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Procedia Manufacturing 38 (2019) 686–693

Procedia MANUFACTURING

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29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019), June 24-28, 2019, Limerick, Ireland.

New motion control machine elements representation for mechatronic education

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Abstract

The paper presents a new proposal for representing machine designs involving motion control. The new mechatronic approach for machine design is moving from a mechanic concept where mechanical transmissions, mechanical gears and coupling etc. are being implemented by electronic coupling, gears, etc. New concepts such as electronic virtual axis are also being employed very often. This brings that, in regards with machine design communication, mechanic elements represented in the past by mechanical drawings are being replaced by new electronic concepts. However, these new electronic motion control concepts should be also represented for a full understanding of the machine behaviors. Drawings are a fundamental tool to communicate preliminary designs, both in an academic and education environments as in professional ones. The new mechatronic elements graphical representation presented in the paper has the objective of bringing the gap between a pure mechanical machine design view and an automated one, including new electronic motion control concepts, and remarking the relevant "mechanic" information from the electronic motion control point of view. All this should facilitate the presentation and explanation of system-based mechatronic designs both in the classroom and at the professional level.

Keywords: Mechatronics; Motion Control; Machine Designe.

1. Introduction

Automated industrial machines design involves several engineering areas and the machine design process produces different technology views where "design element names" are the main relation mechanism. Same object has a similar

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10.1016/j.promfg.2020.01.092

name within different views: for instance, in the machine mechanical plan, in the electrical or electronical plan, in the automation application, etc. Despite this linkage, the mechanical design and the automatization design follow a more or less autonomous development process. Each design process is oriented to their particular scope, and hence to their building elements and relations representation strategies. They hardly include relevant information from another field [1]. This disjunction has been a classical communication problem between mechanical designers and automation software designers, which should be traced up to the mechanic oriented or electronic oriented education programs. A similar communication barrier have been traditionally present in machine design education environments, where graphics and machine parts representations from machines mechanical perspective have been very different than graphics for an electronic and control perspective.

But, with the arrival of new machine controllers, electronic devices and control and automation development software, new mechatronics concepts have appeared in the field of machined designee. As defined by Mechatronics Elsevier Journal editorial board [2], "Mechatronics is the synergistic combination of precision mechanical engineering, electronic control and systems thinking in the design of products and manufacturing processes". This complexity increases with the possibility of defining temporal and electronic kinematic relations between axes–as for instance master-slave relationships, CAM table dependencies, etc.–, as well as the use of virtual axes associated with real axes for control reasons.

This article reviews new mechatronic concepts which should be present in a machine mechatronic sketch valid for a mechanical view, and an electronic view. The paper presents the main characteristics of a new designing information model for these situations. The model presented in this paper will be worth for specification complex machines in the education field, as well as in industry. The use a "graphic" version of the model would bring profits in the communication and understanding between mechanical design training and control design training.

2. From Mechanical solutions to Mechatronic solution

The mechatronic approach for machine implementation switches from a mechanical solution (Fig.1 left) to a mechatronic solution (Fig, 1 right). The mechatronic one takes out the big master axis including all the mechanical couplings for camming and gearing, etc., and replace these functionalities locally with smaller motors, now under software control. This provides the basis to make machines more efficient while being more flexible [3].

