Temperature Based Embedded Programming Algorithm For Conventional Machines Condition Monitoring

Michael Kanisuru Adeyeri
Department of Mechanical Engineering
The Federal University of Technology, Akure
Ondo State, Nigeria
sademike2003@yahoo.co.uk; mkadeyeri@futa.edu.ng

Buliaminu Kareem
Department of Mechanical Engineering
The Federal University of Technology, Akure
Ondo State, Nigeria
bkareem@futa.edu.ng

Adeyemi Adegbemisipo Aderoba
Department of Mechanical Engineering
The Federal University of Technology, Akure
Ondo State, Nigeria
babalojojo@yahoo.com

Sunday Olumide Adewale
Department of Computer Science
The Federal University of Technology, Akure
Ondo State, Nigeria
adewale_olumide@yahoo.co.uk

***Abstract*—** A **temperature-based embedded programming algorithm for conventional machines condition monitoring is being discussed. Machinery health deteriorates day in day out as they are being used for production purposes. If a proper check, maintenance activities and monitoring are not put in place, such machinery would not perform optimally and production efficiency would be affected. Based on this, the present work focuses on programming a temperature sensor AD595 and K-type thermocouple using a C programming language as a means of embedding them into the microcontroller with a real time clock (RTC) incorporated to keep the time of events and temperature readings of the machines' components for effective maintenance plan. The whole design is embedded in production machines to keep monitoring the machines' conditions and behavior as related to temperature induced faults and breakdown matters. The algorithm interprets and reports the fault class name to the operator, diagnosis and proffer solutions based on the embedded decision block. The hardware resulting from the design was tested using a conventional elevator, silos and hammer mill (which are parts of the production set up line for the production of vegetable oil) for a period of four months. The output performance is satisfactory as maintenance decision and machines' health monitoring are optimized.**

Keywords-Temperature; thermocouple; algorithm; conventional machines; condition monitoring; microcontroller.

I. Introduction

Machinery is required to operate within a relatively close set of limits. These limits, or operating conditions, are designed to allow for safe operation of the equipment and to ensure that equipment or system design specifications are not exceeded. These limits are usually set to optimize product quality and throughput (load) without overstressing the equipment.

Conventional machines are machines which are operated manually. These machines are controlled by cams, gears, levers, or screws. Examples of these machines are Lathe, grinding machine, flaking machine, extruder and just to mention a few. They indeed needed special attention to safe guard or vouch safe for their functionality and optimal performance as compared to the non conventional machines which are controlled automatically by integrated computer.

Manufacturing process objective focuses on efficient production of products with specific shape, acceptable dimensional accuracy and quality. Slight deviation of the machine conditions from a prescribed plan will affect the final product quality and standard. Global industrial competition and the current economic conditions have geared up many manufacturing organizations to improve product quality and cut production costs simultaneously. The requirements for increased plant productivity, safety, and reduced cost on maintenance, have resulted to a growth in popularity of methods for condition monitoring to aid the planning of plant preventive maintenance and operational policies [1].

Malfunctions in equipment and components are often sources of reduced productivity and increased maintenance costs in various industrial applications. For this reason, machine condition monitoring is being pursued to recognize incipient faults in striving towards optimizing maintenance and productivity in conventional machines.

From literature, current production systems have unsatisfactory overall availability due to excessive downtime caused by either quality related issues or machine/component failures [2]. Current single station's mean-time-to-failure (MTTF) and mean-time-to-repair (MTTR) assessment does not reveal overall system performance and dynamic resourcing which is not addressed in today's total productive maintenance (TPM) and manufacturing execution systems (MES) [2].

In real life applications, measuring temperature is not really a problem especially in practical applications like medical and air conditioning systems. In industrial setting on the other hand, temperature signal conditioning becomes a concept that needs to be given special attention to convention machines. That is why very high precision and accuracy is the ultimate goal of any model that targets programming ambient physical parameters like temperature. In order to achieve the above, an embedded programming model is established to ensure sensing temperature and delivering the accurate result.

II. LITERATURE REVIEW

Condition monitoring is a maintenance process where the condition of equipment with respect to overheating and vibration is monitored for early signs of impending failure. Equipment can be monitored using sophisticated instrumentation such as vibration analysis equipment or the human senses. Where instrumentation is used, actual limits can be imposed to trigger maintenance activity. Condition Monitoring (CM), Predictive Maintenance (PM) and Condition Based Maintenance (CBM) are other terms used to describe this process.

