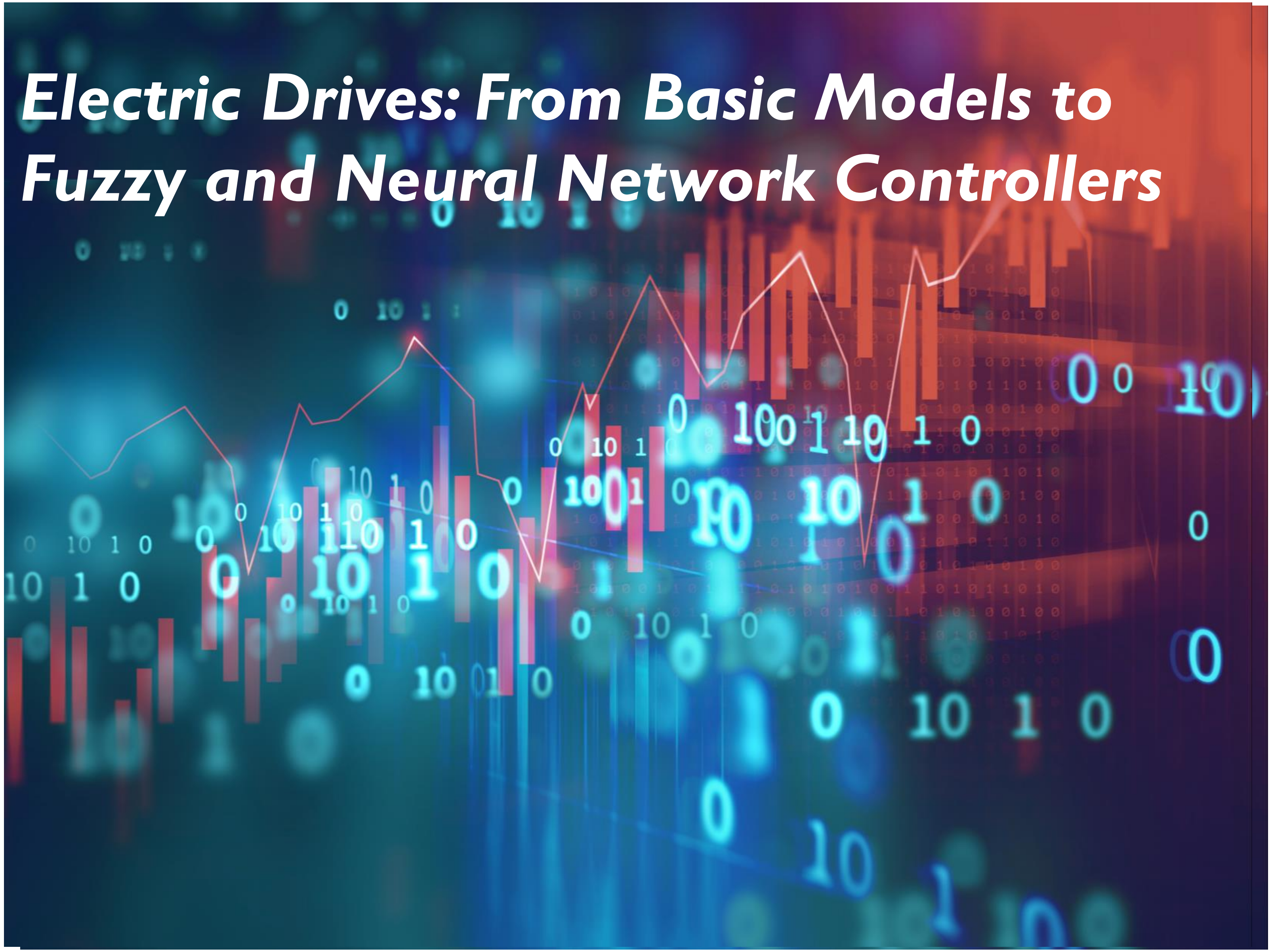
Electric Drives: From Basic Models to Fuzzy and Neural Network Controllers



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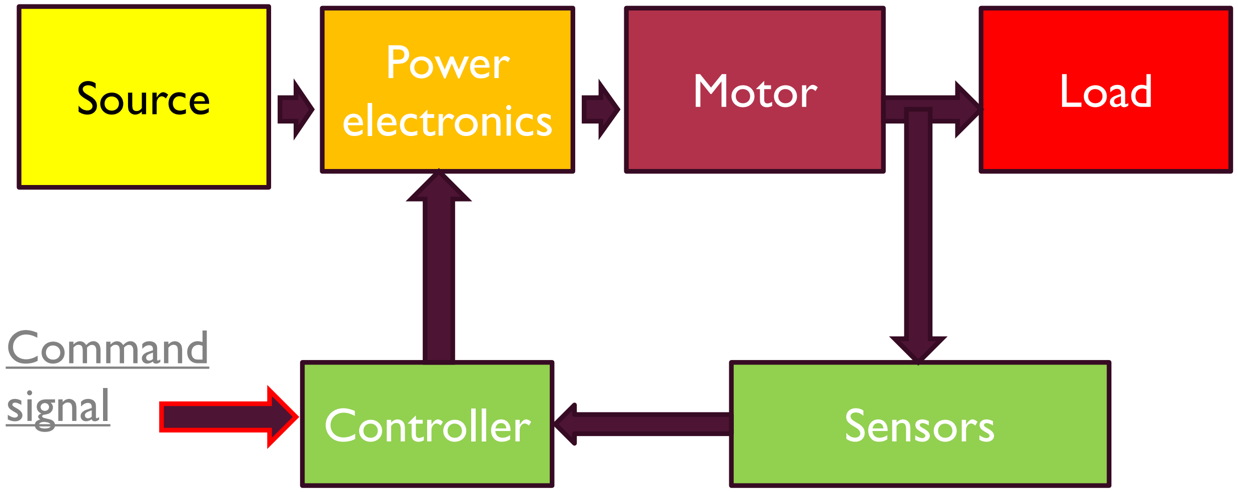
AGENDA

- **Motivation**
- **Integrating a novel education model (Tec21) with the industrial V model**
- **Course content (Models of electric motors, Power electronics and Control of motors)**
- **Student projects with real industry and quality of life relevance**
- **Conclusions**

WHY IS AN ELECTRIC DRIVE COURSE IMPORTANT FOR UNDERGRADUATE STUDENTS?

