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Synchronization of active systems in material handling processes

Sincronización de sistemas activos en procesos de manejo de materiales

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Abstract

The present work proposes an application of automata's language and control systems in discrete events theory in a prototype of material handling system to ensure the continuity in the sequence that a transferred piece will have to execute between two points of a productive process. Also guaranteeing the synchronization of its active elements, in this case, a robot in angular configuration and a conveyor belt, for the fulfillment of its specific task without errors. We describe the development of the prototype for testing, the programming of the digital process controllers based on the theoretical methodology suggested, and finally, the integration of a graphical monitoring and control interface that allows the visualization of the system state to the user. The results suggest the adequate performance of the developed algorithms, the graphical interface and, in general, of the active elements that make up the material handling system.

Synchronization, Active system, Material handling

Resumen

El presente trabajo propone una aplicación de lenguaje de autómatas y de la teoría de sistemas de control en eventos discretos en un prototipo de sistema de manejo de materiales, para asegurar la continuidad en la secuencia que habrá de ejecutar una pieza trasladada entre dos puntos de un proceso productivo. Garantizando, además, la sincronización de sus elementos activos, en este caso un robot en configuración angular y una banda transportadora, para el cumplimiento de su tarea específica sin errores. Se describe el desarrollo del prototipo para prueba, la programación de los controladores digitales de proceso a partir de la metodología teórica sugerida, y finalmente, la integración de una interfaz gráfica de monitoreo y control que permita la visualización del estado del sistema hacia el usuario. Los resultados sugieren el adecuado desempeño de los algoritmos desarrollados, la interfaz gráfica y, en general de los elementos activos que integran al sistema de manejo de materiales.

Sincronización, Sistema activo, Manejo de materiales,

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Introduction

The synchronization of active systems or elements within current manufacturing systems, such as manipulator robots and conveyor belts, promotes the organization of activities (Huang, 2015), resulting in the optimization of human and material resources, as well as in the improvement of the time required for the execution of general tasks (Ore, Hansson & Magnus, 2017). Therefore, such specification must ensure at all times that each element fulfills the function for which it has been considered within the process.

In turn, a set of multiple organized active elements and with a defined sequence of action determine the integration of material handling systems (Björnsson, Jonsson & Johansen, 2018), underpinning the internal logistics of a company, by providing the guide of raw and transition materials or elaborated product, from one section to another within the production process, as well as the distribution that the latter will acquire. Thus, the implementation of the type of system, as well as the components that will be used, may vary depending on the needs of the process in which it is applied.

This paper presents the development and integration of a prototype of material handling system in order to analyze the effect of the application of formal techniques of the automaton and control systems in discrete events theories, for the assurance of synchronization and sequence in transportation tasks, recovery and positioning of parts (Santos-Gomes & Rodrigues-Leta, 2012) (Kumar, et al., 2014) between active elements of a typical manufacturing process. In addition to adapting an interface for monitoring and control of such a system with the LabVIEW software in communication with an electronic card that serves as a process controller (Koniar, et al., 2014).

Background

The knowledge of the conditions to perform an adequate synchronization between the functions of two or more active elements within a material handling system responds commonly to the experience of the person in charge of its planning and to their total understanding of the behavior of the devices involved, which can mean a tedious task of not having the necessary preparation.

Synchronization is based on the full identification of all the signals that converge within the manufacturing process in which it is implemented. However, its use must adopt a systematized form to achieve the objective of the intervened activity, in this case, transportation of materials without duplication of tasks or inactive times; and, if it is translated into a specific language, it can be introduced to the process controller for proper management.

The challenge proposed for this research is the application of a formal methodology, based on mathematical language, for the synchronization of physical operations; in order to provide a support tool for the optimal organization of the tasks to be executed by each active element that constitutes a material handling and positioning system within a given manufacturing process. The above will be implemented through the integration of a simple prototype for testing.

Constitution of the testing prototype

The prototype consisted of a robot in angular configuration with a gripper mounted on its final effector as a work tool, as well as a conveyor belt to which infrared sensors were included at its ends. It should be mentioned that the ends of the band used within the robot's work area were secured, enabling it to reach and adopt the positions. Two areas were also defined within the work area, corresponding to the material supply for process and storage once the proposed transport and positioning sequence was completed. The elements mentioned are shown in Figure 1.