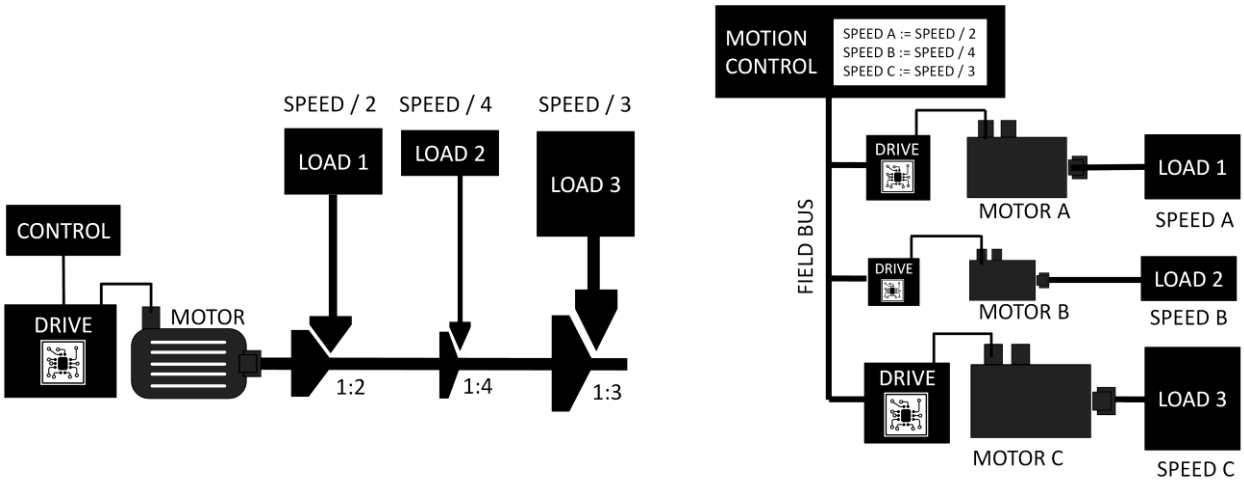

Fig. 1. (left) mechanic approach; (right) mechatronic approach.

The sequences of movements, relations between axes, etc. are described by instructions or functions defined by programming languages. There are numerous solutions to implement and to describe the operation of machines using those languages. The most important standard is IEC 61131-3, [4], which is widespread and widely accepted, not only

by users but also by equipment manufacturers. IEC 61131-3 was adopted by PLC-Open [5], who expanded it by specifying, among other things, libraries for axis control [6]. It defines a set of FBs (function blocks) to program the control of the servoaxes. It comprises from simple movements PTP (point to point), to complex coordinated movements which create logical relationships between axes, equivalent to their mechanic counterparts, such as mechanical cams and others. These software relationships may be activated and altered during the operation of the machine, changing the logical state of the axes with effect on the mechanics. PLCOpen also defines a set of axis logical states in order to represent their kinematic relationship with other axis, the most important are:

- Discrete, free and independent movement of the axis, typically PTP, like MC_Move.
- Coordinated, when two or more axes move to perform complex paths, for example MC_MoveLinear.
- Synchronized, the movement of the axis (slave axis) is conditioned by the movement of other axis (master axis), for example MC_GearIn.

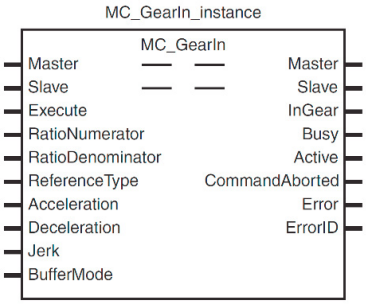

Fig. 2. PLOpen Motion Control Function Block.

The behaviour of the axes of the machine, is the result of the execution of a program by an electronic motion controller. The source code for that program will include the FBs needed to describe such behaviour. Typically, the source code of the programs is accompanied by text comments to facilitate interpretation by the people who have to work with it. The text comments could include information about what it does, but if the mechanics are complex, the description would be complicated and prone to wrong interpretations without some kind of mechanical plan or an equivalent.

The interpretation of the source code of a program of this type with these characteristics can be very complicated, even for specialists in the field. It is not linked to any kind of graphic representation, except graphic records of key axis parameters, such as position, speed and torque.

By other hand, mechanic oriented standards with the most direct application for the representation of machinery with servo axes have several limitations [7][8][9][10][11][12] [13]. Firstly, they include a lot of irrelevant information for the joint representation of the mechanical and motion control information. Secondly, their interpretation requires specialized knowledge. In the third place, obtaining information of common interest is not simple. And finally, the mechanical information is usually represented graphically, while the motion commands are not. Different non-standard solutions used in scientific literature. The following are some examples where axes and names have been drawn on photos of the machine, as in [14]. Examples of computer-generated images of the machine are also found, as in [15] [16] [17]. Or even simplified drawings in sketch mode are found, as in [18] [19] [20]. Even the PLCopen standard itself makes use of this type of drawings [21]. Representations of trajectories of movements as in [22] and [23] can also be found, for example. Those figures are created to explain examples or concrete cases. The manufacturers of components for machinery regularly make use of technical drawing standards in the technical documentation and manuals of their products. However, non-standard or informal drawings and schemes can be found in the documentation of motion controllers or servomotors, as for example in [24] [25] [26] [27] together with explanations and examples of use of motion commands

Therefore, there is no standard for the joint representation of machines with servo axes and its corresponding motion control, and informal mechatronic representations are used in scientific, technological and therefore

educational fields. A new graphic representation system combining mechanical and motion control information may be useful to cover the gap between current standards.

