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CHANNEL/INSTANCE PETRI NETS FOR STRUCTURAL AND FUNCTIONAL MODELING OF INDUSTRIAL EQUIPMENT

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Abstract. *The present study introduces the concepts and applications of Channel/Instance Petri net (C/I net), a structural and functional model for industrial equipment modeling, particularly to automatic systems. Therefore it is a useful tool for situations where there exists the need of a model capable of integrating and optimizing different aspects inherent to design, so that it adapts itself to several technologies and make possible an effective interaction among the involved staff. Graphically C/I net is a bipartite directed graph, composed by two basic elements: active units represented by rectangles and passive units represented by circles, connected by directed arcs representing the resource flow. In order to exemplifier the advantages of opting to a model with the C/I net characteristics, an automatic workstation will be modeled, its used to quality inspection of the workpieces and separates the ones that are in accordance with the specification of the defective ones. The station integrates equipment as pneumatic actuators, sensors, programmable logical control, conveyor belt and camera CCD for image acquisition. The paper also comments on the gotten advances and the research lines that continue searching other fields for the use of this model, as the mathematical formalization of the net structure, analysis and synthesis methods and reliability analysis of automatic equipment application.*

Keywords*: channel/instance net, functional modeling, automatic system, industrial equipment.*

1. INTRODUCTION

The technological growth has implied a greater volume of technical problems to be solved and the necessity of interaction among different areas of knowledge. In fact, as the complexity of the systems increase, either for the dimensions, number of involved technologies or demanded performance, the team will be able to involve specialists in computers, programming, hydraulics, pneumatic, instrumentation and electronics, with each of these professionals used to their own concepts, diagrams and terminologies. Consequently, the difficulty of reaching a global representation and a clear understanding by all the team members demonstrates difficulties of organization and communication.

The channel/instance net (C/I net) is a functional and structural model used mainly in the phase of the conceptual design of technical systems, particularly in automatic systems. This is due to the fact that in this phase of the project the iteration among people with different backgrounds is more frequent. However, this model can also be used to facilitate the explanation and comprehension of an equipment or existent industrial system, possible to be presented with this intention for a machine operator, a maintenance technician or an apprentice.

To improve the communication between trainee and instructor regarding automatic equipment, one of the basic requirements is to establish a systematic that foresees the use of understandable diagrams to all the interested parts. In this sense, this paper stands for the use of C/I net as central model, being used to establish the bonds between the specific technical diagrams and to promote the communication among specialists of diverse areas.

In order to guide, it can be said that the C/I net, according to a functional view, presents similarities regarding the applicability with the functional description according to German school (Pahl and Beitz, 1988), VDI 2860 (1990) norm, function-means tree (Hubka and Eder, 1988), SADT/IDEF0 model (IDEF, 2006) and PFS - Production Flow Schema (Miyagi, 1996).

The C/I net will be used to model a workstation whose function is to analyze the quality of food trays and to separate them in “good” and defective. All the system is controlled for a programmable logical controller (PLC), which controls a CCD camera, responsible for the analysis, and pneumatic actuators, that are responsible for the movement of the parts during the separation process.

As the C/I net is not a very spread out model of use, the second section aims at introducing it and the third section presents the workstation is. The C/I net station model is presented in the fourth section. Some research lines that use C/I net as main focus are reported in the fifth section. Finally, the last section presents the conclusions of this work.

2. CHANNEL/INSTANCE NETS

The C/I net, discussed in Reisig (1985), Heuser (1990), Negri (1996) and Belan (2007), is a diagrammatic representation, composed by two basic elements: active units represented by rectangles and passive units represented by circles, connected by directed arcs representing the resource flow (Fig. 1).

The hidden channel symbology (Fig. 1) indicates that a determined resource is required, consumed, dissipated or stored for the instance (Belan, 2007).

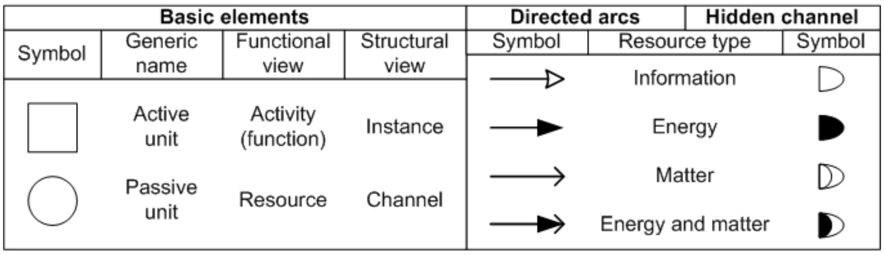

Figure 1. The C/I net basic elements.

