Differential Prediction Based Safety Device

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Abstract: The aim of this research was to develop an algorithm which can analyze a physical quantity, like temperature, in real time and based on the measured values of the quantity under observation, it can predict the occurrence of an undesirable catastrophic situation, like a fire outbreak, with a time margin large enough to initiate appropriate sequence of actions so as to alleviate the damage to human life and property as much as possible. A prediction equation is developed to support the algorithm. This algorithm is then validated graphically for different cases using an experimental setup which uses temperature as the input quantity. Most of the algorithms which aim at modeling of a physical quantity have an inherent drawback that they are valid for one medium only. The algorithm presented in this paper overcomes this limitation and hence lends versatility to the device in which this algorithm gets implemented. Since the algorithm is able to predict a value before it is actually detected by the device, it is useful in sensors which have a finite response time so as to boost up their performance. The algorithm here is verified for temperature as the physical quantity but it is equally valid for any other physical quantity as well.

1. Introduction

We are living in a technology ruled world where the gap between the present and the future has shrunk down to a mere division of seconds. With this decline in the time of action, there has been an increase in the number of accidents, claiming a significant share of life and property. Wiki defines an accident as: “An accident is an undesirable, incidental and unplanned event that could have been prevented had circumstances leading up to the accident been recognized, and acted upon, prior to its occurrence”. This means that accidents can be prevented if appropriate measures are adopted at the right time. This is the soul of the work discussed in this paper. Here we discuss about a fundamental method of Short Time Prediction that can envisage a disaster based on the rate of change of the physical entity in consideration. The research here has been conducted by taking temperature as the input quantity and monitoring its rate of change and making an approximate prediction of the temperature after a defined interval. Taking temperature under consideration allows us to directly deal with rate of heat transfer (as explained in the next section and if the temperature value predicted comes out to be more than permitted, it indicates the occurrence of an unwanted heat introducing process and hence an alarm is sounded to draw attention of the responsible staff towards the state of emergency.

2. Heat and Temperature

Heat is energy in transition under the motive force of a temperature difference and the study of heat transfer deals with the rate at which energy is transferred [1]. With heat inflow, the temperature of a body rises and thus, if the increase in the temperature is monitored, an estimate of the rate of heat flow can be made and based on this, the temperature at the end of the measuring interval can be predicted within acceptable margin of error. Heat is transferred in different mediums via one of the three modes [2]: Conduction, Convection, and Radiation. The described algorithm works in all three modes as explained below:

Conduction

The kinetic energy of the atoms depends on the absolute temperature of body. This implies that an increase in temperature of a body (or the containing medium) is accompanied by a consequent increase in kinetic energy of the atoms (or molecules). We can correctly say that if temperature at any point in solids or fluids is monitored and a heat inflow occurs, owing to the movement of electrons or molecules (depending on the medium), an increase in temperature will be observed.

Convection

Convection uses the motion of fluids to transfer heat. In a typical convective heat transfer, a hot surface heats the surrounding fluid, which is then carried away by fluid movement such as wind. The warm fluid is replaced by cooler fluid, which can draw more heat away from the surface. Since the heated fluid is constantly replaced by cooler fluid, the rate of heat transfer is enhanced. The rate of heat transfer depends on the fluid density,
viscosity, velocity and temperature difference between the surface and ambience.

Radiation

Radiative heat transfer occurs when the emitted radiation strikes another body and is absorbed. If a piece of metal is kept inside a fire and then taken out after a few instants, the atmosphere around the metal piece feels hot. That is because it radiates out energy to the surroundings which are at a lower temperature than the metal piece. Similar is the case of a fire outbreak. When the temperature of a body starts increasing at a tremendous pace, it starts radiating energy causing the temperature of the surroundings to rise at a similar rate. If a device equipped with our prediction algorithm is installed in such a place, it would be aptly able to detect the unnatural growth rate and in case of emergency, it can sound an alert signal.

3. Picking the Sensor

In critical applications where even the slightest delay in sensing the temperature can prove fatal, sensors commonly available in market prove to be of little use due to their large response time. In some situations, the limiting point at which a warning needs to be sounded is a value which if reached might render things out of control. In such cases it is imperative for the sensor to have an inherent intelligence so as to be able to predict the situation a few intervals before the actual situation and take appropriate action based on the predicted value rather than the actual value.

There is one more catch in using the conventional temperature sensors. As explained earlier, heat flow can happen in broadly three unique forms applicable in different mediums. Therefore its quite obvious that the rate of flow of heat will be different in all these three different forms namely conduction, convection and radiation. We cannot assume that a sensor which is installed for recording temperature change in air will also work for detecting heat or temperature change in liquid as the rate and range till which a liquid gets heated is different than that from air. Hence there is a need of inclusion of a control feature which lets the observer control the rate of recording the temperature depending on the medium in which the heating is occurring. All these drawbacks of the conventional sensors formed the primary motivation for this research and the prediction algorithm explained next helps combating these shortcomings efficiently.