- *"Electric motors consume nearly 65% of energy produced in the USA"- R. Krishna- Electric motor drives*
- *Electric drives are fundamental components in manufacturing process, agriculture, electric vehicles, aeronautics, etc.*
- *Today, engineering students need to create solutions that increase the quality of life in rural or urban communities.*
- *Innovative ideas are essential, but designing prototypes based on those ideas generate products.*



Electric drive

HOW TO INSPIRE UNDERGRADUATE STUDENTS TO DEVELOP NOVEL IDEAS, VALIDATE THEM, AND MAKE PROTOTYPES

Challenges:

- There are low retention rates, and students lack knowledge in specific areas to solve complex problems.
- The students usually do not connect their courses with real-world problems.
- Cities need novel products to improve quality of life
- Real-world problems require complex thinking

Solutions:

- Give freedom to the students to propose new ideas to solve real-world problems (make mistakes)
- Teach students how to work in teams and individually (share and create ideas- self-study)
- Teach students how to write and give oral presentations (communication skills)
- Select the correct educational tools (software and hardware) that allow students to move from the theoretical knowledge to the experimental one in a friendly manner

TEC21 MODEL (TRANSVERSAL AND DISCIPLINARY COMPETENCES) AND V MODEL (INDUSTRIAL MODEL)

Students can tackle difficult problems using complex thinking

Tec21 model (Transversal and disciplinary competences)

V model

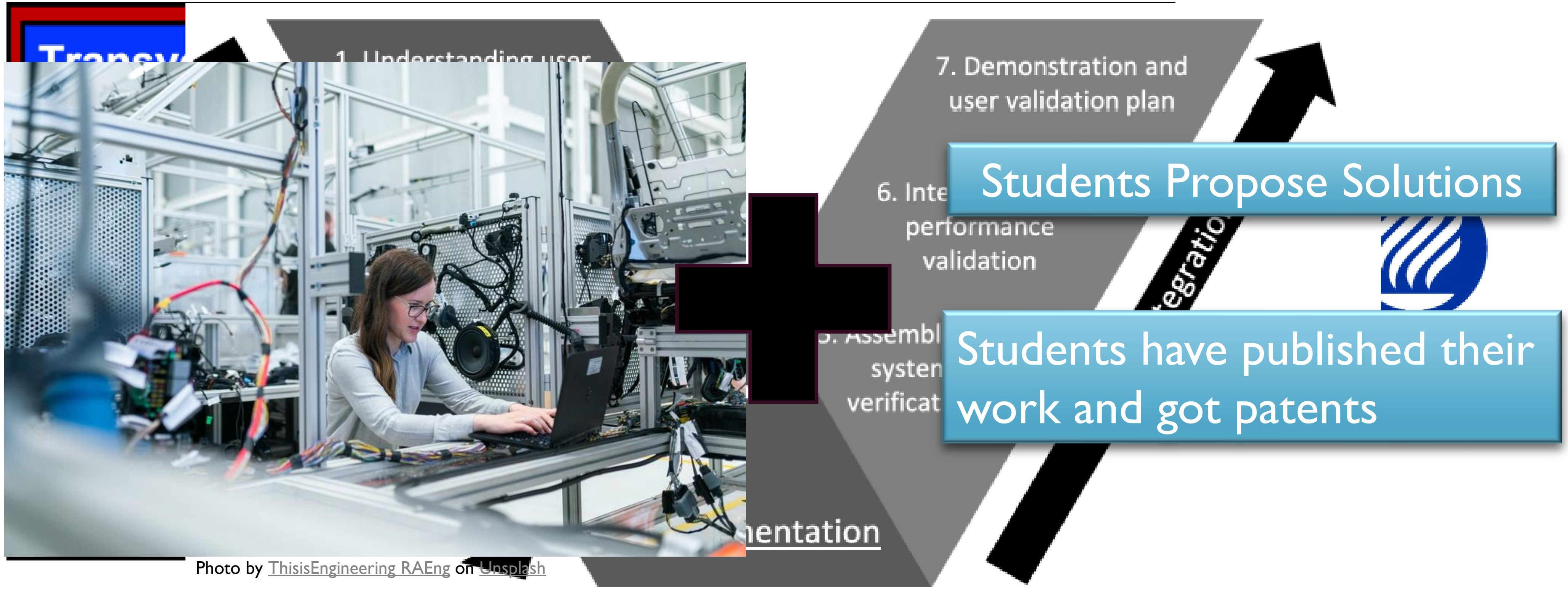
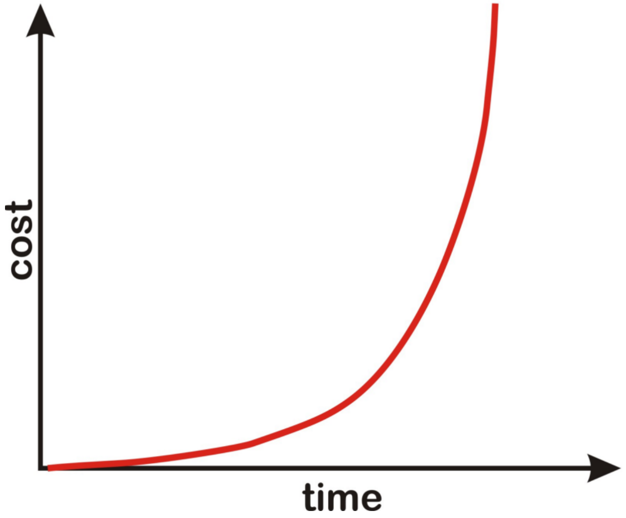


Photo by ThisisEngineering RAEng on Unsplash

WHEN IS THE CORRECT TIME FOR PROTOTYPING DURING CLASSES?

