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DEVELOPMENT OF A TRAINING PROGRAM FOR ENHANCING THE USE OF ICT TOOLS IN THE IMPLEMENTATION OF PRECISION AGRICULTURE

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Lecture 3 : Control of an Automated System

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Contents

1 Objectives

The objectives of this lesson are:

- Give an overview of the different ways of control of an Automated System
- Understand the concepts of Open loop, close loop and PID controller
- Understand control rules in the case of a fertilizer or manure spreaders

2 Tutor instructions

This is a 2h lesson in presence. This presentation will lead the attendant to get an overview of the control of Automated Systems (AS) with an insight on fertilizer and manure spreaders.

3 The basis of the control of automated systems

Slide 3 from document Lecture_Control_AS.pptx*)*

This slide is a schematic representation of an automate system already shown in previous lesson. The control part is the “brain” of the AS taking information from both the operator through the MMI and from sensors of the operative part. The control part will then command the operative part through actuators.

Slide 4 from document Lecture_Control_AS.pptx *introduces 4 different levels of control developed in this presentation:*

- All-or-Nothing control Systems
- Open Loop Control
- Closed Loop Control
- PID Controller Principle

3.1 All-or-nothing control systems

Slide 5 from document Lecture_Control_AS.pptx introduce the concept of binary logic that is the core concept of all-or nothing control systems. Using the example of a (leaking) container filled with water, the idea is to keep the water level between minimum and maximum levels (using level detectors). The valve feeding the system with water that can only be fully open (state 1 or

ON) or fully closed (state 0 or OFF), illustrating the concept of binary logic. A convenient way of representing the different situations is a resolution table where the status of the system (valve) is defined considering the status of the 2 detectors.

The activation of the valve is only possible when max level detector is 1 whatever the status of the min level detector (in fact this min level detector could be removed…).

Slide 6 from document Lecture_Control_AS.pptx

Another All-Or-Nothing system is presented here with a door lock. Two doors are necessary to enter the building. The second door can only be open after the first door is closed. Both doors are equipped with control buttons located both side of the doors having 2 positons (0 or 1). Door locks have also 2 positions (0 or 1). The system is completed with a controller and a power supply.

Slide 7 from document Lecture_Control_AS.pptx

The process is the following:

Step 1: both doors are closed and both locks are activated.
Step 2: The button 1 is activated that deactivates the lock1: Door 1 opens
Step 3: When Door 1 closes, a position sensor of the door activates Lock 1
Step 4: When the button 2 is activated, the Lock2 releases the Door2.
Step 5: When Door2 closes, the second position sensor of the door activates lock 2.

If a button is activated in the appropriate order (example Button 2 at step 3 or button 1 at step 4), the system is not reacting.

The resolution Table illustrates this combinatory process. The opposite process (from Door 2 to Door 1 can be discussed with participants.

3.2 Boolean algebra

Slide 8 from document Lecture_Control_AS.pptx

All-Or-Nothing systems (AON) are based on binary logic that uses combinatory (2 states) components.
An example is given with the buttons related to a switch:

A normally open (N/O or NO) switch means that the switch is open when the button is released and automatically closed when the button is activated.

A Normally Closed (N/C or NC) switch is closed when the button is released and automatically open when the button is activated.

These two switches have complementary advantages:
A NO switch can be used as the Door button or the Door sensor as a NC switch can be used as a safety button that opens the electrical feed) or as an end sensor.

Slide 9 from document Lecture_Control_AS.pptx illustrates different types of NO / NC switch that can be activated manually or electrically with a coil. Switches may also have a non-permanent position as a spring is generally used to automatically release the position when the action is released on the button.

For practical reasons, all components can be represented with normalized symbols from EN 60617-7.

Slide 10 from document Lecture_Control_AS.pptx

Binary logics allows the combination of components for more or less complex functionalities. In this purpose, Gates are used and are characterized by inputs, outputs and a combinatory action of the gate.

