TES1-04915, where only the maximum current (4A) and the operating voltage (6V) were known, however, its behavior is not available by the manufacturer, so for lack of these information, some experiments were carried out to determine the behavior of the temperature differential (Δt^{o} C) related to variation of voltage (V) and current (A), considering an ambient temperature of 25^{o} C. Figure 3 shows the behavior of the current consumed as a function of the voltage applied. To control the current applied to the Peltier module, a microcontrolled current driver was developed.

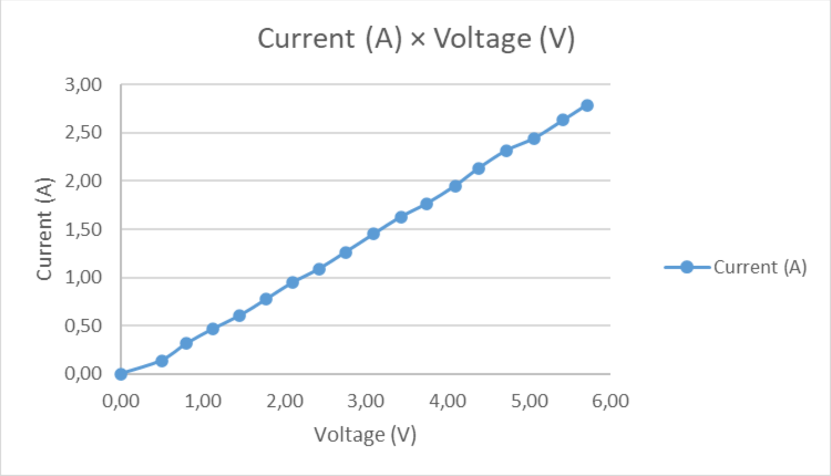

Figure 3: Voltage (V) × Current (A)

The graph in Figure 3 shows that there is a direct and linear relationship between the current and the voltage applied in the Peltier module, which does not happen in relation to the applied current and the temperature differential (Δt° C) , as shown in Figure 4.

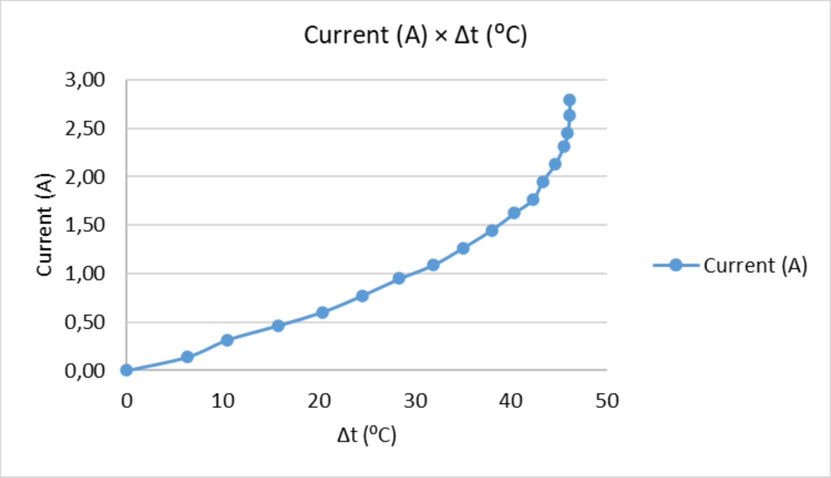

Figure 4: Current × Δt° C

Using this data, was possible to estimate the differential temperature of approximately -46°C in an environment at 25°C using the current and voltage at maximum level, 3A and 5.78V, respectively. This shown a difference between the manufacturer information from real specs.

2.2. Simulation scheme developed in the Simulink of MATLAB

For conducting the experiments, a scheme (Figure 5) was developed in MATLAB's Simulink using basically two libraries, the first being Fuzzy, responsible for loading the Fuzzy models created in MATLAB's own

Toolbox, and the ArduinoIO library, provided by MathWorks, where it is possible to interact in real time, through Serial communication and the computer's USB port, reading information from all sensors (PT100, current sensor, hall effect voltage and ambient temperature with the LM335 component) sending the information necessary for the current control by the driver.