Machine condition monitoring involves the intermittent or continuous collection and interpretation of data relating to the operating condition of those critical components of a machine. Monitoring can greatly reduce maintenance costs by giving adequate notice on pending failures to permit planned repairs, as opposed to costly emergency breakdowns with their attendant lost production, overtime, and expediting costs [3].

Failure occurs when a component, structure, or system is unable to fulfill its intended purpose, resulting in its retirement from usable service. Possible failure modes include component deformation, fracture, surface changes such as cracks, material changes, displacement, leakage, and contamination [4]. Secondary effects, or symptoms, often occur prior to total machine failure, providing indicators for predicting failure onset. Frequently used indicators are vibration signals; noise, heat generation, and particle wear levels as measured in machine lubricants.

Condition-based maintenance is a maintenance strategy that recommends maintenance actions based on the information collected through condition monitoring. And the aim of this strategy is to improve the equipment's reliability, availability, or its associated life cycle costs [5].

Neelam [6] researched on condition monitoring and fault diagnosis of induction motor using motor current signature analysis. Neelam's research consists of experimental characterization of rotor faults in induction motors operating under different loading conditions in which the fault algorithm developed monitors the amplitudes over time. And five different faults *vis a viz*, rotor fault, short winding fault, eccentricity fault, bearing fault and load fault are practically implemented and their effects on motor's current are considered with help of different signal conditioning techniques.

Condition-based maintenance is the diagnosis of component failure or a prognosis of a component's time to failure [7]. Jasper *et al.* [7] aimed at formulation of empirical postulates regarding the technical system, managerial system and workforce knowledge.

Mahantesh *et al.* [8] developed and tested a condition-monitoring sub-module of an integrated plant maintenance management application based on artificial intelligence (AI) techniques, mainly knowledge-based systems, having several modules, sub modules and sections. The paper collectively deals with the analysis of the state-of-the-art expert systems for diagnosis and maintenance of general-purpose industrial machinery.

Christian [9] researched on competing through maintenance strategies in which the competitive factors were examined. The research work shows that equipment maintenance and reliability management are importantly associated with an organization's competitiveness and be given adequate attention in the organization's strategic planning.

Liliane *et al*. [10] evaluated the effectiveness of maintenance strategies under four frameworks that can identify and evaluate the effectiveness of a given maintenance strategy in a company. The four frameworks implored are minimization of manufacturing's negative potential, achievement of parity (neutrality) with competitors, provision of credible support to the business strategy and aiming a manufacturing-based competitive advantage. And it is found that the framework is applicable and useful for the strategic management of the maintenance function as well as enhancing the competitive advantage of a company.

Jihong [11] modeled a prognostic algorithm for machine performance assessment and their applications explored a performance model through the advantage of logistic regression analysis with maximum likelihood technique and predict the remaining useful life, which would lead to proactive maintenance processes in minimizing downtime of machinery and production in various industries, thus increasing efficiency of operations and manufacturing. They buttress their research with two kinds of application situations with or without enough historical data.

Today's technology has given room for invention of computer numerically controlled machines for production purpose in which integrated circuits and sensors related to maintenance information are embedded to keep track of machines' health for effective and optimized performance of the machines. But there is need to bridge the gap between these computerized and conventional machines age so that the conventional machine users can effectively enjoy the machines' throughput with minimal breakdown and compete in the industrial world without abandoning the conventional machines. Hence the needs for this research work to provide a medium where temperature sensors could be embedded in conventional machines for monitoring their health status and functionality. Therefore the present work describes temperature algorithm for temperature sensor that is needed in assisting, monitoring the behavior of machines' performance or health status and the maintenance activities required for maintaining or preventing temperature related faults or breakdown of conventional machines such as elevator machine, silos and hammer mill.

III. METHODOLOGY

A. Temperature Model Equation

Temperature measurement (e.g., temperature-indicating paint, thermograph) helps detect potential failures related to a temperature change in equipment. Measured temperature changes can indicate problems such as excessive mechanical friction (like faulty bearings, inadequate lubrication), degraded heat transfer and poor electrical connections (for examples, loose, corroded or oxidized connections). The below equation1. is used in modeling temperature monitoring for machines.

$$T_i^{ta} = T_i^{o}[1+U_T]_b^{t_n} \tag{1}$$

where

$T_i^{t_a}$: the predicted value of temperature at next planned measuring time

T_i^o : the current temperature value

t_n : periodic time numbering of readings

U_T : temperature deteriorating factor and it is expressed as

$$U_T = \frac{T_i - T_o}{T_m^c} \tag{2}$$

T_i : initial temperature value

T_o = measured Temperature before $T_i^{t_a}$

T_m^c = Critical temperature limit level

b : is a function of speed, environmental condition and demand frequency.