A practical representation of a gate AND can be given with two switches, connected in a serial way. Both switches are to be activated to feed the light with electricity. The resolution table illustrates the different sates of inputs and outputs. Different symbols can be found to represent a gate AND.

A practical representation of a gate OR is given with two switches mounted in parallel. In this case the light bulb is activated when either one or the two switches are activated.

A third gate that is commonly found is a gate NO for which the output is always opposite to the input.

The combination of inputs/outputs is ruled by the Boolean Algebria: A gate AND is like multiplication between (0 and 1); as a gate OR is like an addition or 0 and 1.

Slide 11 from document Lecture_Control_AS.pptx

Gates AND and NO or OR and NO can be combined to give gates NAND (parallel combination of NC switches) and NOR (serial combination of NC switches).

Slide 12 from document Lecture_Control_AS.pptx

Additional gates can be defined when excluding the possibility to have similar results when activating one or the switches and both switches. This exclusion leads to the definition of XAND and XOR gates. A XOR gate is typically found with a 2 way switch (2 switches with permanent position are used). XNOR is also called the "coincidence", the activation of the output is only possible when both inputs are at similar state.

Slide 13 from document Lecture_Control_AS.pptx

illustrates another example where binary logic can be used to control a bottling process. First, it is suggested to describe the 4 unitary processes and imagine how to control each of them by using switches, sensors and actuators (valves, rams, etc.)

Example

Unitary process	Functions	To be controlled	Sensors	Actuators
Filling	Fill the bottle up to a limit	Level in the bottle	Volume sensors, level, position	Valve
Plugging	Insert a plug up to a limit	Position and distance inside the bottle	Position, force	Pneumatic ram
Covering	Insert cover at the right place	Position and distance around the bottle neck	Position, force	Pneumatic ram
Labelling	Place a label at the right place	Position on the bottle	Position	Rolls, rams

Second the link between unitary processes can be developed using position sensors (ex a light barrier or position sensor, etc.)

Slide 14 from document Lecture_Control_AS.pptx

Binary systems can rapidly become complex when many components (sensors, actuators) are combined. It is then necessary to reduce the number of gates using some laws on binary logics that are the basis of Boolean algebria:

- Commutativity : the order of the gate inputs does not modify the result:

ex. 3+2 = 2+3; 3x2 = 2x3

- Associativity : when the same operator is used between several inputs, there is no predominance of a specific association : ex: 3x(2x4) = (3x2)x4
- Distributivity of the multiplication over the addition allows to convert a product of sums (or differences) to a sum (or difference) of products.

Ex: 5x(1+3) = 5x1 + 5x3 or 5-(1x3) = (5-1)x(5-3)

- Idempotence: denoting an element of a set which is unchanged in value when multiplied or otherwise operated on by itself.
- Absorption: for this example, replace + by OR and x by AND
- Involution

Slide 15 from document Lecture_Control_AS.pptx

More complex Boolean algebra are known as De Morgan Theorem that is widely used to solve complex Boolean equations in electronics.
Many web sites propose additional information on De Morgan Theorem and laws.
Ex : https://www.allaboutcircuits.com/textbook/digital/chpt-7/demorgans-theorems/

3.3 Fuzzy logics

Slide 16 from document Lecture_Control_AS.pptx

Binary logics is convenient to control automated systems but, sometimes, things are like shades of grey instead of black and white…

Fuzzy logics was developed to manage and control such automated systems with a higher level of uncertainty.

Slide 17 from document Lecture_Control_AS.pptx

The binary situation is explained by the plain red dot and the step curve shows the colour as a fonction of the position along the array.
In the case of the fuzzy logics, the green intensity is variable depending on the position; the curve is not a step but a slope.

Slide 18 from document Lecture_Control_AS.pptx

Another way of illustrating fuzzy logics concepts is through the evolution of different variables on the same scale: here variables are “sensations” and the scale is a quantitative value. Sometimes, the distinction between cold and warm or between warm and hot is highly uncertain. Fuzzy logics uses such diagrams to control automated systems under uncertain conditions.