According to De Negri (1996), a structural and functional connotation can be attributed to the model created. According to the functional view, the passive units correspond to a place where the resources flow through the system, that is, the energy, matters and information or its forms of manifestation, such as electricity, workpieces, tools, signals and data. The active units, in turn, are activities, corresponding to the operations applied on the resources, such as: pumping, assembly, transport and processing.

Under a structural view, the passive units are channels, indicating those system components that give support so that the resources can flow without causing modification in their state. Pipes, shaft, wires, magazines and memories are cited as examples. The rectangles represent the instances, which correspond to the places where the activities happen (Heuser, 1990), such as pumps, components of machines, workstation, chemical reactors and objects (software).

It is important to mention that the direction indicated by the arcs that connect the elements in the C/A net, has no meaning under the structural view because, in this case, they represent the existing interconnection, that is, the way in which the system is constituted. According to this view, it can be concluded that the arcs only indicate which the passive component necessary to establish the connection among the active components is, however functionally, the arrows indicate the flow direction of the resources. In this representation, the net explicit the physical interconnection between the machines or devices, as well as indicates the channel through which the matter flows, being a similar representation to the PFS - Production Flow Schema (Miyagi, 1996).

It is important to emphasize that this notation is not exclusively linked to any specific technical area, therefore it can be applied whenever describing functional and structural aspects is necessary. Heuser (1990) uses the C/I net for data base modeling and establishes equivalence with the data flow diagram (DFD). Similarly, in the scope of the products design, it is possible to represent the functions structure used in the conceptual phase by the C/I nets, with the advantage of making the designer identify intermediate resources which will obligatorily exist (De Negri, 1996).

The basic rule for the use of this notation is that the interconnection only is allowed between channels and instances, that is, in a C/I net two channels or two instances connect by the same arc cannot exist. An arc binding a channel to an instance implies that the activity can depend on the content of the channel, but not necessarily does, or, in other words, the resources can be used by the activity. In turn, an arc that binds an instance to a channel indicates that the content of the channel can be modified, but not necessarily is, by the activity, that is, the resource can be made or modified by the activity.

3. WORKSTATION

The workstation presented in Fig. 2 is a fictitious example (Festo, 2000), however with real characteristics of an automatic system that is part of a food tray production line. The main station function is to analyze the product quality and to separate the defective ones from the “good ones”.

The workpieces (food trays) need visual inspection after the stamping process, in order to verify the product quality and to allow that the defective workpieces are identified and rejected. The inspection is made by a CCD camera (Fig. 2 - 11).

The workpieces that are considered defective, according to the evaluation method, continue in the conveyor belt and are rejected in a posterior action (Fig. 2 - 13). “The good” workpieces are piled up in an appropriate compartment (Fig. 2 - 8). The stack top height of “good” workpieces magazine is kept constant, being measured by a diffuse optical sensor (Fig. 2 - 9).

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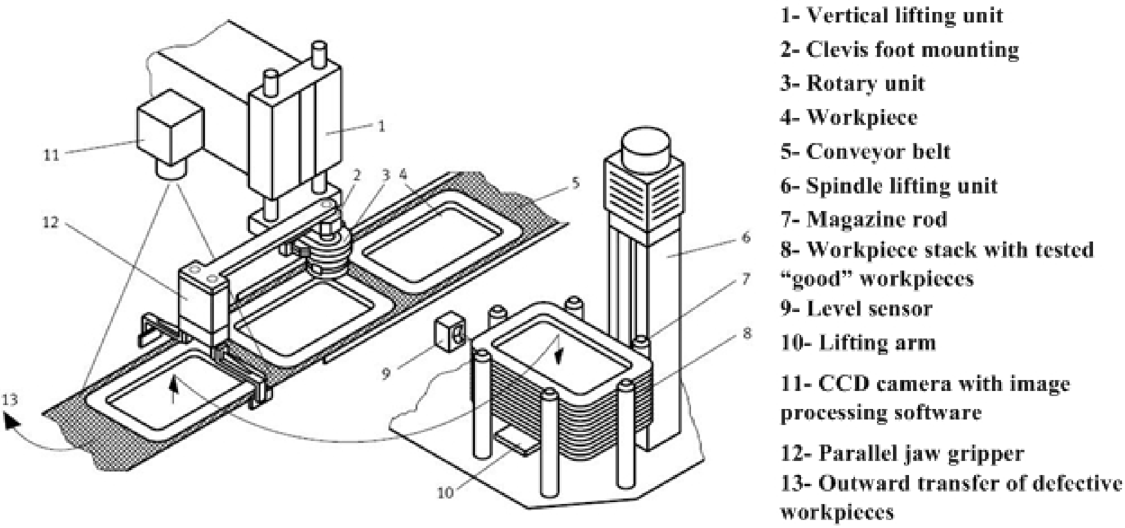