Therefore, if $T_m^c \geq T_i^{t_a}$, then maintenance is required, otherwise do not.

B. Factors influecing the choice of Temperature sensor

The difference between serial and special manufacturing is only the mechanical structure of the sensors. The criterions used in choosing temperature sensor are as listed below:

- At which position is the temperature to be measured?
- The medium at which temperature is to be determined?
- Which diameter can be installed in the production process?
- Mechanical process connection to be used
- The type of electrical connection
- Which mechanical and thermal stress is the sensor subjected to?

The answers to these questions are the basis for the choice of special temperature sensors for mechanical machines and these have assisted in choosing k-type thermocouple for this research.

A block diagram of the AD594/AD595 thermo-couple signal conditioner IC is shown in Fig. 1. A Type K thermocouple is joined to amplifier differential Pins 1 and 14 so as to reference the local temperature. With the IC also at the local temperature, an ice point compensation circuit develops a voltage equal to the deficiency in the locally referenced thermocouple loop. This voltage is then applied to a second preamplifier whose output is summed with the output of the input amplifier. The resultant output is then applied to the in-put of a main output amplifier with feedback to set the gain of the combined signals. The ice point compensation voltage is scaled to equal the voltage that would be produced by an ice bath referenced thermocouple measuring the IC temperature. This voltage is then summed with the locally referenced loop voltage, the result being a loop voltage with respect to an ice point [12]. The circuit description diagram for this thermocouple is as shown in Fig. 2.

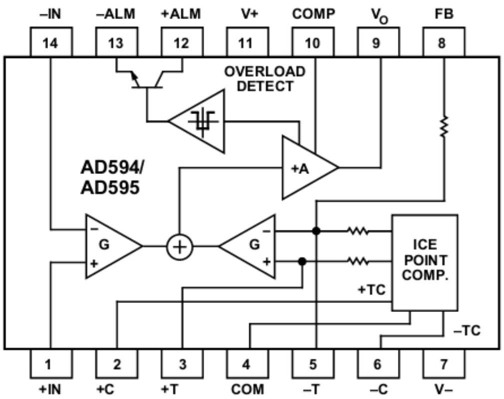

Figure 1. AD595 Block Diagram

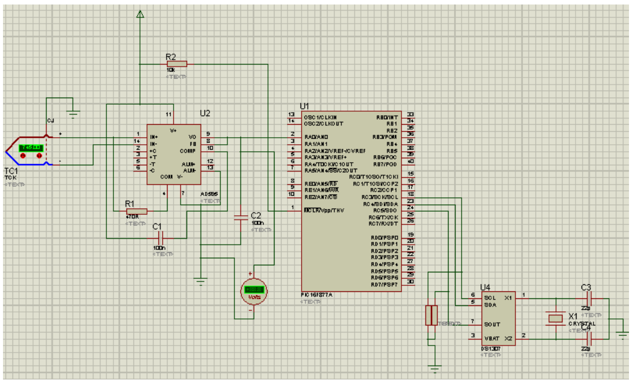

Figure 2. The AD594/AD595 Circuit Description

C. *Embedded interface*

The following components are used in keeping track of the system:

i. Analog Digital Converter (ADC): The output from the sensor is usually an analog signal that needs to be converted to a discrete signal for proper digitization. In order to achieve this, an analog to digital conversion module is required. For this model, a 10 bit ADC resolution is made used of.

ii. Microcontroller: The microcontroller used for developing this model is Atmel Atmega 16 MCU, this is an 8 bit MCU but with internal 10 bit resolution ADC module. This makes the MCU a choice for this model.