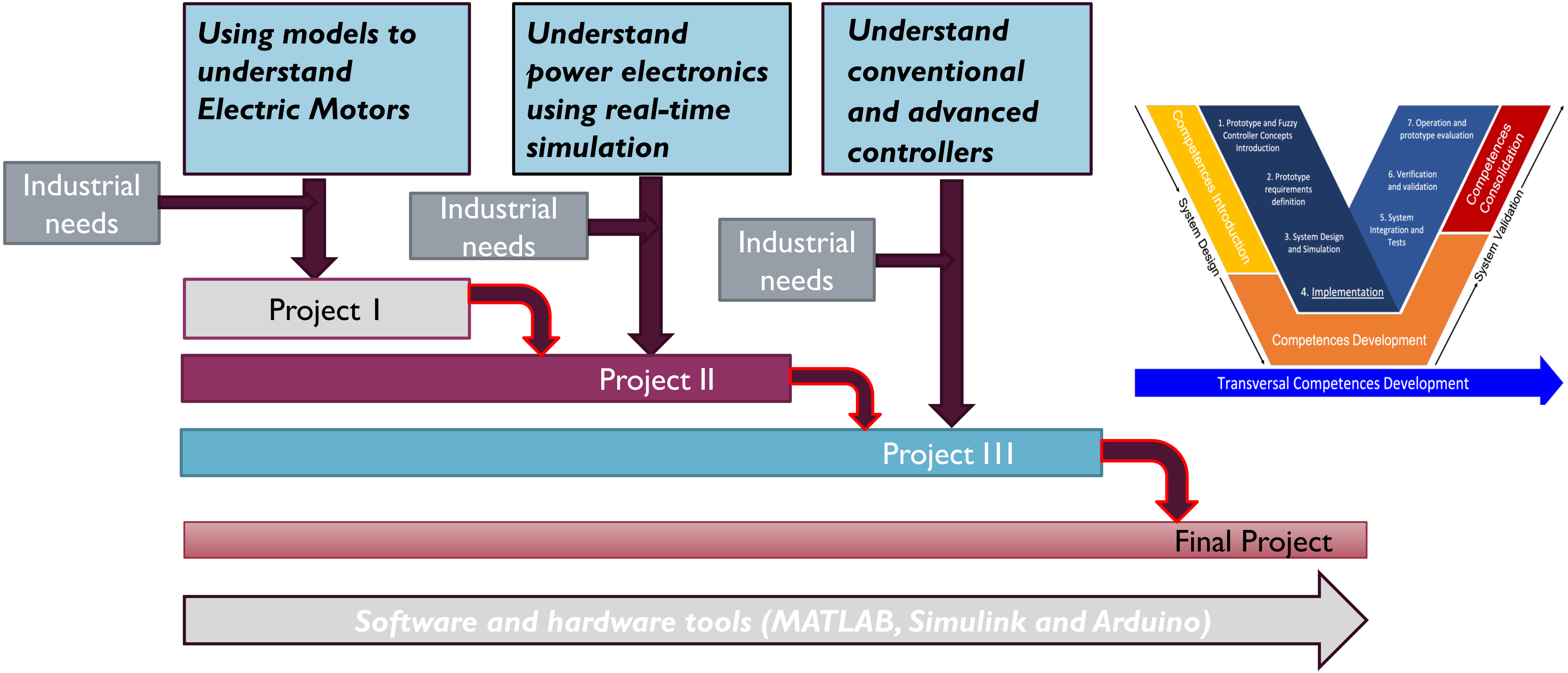


As soon as possible!

Photo by Jp Valery on Unsplash

When students have the suitable tools and knowledge, students can generate prototypes

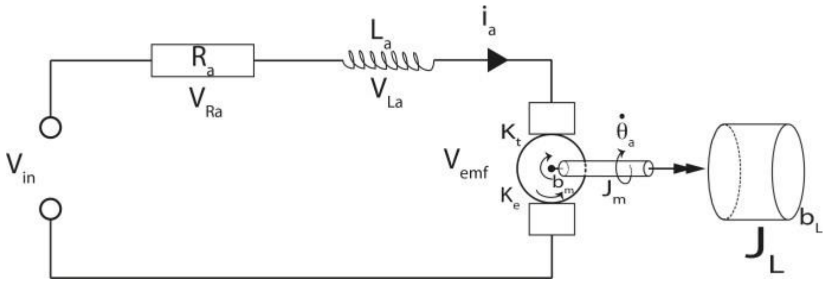
COURSE CONTENT



DC AND AC ELECTRIC MOTOR MODELS

Models represent real-world systems (an approach), so models are required to understand electric motors.

- **First-Principle Models**
- **Gray Models**
- **Black Box Models**



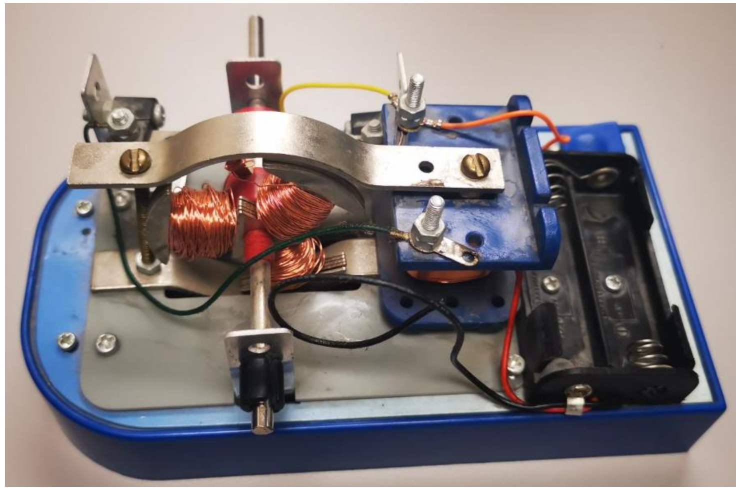
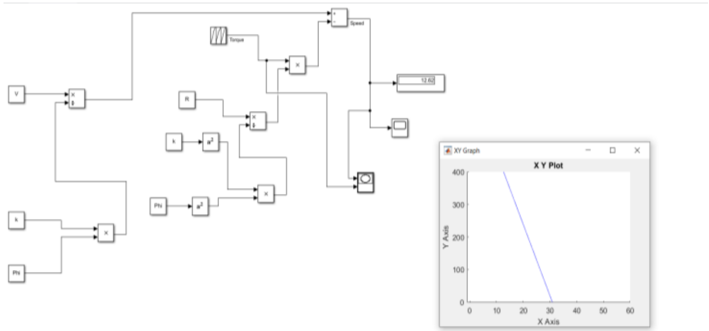