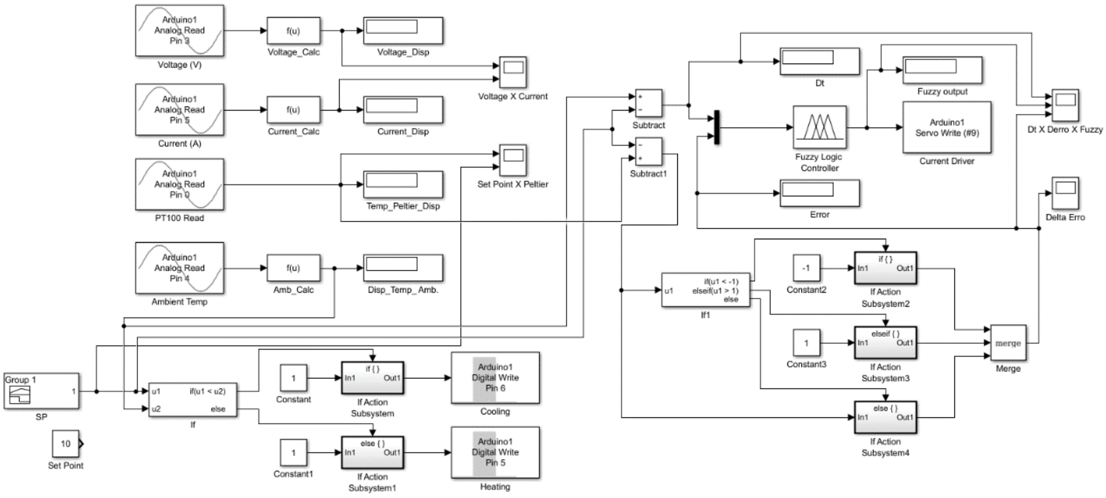

Figure 5: Simulation scheme

The operation of the plant follows the following steps: initially as the dew point value is not known, the set point is adjusted for the maximum differential temperature. Once adjusted, the system begins cooling the Peltier module and monitoring the response received from the light emitter by a phototransistor. As soon as there is a variation in the light intensity, the system adjusts the Set Point and control of this temperature starts via a Fuzzy controller.

2.3. Proposed Fuzzy Control System

Some different Fuzzy sets were built, thus enabling a performance comparison between different pertinence functions as well as the Mamdani [14] and Takagi & Sugeno [15] defuzification methods. Finalizing this experiment can be noted that the Takagi & Sugeno defuzification method with triangular functions had a better performance mainly due to the performance in the microcontroller used. The proposed system has two input variables, Δt and Δerror, and as output variable is the current driver power in percentage. Figures 6, 7 show the two input variables.

