# Design Methodology of a Fault Aware Controller Using an Incipient Fault Diagonizer

**Joydeb Roychoudhury[1], Tribeni P. Banrerjee[1], Anup K. Bandopadhaya[2] and Ajith Abraham[3]**

[1]*Central Mechanical Engineering Research Institute, Embedded system Laboratory, Durgapur-713209*
[2]*Electronics and Telecommunication Engineering Department, NIT Durgapur Durgapur-71320*
[3]*Machine Intelligence Research Labs, Scientific Network for Innovation and Research Excellence, USA*
*jrc@cmeri.res.in, tribeniju@gmail.com, akbece12@yahoo.com, ajith.abraham@ieee.org*

**Abstract**

*The problem of failure diagnosis has received a considerable attention in the domain of reliability engineering, process control and computer science. The increasing stringent requirement of quality of a product needs considerable attention in the performance and reliability of the manufacturing system. In general, the feedback control algorithm for a process designed to handle small perturbation that may arise under normal operating condition but can not accommodate any abnormal behavior due to fault. Thus the automated maintenance or early detection of worn equipment is becoming a critical issue. This justifies the need of development of effective methodology in the area of fault aware controller. In this paper we proposed a novel Algorithm and it have been tested and implemented for making Highly reliable system like Automated Cricket Ball Stitching Machine. Considering this need the present paper proposes the work on the development methodology of fault aware controller using embedded processor with reference to an early needle failure detection of a leather stitching machine.*

## 1 . Introduction

Any incipient faults have a serious consequences and needs to be addressed properly so that it can be accommodated properly through a fault Diagonizer.

In general, failure is described as an abrupt change which can be modeled as a stepped event. The incipient fault is apparently remaining silent but change occurs slowly in a dynamic system with time [1]. This can be modeled as extended timed automata. We consider development of a diagoniser which can detect an incipient failure in a dynamic process and take necessary timely measure before occurrence of any undesired event. In this paper we consider the wear out phenomena of a mechanical component where the fault remains incipient in the system for some time due to partial degradation of the internal state of the component and remain unobserved due to its low latency period, non availability of proper sensor technology etc. [2]. Wear out of a component in a manufacturing system is inevitable and bound to occur in course of time. The main issue is how to address the detection methodology of component behavioral discrepancy in right time. The paper discusses the methodology of development of a Diagonizer which can detect the undesired or off specification behavior of the component or fault using extended timed finite state automata. The same is used to design an observer using embedded micro controller.

## 2. Problem Definition and Design Methodology

One of the main difficulties in dealing with an incipient fault in a process controller arises due to the compensating effect of the feed back control system- which diminishes the small effect of incipient fault during tracking its performance. Hence a suitable observer is to be designed which can detect this small effect at an early stage of occurrence and communicates to the controller for taking necessary corrective measure.

Under this condition the controller is fault aware controller with following additional features

- -The controller is aware of its own state
- -The controller can quickly detect if a fault has occurred.
- -The controller can deal with the fault by correcting it or minimizing its adverse effects.

Recently various approaches has been adapted for development of algorithm for process monitoring and diagnostic systems like Timed Petri nets, Stochastic Automata ,Timed Automata or Semi Markov Process. The main idea behind this is to simulate normal and faulty system behavior with discrete timed model. We consider a timed dynamic process whose dynamics changes at some unknown time due to failure of its internal structure (wear out phenomena) – which is not directly available as an output signal till it generates an undesired result. Hence proper modeling is required which can capture this change of internal state due to wear out before failure occurs.

This paper discusses the methodology for development of a fault diagoniser applicable for incipient fault detection based on duration measurement of a task executed in a dynamic process [2]. This temporal measurement of duration (time period) of activity of a particular component changes when it operates in a degraded condition (under constrain).Thus the duration captures the internal. Based on this principle we propose how extended time automata can

978-0-7695-3745-0/09 $25.00 © 2009 IEEE
DOI 10.1109/HIS.2009.216

help to develop a qualitative model of behavioral discrepancy state of a degraded component in a dynamic process. The paper also shows how the model is used for development an algorithm of a fault ware controller with an early detection of fault.

