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J. Machado / E. Seabra

Automation Systems Design using Advanced Computational Tools

ABSTRACT

It is presented, in this paper, a methodology that can be applied since the definition of the specifications set for the behaviour of an automation system until the complete implementation of the system controller. For this, it is used the GEMMA for the controller structure, the SFC for the controller specification, the Automation Studio software for the controller simulation and Timed Automata and UPPAAL software for the controller Formal Verification.

The application of the related methodology is shown on a case study based on an Automated Production Line and the obtained results are extrapolated for other systems of the same type.

INTRODUCTION

There are several approaches that can be used in automation systems controllers' development. At present, with the simultaneous goals of reducing the time of automation systems controllers' development and, also, improving the safe behaviour of those systems it is possible to chose, and apply, several Formalisms and Advanced Computational Tools that, when used together, may improve, considerably, the quality and robustness of the obtained controllers.

The fact that it still does not exists the automation system plant during the development and design of the controller program does these techniques more important and needed during automation systems design.

Between many formalisms and analysis techniques the important is not so much which technique, formalism and software tool are chosen but the important is to choose, between them, a set of formalisms, techniques and software tools that allow the designer to develop safe controllers.

In this paper it is shown that a set of chosen formalisms techniques and software tools are well adapted in this context of automation systems controllers design.
In order to achieve the goals of this paper there are presented the following subjects in the following chapters: we start with a description of some important concepts about Automation Systems Design; next, there are presented and adopted the specification formalisms that are used in this work; followed by the analysis techniques used in Industrial Controllers Analysis. Finally, it is presented a case study where are applied all the mentioned concepts before.

AUTOMATION SYSTEMS DESIGN

From the analysis of needs, passing by the conception, realization into the implementation and exploitation of an automation system there are several steps that must be realised (figure 1). All the system (controller and plant) must be developed in parallel. In this paper we focus on the controller development but, more precisely, on the steps 3 and 4 of the figure 1, because there are the steps where it is important to develop the controller program and the plant still does not exists; so the formalisms and tools and the analysis techniques are very important in these steps. During each step of the controller development it exists a corresponding step corresponding to the development of the plant. For instance, the step 2 corresponds to the specification of the controller and the step 2' corresponds to the specification of the plant.

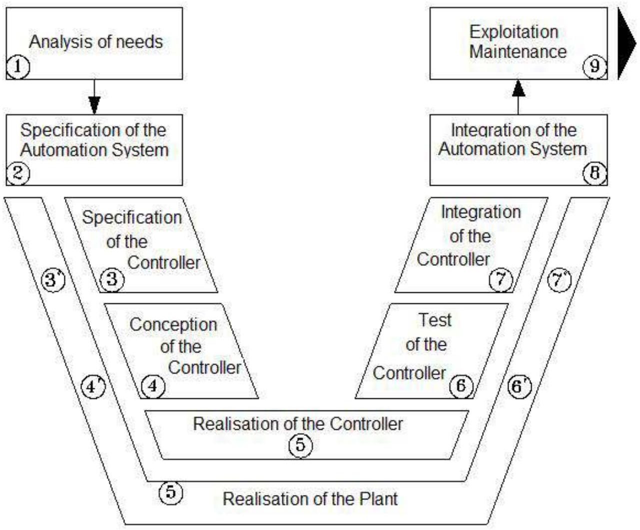

Figure 1. Steps considered on the design of an automation system.

SPECIFICATION FORMALISMS

Currently, there exist some suitable formalisms for the development and creation of the structure and specification of an automated production system controller. Between these formalisms, are distinguished the GEMMA (Guide d'Étude des Modes de Marche et d'Arrêt) [1] and SFC [2] , both developed in France. The GEMMA is well adapted to define the controller structure and SFC is well adapted to the complete controller specification.

SFC

The implementation of the automation system requires, in particular, a description relating cause and effect. To do this, the logical aspect of the desired behavior of the system will be described. The sequential part of the system, which is accessed via Boolean input and output variables, is the logical aspect of this physical system. The behaviour indicates the way in which the output variables depend on the input. The object of the SFC is to specify the behaviour of the sequential part of the systems.