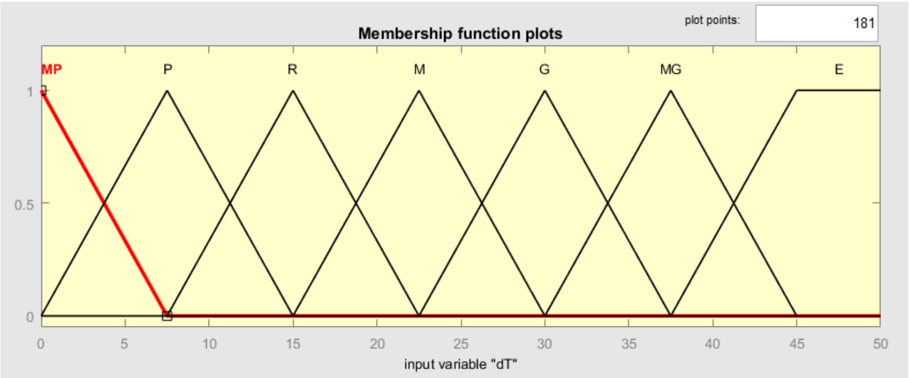

Figure 6: Input variable Δ_t

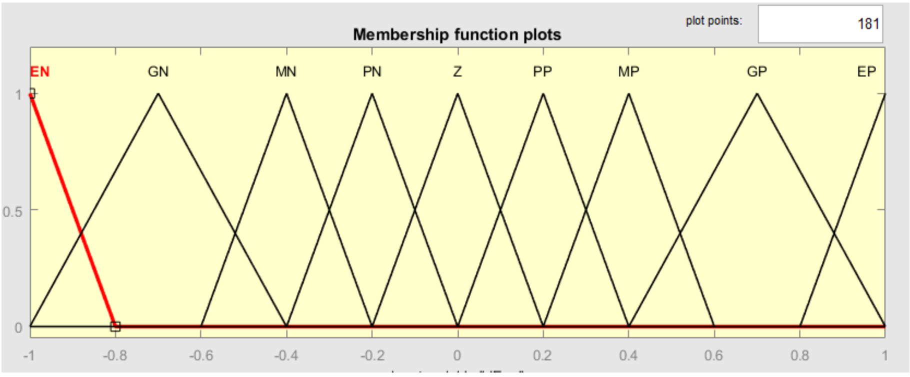

Figure 7: Input variable Δ_{erro}

Table 1 shows the set of rules used in the proposed system. As output variable is the power of the current driver, being MB, B, M, A, MA and E, containing the values 20, 35, 42, 63, 75 and 100 respectively.

Table 1: Rules of the proposed Fuzzy system

		Δ_t						
		MP	P	R	M	G	MG	E
Δ_{erro}	EN	MB	MB	MB	B	M	A	MA
	GN	MB	MB	MB	B	M	A	MA
	MN	MB	MB	B	B	M	A	MA
	PN	MB	MB	B	B	M	A	MA
	Z	MB	B	B	M	M	A	E
	PP	MB	B	B	M	A	MA	E
	MP	MB	B	M	A	A	MA	E
	GP	B	M	A	A	A	E	E
	EP	B	M	A	A	A	E	E

2.4. Developed Prototype

To conduct and validate the final phase of the experiments, a prototype was developed (Figure 8) which was used in a climate chamber together with a dew point chilled mirror from Michell Instruments company, with a resolution and accuracy of ±0.1°Cdp, which has calibration certificates, providing accurate measurement values.