4. Prediction Algorithm

As is manifested from above, the rate of heat flow is dependent on temperature in one way or the other. So it is evident that if an unusual increase in temperature is detected, it is sure to be caused by a sudden inclusion of a heat source which can be due to a fire outbreak. This forms the basis of our algorithm used in this paper.

Depending on the medium in which the experiment is being conducted, an interval is decided which is termed as the ‘difference interval’ $\Delta_r$. The difference between the first and the last sample is taken as our ‘deciding gradient’ $\Delta_d$ for prediction of the temperature at the end of the next interval. This gradient is added to the present temperature to predict the next temperature, $T_{pr}$. Mathematically this can be represented as the following equations:

$$\Delta_d = T_{\text{present}} - T_{\text{initial}} \quad \text{Eq(1)}$$

$$T_{pr} = T_{\text{present}} + \Delta_d \quad \text{Eq(2)}$$

Where

- $T_{\text{present}}$ is the present temperature or the end sample of the difference interval,
- $T_{\text{initial}}$ is the first temperature of the difference interval.

This can be explained better using an example. Let $\Delta_r$ be chosen as 10 seconds. If the temperature at the beginning of this interval is 120°C and at the 10th second the temperature observed is 135°C, $\Delta_d$ becomes $138°C - 120°C = 18°C$. Now the temperature predicted, $T_{pr}$ becomes $138°C + 18°C = 156°C$. This means that the expected temperature at the 10th second from now is 156°C. If the permissible limit of temperature is say 150°C, a warning can be sounded 10 seconds prior. Apart from providing a margin of safety, this prediction process is beneficial in cases where the response time of the sensor is particularly high. In such cases the algorithm aids in virtually enhancing the sensitivity of the sensor used, increasing the degree of accuracy with which the sensor can predict the temperature.

The following are the two phases of the above depicted progression:

**The ‘Learning’ Phase**

This phase takes place at the preliminary stage when the device is first powered on. Here the samples are
taken and for two consecutive sets the two differences are noted. At the end of this phase, the higher difference is chosen as the deciding gradient and the initial prediction takes place.

The ‘Working’ Phase

This phase takes place just after the learning process is over. As described before, temperature samples are noted and difference between consecutive samples is recorded for the predetermined number of samples. The sampling and the gradient recording is on a sample-to-sample basis rather than just the difference of the starting and ending sample of the difference interval so that if an intermediate disturbance occurs which reports an out-of-range sampled or predicted temperature, suitable action in terms of sounding the warning alarm or turning off the source of heat can be taken. The block diagram of the working phase is shown in fig 1.

Now let us get back to the sensor issue discussed above. The sensor used in this work is RTD PT100 platinum thermal resistance which has a fairly good accuracy over a wide temperature range (from –200 to +850 °C). The principle of operation is to measure the resistance of a platinum element. RTD PT100, although quite accurate in its measurement of temperature, has an inherent drawback that it takes a finite time (thermal response time) for the resistance to change in accordance with change in temperature. This thermal response time is different for different mediums but all the same it introduces a lag between real time change and sensing the change. This ‘lag’ can become a matter of concern if the temperature changes abruptly and goes out of the permissible range before the sensor can detect and report it. And it is where our algorithm comes to the rescue. As soon as the ambient temperature becomes high, the deciding gradient as reported by the sensor starts to increase rapidly. By using the equation for Tpr, the temperature value at the end of the next few seconds can be predicted and a warning alarm can be issued. Thus a relatively cheap sensor with a finite response time, starts functioning like its faster but costlier counterpart. An important point to stress here is that as the thermal response time is different in different mediums, it becomes necessary to adjust the ‘deciding gradient’ according to the medium of interest. And this feature is incorporated in this algorithm lending it an extra virtue of versatility.

The relationship between temperature and resistance is approximately linear over a small temperature range. For precision measurement, it is necessary to linearise the resistance to give an accurate temperature. The most recent definition of the relationship between resistance and temperature is

International Temperature Standard 90 (ITS-90)[3]. The linearization equation is:

\[ R_t = R_0 \times (1 + A \times t + B \times t^2 + C \times (t - 100) \times t^3) \]

Where:

\( R_t \) is the resistance at temperature \( t \), \( R_0 \) is the resistance at 0 °C, and

\( A = 3.9083 \times 10^{-3} \)
\( B = -5.775 \times 10^{-7} \)
\( C = -4.183 \times 10^{-12} \) (below 0 °C), or
\( C = 0 \) (above 0 °C)

As the aim of this work demands that the temperature be above 100 degrees, the term involving \( C \) can be dropped. Also, as the value of \( B \) is very small, the expression can be reduced to the following one:

\[ R_t = R_0 \times (1 + A \times t) \]

Eq(4)

According to Ohm’s Law[4], the relation between voltage and current is given by

\[ \frac{V}{I} = R \]

Eq(5)

Where:

\( I \) is the current through the conductor in units of amperes
\( V \) is the voltage measured across the conductor in units of volts
\( R \) is the resistance of the conductor in units of ohms

Thus if the voltage difference is measured, with known value of current (here 1mA), the resistance can be calculated and from equation 3, the value of temperature can be known.