### 2.1. Timed Automata

Timed automata (Alur & Dill ,1994) are a popular plant model for time dependent system that extended from classical finite state machine with real time clocks [3][11]. Here the clocks can record the passage of time in states and can be used to guard the occurrence of transitions. A timed automation generates timed sequence of events i.e alternating sequence of real valued duration corresponding to an event. Fault diagnosis problem for a timed plant is to detect faulty behavior from a given timed sequence of observable events of the plant.

### 2.2. Extended Timed Automata

We consider a timed automation as an abstract model of a running process. The model describes the possible events (i.e alphabets accepted by the automation) that may occur during the execution of the process. The occurrence of the events must follow a timing constrain available from the actual model of the plant. But the model gives no information on how these events should be handled. It has been found this extended timed automata can be used to model the behavior of a dynamic system and corresponding state transition diagram can be used for the development of a fault Diagonizer [4].

We define the Diagonizer as a function (F(d)) which can tell us from a given sequence of observable state transition generated by the plant whether an internal fault occurred or not. The primary requirement at this stage is to associate a task corresponding to a transition. In this case we compare the estimated duration in response to an event which changes with time and generate a deterministic output [5].

Once the plant is modeled then it necessary to associate each discrete transitions in a timed automation with a task i.e an executable program with worst case execution time and dead line. Each transition linked to a task and a guard moving from one state to other state depends on the duration state of the degraded component.

The timed system can be modeled as automata or in general through a discrete transition structure extended with real variable clock. Thus a timed system can be specified as a composition of timed transitions which measures the time elapsed since initialization and have following features:

States are associated with time progress and condition specifies how the time is advancing with qualitatively.

At the time of transition the corresponding clock value can be tested and subsequently modified. This usually done with the transition guards, which defines conditions of the clock.

Each action defined by a program called task η with known worst case execution time t and deadline d. We shall specify the arrival time of the task by the cock constrain. Thus the task η is character sized as a pair (t,d) of natural number where t <=d.

## 3. Practical Implementation of Early Needle Wear Out Detection

Cricket ball is generally manufactured by a manual process using different kinds of needle, dies and punch. Decorative stitching is required for better gripping and better swing of the ball. At present two hemispherical leather cups are stitched manually along the circumference using a needle. This is a laborious and lengthy process with minimum hourly production rate.

In order to improve this manual stitching process an electromechanical automatic stitching machine shown in the figure 2, has been developed which operates automatically for a pre programmed number of stitches along the periphery of a 4mm. width hemi spherical leather cup [9]. The control system is designed using an ATMEL 89C2051 microcontroller [8], which interacts with a stepper motor for controlled rotational movement of the ball and a geared DC motor for up or down movement of the needle through its out put port..

The programmable rotational movement of the cricket ball is measured through a 5000 PPR (Pulse Per Revolution) encoder. After each pre programmed rotation of the ball it stops for some time till the stitching is complete .The rotational motion of the ball and vertical up down motion of the needle is synchronized by the micro controller.

### 3.1. Problem with Existing System

In general, the breakage of the needle in the mid way of stitching process along the circular periphery of a cricket ball is undesired because it increases no. of rejection of cricket balls in a commercial production setup. This needs an early detection of breakage of needle and subsequent replacement of the needle at the right time. Here the breakage (fault) occurs due to the degraded sharpness of the operating needle which remains undetected by the controller during stitching process.

The basic objective is to design a Diagonizer which can detect and correct the fault in right time. We consider the problem as failure detection due to the breakage of needle at an early stage [6].

### 3.2. Solution to the Problem

As direct measurement of the sharpness of a needle is difficult - we consider the system as a timed system where the time of stitching is proportional to the sharpness of the needle. This implies that the sharp needle will take less amount of time than a blunt needle for stitching the same width of leather cup. An extended timed model is considered for better understanding of the internal state change of the needle when it is under constrain and used for fault observer design. The prime requirement is to qualify the time through an extended timed automata so that behavior can be estimated in proper time.

### 3.3. Proposed Duration Modeling

The Unique and the novel approach of the paper is Modeling of the Duration constrain and measuring this through a proper algorithm using a Microcontroller [7]. The Duration constrain help us to describe the formal specification of a dynamic system more accurately. Generally the behavioral constrains ensure whether the environment of a system is well behaved. Our Consideration is to estimate the behavior of the environment through timed automata and this leads to develop suitable algorithm for development of a fault Diagonizer. Duration constrain of an event specifies the time period over which the event remain active and help us to qualify the behavior of the system. A duration constrain can either be minimum or maximum type. The minimum type duration constrain requires that once an event starts the event must not end before a certain minimum duration where as a maximum event duration constrain requires that once the event starts it must end before a certain maximum time. The lower and upper limit if quantified properly then this timing constrain can help to detect the malfunctioning of a component at an early stage of occurrence. The extended timed automata can be utilized to model and estimate the limits. An advantage of this method is that the detailed list of failure modes is not required and the failure can be estimated on the basis of online diagnostic process. This implies an online diagnostic scheme instead of test inputs.