Photo by Mika Baumeister on Unsplash

CREATING A DIFFERENT WAY OF LEARNING DC AND AC MOTORS BY MODELS



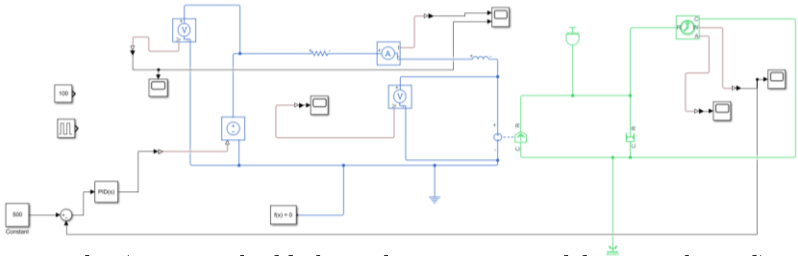
DC motor steady state and field weakling region in Simulation and laboratory (sensing armature and field parameters).

$$\frac{di_a(t)}{dt} = \frac{1}{L_a}e_a(t) - \frac{R_a}{L_a}i_a(t) - \frac{1}{L_a}e_b(t)$$

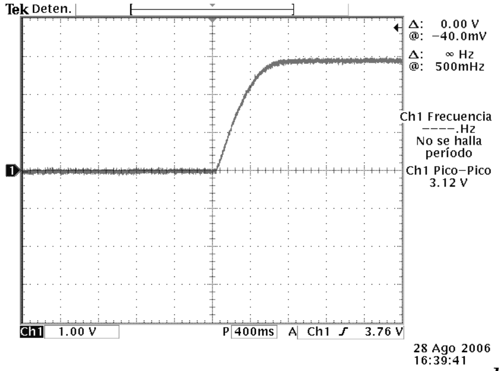
$$T_m(t) = K_i i_a(t)$$

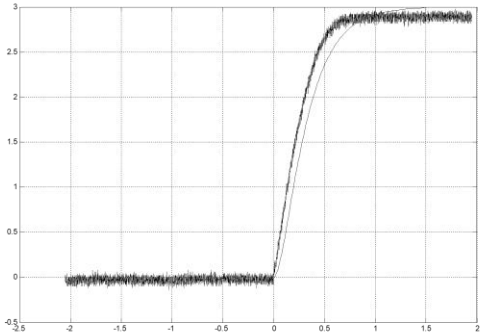
$$e_b(t) = K_b\frac{d\theta_m(t)}{dt} = K_b\omega_m(t)$$

$$\frac{d^2\theta_m(t)}{dt^2} = \frac{1}{J_m}T_m(t) - \frac{1}{J_m}T_L(t) - \frac{B_m}{J_m}\frac{d\theta_m(t)}{dt}$$



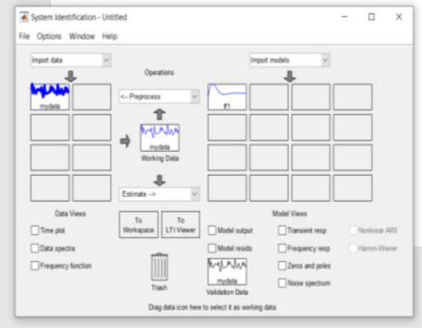
First principles (Simscape-build physical component models using physical)



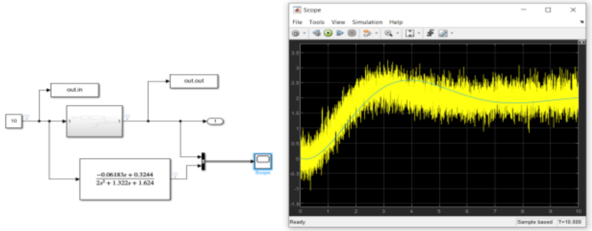


$$Y(s) = \frac{k}{s(s+p_1)(s+p_2)} = \frac{A}{s} + \frac{B}{s+p_1} + \frac{C}{s+p_2}$$

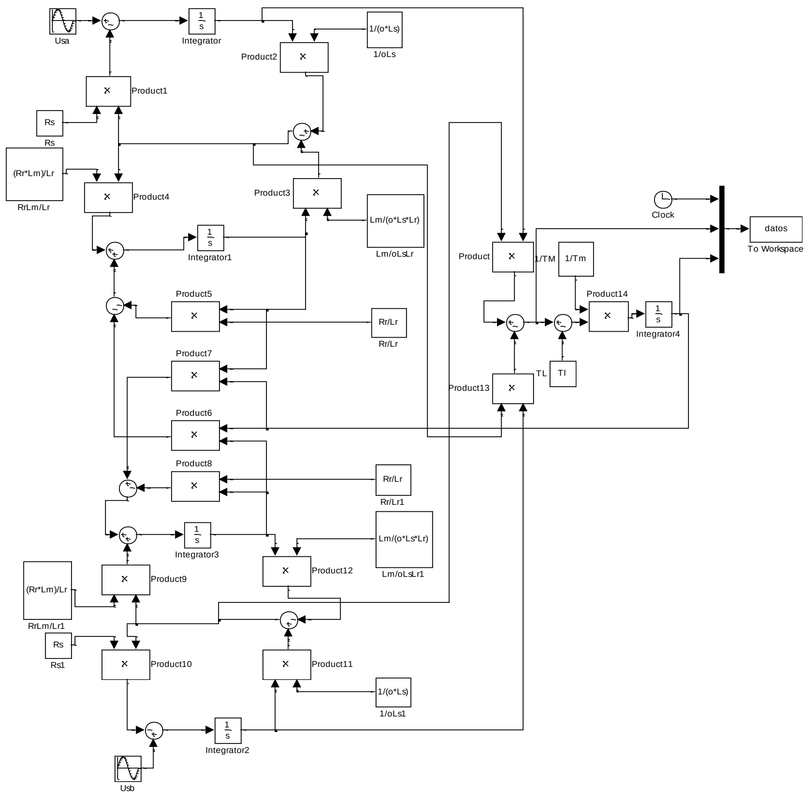
Black box model for a DC motor based on second order transfer function. (a) experimental speed response, (b) Transfer function approximation

