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Microcontroller-based process monitoring and management using embedded Petri-nets

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ABSTRACT

This paper presents a methodology enabling the deployment and utilisation of a microcontroller based process monitoring system. This approach utilises the results of research into the embedding of Petri-net functions within microcontroller based architectures. This research is presented here through its application to the design, development and deployment of a process monitoring system into a laboratory based hydro-forming press test rig. The paper illustrates how this approach can provide real time online process information and demonstrates how the microcontroller-based architecture can be used to identify the cause and effects of process faults. The paper further considers how results are captured and processed, and how the management information that they enable can be displayed using a web page based architecture.

1. Introduction

This paper utilises a case study to illustrate the application of research into a Petri-net based approach to the monitoring and management of manufacturing processes. The research upon which this work is based brings together two discrete but synergistic activities: the development of a Petri-net modelling methodology and its deployment within a microcontroller architecture. This work builds upon previous research into the potential benefits of utilising Petri-nets which was focused on the development of platform independent modelling techniques, with enhanced functions engineered to support accurate and timely fault diagnostics. Initially these solutions were deployed within a PC based environment because of the demands on processing power and memory capacity. A second, parallel activity was therefore undertaken to support the deployment of these monitoring solutions on a more robust, practical and affordable microcontroller platform. The work presented in this paper extends this research by demonstrating the integration of this approach within a realistic computer controlled manufacturing context.

The basic concepts of Petri-net modelling, initially presented by Carl Adam Petri in the early 1960s, have been widely developed and explored. In many cases the original concepts have been modified and added to in order to meet the perceived requirements of the tasks to which they have been applied. This paper considers specific examples of such modifications and shows how they can add functionality to the approach. It does not consider in full detail the formal representation, structuring and definition of Petri-nets, which has been previously reported by the authors [1]. It considers the extension of this previous research by demonstrating the integration of a Petri-net based monitoring approach into a hydro-forming press test rig that simulates the operation of a computer controlled pressing process. As such the work seeks to demonstrate the benefits to be gained in process management and fault diagnosis using the advances made in microcontroller functionality. In particular these include the deployment of research that supports the engineering of innovative solutions adopted to support the provision of a new Petri-net element termed as an analogue transition. In doing so the basis and benefits of the methodology deployed in this application are outlined.

The potential of deploying Petri-nets to exploit their ability to accurately model process events has been recognised since the 1980s [2]. Petri-net models have been shown to be powerful and flexible tools with many potential applications including fault detection and isolation [3]. This process is on-going and includes contributions to represent real-life situations better [4]. The key feature associated with this application of Petri-nets is their ability to depict the anticipated and actual behaviour of a system in a graphical format [5,6]. More recent work aimed at model validation [7] is an indicative of an increasing level of interest in Petri-nets and their application.

As an indication of this increasing interest there are numerous recent applications based upon the adoption of solutions exploiting the advantages of Petri-nets. As such, confining the field of

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interest to manufacturing and the machinery and plant deployed there in is perhaps sensible in the context of the research presented in this paper. Refinements in the Petri-net approach specifically targeting applications in manufacturing have been previously considered [8]. An example of such a deployment considers a robotic assembly system targeting the control of feeder conveyor belts based upon a set of position sensors. This is a relatively simple system and consideration is given to how the deployed Petri-net approach and associated control system design toolkit may be further developed [9]. A similar robotic manufacturing system application is presented in a recent paper in the context of the development of a Petri-net based hierarchical distributed control system [10]. Using what are effectively sub-nets the developed system embeds machine specific Petri-nets within the dedicated machine controllers. Overall control is managed using a main net. As a consequence of the approach it is argued that more complicated systems may be thus controlled.

The deployment of Petri-nets to complicated process based applications depends upon the development of a flexible and adaptable approach that can overcome their tendency to rapidly increase in size and complexity. This tendency towards a so called ‘‘state space explosion’’ and possible developments to Petri-net formulation to overcome has been considered [11]. The consequence of this tendency is that large and complicated Petri-nets lose their ability to respond to system changes. In the Petri-net approach outlined here-in the adoption of flexible sub-net microcontroller based systems is proposed to overcome this limitation. This represents an important stage at which the approach utilised perhaps diverges from the original basis of ‘‘classical’’ Petri-net modelling. Similar advancements to the approach normally intended to increase the relevance and flexibility of Petri-nets have been reported, with for example the integration of Petri-nets into object oriented design processes as part of an agent based flexible manufacturing system control strategy [12].