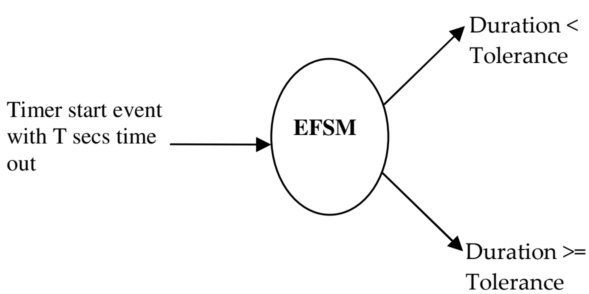


**Figure 1.** The function description of the EFSM

The proposed approach takes the degraded functioning mode of a component with real time taken into consideration. When a particular task of the process is executed within a predefined interval 'd' the system is in a good working condition and if it exceeds this - but remain within a tolerance level it is considered as degraded condition where as if the duration time exceed the tolerance level it is in failed mode.

From the modeling point of view the normal and degraded states are similar i.e same structure with associated sub states and transitions are isomorphic, where as the failure state is an absorbing state and it needs maintenance intervention. The primary requirement is to identify a fault prior to the failure state related to the timing sequence. The correct and timely identification of a fault at an early stage is challenging because the similar nature of two conditions of a component i.e 'good and degraded' and is difficult to identify with reference to the value with high possibility of false detection.

We assume the duration for which a needle is engaged for stitching is changed with the sharpness (internal state) of the needle. It is necessary to map this internal state to a corresponding stitching duration correctly so that measuring duration within a fault latency the internal state can be quantified and subsequently used for generation of an alert signal.

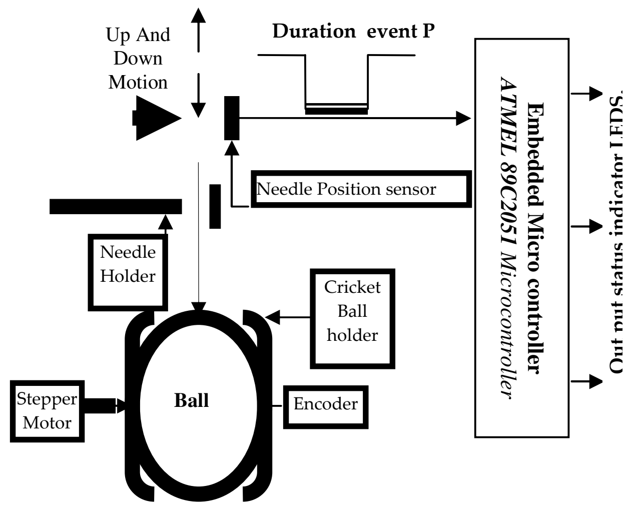


**Figure 2.** Embedded Micro controller based Stitching

We declare the condition guided by the sharpness have three mode (i) Good (ii) Degraded and (iii) Failed. We have to optimize the duration which tells the right time for replacement of the needle before breakage.

Thus the primary objective of the diagnostic process is to quantify these three timing duration through a proper deterministic model. The difference between these modes lies within the tolerance associated to the task duration [10].

Let us consider a discrete system whose in put is sharpness (v) and out put is pulse width (w) represents a needle and assume the output can only be qualitatively measured with reference to the needle condition.

Under this condition the system state x is considered in the discrete state space which can estimate the internal state of the component (needle) and needs to be mapped properly to the corresponding stitching duration. Assume that every state partition is associated with duration which is unknown but can be determined by state observation using an input output sequence.

We consider the stitching duration as an action defined by a task η with known worst case execution time t and deadline d. We shall specify the arrival time of the task by the cock constrain. Thus the task η is character sized as a pair (t,d) of natural number where t <=d. If the stitching process is complete within t seconds then the needle is in good condition and if it exceed to t+T where T < tolerance level then the needle is in degraded condition and if T > tolerance level then the needle is in Bad condition. We have to estimate the tolerance level for a particular needle and compare the time out event T with this for generating an alert signal through the output port for necessary preventive action.