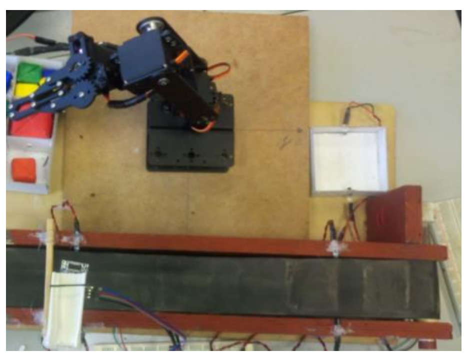

Figure 1 Physical distribution of the prototype
Source: Prepared by the authors, 2019

The robot is made up of three links and three joints, allowing movement to enter the structure to place the end of it in any desired position within its work area.

The band has been implemented from a cycle belt of synthetic material, at the ends of which is supported by two rollers, one of them attached to a direct current motor that induces movement to the system. The supply is done manually, considering, in this case, pieces with the same dimensional specification 3x3x3 cm, since the robot's gripper was conditioned to close with this particular thickness.

Signal definition and process sequence

The interacting signals within the developed process can be categorized as parameters if they are inputs, or alternatively, variables if they are outputs. According to the type of signal given, these are discrete parameters and variables since they can only acquire certain values within a set range, commonly: activation or deactivation, or a pulse trains. For this analysis, the parameters come from sensors and buttons the function of which is binary. The processing of the parameters favors the generation of the variables that can take an on or off value, as is the case with the band, or use a pulse train to control the servomotors which move the robot. The information of the process signals is presented in Tables 1 and 2.

Identifier	Signal	Active system
PB0	System on	General System
ZS0	Supply Sensor	General System
ZS1	End sensor 1	Conveyor belt
ZS2	End sensor 2	Conveyor belt
X0dn	In rest position	Robot
X1dn	In end position 1 in the band	Robot
X2dn	In end position 2 in the band	Robot
X3dn	In storage position	Robot
Gcldn	Closed	Gripper
Gopdn	Open	Gripper

Table 1 Process parameters
Source: Prepared by the authors, 2019

Identifier	Signal	Active system
X0	To rest position	Robot
X1	To supply position	Robot
X2	To end position 1 of the band	Robot
X3	To end position 2 of the band	Robot
X4	To storage position	Robot
X5	To rest position	Robot
Gcl	Close	Gripper
Gop	Open	Gripper
MT	Active motor	Conveyor belt

Table 2 Process Variables
Source: Prepared by the authors, 2019

The process sequence proposal is made from the signals shown above, allowing the synchronization of the active elements, as described below:

1. If the system is on and, when the piece is detected in the supply area of the prototype, the movement of the robot will be enforced to take it to a first end of the band.
2. Once the robot arrives at the first end of the conveyor belt, its operation will be activated to allocate the piece to the opposite end.
3. The robot must remain at rest for as long as the piece travels the length of the band.
4. When the piece reaches the opposite end of the band, it will stop its movement.
5. The robot will emit a movement, moving towards the opposite end of where it originally placed the piece.
6. Such element will describe a trajectory that allows it to take the piece towards the respective shortage area.

It should be noted that the initial conditions for the operation of the system are:

– The robot will start from a rest position where it will remain with the gripper open.
– There should be no piece in any part of the process.
– Once the process is executed, it will repeat its sequence indefinitely.
– There is the possibility of stopping the process at any time.
– If the process function is restored, its operation will be executed from the beginning.

Deduction of the model for synchronization

The sequence of the analyzed process can be defined from a mathematical formalism which relates the input signals of the process, the stage or state that will activate each of these, and the generation of the signals that allow the activation of the electric charges (Zhang, et al., 2012), which are part of the active elements of the prototype; with the aim of promoting their movement. Thus, in control systems of discrete events (Barkalov, Titarenko & Chmielewski, 2013) and specifically, in the theory of automatons (Ahmad, Ali & Shoba Das, 2006), the previously exposed signals, as well as their relation with each stage of the process, can be represented mathematically through the definition of a finite alphabet (1) corresponding to the input signals of the system.

E = {PB0, ZS0, ZS1, ZS2, X0dn, X1dn, X2dn, X3dn, X4dn, X5dn, Gcldn, Gopdn} (1)

In addition to requiring the declaration of a set of values that imply the different states which the system elements (2) will acquire throughout the evolution of the process sequence.

X = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11} (2)

Through the combination of states and transitions, specific values acquired by an input or set signal, the proposal of the functions which define the sequence (3-14) is made to be executed by the active elements of the material handling system , also ensuring synchronization between its functions.

f (0, PB0 ZS0) = {1} (3)
f (1, X1dn) = {2} (4)
f (2, Gcldn) = {3} (5)
f (3, X2dn) = {4} (6)
f (4, ZS1 Gopdn) = {5} (7)
f (5, X0dn) = {6} (8)
f (6, ZS2) = {7} (9)
f (7, X3dn) = {8} (10)
f (8, Gcldn) = {9} (11)
f (9, X4dn) = {10} (12)
f (10, Gopdn) = {11} (13)
f (11, X0dn) = {0} (14)

The establishment of the initial (15) and final (16) states within the process sequence allows the conclusion of the model that defines it.

x0 = {0} (15)
F = {0} (16)

After interpreting the numerical outputs to the states that the system will have to adopt in a real form, a set of the corresponding physical outputs is generated, defined by (17).