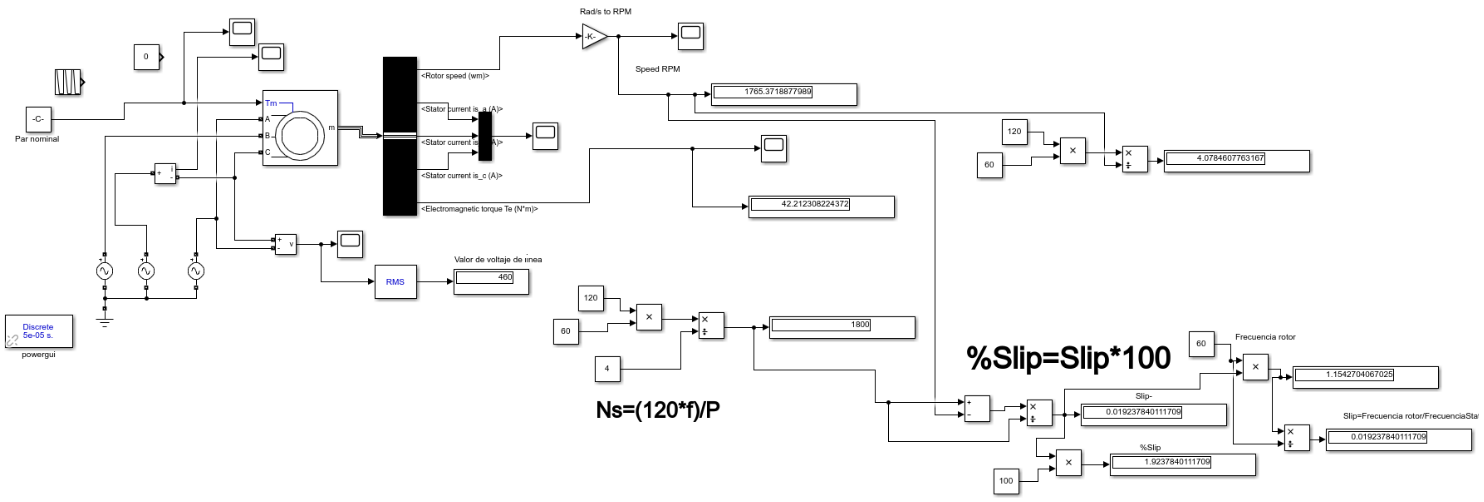


System Identification Toolbox



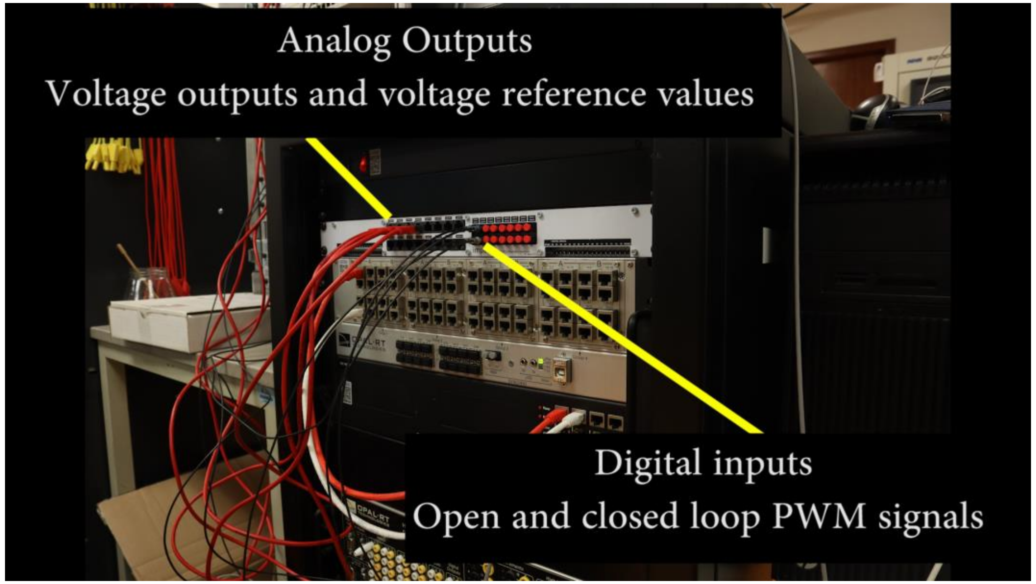
DYNAMIC MODEL OF AN INDUCTION MOTOR

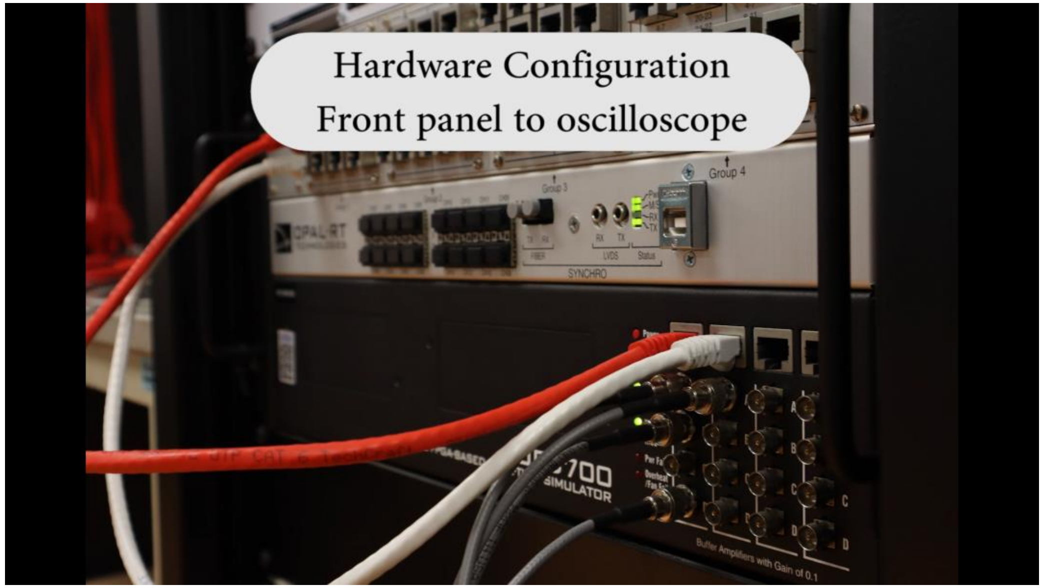




Simulink / block diagram of an AC induction motor ⟷ **Simscape** / block diagram

REAL TIME SIMULATION- "**REAL-TIME SIMULATION** REFERS TO A COMPUTER MODEL OF A PHYSICAL SYSTEM THAT CAN EXECUTE AT THE SAME RATE AS ACTUAL WALL CLOCK TIME" (WIKIPEDIA).

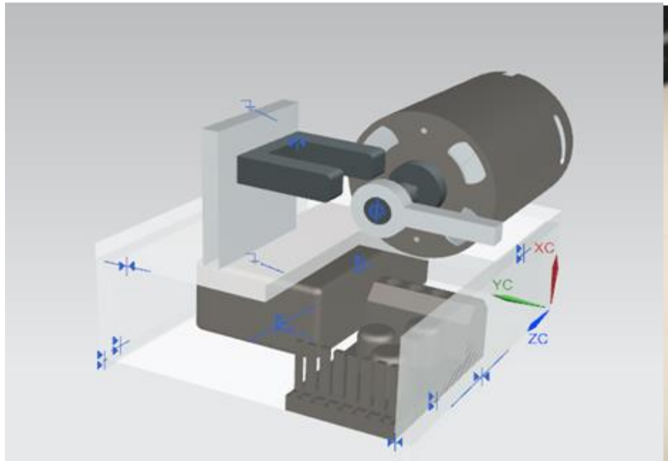