Slide 19 from document Lecture_Control_AS.pptx

An example of application is given here with the detection of vegetation on images (application weed detection for example). 2 variables are considered as inputs in this case: the weed coverage (% of surface area covered) and the spread of the weed patch. Each variable is defined by membership functions. As an output, the herbicide application is also ruled by fuzzy logics based on a combination of previous variables.

Slide 20 Notion of Inference system

Many additional examples can be found :
Harpreet Singh, Madan M. Gupta, Thomas Meitzler, Zeng-Guang Hou, Kum Kum Garg, Ashu M. G. Solo, and Lotfi A. Zadeh, 2013. Real-Life Applications of Fuzzy Logic. Advances in fuzzy Systems, volume 2013. https://doi.org/10.1155/2013/581879

Slide 21 from document Lecture_Control_AS.pptx

The integration of a FIS requires several operations :
Fuzzification module: transforms the system inputs, which are crisp numbers, into fuzzy sets. This is done by applying a Fuzzification function. • Knowledge Base: stores IF-THEN rules. • Inference engine: simulates the human reasoning process by making fuzzy inference on the inputs and IF-THEN rules. • Defuzzification module: transforms the fuzzy set obtained by the inference engine into a crisp value.

3.4 Sequential logics

Slide 22 from document Lecture_Control_AS.pptx

Sequential logics represents an evolution of combinational logics that includes a “memory effect”. The output is not only defined by the state of inputs but also by the clock. In other words, output depends on inputs but also on the previous step of the process

Slide 23 from document Lecture_Control_AS.pptx

Sequential logics uses controllers to operate inputs and outputs.

3.4.1 Open Loop Control Systems

Slide 24 from document Lecture_Control_AS.pptx

The first step of sequential logics is the Open Loop where the input will generate an output according to the rules and settings. Most of time-based automated systems are open loops: washmachine, toaster…

In this example, the light is only controlled according to the natural light so that artificial light only used when needed.

But the limit of open loop systems in this case is that no feedback from the controlled system is operated. Another practical example concerning irrigation: a sprinkler that is only controlled with a timer is an open loop. If controlled by the humidity of the soil it is a close loop.

3.4.2 Close Loop Control systems

Slide 25 from document Lecture_Control_AS.pptx

In the case of Close Loop, there is a feedback from the system that is considered. In this example the WorkPlan Illuminance (WPI) sensor is oriented towards the workplan and NOT towards the sun. Then the artificial light is controlled according to the real working conditions.

Slide 26 from document Lecture_Control_AS.pptx

It is possible to mix the type of control loop :
The close Loop control systems takes into account the information from the illuminance sensor as the Open Loop control light is only based on indirect information.

Slide 27 from document Lecture_Control_AS.pptx

The complexity of sequential Logics controlled systems may require a way to describe the process through the definition of steps, transition phases and operational conditions (receptivity). It is then possible to have different scenarios depending on whether the conditions are met or not.
We talk about SFC (Sequential Functions Charts). GRAFCET is one example of such a diagram.

3.4.3 PID control principle

Slide 28 from document Lecture_Control_AS.pptx

Sequential Close Loop systems may require control systems that are adapted to the system in terms of reactivity and stability. PID stands for Proportional, Integrate and Derivative) controllers are commonly found on such systems.

They produce different type of output (measured variable MV) according to the input (setpoint SP) through the calculation of an error (e). As I concerns sequential process, this error may vary according to the time.

Slide 29 from document Lecture_Control_AS.pptx

PID controllers associate simultaneously 3 different levels of correction but single (P, I, or D) or twin corrections (PI) can be also found.

Slide 30 from document Lecture_Control_AS.pptx

In the case of P controller the correction will be proportional to the error considering a gain called Kp. But a single proportional controller may involve instability because the correction is only activated when a difference between MV and SP exists. For more stable systems, the stability stage may require longer time. (Slide 31 from document Lecture_Control_AS.pptx) also show the influence of Kp value on the stability or the time to reach the stability. Kp shalml be defined for a given system.