X = {X0, X1, Gcl, X2, Gop, X0, MT, X3, Gcl, X4, Gop, X0} (17)

The concentration of the data specified in a functional scheme, still represented in a symbolic way, allows the analysis of the input and output signals of the process and the visualization of the activation of the necessary stages exclusively at the time it is required, ensuring at all times the action of the different states in the active systems and, therefore, the proper sequence of the process.

Programming of the control system

The adequate fulfillment of the proposed tasks to be executed by the prototype and its general operation will depend on the correct selection, programming and use of process controllers. In this case, two Arduino UNO electronic cards are used to carry out these activities. A scheme of the interaction between the controller cards, the sensors, the process control and monitoring interface, and the active elements of the prototype are shown in Figure 2.

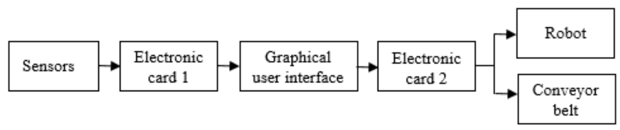

Figure 2 Interaction between prototype components
Source: Prepared by the authors, 2019

It is clear the use of a first card as an element to collect information from buttons and sensors used as a means of knowing the work environment of the prototype. To a second card are connected, using the appropriate power management means, the actuators that will allow the transmission of movement both to the robot's joints and to the band itself.

Both cards remain in communication with a computer through two USB ports and the serial communication protocol. Therefore, it will correspond to the latter to contain the program that performs the management of the process executed by the prototype and ensure the succession of the states which must be addressed. The main concern in developing such a program was to provide accessibility and easy handling to the users, informing them at all times of the evolution of the system states from the signals derived from the input devices.

Management Interface Development

Since most of the actions are performed automatically, the control and monitoring interface developed from a virtual instrument in the LabVIEW software (as shown in Figure 3), presents an information environment to the system user, which enables feedback on the state of the managed system (Gasparic, et al., 2017).

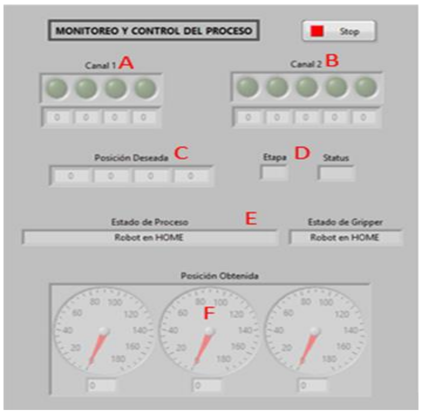

Figure 3 Interface developed for process control and monitoring
Source: Prepared by the authors, 2019

For this, such an interface can be divided in various areas according to the information presented:

a. Information that the process controller will issue as output for the activation of active systems.
b. Status of the process inputs, allowing the detonation of a specific task by the system.
c. Information of the angular position that the controller sends to each of the articular coordinates.
d. Alphabetical references of the state of the process and the particular state of the robot's gripper.
e. Complementary message that alerts the user of the current state of the process, indicating the location of the robot, and the status of the band and the gripper.
f. Feedback of the articular variables of the robot as the controller orders the modification in the Cartesian position of the robot.

However, giving the user the possibility of modifying the position that the robot's gripper can reach according to the progress of the process sequence, involved the addition, to the developed interface, of a section that allowed the entry of strategic points that would lead to the evolution of the movement from an initial position to a different one within its area of action. Of course, to limit the occurrence of collisions between active systems, it is necessary for the user to propose a series of movements considering the physical location of the robot and its gripper, specifically with respect to the band and the location of the sensors, in order not to cause involuntary damage during the execution of movement.

The enabled spaces allow the placement of the values which the joint variables must assume as they carry out an evolution, ensuring the recovery and positioning of any object present at some point in the process and its destination to another position, without jeopardizing the integrity of any element. As well as to make an adequate combination between effective positions to reach the pieces and the state that the gripper must assume, depending on the case.

For example, when executing a movement for the collection of a piece, it will be necessary to pre-open the gripper and quickly position it on the object, ensuring that it is in a position just in the center of the opening margin, and continue with a movement of the final effector at a point of lower height, which favors the holding of the piece. Such a case may also operate in reverse, that is, when placing an object in a given location, it will be necessary to choose a timely position that allows its release and thus guarantee the sequence of the executed process.