Figure 2. Workstation (Festo, 2000).

With the station specifications, informed at the beginning of this section, and the structural project (Fig. 2) understanding superficially the system functioning is possible, considering that it is a small system. However, for a more complete understanding about the workstation, an information lack exists regarding with whom these equipments communicate as well as who controls and guarantees the accurate functioning of the station.

The missing information is normally documented in specific diagrams. For example, the linking among the sensors, conveyor belt electric motor, pneumatic valves (considering drive by solenoid) and programmable logic control - PLC can be understood through an electric circuit. In turn, the functioning of the pneumatic actuators can be verified through a pneumatic circuit. This considering the functional view alone.

In order to detail the behavioral characteristics that have as purpose to inform *when* the actions happen, the presentation of a behavioral model is still necessary. In this in case, as the PLC is the entity that controls the system, the system behavior can be defined by a proper PLC language (ladder and instruction list) or an auxiliary diagram (SFC - Sequential Function Chart) (IEC, 1988, 1993).

In practice a "jump" between the literal specification and the specific diagrams is noticed. As, depending on the complexity, the systems are treated by professionals with differentiated formations, a specialist who has easiness in working with electric circuits may not understand the information contained in a pneumatic circuit.

The C/I net is a model that aims at minimizing these difficulties, supplying orientation of with whom each equipment relates, either by means of energy, matter or information, and favoring an agreement about the function of each system component.

4. MODELING

Figure 3 presents the C/I net that shapes the workstation showed in Fig. 2. By means of this model, getting some information that had not been clarified with the literal description is possible. For example, the existence of an image processing agent (Fig 3 - a2) can be noticed. Such agent indicates for the PLC (Fig 3 - a1) if the workpiece is defective or not (Fig 3 - c4), that is, it is not the PLC that evaluates the quality of the workpieces, it simply "orders" the reading (Fig 3 - c4) and receives the reply. Also, it is possible to observe that from the point of view of information exchange, the sector that makes the image evaluation (Fig 3 - a2 and a3) is independent of the storage unit (Fig 3 - a5) and do not exchange information. Also, it is the PLC that commands the entire system ordering the picture processing (Fig 3 - c4) and controlling the movement of the workpieces (Fig 3 - c6) and the height of "good" workpieces magazine (Fig 3 - c7). The user (external environment) interacts with the workstation (Fig 3 - c1 and c2) through the PLC as well.

The matter flow (workpieces) is represented in the inferior part of the C/I net (Fig. 3). This allows visualizing that there are two ways for the part to reach the limits of the system, one in case the food tray is considered defective (Fig 3 - c10) and another in case it is considered "good" (Fig 3 - c12).