We consider extended finite state machine for stitching duration constrain modeling. EFSM (figure 1) extends the traditional finite state machine by in corporating the action of setting a timer and subsequent expiry event of the timer. We describe an event e occurs when the current state of the event is s. Then the action will be after initializing and staring the timer and keep an watch whether timer expired in a predefined deadline.

In the ATMEL 89C2051 micro controller the timer 0 operates at 1 Mhz at 12 Mhz. operating clock frequency. Which means each decrement of the timer register takes 1 micro seconds of time.

A full scale model of the decorative stitching machine (figure 2 ) was developed used for stitching on a hemispherical leather cup using wax coated thread. It has been found for a thickness 4 mm. hemispherical leather 65 nos. stitches along the periphery of a semicircular leather segment takes approximately 100secs.Hence for one stitch it takes 1.5 secs. Which implies if with in .75 sec the fault can be detected then it is possible to replace the needle before next stitch and it is validated with the proposed hardware.

### 3.4. Pseudo Code for the System Design

*Clear the Register();*
*Reset the Flag =0*
*Set the End_Stitching ==65*
*Set the Start _Stitching==0*
*Reset the Ball Initial_Position ();*
*Reset the Needle_Position();*
*Reset the Encoder_Value();*
*Set The wd_Timer();*
*Set the Timer_Period =1.5 Sec;*
*Set the motor_Speed=3.6 deg/secs;*
*Do (Start_Stitch= End_Stitch)*
*Needle_voltage = 1*
*Push_In_Out(<=1.5 Sec)*
*Rotate Stepper_motor();*
*Set_Timer=1;*
*Set _flag=1;*
*Call wd_monitor();*
*Reset wd_timer();*
*Start _Stitching=Start_Stiching+1;*
*Clear;*
*Set_flag= 0;*
*Increment_Encoder_Value;*
*If (>1.5sec) then*
*Call wd_monitor();*
*Stop;*
*Reset the Needle_Position;*
*Encoder_Value=Previous_Encoder Value;*
*While(Start_Stitch< End_Stitch)*
*Stop needle();*
*Cheek_Status =Compare_All_Stitching;*
*Reset All();*

We apply the a new concept that is if the needle misses the task within the critical time period and it misses the deadline for that reason we implemented one watchdog timer portion that will look after the deadline misses. The watchdog timer is extensively used in real time system design.

Within the Algorithm the timer start a certain critical function f () though a wd_start ($t_1$) call. The wd_start($t_1$) call activate a timer that is function with the counting how many times the needle misses the time duration that is specified by the wd_timer().The wd_starts() from the stating of the task. If the function f()does not complete even after $t_1$ time units have elapsed, then the watchdog timer expires, indicating that the task deadline is missed(i.e. >1.5sec) and the exception handling procedure is initiated. If in case the task completes before the watchdog timer expires (i.e. within the <1.5 sec) then the watchdog timer is reset using a function wd_monitor () as shown in to the figure 3 and 4.