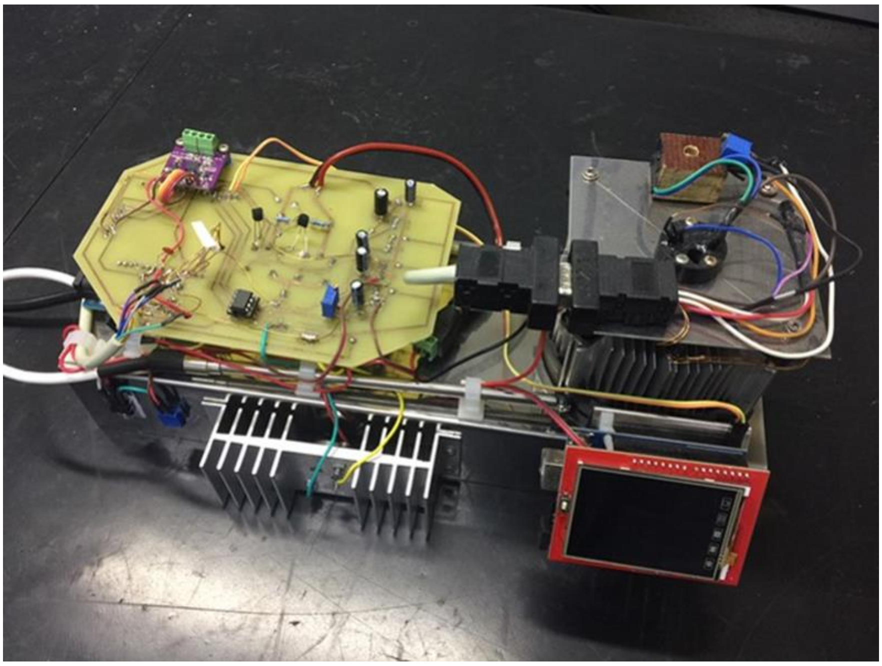

Figure 8: Developed Prototype

The prototype consists of an ATmega328P microcontroller, a touch screen for viewing and adjusting parameters, two temperature sensors, one PT-100 sensor near to the polished metal plate, to carry out the dew point temperature and the other to read at ambient temperature, a DC 15V–8A power source, a current driver designed to control the Peltier module, a Peltier module model TES1-04915, a 625nm LED and a 450→1080nm spectrum phototransistor . The microcontroller was used to perform all system control, reading all information from the sensors, performing the processing of the Fuzzy logic, as well as controlling the driver current of the Peltier module. The embedded Fuzzy system was the developed in MATLAB, and it was completely applied to run on ATmega328P, removing any dependency of the MATLAB.

3. Results and discussion

The prototype was subjected to tests in a metrology laboratory with the use of a climatic chamber, with variations being made in the set point of temperature and relative humidity of the chamber's air, aiming at validation in several different dew point temperature points. For each pair of set point (temperature and relative humidity) the equipment was tested for 30 minutes. Experiments were carried out with 25 different set points, each of which was carried out twice, thus totaling 50 experiments. The dew point temperatures explored in this work was in the ranged from -20 to +20°Cdp , this range was chosen considering the characteristics of the Peltier module used, and can be easily adjusted for other measurement ranges using a module with a Δt bigger. The data of this experiment were collected and stored by a datalogger, where the data collection of the two equipment (prototype and the reference dew point of Michell Instrument’s) occurred every 10s , thus recording the dew point temperature of the two equipment at the same time, thus enabling the correct comparison between the equipment. For all the data collected, the greatest variation occurred in the stabilization time of the devices, with the prototype having a time slightly longer than the reference. The prototype stabilization time was around 20% higher, so all data between the set point and prototype stabilization were discarded for analysis purposes. Even with this short stabilization time superior to the reference equipment, it can be considered that the prototype obtained a fast response speed. In general, the reference dew point stabilization time was a maximum of 1 minute, since the jumps between the points are not large, never exceeding 5°Cdp. When the variation of the °Cdp is much higher than these values, the stabilization time can grow considerably, and the prototype responded adequately also in the stabilization, always within a range of up to 20% more in this stabilization time. The largest deviation observed in all data collected was ±0.2°Cdp between the two devices, however this deviation represented only 0.04% of all data collected. The deviation of ±0.1°Cdp occurred in 0.07% of the data and the rest of data (98.9%) were the same when compared with the reference equipment. Thus, as can be seen, the prototype had a very satisfactory performance, being able to be classified as a high accuracy equipment. Several other equipment in the market, with similar technologies, do not reach this deviation range, with declared higher errors and reproducibility. According to analyzes carried out by the metrological laboratory, taking into account the international standards of methodology, the device meets the necessary specifications to be declared with an accuracy of 0.1°Cdp, which meets the expectations of this work, being a device of high precision as several others available on the market, however it can be implemented at a much lower cost than currently available. As for the cost of developing the equipment, it can be considered as low-cost, since the purchase of the necessary items, as well as the making of all the necessary items, was approximately US$ 120.00.

4. Conclusion

The results obtained in the conducted experiments of this work show the robustness and precision in the dew point temperature measurement by the developed prototype. The prototype was able to carry out the precise measurements of the dew point temperature in 98.9%, when compared with the reference equipment, being the biggest reading error 0.02°Cdp, which is considered extremely low when compared with other equipment already available on the market, thus showing its technical feasibility. Another important factor is the cost of development, of approximately US$ 120.00, which can be considered as low-cost, making it possible to implement it in companies of any size, thus making it possible to increase the quality of their processes. Another important point is the behavior of the Fuzzy control system implemented in this work, which proved to be extremely stable, when compared to other methods described in the literature. Thus, it can be concluded that the purpose of this work was achieved, obtaining equipment with high precision for measuring dew point temperature (°Cdp) and low-cost development of the equipment.

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