5. Experimental Setup

The following section deals with the description of the hardware utilized in performing this research work.

Hardware Description

The schematic of the hardware setup is shown in fig 2.

Microcontroller

This is the brain and the soul of this research. The microcontroller used in this work is Atmega328P of the Atmega Series from the Atmel Company. The use of the microcontroller is multifold as explained below.
Analog to Digital Converter

The ATmega328P features a 10-bit successive approximation ADC. The ADC converts an analog input voltage to a 10-bit digital value through successive approximation. The minimum value represents GND and the maximum value represents the voltage on the AREF pin minus 1 LSB[5]. The measured voltage is input to the ADC(analog to digital converter) and using the following equation, the input or the measured value of the voltage can be known.

\[ V_{\text{measured}} = V_{\text{ref}} \times \left(\frac{\text{ADC}}{2^n}\right) \]  

Where

- \( V_{\text{measured}} \) is the measured value of voltage,
- \( V_{\text{ref}} \) is the reference voltage of the ADC
- \( ADC \) is the output value of the ADC
- \( n \) is the number of bits used for the ADC

The ADC needs a trigger to start its conversion. This trigger is provided here by the use of another peripheral of the microcontroller: the 16-bit timer [6]. The duration between two successive triggers is controllable and depends upon the response time of the medium under consideration. This additional control successfully solves the problem of using the same sensor in different mediums hence lending the device an edge in versatility. The minimum duration is limited by the maximum allowable frequency of the ADC conversion which here is 200 kHz.

Displaying the Values

The mathematical analysis of the prediction algorithm was done in theory section. The Microcontroller receives temperature samples from the ADC (after calibration) and feeds them to the prediction expression for predicting the next temperature. The present and the predicted values can be sent to the UART of the microcontroller and can be displayed on the laptop screen using any Serial/TCP Terminal. The terminal used for this project is RealTerm.

Software Used and Block Diagram

The software used for this work is Atmel Studio 6.2.

6. Graphical Verification

The following graphs were plotted between the real temperature and the predicted temperature for two cases:

1) For constant heating
2) For extreme heating

For the second case, the test was conducted using a candle flame and the results are shown in fig 4. Here it can be seen that during the learning phase, the predicted value is zero. After the learning phase is over, prediction starts. As is evident from the graph, the predicted value is almost always higher than the current value providing a margin of safety to sound the required alarm

7. Practical Application and Scope

The above mentioned experimental setup can be used in places more vulnerable to fire such as smelting plants, petroleum industry, power plants etc. This can also find use in common household especially in the kitchen area. The device can be used as a general precautionary measure in places involving masses such as schools, hotels, hospitals, malls and other places that have a heating unit in one form or the other.

There is yet another use of the device. In many applications like baby incubators, there is a need of a controlled environment with the temperature being more or less constant. In such situations, if the device experiences a sudden deviation from the set value, it can immediately sound an alert and if required, it can turn off the source of heat as well.

The same algorithm can also be used in case of chemical reactions. In chemical industries, often mishaps occur when some unprecedented reaction which releases huge amount of toxic substances in the atmosphere. The Bhopal Gas Tragedy [7] is one such instance where negligence of a proper monitoring system led to an enormous loss of life and property. If a setup similar to the one used in this research work is employed with the temperature sensor being replaced by an appropriate chemical sensor, such life threatening events can be avoided and controlled to a large extent.

There is another use of the same setup. Using the same setup as above along with a heating source which has a constant heating rate and a sink, the substance property such as conductivity can be calculated. Just a simple modification in the algorithm is required which does not delve into the prediction algorithm and just records and reports the sensed temperature value.

8. Conclusion and Summary

As technology is progressing by leaps and bounds, so is the occurrence of accidents due to lack of proper means to monitor and interpret the required
physical quantities. The work presented in this paper aims at developing a versatile algorithm which can be used with different sensors and which can predict from the values sensed by the sensor if a sudden disturbance has occurred in the system and which can issue an alert signal if it predicts a physical catastrophe due to the occurred disturbance. A block diagram has been explained showing the algorithm implementation. Hardware setup for using the algorithm in conjunction with a temperature sensor has been shown and explained with special care on the hardware features majorly addressed by the algorithm like sensor response time and trigger time of the ADC. The equations and the algorithm suggested have been verified experimentally and show a high degree of accuracy in predicting the temperature in real-time.

![Fig 1 Block Diagram of the Working Phase](image1)

**LIST OF REFERENCES**

By Gordon Rogers