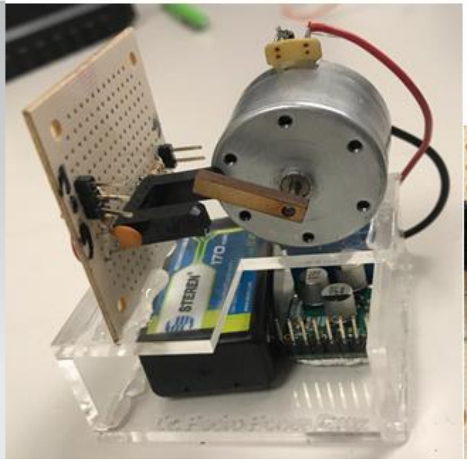
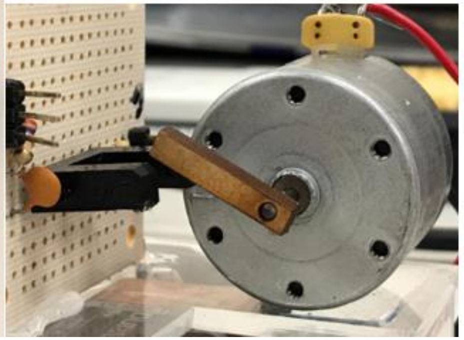


DC-DC Converter

DC-AC Inverter

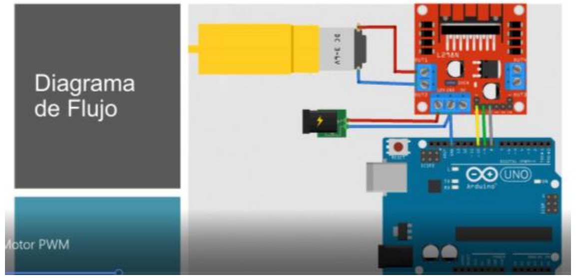
DC MOTOR WITH A BASIC SPEED SENSOR FOR TEACHING ESSENTIAL OPERATION OF SENSORS AND CLOSED-LOOP SPEED CONTROLLERS

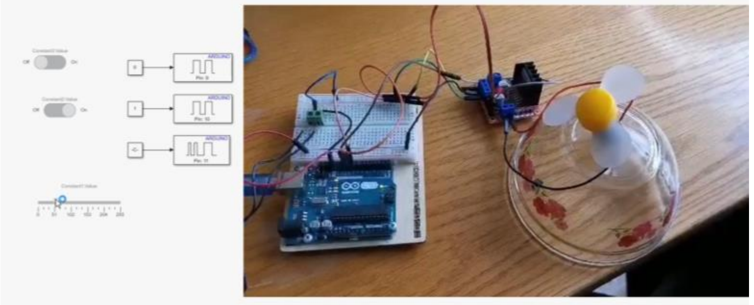


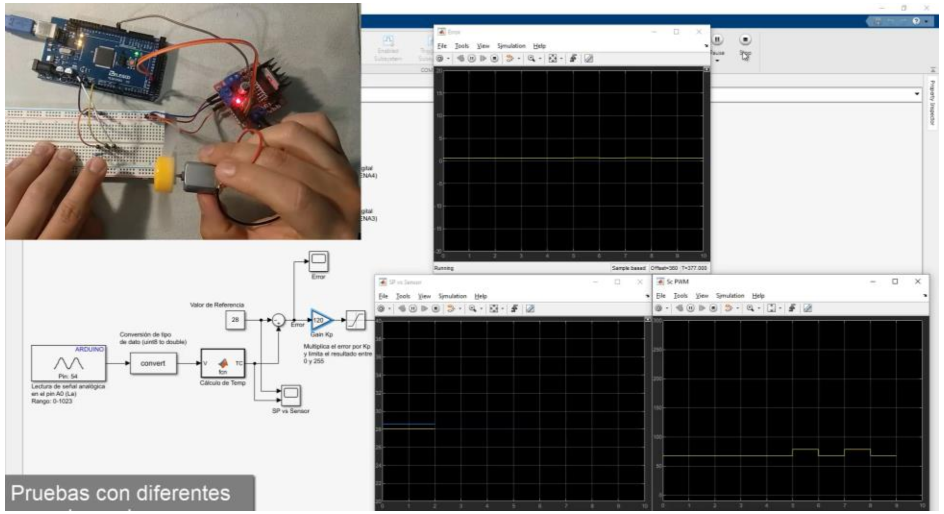

DC motor with a basic speed sensor for teaching basic operation of sensors and close-loop speed controllers