Results of the system operation

The response generated by the graphical interface was favorable at issuing at all times the information related to the current state of the process and its evolution as the succession of tasks was executed. Such information, of course, coincided with the real state adopted by the active elements of the physical prototype, which can be corroborated in the evidence presented by the following figures. The sequence proposed for the prototype implemented was performed correctly, according to the organization proposed in the mathematical model of the process (1-17), clearly prescribing each of the indicated transitions from the corresponding input signals.

Figure 4 reports the robot's resting position waiting to begin the execution process of the material handling system. So, as determined from the beginning of this work, when energizing the system this will be the position that the robot will adopt by default.

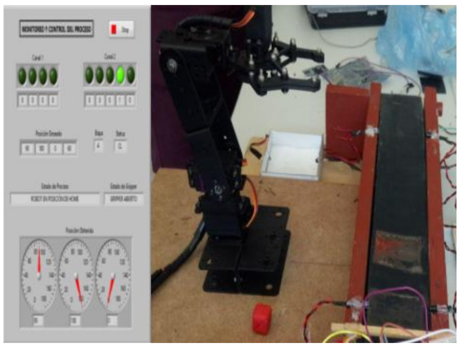

Figure 4 Resting robot.
Source: Prepared by the authors, 2019

Highlighting the opening state in the gripper during the adoption of this last position. Figure 5 shows the evolution of the robot's movement when the system has detected a piece in its supply area, immediately allocating the robot's gripper to reach the object and perform its holding.

Figure 5 Robot in supply area
Source: Prepared by the authors, 2019

In the figure below it can be seen that the robot makes the placement of the piece on the first end of the conveyor belt, which will be activated by allocating it towards its opposite end.

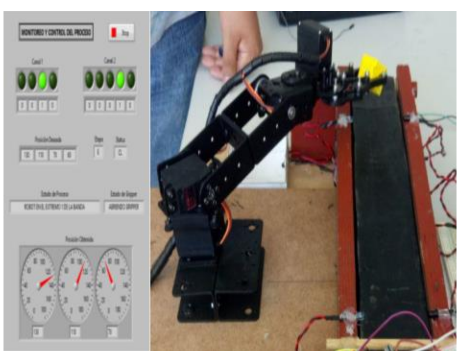

Figure 6 Robot on first end of the band
Source: Prepared by the authors, 2019

Precisely at the other end of the band, the robot is guided to hold the piece in this last position, as shown in figure 7, and allocate it to the corresponding shortage area.

Figure 7 Recovery of piece on the second end of the band
Source: Prepared by the authors, 2019

The results of the final arrangement of the piece according to the executed sequence are presented in Figure 8.

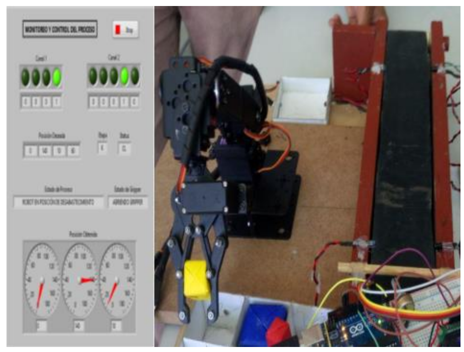

Figure 8 Robot in shortage area
Source: Prepared by the authors, 2019

Conclusions

The internal logistics of a company focuses on the proposal of an adequate distribution of the material handling system and the sequence that must be executed to supply the work stations, as required by the production process. Therefore, the adoption of formal methodologies and their application in the planning of transport activities, recovery and positioning of pieces directly leads to assurance in their succession.

However, the success of the sequence of actions to drive the products from one point or another will depend on the adequate definition of the states, the transitions that will allow going from one state to another, the knowledge of an initial condition of the system and the objective proposal of its final situation.

In this case, the foundations of the theory of control systems in discrete events and, in particular, of automaton, allowed us to deduce a mathematical model of the process; which was translated into the programming algorithms required on specific digital controllers, such as the Arduino electronic cards employed.

This control system, in direct communication with a computer graphic interface, allowed the total management of the actions performed within the process; which enabled the synchronization of the active elements, the robot and the conveyor belt.

Although the experimentation was developed from a physical prototype of simple constitution the implements of which imply the provision of more robust equipment, it was possible to characterize the programming behavior of a sequence proposed at the beginning of the analysis. The above, makes possible the complementation of the function achieved by the integrated material handling system with the addition of some other element that allows the flexibility of the process, determining the continuity of this work.

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