The specification language SFC enables a Grafcet to be created showing the expected behaviour of a given sequential system. This tool is characterized mainly by its graphic elements, which, associated with an alphanumerical expression of variables, provides a synthetic representation of the behaviour, based on an indirect description of the situation of the system.

GEMMA

The GEMMA (Guide d`Etude des Modes de Marches et d`Arrêts), developed in France by ADEPA (Agence Nationale pour le Developpement de la Production Automatisée) is a method that, on the basis of a very precise vocabulary proposes a simple structured guide, to the designer, based on a graphical chart, that contains all the run and stop modes, or states, that a machine or an automated system can assume. It is a tool for helping the system analysis, being used for its supervision, maintenance and evolution definition.

The GEMMA method is based in three basic concepts:

- The Ways of Run are seen by the command module in the Way of Run. All the systems are composed by a command module and an operative module. In the application of GEMMA, it is assumed that the command module is always on power.
- The Production Criteria. Two states are considered for the production systems: ON production and OUT of production. That states are shown on the graphical

chart of the method.

- The three groups of run and stop ways or states of the Plant.
  - States “A”: Stop states
  - States “D”: Failure ways
  - States “F”: Running ways

The graphical chart of GEMMA is composed by three parts corresponding each one to each group of run and stop described ways or states and it will be described and presented, in detail, during the case study analysis presented on this paper.

SIMULATION AND FROMAL VERIFICATION TOOLS AND FORMALISMS

Among the several techniques of industrial controllers analysis available, Simulation [3] and Formal Verification [4], can be distinguished due to their utility. In the research works on industrial controller’s analysis, these two techniques are rarely used simultaneously. If the Simulation is faster to execute, it presents the limitation of considering only some system behaviour evolution scenarios. Formal Verification presents the advantage of testing all the possible system behaviour evolution scenarios but, sometimes, it takes a large amount of time for the attainment of formal verification results. In this paper it is shown, as it is possible, and desirable, to conciliate these two techniques in the analysis of industrial controllers. With the simultaneous use of these two techniques, the developed industrial controllers are more robust and not subject to errors.

Using this approach, the command of those systems can be simulated and tested when the physical part of the machine still does not exist. This way of simulation allows to reduce the production times of the automation systems because the manufacture do not need the physical part of the machine for later perform tests and simulation of the controller of the system.

In Simulation there are several tools and formalisms that can be used. Between them, Modelica language [5] associated with Dymola [6], or Automation Studio [7] are very performing in this domain.

In Formal Verification there are many ways to perform this technique but timed automata [8] associated with UPPAAL software [9] are very powerful and very used on formal verification of industrial controllers. They are, also, used in this paper.

CASE STUDY : APPLICATION OF THE CONCEPTS

The automated line production which was used in this study is a machine for the automatic assembly of car wheels. It is a system that puts in the wheel in the cube of the car. The machine is composed by three modules:

- Module 1: It receives and rotates the wheel for a known position (alignment of axes of the holes);
- Module 2: It distributes and it transports the screws for the wheel;
- Module 3: It puts the wheel in the cube and it tightens the screws.

Figure 2 shows the plant of the case study, which it can be seen in detail the three modules with the respective switches, sensors and actuators used.