DC MOTOR CONTROL –OPEN-LOOP AND CLOSED LOOP COURSE MATERIAL

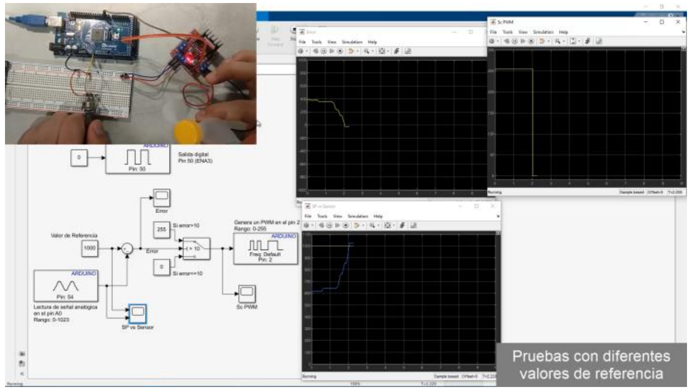


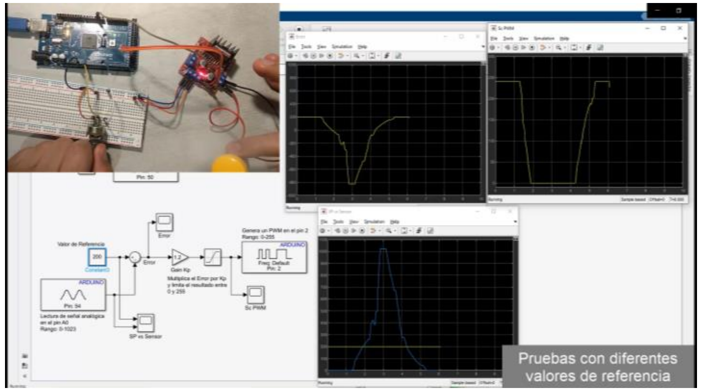


Simulink, DC Motor, Power Electronics and Arduino

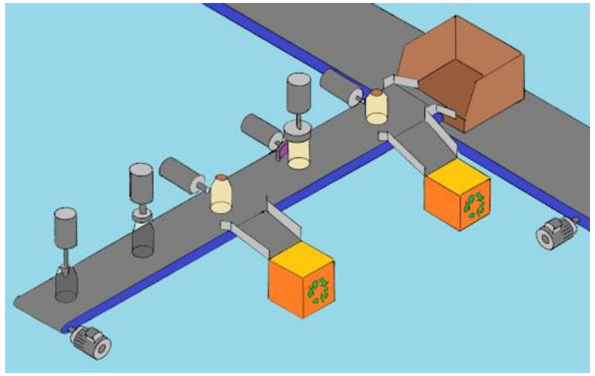


Simulink and Arduino
PWM/ ON-OFF Controller/ PID Controllers



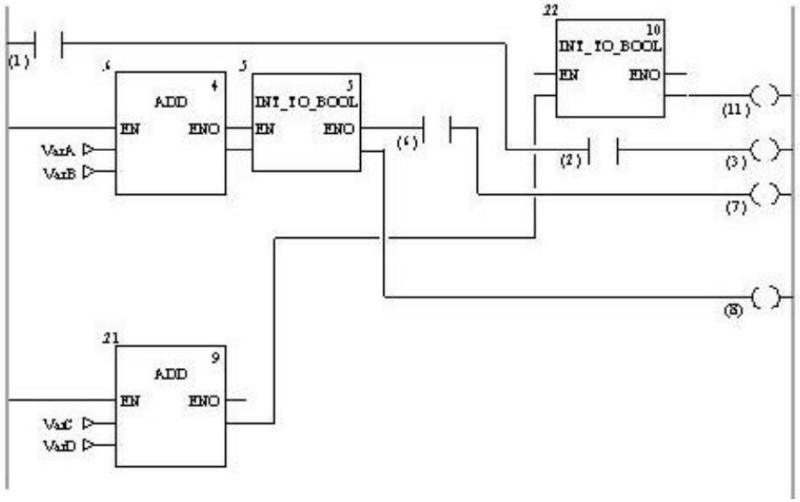


PRIMARY CONTROLLERS IN THE INDUSTRY SEQUENTIAL PROGRAMMING INTO A MANUFACTURING LINE (INDUSTRIAL NEEDS)