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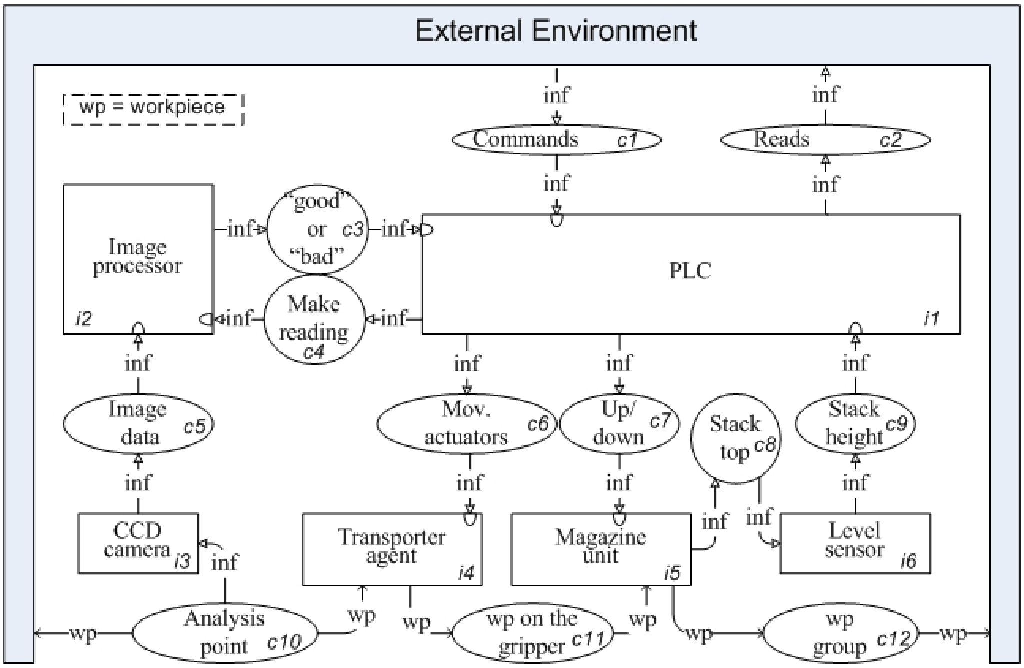

Figure 3. C/I net that model the workstation.

In order to simplify, the model does not represent the energy flow. In case it were of interest, directed arcs should be linked to all the instances that need energy either from pneumatic, electric, hydraulic or mechanic nature. In the specific case of hydraulic energy the used arc must inform that there is energy and matter flow, because it is physically essential that some exit pipe of the agency oil exists.

The refinement process is a possibility in the C/I net, being used to model the system in different levels of detailing. This way, the refinement of a channel or instance consists of their detailing, identifying other internal channels and instances. In the opposing direction, channels and instances can be grouped forming condensed nets. The basic rule of only having interconnection between channels and instances must be kept, implying that the refined or condensed net will have to result in a net as well.

De Negri (1996) clarifies that the C/I net used in the phase of product conception is useful to represent functional requirements and as the detailing level rises, it is gradually refined assuming a structural view. Functional and structural proper models to each equipment part can be created and directly related to the C/I net, as circuits diagram and technical drawings. The behavioral aspects are modeled by appropriate means as transfer functions and states diagram, but must be entailed to an instance of the net.

5. RESEARCH LINE ABOUT C/I NET

In recent years, studies using the C/I net as central model have been carried out in the Laship (Laboratory of Systems Hydraulics and Pneumatics /EMC/UFSC). The intention is to establish methods for the automatic systems design, since according to De Negri and Santos (2007), there is no design methodology consolidated for systems of this nature.

Amongst the results obtained, Belan (2007) proposed the formalization of the C/I net structure, making possible a unique mathematical representation of the model.

With the formalism inserted into the C/I net, elaboration of mathematical methods of analysis and synthesis also become possible. Belan (2007) displays three mathematical methods that evaluate the structural coherence, resources flow coherence and dependence of the model.

Santos (2003), in turn, carried out studies aiming at generating the system controller from the C/I net. To do so, Santos (2003) presents a proposal of functional, structural and behavioral description using the C/I net (De Negri, 1996) and models of discrete events' systems based on automatons. This way, the author inserted in the design activity formal tools of modeling and synthesis of controllers (Ramadge and Wonham, 1989), (Queiroz and Cury, 2002). In the same research line, Souto (2005) uses the methodology proposed by Santos (2003) and extends the studies carried out by Queiroz and Cury (2002) in order to hold the communication with the external environment.

Likewise, Miyagi (1996) and Villani (2000) also suggest methods for arriving at the controller of the system from a functional model, that in this case is called PFS and is similar to the C/I net. However, different from Santos (2003), they opt to establish behavioral models using Petri net (Cardoso and Valette, 1997). This fact along with the equivalence between the PFS and the C/I net, allows us to assume that a technique to arrive at a controller in Petri nets from the C/I net already exists.

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Recently, Porciúncula (2009) proposed a methodology for analysis of automatic systems' reliability, where he uses C/I nets to represent the functional and structural model of the system. From the matrixial manipulation, inherent to the formal representation of the C/I net as defined by Belan (2007), and from information of the behavior of the system it is possible to automatically define the reliability models of the system, for the different operational states.

6. CONCLUSION

Based on the presented information, this paper suggests the structuring of the functional description of the system around a central model, which has as objective to store the main information contained in the different specific models and also to manage its use and updating.

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8. RESPONSIBILITY NOTICE

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