Slide 32 from document Lecture_Control_AS.pptx shows the second term that is an integral upon time of the error. It can be represented by the surface area of the error curve. The more the error lasts in time the more the corrective will be great but the risk of overshooting the setpoint is also high (cf *Slide 33 from document* Lecture_Control_AS.pptx). Ki shall be defined for a given system.

Slide 34 from document Lecture_Control_AS.pptx. The last term is Derivative meaning that it considere the slope of the variation of the error as a reference. It is a more predictive term. Kd shall be defined for a given system.

Slide 35 from document Lecture_Control_AS.pptx*.* When the 3 terms are found in a PID controller they act in complementary ways. The video shows the reaction of time depending on the 3 constant values.

Sometimes when the system is highly variable due to high frequency signal, a PID controller is not always sufficient. In this case the loop tuning may integrate low-pass filters.

4 Applications to Fertilizer Spreaders

Slide 36 from document Lecture_Control_AS.pptx

General issues for a precise and optimized fertilizer spreading are shown here. To minimize environmental impacts, the fertilizer dosage i) shall be adapted to the needs of target crops* ii) shall minimize losses using boom section control and iii) shall integrate ballistic issues to according to the slope.

*the map shown here correspond to the application map where a constant dosage is expected. Control system will mainly act on headlands and boom section control. Other cases can be found where nitrogen application may be adapted to local needs.

4.1 The bases of fertilizer spreading control

Slide 37 from document Lecture_Control_AS.pptx *introduces the general context. A prescription map results from the aggregation of information from previous applications, soils analyses maps and an agricultural model adapted to the crop. Any difference between the prescription and the further application map will lead to two main situations: an under dosage may involve yield (an income) losses as an over dosage may lead to environmental impacts as well as economical losses too.*

The application technique is supposed to operate accurately the prescription map taking into account the spreader internal settings and fertilizers characteristics:

- The design of the disc and blades
- The disc's revolution speed
- The angle of the discs with the horizontal
- The flowrate of fertilizers
- Fertilizer's density and shape
- Fertilizer's drop point on the disc

Slide 38 from document Lecture_Control_AS.pptx introduces how the application rate objective depends on spreader intrinsic characteristics as well as external factors. Intrinsic parameters correspond to the crossing of :

- *The spreader "footprint" : according to the settings and disc/blade characteristics, the spreader output is represented by a banana shape pattern obtained with a static position of the spreader. Typically this footprint represents a swath of a surface area of 1/3 of hectare.*
- The "buffered" flowrate means that the instant flowrate is not always constant due to mechanical/material effects. In the case fo mineral fertilizers, the measured flow follows the target flow as for organic

spreaders, the flow of material is only constant for a portion of manure release. However the control law is based on a constant target flowrate.
- *When this footprint is displaced inside the field and considering side recovery and boom section control, an application map can be drawn.*

External factors affecting the target application rate are
- The wind that may affect ballistics and the resulting footprint
- The variability of fertilizers type (organic or mineral), shape, size and density affecting the footprint and flow
- The slopes of the field affecting ballistic and the footprint
- The shape of the field generating potential over or under dosing

Slide 39 from document Lecture_Control_AS.pptx

Spreaders have to respond to two main problems :
- The global application rate shall be conform to the target dosage. Global Offset is generally due to errors in determining the exact flowrate.

- The variability of local application rate are due to either cross distribution characteristics and flow error generating a variability when layers overlap (figure).

The diagram shows a typical distribution of the dosage error of a conventional spreader.

Slide 40 from document Lecture_Control_AS.pptx

This slide shows a schematic representation of a spreader functionalities and where a control may be needed.
1) Black boxes: The prescription map is issued from previous levels and a spatial information provided by a GPS) theoretically lead to the definition of 2 setpoints : the dose and working width.