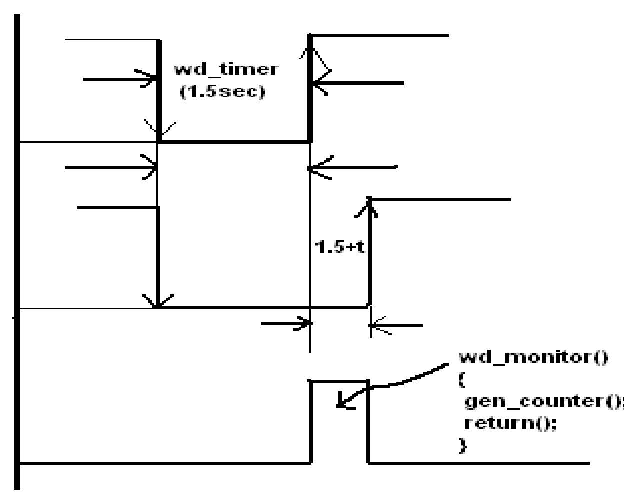


**Figure 3.** The function description of the watch dog timer (wd_timer)

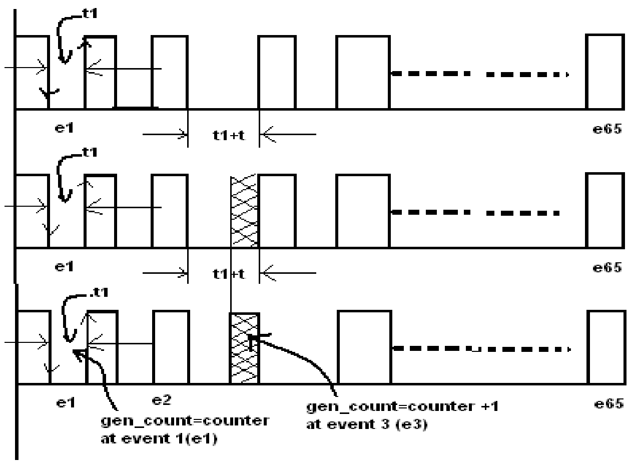


**Figure 4.** The Sequence of the Counter (gen_counter)

This wd_monitor function basically counts how many times the timer exceeds the time period. If it is pass the threshold value then a alarm is generated. If we plot the value of the timer with reference to the iteration then we can measure the efficiency of the needle.

### 3.5.Pseudo Code Of The Wd_Start () Function

```
wd_start ();
{
Reset the counter= 0;
If
wd_monitor (t1 < 1.5);
gen_counter =counter-1
else
   if  wd_monitor(t1=1.5)
   gen_counter=counter
gen_ counter=counter+1
return counter();
}
```

The counter gives a significant value which is indicating no of missing deadline or misses the time period and it helps to determine the state of the needle which is good or bad state. The minimum no of miss means the needle is good and if its very high then the needle should replaced.

The value of the counter increases to 1 when it exceeds the tolerance level and decreases to 1 when it is performed within tolerance level. The net value of the counter gives an indication of the condition of the health of needle.

## 4. Conclusions

The paper describes design methodology of a fault diagonioser based on embedded micro controller which is used for monitoring a real time decorative stitching machine. The paper describes how the extended timed automation can be used for modeling the fault through duration measuring of an activity of a component at different stages of its health. It also describes subsequent implementation through an embedded processor. This method is applicable for an early detection of failure in an automatic production setup using a qualitative duration modeling and validated with quantitative data available from the process.

## References


[1] Michel A Demetriou, Marios M, Polycarpou, Incipient fault diagnosis of dynamical systems using online approximation IEEE transaction on Automatic Control vol. 43, no. 11, pp. 1612-1617, September 1998.

[2] Zineb Simeu-Abazi, Zouhir Bouredji, Monitoring and predictive maintenance Modeling and analyze of fault latency, Journal of Computer in Industry, Elsevier publication vol. 57, no 6 pp. 504-515, 1996.

[3] Alur R., Dill D., A theory of timed automata, Journal of Theoretical Computer science (TCS) 126(2) 1004 pp 183 235.

[4] P.Supavatanakul, C. Falkenberg, J.Lunze, Identification of timed discrete event models for Diagnosis Institute of automation and computer control, Ruhr university Bochum, D-44780, Germany.

[5] Zineb Simeu Abazi, Maria Di Mascolo, Michel Knotek, Diagnosis of discrete event systems using timed automata, Honeywell Brno Aero space.

[6] Jan Lunze, Peerasan, Diagnosis of discrete event system described by timed automata, Aupavatanakul Instuitute of Automation Control, D-44780, Bochum, Germany.

[7] Rajib Mall, Real time systems Theory and practice, Pearson Education, 2007.

[8] www.atmel.com – ATMEL Corp. USA, Manufacturer of 89c 2051 chip.

[9] US Patent 7308860 - Sewing machine for decoratively stitching a cricket ball

[10] Patent: Singh, Hardyal; Sehmby, Surinder Singh; Mukherjee, Narayan Prasad; Balamurugan, Gopalsamy; Datta Uma; Roychoudhury, Joydeb; Central Mechanical Engineering research Institute Durgapur 7132. http://www.freepatentsonline.com/EP1537269.html

[11] Christer Norström, Anders Wall and Wang Yi, Timed Automata as Task Models for Event-Driven Systems, Proceedings of the Sixth International Conference on Real-Time Computing Systems and Applications, ISBN: 0-7695-0306-3, pp. 182, 1999.