3. Main proposal elements

This section presents a list of elements and symbols that are part of the MMCS proposal. MMCS stands for "Mechanical and Motion Control Schematics", and a more detailed explanation may be found in [1]. Graphic elements may be organized into two groups, according to their initial origin, and see them in Fig. 3:

Mechanical elements
- Linear, guided or unguided axes (object on conveyor belt).
- Rotating axes.
- Structures, whether they are supports, joints, movement delimiters, tools, clamps, etc.
- Active elements, linear carriage or rotating structure.
- Labels, dimensions, reference points, measures of components and distances to the reference points, such as "Zero Machine"

Control elements
- Virtual axis
- Sensory axis (artificial vision, distance measurement, etc.)
- Axis notation, notation of positions
- Axis status (master, slave, coordinate, independent)
- Wheel ratio
- Source reference or zero point
- Direction of movement (normally positive)

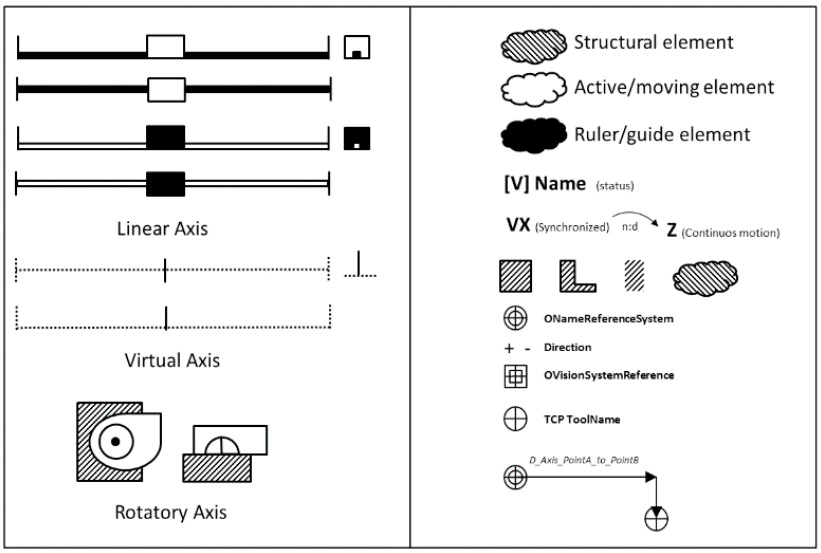

Fig. 3. Main elements proposal.

4. Applying the new specification: an incremental example

This section presents an example with increasing complexity. It starts with a linear axis representation. Next, this linear axis is used (three times) to represent a Cartesian system, and finally a pick and place system using previous Cartesian one is presented.

4.1. Linear Movements

This is one of the simplest cases. It is proposed to use the capital letter "O", to note the origin of the axis and an arrow with a + or - sign, as appropriate to indicate the direction. Once the point from which the measurement is to be made, the second point must be indicated. It could be an end of the mobile carriage or its midpoint or a notable point of the tool that carries, see Fig. 4.

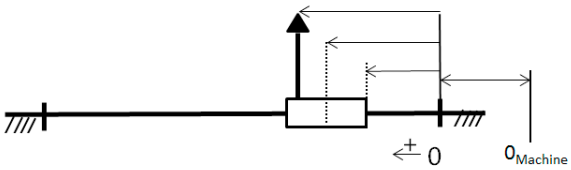

Fig. 4. Simplified representation of a linear axis, showing origin or zero, and variants for measuring the position of the carriage or tool.

4.2. Cartesian system

Cartesian system of 3 axes is represented in Fig. 5. Two perpendicular axes position in the plane are moving a third perpendicular to both. In this case, the vertical axis guideway is smaller than the moving carriage. In Fig. 5 there is a 3D drawing.

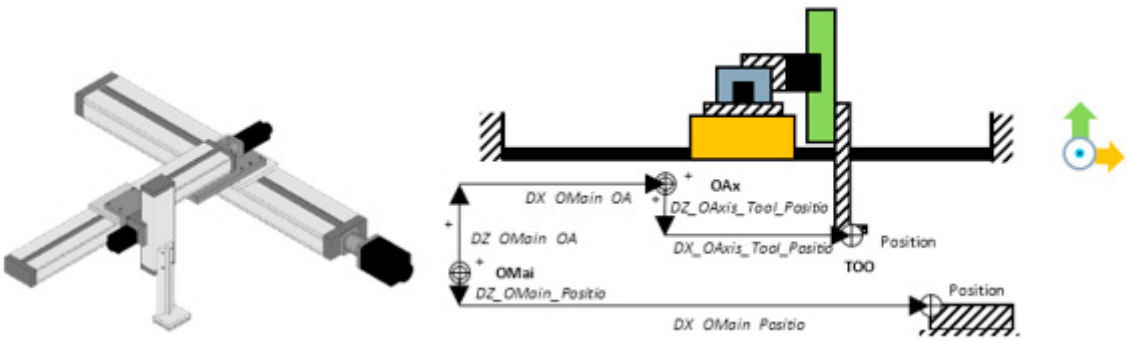

Fig. 5. Cartesian axes.