Both information are reference for the control unit. This CU is mainly devoted to the calculation of the Dosage “law”

D = (Q x L x V)/600
where
D is the flow (kg/min)
Q is the application rate (kg/ha)
L is the spreader width (m)
V is the velocity (km/h)

2) Orange boxes: the flowrate (D) is dependent on the position (opening) of the tank trapdoor that is to be calibrated (Action). The dosage law generates a target trapdoor position that is compared with the current

trapdoor position provided by a trapdoor position sensor. This control system is also able to react according to GPS position

3) Blue boxes : The working width is to be calibrated (Action) because it depends on the combination of disc/blade/fertilizer. A target width is defined according to the application law and, if existed, a work width sensor may correct the initial setting. This happens when spreader boom section control is activated
4) Brown boxes : the last parameters is the forward speed that is set and a velocity sensor is present when DPA (Débit Proportionel à l'Avancement – proportional flow to the travel speed) functionality is running

4.2 First level of control: reducing the offset of the dosage

Slide 41 from document Lecture_Control_AS.pptx introduces a first level of control focusing on the reduction dosage offsets.

A first order action is to control the flowrate.
Two ways are possible through the measurement of the current flow and the trapdoor position.

- Either a global weighting is possible using load sensors and a double chassis. This solution is existing on a majority of spreaders and is globally sufficient
- Or the weight is indirectly measured through the measurement of the mechanical torque on each disc axle.

Slide 42 from document Lecture_Control_AS.pptx

A second order parameters is to control the travel speed using an electronic DPA

Slide 43 from document Lecture_Control_AS.pptx

A third order parameter is the spreading width

Slide 44 from document Lecture_Control_AS.pptx

A fourth order parameter is the distance/position in the field

4.3 Second level of control : avoid variability

Slide 45 from document Lecture_Control_AS.pptx *introduces how technological innovations may allow to offer sprayer functionalities to a spreader.*

A traditional spreader is characterized by a continuous flowrate and possible adjustment of the working width. When the spreading pattern is characterized, it is the possible to add typical “sprayer” functionalities like a real boom section control. In practice it corresponds to a modification of the spreading pattern.

Slide 46 from document Lecture_Control_AS.pptx explains the purpose of a boom section and requirements in terms of the measurement of the target working width and control of the flowrate. The figure introduces a first simulation based on the online modification of the flowrate according to the distance (from 200m to 375 in this case). The spreading pattern is kept the same (left) but transversal distribution is modified (right). The angle of each disc is kept the same (bottom).

Slide 47 from document Lecture_Control_AS.pptx

In this case, the boom section control is obtained with an adjustment of the spreading width and angles of the right disc is modified.

Slide 48 from document Lecture_Control_AS.pptx *shows a commercially available example of the boom section control.*

Slide 49 from document Lecture_Control_AS.pptx

The control of the working width is of great interest for precision spreading. The example of the JUSTAX system composed of piezoelectrical sensors hit by the granules when ejected from the disc. The result corresponds to a density of impacts according to the angle. The modification of the pattern distribution according to the angle is shown with the animation. Equivalent transverse distribution are also presented.

Slide 50 from document Lecture_Control_AS.pptx

Similar retrofit systems are provided by other manufacturers (ex Kuhn, Amazone and Rauch with Doppler effect sensor).

Slide 51 and Slide 52 from document Lecture_Control_AS.pptx

The slope and wind control are also possible if basic settings of the spreading as well as external conditions (wind or slopes) are measured. Slide 51 mainly focuses on slope correction as slide 52 mainly focuses on side wind control.

Slide 53 from document Lecture_Control_AS.pptx

The integration of spatial needs (prescription map) is possible in order to manage optimal local dose.

Slide 54 from document Lecture_Control_AS.pptx *introduces error map compared to the prescription when the application is uniform.*

Slide 55 from document Lecture_Control_AS.pptx

Shows an example of transcription of the prescription map for each disc and Slide 56 from document Lecture_Control_AS.pptx introduces the resulting map considering left and right modulation of the dose.