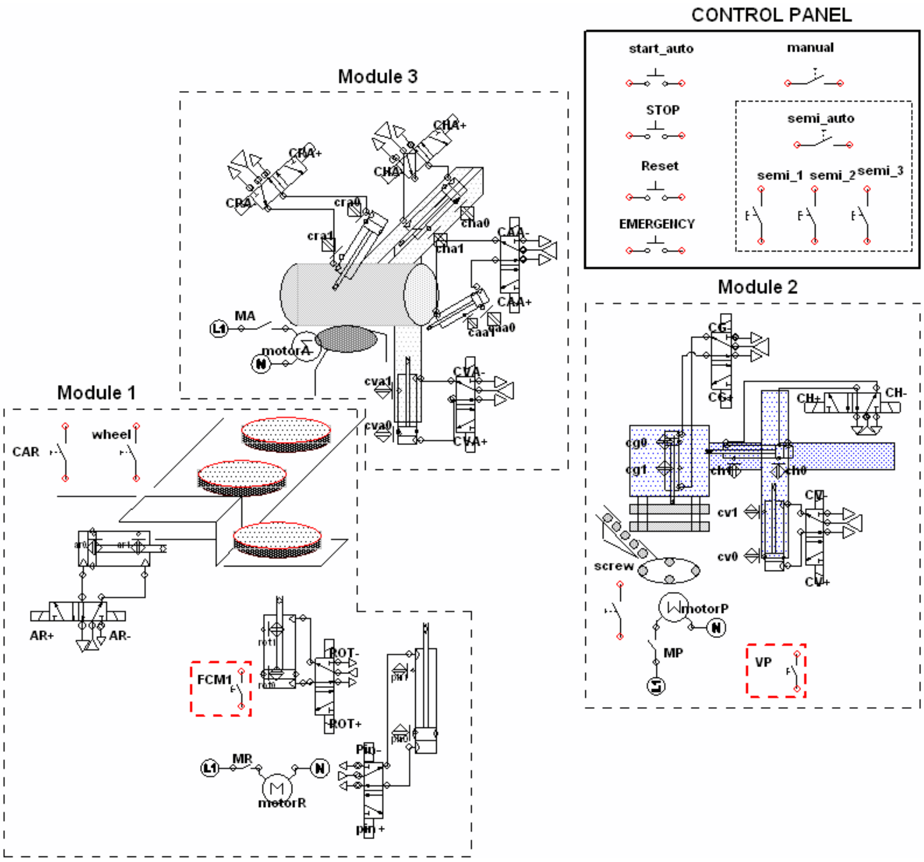

Figure 2. Plant of the machine for the automatic assembly of car wheels.

All the command structure was developed based on the direct application of the GEMMA method. In order to facilitate the understanding of the GEMMA application, a short description of the system presented in figure 2 is given:

Being detected a car by the sensor CAR, in the main platform, the operation of the machine starts.

The wheel positioned in the feeding runner is pushed by the cylinder AR to the alignment

platform. The cylinder PIN moves forward and it beats in the wheel being half advanced. The motor R moves the cylinder PIN along the circumference where are made the holes of the wheel. As soon as, the cylinder PIN is aligned with the hole moves forward and the motor R stops. The cylinder ROT moves forward to allow the rotation of the wheel. The motor R is again turned on until the position of sensor FCM1 to be reached. Following, the cylinders PIN and ROT move back.
However, the screws were already loaded in the gripper in agreement with the following steps:

- The motor P gives a whole rotation, so that the four screws are positioned;
- The cylinder CV moves back allowed the individual gripper to be on the screws;
- The cylinder CG moves forward doing with that the gripper catch the screws.
- The cylinder CV goes up;
- The cylinder CH moves forward, being the gripper on the wheel;
- The cylinder CV goes down;
- The cylinder CG opens the gripper and the screws fall in the holes of the wheel;
- The cylinder CV goes up;
- The cylinder CH moves back.

After that, the wheel is in a known position with the respective screws. At this time, the module 3 begins its operation. The wheel is fit in the cube of the car by the motion of the cylinders CVA, TEA and CRA (this allows the rotation of 90º of the wheel). The screws are tight for the actuation of the motor A. The gripper release the wheel and it moves back and finally rotate 90º, being the machine ready for a new production cycle.

<u>Application of the GEMMA method</u>

In the graphical chart presented in figure 3, based on the general graphical chart of GEMMA, it is possible to identify the run and stop ways or states that can be considered for the system.