The block diagram shown in Fig. 3 depicts the proposed arrangement of the embedded temperature sensor interface with the machine

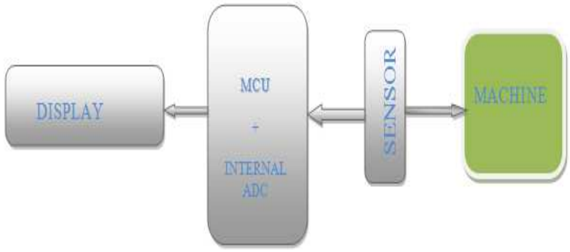

Figure 3. Block diagram of proposed arrangement of temperature sensor interface with conventional machine

D. *Model Algorithm*

The code for the microcontroller is developed in C language which is not included in this paper. The preliminary exercise carried out in order to get the basis of the conventional machine is to:

i. study the temperature behavioural pattern of the machine to model; and
ii. get the trend of the temperature pattern of the machine system by recording ten to twenty readings of the temperature over a wide period of time and noting the performance rating of the machine against the corresponding temperatures.

While the algorithm developed for the model is as stated below:

Step-1 Setting up: set up display, set up real time clock and set up the internal analog to digital converter
Step-2 Wait for responses
Step-3 Set timer T to zero second and the counter to zero
Step-4 Initialize timer
Step-5 Is timer equals 10seconds?
Step-6 If no, go back to timer initialization, else get the ADC value
Step-7 Counter stores value to RAM
Step-8 Has counter counted to ten values?
Step-9 If no, continue with timer initialization, else counter reset to zero
Step-10 Calculate average temperature
Step-11 Store value in EEPROM, convert temperature value to ASCII and get real time
Step-12 Display value and time
Step-13 Use inference decision block: for example, if $T_m^c \ge T_i^{t_a}$, then maintenance is required, otherwise do not; make inference on machine parts affected and give suggestion
Step-14 Is decision made? If yes, display decision
Step-15 Delay sets in to cater for decision displayed, else back to reset
Step-16 Go to start

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This algorithm is therefore translated into flowchart shown in Fig. 4, so as to have a better understanding of the system.