Other interesting variations specifically undertaken within the context of a manufacturing system environment include the development of a timed Petri-net approach [13]. This model is incorporated into the control logic housed in a workstation and is used to reinstate a production system back to a normal state following an error or loss of sequencing between a processing machine and its workpiece handling systems. The strategy proposed to overcome possible losses of co-ordination that leads to a deadlock situation is to create temporary overflows using storage buffers which in practice indicate that the researchers are developing the concept of negative tokens. Timed Petri-nets were also proposed as a mechanism allowing more effective scheduling of assembly tasks within a flexible manufacturing system [14].

Given the developments cited above it is clear that the boundaries of the application of Petri-net based modelling approaches are continuously being widened. This is particularly related to their suitability for integration into systems seeking to exploit advancements in information and communication technology (ICT). Examples of this in the context of manufacturing include an advanced web-based diagnostic approach where the use of fuzzy Petri-nets is considered in the context of the deployment of a low cost fault detection and diagnosis system [15]. The approach is aimed at aiding the enactment of timely maintenance actions within modern manufacturing systems. The work is presented in association with the operation of a tool management system. The authors claim that remote diagnostic functions will aid maintenance staff in the diagnosis of tool related problems and make effective savings in the time spend on detecting and rectifying such faults.

On-line fault diagnosis based upon the application of a Petri-net modelling approach in which the current state of a continuous process as represented by a marked Petri-net is compared to the anticipated state is a further development [16]. This is a more challenging proposition than the application of such an approach to discrete event based processes and is made possible by the real time information sharing made possible by developments in ICT. Another such development is the proposal of an innovative ‘‘intelligent’’ control system based on the concept of a Fuzzy Neural Real Time Petri Net [17]. However it has been recognised that the application of Petri-nets and Fuzzy Logic to real life manufacturing end-users remains a challenge due to the complexity of the techniques and the demands that they make on ICT enabled data processing and analysis functions [18].

One approach to overcoming these challenges suggests the distribution of the processing power needed to support concurrent monitoring and diagnosis. The possibility of using Petri-nets within a microcontroller-based architecture was identified early in the development of such systems [19,20]. The potential benefits of applying these techniques to machine and process monitoring was recognised in previous research by the authors [21–23]. The work presented in this paper should be viewed as providing a vehicle for the wider presentation of these benefits via the application of the approach to the hydro-forming press test rig. The method developed is based upon the built-in capabilities of microcontrollers to perform data acquisition and analysis functions [24,25]. These developments should be suited to being deployed within any comparable operating platform, as in the example of an embedded system based upon FGPA/microcontroller architecture [26].

Innovations supported by the production of ever more powerful microcontrollers have allowed the further development of such approaches, including real-time and online monitoring functions [27,28] and supported the embedding of the resulting solutions into a microcontroller-based architecture [23]. This process is ongoing and reflects innovations made in ICT; with for example the design and operation of an intelligent monitoring system based upon a distributed wireless sensor network [29]. Although at an early stage the system described adopts the approach using a main net (defined as a kernel in the paper) to access and acquire data from a distributed set of sensors. This is very much at the centre of the method outlined in this research. The key concept supported is that of re-configurability, in the context of the response of the monitoring system to changes, intentional or accidental, to the system being monitored. Such an approach is very applicable to diagnostic systems and may allow for example diagnostic functions to proceed even when sensor faults arise.

2. Petri-net representation

A Petri-net can be used to represent a system or process as a graphical model. The resulting structure is formed from a defined set of places that can be used to provide the representation of a system state. The approach taken by the authors has been fully detailed previously [1]. Only the essential elements are therefore provided here in to aid understanding. Places in effect can be used to indicate stages within the conduct of a process, indicating for example that a motor is on or off. A set of transitions can then be used to represent the events that must occur to enable the execution of all or part of a process within the system; in order for the state of an electric motor to change perhaps a switch will need to be activated. In actuality one of the several switches could produce the same change, for example a machine tool spindle motor can be turned off by the operator, by the CNC program, by the action of a limit switch or overload sensor or by the action of an emergency stop possibly activated in regard to a problem unrelated to the motor. This represents the challenge that must