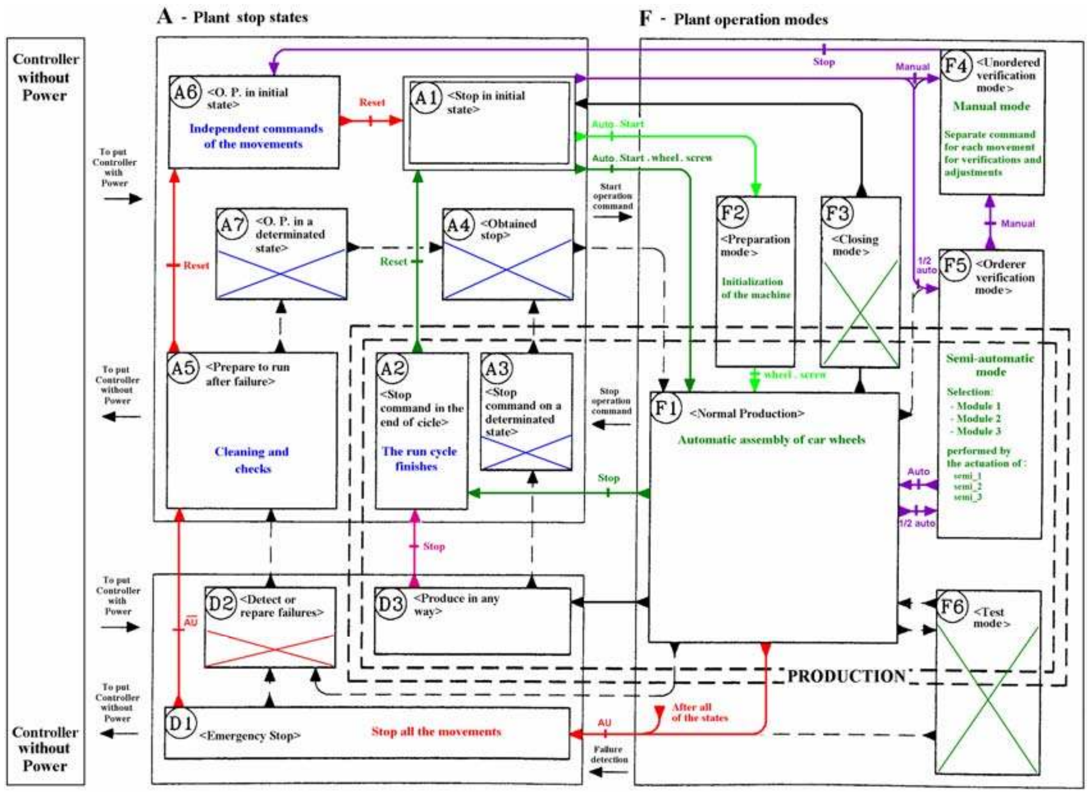

Figure 3. Graphical Chart GEMMA applied to the Plant and Controller.

In this case, were considered the following run and stop ways or states:

A1 - In this state all the cylinder are retreated less those that can be advanced for the action of the gravity force. There is therefore needed to go through a preparation operation mode;

A2 – After running the system in production in any way, it is previewed a state of stop in the end-of-cycle;

A5 – After any failure of the system, it will be necessary to perform a checking/cleaning to the system before being restarted to the normal production mode;

A6 – After A5, is defined a state in which the machine returns to the initial state;

F1 – After A1, when it occurs the actuation of the button start_auto, it happens the execution of the main program corresponding to the automatic assembly of car wheels, whose short description was presented previously;

F2 – In the preparation mode it is verified if the vertical cylinders of the transport of screws (cylinder CV) and the vertical cylinder of transport of the wheel (cylinder CVA) are advanced. In case they are not, it will be given an order to validate this condition. It is also verified the existence of screws and wheels in the respective feeders, if it doesn't verify, an error message of the respective component it appears in the display of the machine control panel;

F4 -In the unordered verification mode the machine is supplied with electricity and compressed air, but commands of the controller for the plant don't exist, allowing to the operator the manual actuation of cylinders and motors of the plant;

F5 – In ordered verification mode, being the system in the state of normal production is possible to perform an individual verification of the modules 1, 2 and 3 with the actuation of the button semi-auto conjugated with an selector button that define which module will be checked;

D1 – When the operator detects any problem in the line, he must press de Emergency switch to immediately stop the system.