The axes are joined together with an auxiliary or structural part. These pieces are fundamental elements for the mechanical design but also important for the control of the axes since they define distances between the different elements. In addition, there is usually a piece that is only attached to the last axis, which is the tool. Typically, the coordinates of this tool are relative to the work reference system and their values are used to specify the movements in the control program. To represent the structural elements, it is proposed to use the simplified outline of the same, with a pattern of parallel lines.

To name the axes it could be used conventions described for that purpose of the ISO841 standard [28]. For example, the point at which the position of the axis is measured would be the center of the tool, the letters X, Y, Z would be used for linear and perpendicular axes. The subscript would be used to note parallel axes, X1, X2.. ,Xn. By reserving

the letters, A, B, C for rotary axes with center in X, Y, Z. If the function of the machine has a function similar to a CNC, the positive Z axis could be assigned to the direction and direction of the working tool to the piece.

4.3. Cartesian Pick&Place system with virtual axes.

The Pick & place applications basically consist of taking one or several objects (picking operation) and placing them in a new location (place), Fig. 6. The parts to be handled and the positioning point may be fixed or in motion. Depending on the application, we can have enough information about the parts (measurements, position, etc.) before starting the process or it is necessary to obtain more data of each piece just before starting the operation, such as position, orientation, type of piece, etc. It is therefore a process whose complexity can vary greatly [29].

In the following example of which the corresponding MMCS will be presented, the mechanical manipulator consists of a Cartesian system like the one seen in Fig. 5; a conveyor belt, drags the pieces into the work area of the XYZ system. The motor of the belt is controlled by external system and independent of the pick & place system (as in many cases).

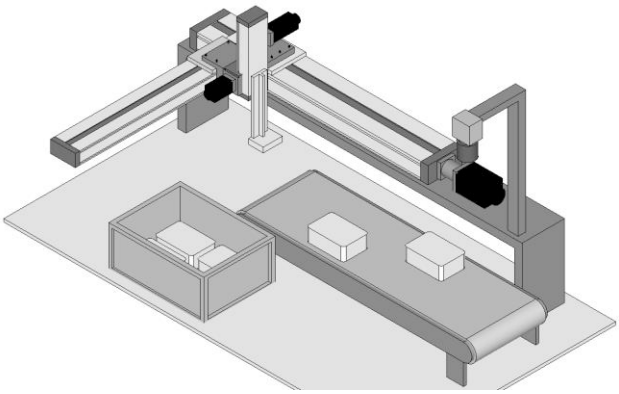

Fig. 6. Pick&Place system.

The pieces rest, without sliding, on the conveyor belt and can be anywhere on the surface. An artificial vision system will calculate the position of the object. The digital camera will focus on the surface area of the conveyor belt prior to the work area of the XYZ manipulator. The horizontal axis of the camera sensor will be aligned with the conveyor belt. The image processor will obtain the position of the object in pixels, with respect to the coordinates of the image sensor. Therefore, a scaling to longitudinal units is necessary and a correction to reference this position with respect to the coordinate system of the manipulator.

Once the capture point of the object is located and calculated because it is displaced by the conveyor, it will be necessary to update the coordinate on the X axis continuously so that the manipulator can pick it up without having to stop the conveyor after processing the picture.

The capture operation of a moving object is typically referred to as "catch on the fly". In this type of operations, a slave axis must be synchronized in speed and position with a master axis. In this case the slave axis would be the X axis of the XYZ system and the master axis a virtual axis representing the position of the object at any given time. In

addition, this virtual axis will be slave to the axis of the conveyor, of which only the relative variation of the position is of interest.