5 Application to Organic Fertilizer Spreaders

Slide 57 from document Lecture_Control_AS.pptx

Organic Fertilizer spreaders are also concerned by the development of precision application. Although considered as low tech machines for many years, technological improvements are ongoing in order to optimize organic matter spreading. Most of modern machine are equipped with vertical beaters.

Slide 58 from document Lecture_Control_AS.pptx

The bottom of the trailer is moving in order to push the matter towards the beaters but compared to a theoretical process (piston), the actual flow is not constant due to the transfer of matter frontward. The green curve corresponds to a traditional machine without control. It also shows that the emptying time is longer in this case. The orange curve corresponds to a controlled speed of the bottom table improving the flowrate regularity but still generating a longer emptying time. The blue curve corresponds to the situation where both the bottom table and a weighting are controlled.

Slide 59 from document Lecture_Control_AS.pptx

DPA functionalities are found for some manufacturers improving the homogeneity of the flowrate according to the travel speed.

Slide 60 from document Lecture_Control_AS.pptx

Gives some conclusions that can be discussed with the audience

6 Related links

Online Resources on Binary logics : http://binary-academy.com/dnld/ (in English and Spanish) more adapted to kids and teens

M. Zegarelli, 2007. Logic for dummies, Wiley Publishing, Inc. ISBN-13: 978-0-471-79941-2. 330p. Note: extensive overview of all intellectual logic.

Fuzzy logics :
https://www.tutorialspoint.com/fuzzy_logic/fuzzy_logic_introduction.htm
Harpreet Singh, Madan M. Gupta, Thomas Meitzler, Zeng-Guang Hou, Kum Kum Garg, Ashu M. G. Solo, and Lotfi A. Zadeh, 2013. Real-Life Applications of Fuzzy Logic. Advances in fuzzy Systems, volume 2013. https://doi.org/10.1155/2013/581879

Grafcet :
https://www.mhj-tools.com/?page=grafcet-studio&gclid=EAIaIQobChMI_KO11-nz7wIVxYbVCh29WwI7EAMYASAAEgJcRvD_BwE

Introduction to Sequential Function Chart (SFC) :
https://assets.omron.eu/downloads/manual/en/r149_sfc_getting_started_guide_en.pdf

introduction to PID controller: https://www.dataforth.com/introduction-to-pid-control.aspx

Fertilizer spreading information :
J. van Bergeijk, D. Goense, L.G. van Willigenburg, L. Speelman, 2001. Dynamic Weighing for Accurate Fertilizer Application and Monitoring, Journal of Agricultural Engineering Research, Volume 80, Issue 1, 2001,Pages 25-35, https://doi.org/10.1006/jaer.2001.0714.

E.-M. Abbou-Ou-Cherif, E. Piron, Alaa Chateauneuf, D. Miclet, R. Lenain, et al.. On-the-field simulation of fertilizer spreading: Part 1 – Modeling. *Computers and Electronics in Agriculture*, Elsevier, 2017, 142 (A), pp.235-247. ⟨10.1016/j.compag.2017.09.006⟩. ⟨hal-02053096⟩

E.-M. Abbou-Ou-Cherif, E. Piron, A. Chateauneuf, D. Miclet, R. Lenain, et al.. On-the-field simulation of fertilizer spreading: Part 2 – Uniformity investigation. *Computers and Electronics in Agriculture*, Elsevier, 2017, 141, pp.118-130. ⟨hal-02053106⟩

El Mehdi Abbou-Ou-Cherif, Emmanuel Piron, Alaa Chateauneuf, Denis Miclet, Sylvain Villette. On-the-field simulation of fertilizer spreading: Part 3 – Control of disk inclination for uniform application on undulating fields. *Computers and Electronics in Agriculture*, Elsevier, 2019, 158, pp.150-158. ⟨10.1016/j.compag.2019.01.050⟩. ⟨hal-02067177⟩

Alare, Taiwo & Alare, Kehinde. (2020). Application of Control System and Digital Techniques: An Approach of Achieving Smart Agriculture. 10.13140/RG.2.2.10895.74408.