<u>Application of SFC</u>

Each mode considered on the application of GEMMA was traduced on the respective SFC. It has been adopted the vertical coordination of the different SFC considered and some results are illustrated in figure 4.

<u>Simulation of the system (controller and plant)</u>

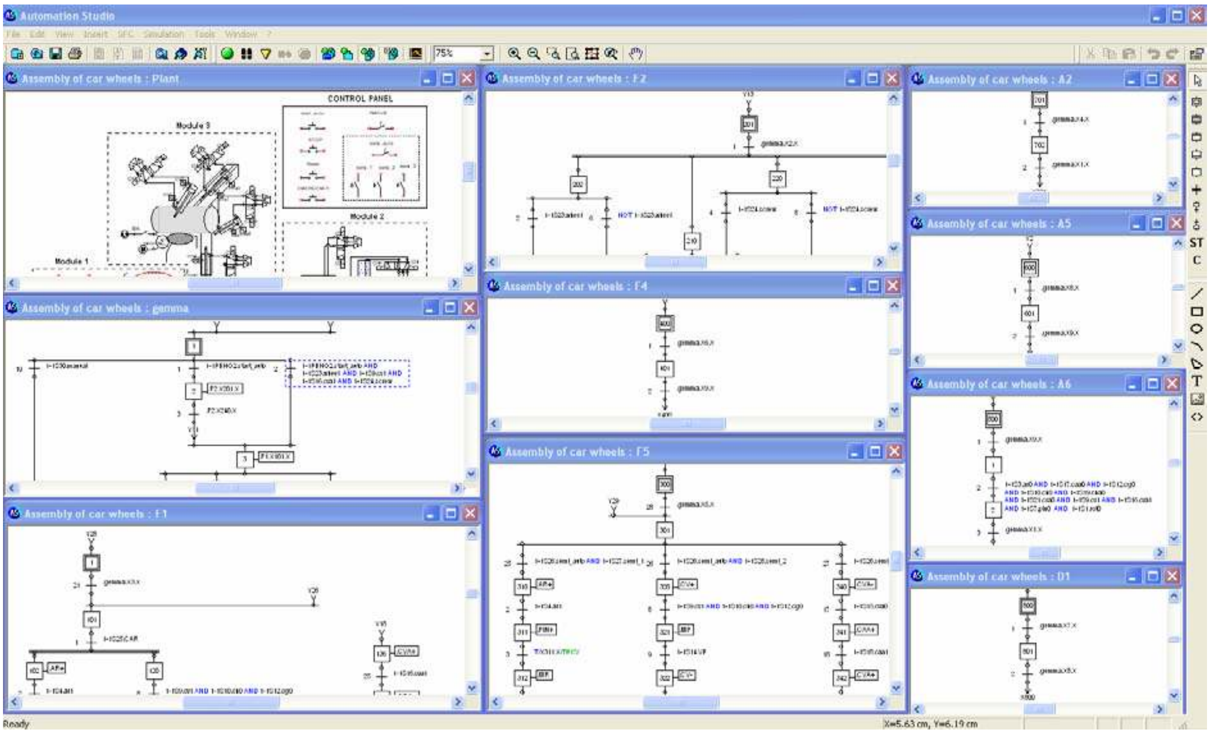

Figure 4. Programming windows of the implementation in Automation Studio

Figure 4 shows, the implementation of the system in the Automation Studio Software that it was performed to simulate and validate the controller developed in SFC. In this figure, it can be seen various programming windows with the SFC corresponding to each state of GEMMA considered in this example, which correspond to the system controller. To carry out the synchronization of these SFCs, it is used the vertical coordination, that means that exists a “gemma” that is a SFC corresponding to the graphical chart of GEMMA that corresponds to a superior abstraction level. Finally, on the other hand, it can be also observed a window related with the plant of the system. This manner, using these programming windows together will be possible to simulate the system’s behaviour and to detect easily some errors, or mistakes, if they exist.