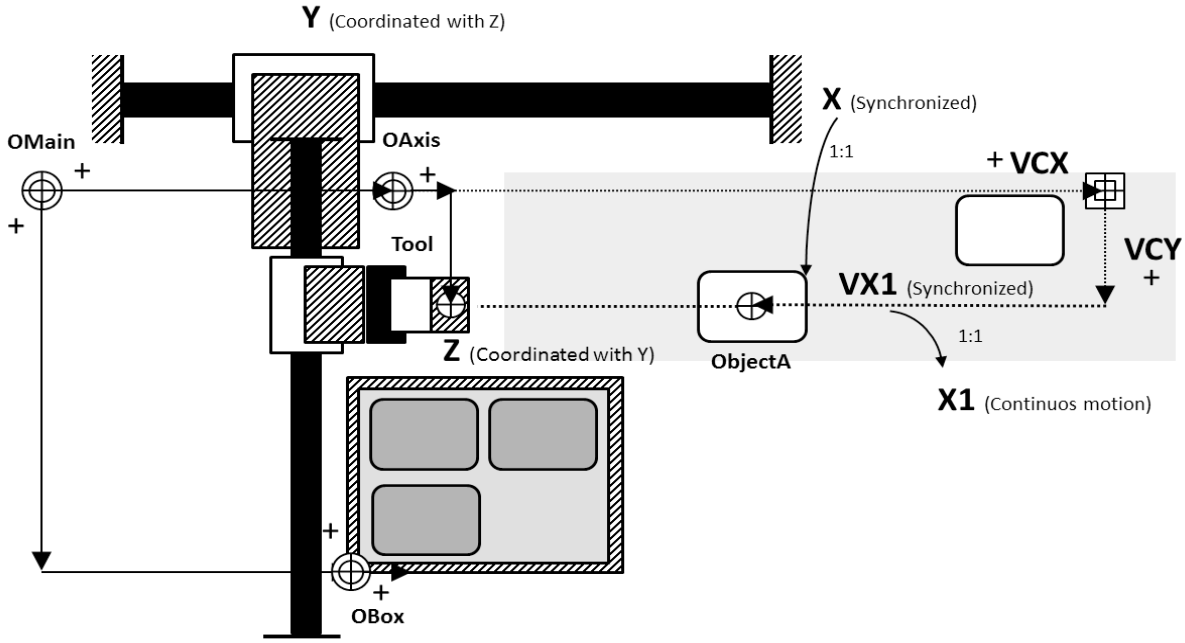

Fig. 7. Pick&Place system in MMCS.

In this example, a virtual axis is used so that an object that is not actually an axis can be master of a real axis. In case of multiple pieces, different virtual axis would be assigned to each of them. The virtual axis will be created when the artificial vision system locates it and will be eliminated when the Cartesian system picks up the piece.

Both the initial position calculated by the artificial vision system and the virtual axes representing the positions of the pieces are digital information that can be represented on the mechanical planes or diagrams to facilitate an understanding of the overall operation of the system. And in this way to link, coordinate and visualize the interactions between the mechanical system and the control system.

The MMCS corresponding to this system can be seen in Fig. 7. To emphasize that although the conveyor belt is a rotary movement that becomes linear, from the point of view of its function, it is simply a linear displacement of an object.

We can observe 3 types of axes according to their nature, real mechanical axes, axes of the image that captures the camera of artificial vision and virtual axes. Again, in the same mechanical drawing, logical and control elements are represented.

In this example, a digital camera was used, but another type of sensor could also have been used as triangulate lasers [30]. Finally, different MMCS could be used to represent the evolution of the machine cycle in different stages. For example, virtual axis assignment, on-flight synchronization phase, part capture, part placement, etc. And referencing these MMCS from the corresponding program code and chronograms as discussed above.

5. Conclusions and future work

A new system of schematic representation of mechanics and motion control or MMCs is proposed. A system of combined representation would allow the exchange of information between different areas of engineering without having to know the tools and graphic standards of others. It would be a common area of work from which different specialists could develop their part to the level of detail needed to finish their work. Increasing the efficiency and reducing errors in the different stages of the creation of machinery with servoaxis.

The next step in the development of the MMCS model, once the conceptual model reaches a mature state, should be the creation of an electronic information model. This model (using UML, or ISO10302-11 Express language, for instance) would allow having electronic designs of MMCS mechatronic elements. This digital representation, can help to achieve some objectives of an industry 4.0 implementation: “a model of the ‘smart’ factory of the future where computer-driven systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions based on self-organization mechanisms” [31]. In other words, this electronic model could act as a glue of other electronic models, as it has, in one model, the essential of different technological views: structure and mechanical behaviour, electronic axes, control rules, motion automation sequences, etc.

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