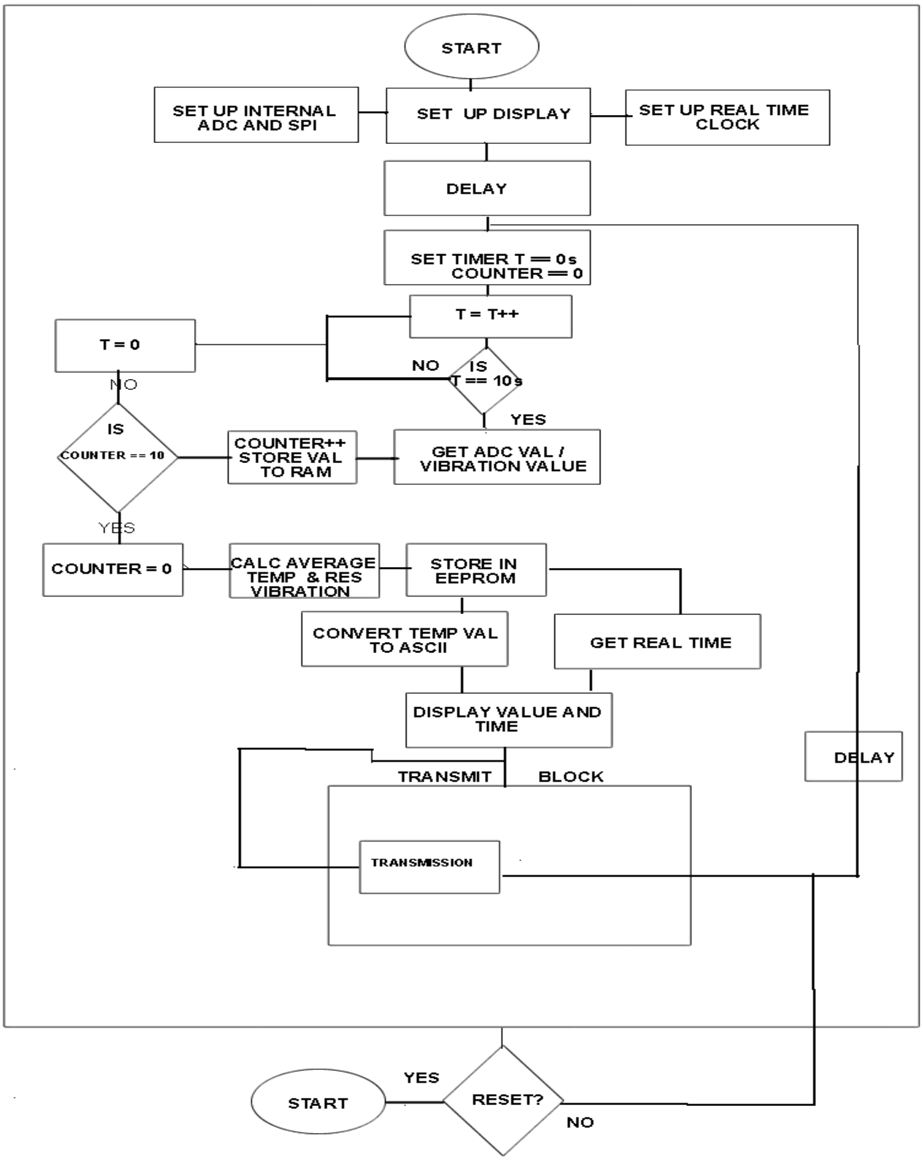

Figure 4. Flowchart of the Temperature sensor Model Algorithm [12]

IV. MODEL VALIDATION

The stated algorithm had been transformed into codes in C programming so as to ensure the practicality of the model (though this aspect will not be discussed in this submission). The whole system is tested by using a conventional elevator, silos and hammer mill which is a part of the production set up line for the production of vegetable oil for a period of four months. The readings taken are as shown in table1. The machine components being affected by temperature are listed with their corresponding readings. N denotes normal machine temperature reading on on-load condition and A connotes abnormal temperature reading.

TABLE I. GEARBOX TEMPERATURE TREND READINGS AND MAINTENANCE MODEL SUGGESTION DECISION OF ELEVATOR, SILO AND HAMMER MILL MACHINES

Sampling dates	**Elevator's Gear box temperature (°C), conditions and decision**			**Silo's Gear box temperature (°C), conditions and decision**			**Hammer mill's Gear box temperature (°C), conditions and decision**		
	Temp.	***conditions***	***Model decision suggestion on maintenance activities***	***Temp.***	***conditions***	***Model decision suggestion on maintenance activities***	***Temp.***	***conditions***	***Model decision suggestion on maintenance activities***
01/11/2011	40.0	N		49.5	N		69.6	A	Poor lubrication
10/11/2011	40.8	N		50.0	N		42.6	N	
15/11/2011	40.8	N		50.0	N		42.7	N	
20/11/2011	46.0	N		50.0	N		43.0	N	
01/12/2011	46.0	N		51.0	N		43.0	N	
05/12/2011	46.2	N		51.3	N		43.2	N	
10/12/2011	46.1	N		52.0	N		44.1	N	
15/12/2011	46.2	N		52.0	N		44.1	N	
22/12/2011	46.5	N		52.0	N		44.5	N	
01/01/2012	46.6	N		52.0	N		46.6	N	
10/01/2012	46.7	N		52.0	N		48.9	N	
20/01/2012	47.0	N		65.0	A	Stop machine. Check for foreign materials and dirt in ball bearing	50.0	N	
01/02/2012	45.9	N		50.0	N		45.9	N	
25/02/2012	75.0	A	Stop machine. Check ball bearing	50.0	N		46.0	N	

As seen from Table 1, on the 1st of November, 2011, the temperature readings sampled from the production process revealed that the temperature values of the elevator gear box, silo gear box and hammer mill gear box read 40 °C, 49.5 °C and 69.6 °C respectively. And the corresponding health status of these machines indicated that they are normal except that of hammer mill which is abnormal. On this note, the model gave a maintenance suggestion clue that the temperature abnormality is as a result of poor lubrication. Looking through the Table 1, it has shown that the model algorithm is correct as it could distinguish between when the machine conditions are normal, abnormal and display maintenance suggestion messages which are valid and result oriented.

V. CONCLUSION AND FUTURE WORK

The efficient and optimum performances of machines lie on the prompt and on-line monitoring of the machine components and behavior. The research work under discussion has really shown that temperature which is one of the key factors affecting machine performance could be monitored to aid maintenance plan. It is to be hoped that the tool herein described will assist conventional equipment maintenance and personnel in decision making as they progress towards optimizing maintenance plans.

The present work could not give the overall true picture of the machine health status, therefore the future work would entail building an integrated sub-system hardware that incorporates other machine condition monitoring indices such as vibration and machine wear sensors which will assist in having a full diagnosis of the machines, and thus enhancing its functionality.

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