Formal Verification of the system (controller and plant)

The Formal Verification technique is used when it is intended to guarantee that some behaviours of the system are going to happen or not to happen (for instance safety behaviours or liveness behaviours). This technique must be used complementarily with simulation because simulation is more suitable and, with it, more than 90% of errors, or mistakes, presented in the controller program can be “detected”. In this case, the Formal Verification was used to guarantee that some behaviour properties are always true: for instance, “*if the motor R is rotating, it must continue rotating until the PIN cylinder is detected by sensor FCM1*” or “*the PIN cylinder must go out if the motor R is stopped*” or “*during all the time, the motors R and A must not rotate in simultaneous*”. All of these, and other safety and liveness behaviours, were traduced to Timed Computation Tree Logic (TCTL) [10], following some rules described in [11]. The controller and the plant behaviour were modelled too by timed automata and the formal verification approach was the same as described at [12]. All the expected behaviours were guaranteed by formal verification with UPPAAL model-checker.

CONCLUSIONS

With this paper it was shown that the use of a set of formalisms techniques and advanced software tools are crucial in the guarantee on the obtained safety and robustness during the industrial controllers design.

The considered formalisms (GEMMA and SFC), analysis techniques (Simulation and Formal Verification) and software tools (Automation Studio and UPPAAL, with timed automata) fulfil all the requirements during industrial controllers design. Still more important is that the chosen set allow the designer to have the possibility to test the controller when the plant of the automation system still not exists.

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References:

[1] GEMMA – ADEPA, France,1992.
[2] IEC 60848 - GRAFCET specification language for sequential function charts. Edition 2.0 b: 2002.
[3] Baresi L., M. Mauri, A. Monti and M. Pezzè (2000). PLCTOOLS: Design, Formal Validation, and Code Generation for Programmable Controllers. Simulation software.
[4] Moon I. (1994). Modeling programmable logic controllers for logic verification. IEEE Control Systems, vol. 14, nº2, pp. 53-59.
[5] Fritzson, Peter, Vadim E., 1998. Modelica, a general object-oriented language for continuous and discrete event system modeling and simulation, 12th European Conference on Object-Oriented Programming (ECOOP'98). Brussels, Belgium.
[6] Otter M., K. Årzén and I. Dressler (2005). StateGraph - A Modelica Library for Hierarchical State Machines. In: Modelica 2005 Proceedings.
[7] Famic Technologies, Automation Studio – User´s Guide, Famic Technologies Inc, Canada, 2003.
[8] Alur R. and D. L. Dill (1990).,. Automata for modeling real-time systems. Proc. of 17th Int. Coll. Automata, Languages, and Programming (ICALP'90), England.
[9] David A., G. Behrmann, K. G. Larsen and W. Yi (2003). A Tool Architecture for the Next Generation of UPPAAL, Technical Report n. 2003-011, Uppsala University, February. 20 pages
[10] Alur R., C. Courcoubetis and D. L. Dill. Model-Checking in Dense Real-Time, Information and Computation, vol. 104, n_ 1, pp. 2-34, 1993.
[11] Campos J., J. Machado and E. Seabra "Property Patterns for the Formal Verication of Automated Production Systems" Proceedings of IFAC'2008 – 17th IFAC World Congress, July 6-11th, Seoul, South Korea, 2008
[12] Machado J., E. Seabra, F. Soares, and J. Campos. "A new Plant Modelling Approach for Formal Verification Purposes". Procfeedings of 11th IFAC/IFORS/IMACS/ IFIP Symposium on Large Scale Systems: Theory and Applications. 23 th - 25th July, Gdansk, Poland, 2007

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