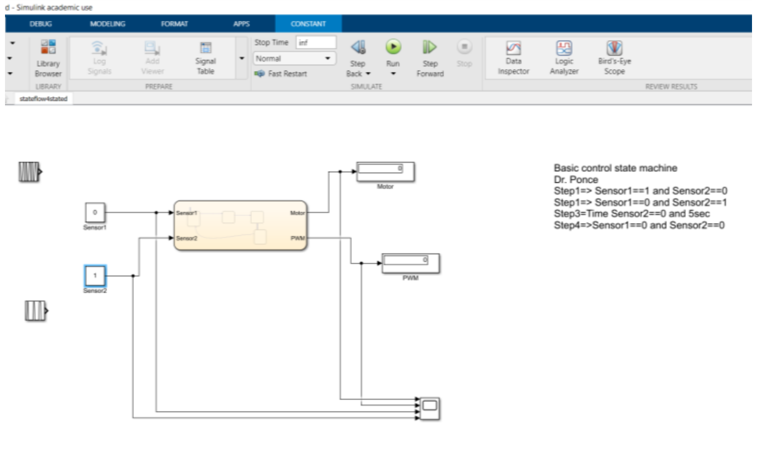


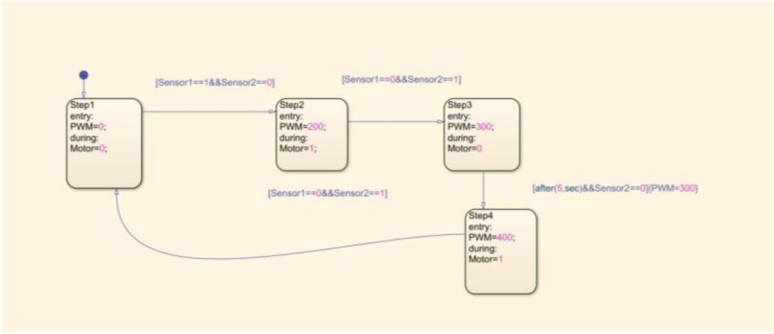
http://wikifab.dimf.etsii.upm.es/wikifab/index.php/8032_Proyecto_de_Automatización_B%C3%A1sica

Example of the Execution Sequence of Objects in an LD Section:



PLC-LADDER SCHNEIDER





Industrial Problems (Satet Machines)

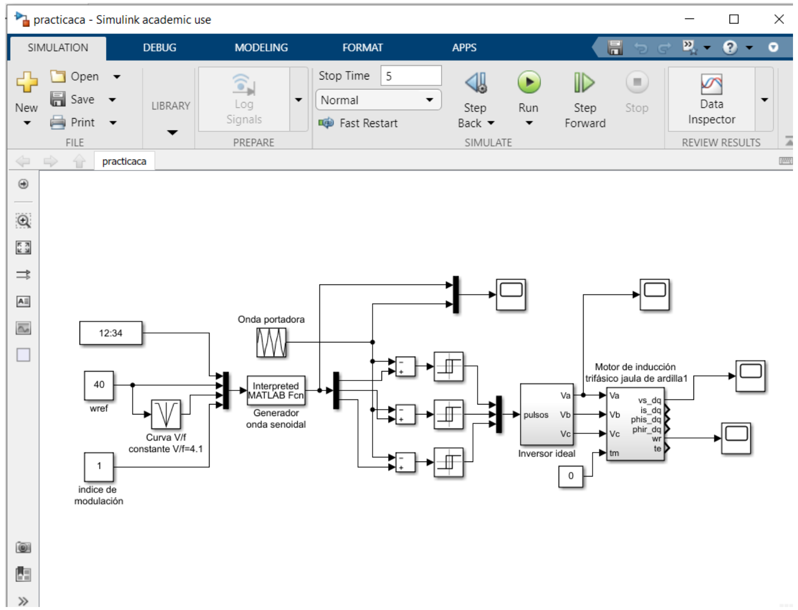
A conveyor system moves materials from one location to another (save time and energy)

Stateflow

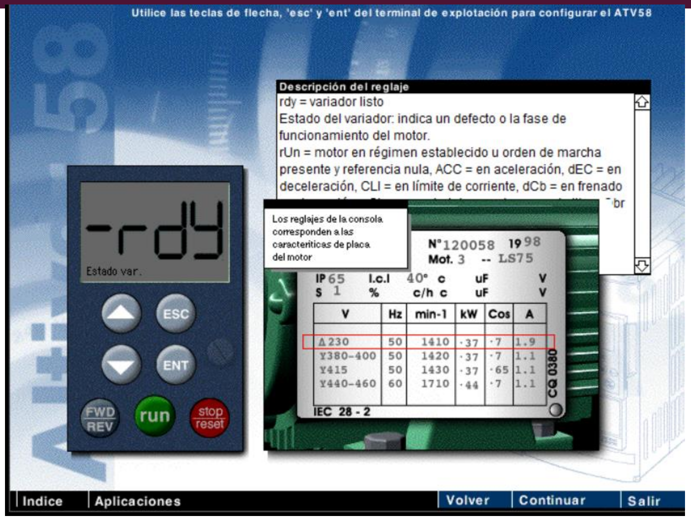
Model using state machines

Students' solutions

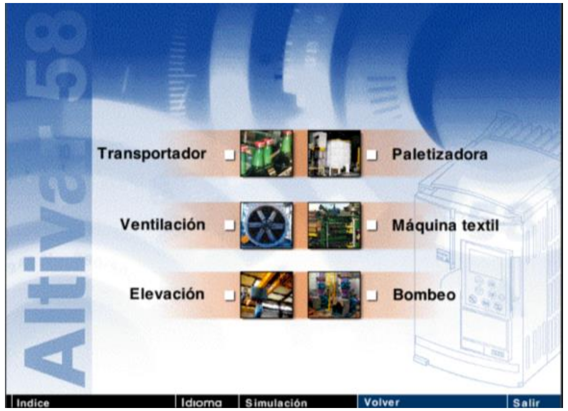
AN INDUSTRIAL CONTROLLER CONNECTED WITH SIMULATION (V/F SCALAR CONTROL FOR AC MOTOR) INDUSTRIAL NEEDS

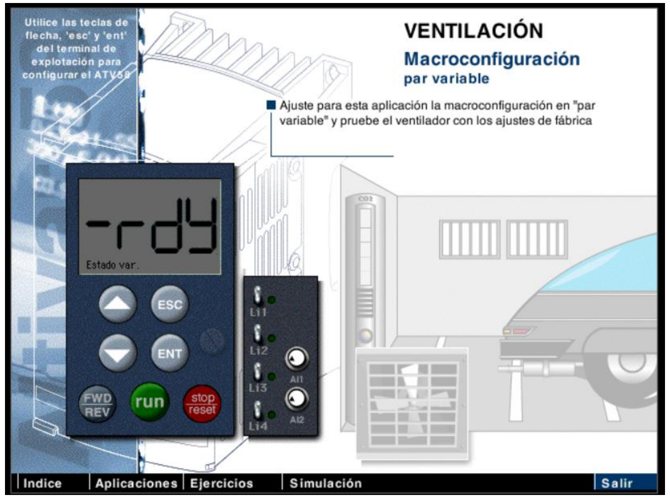


Simulink block diagram

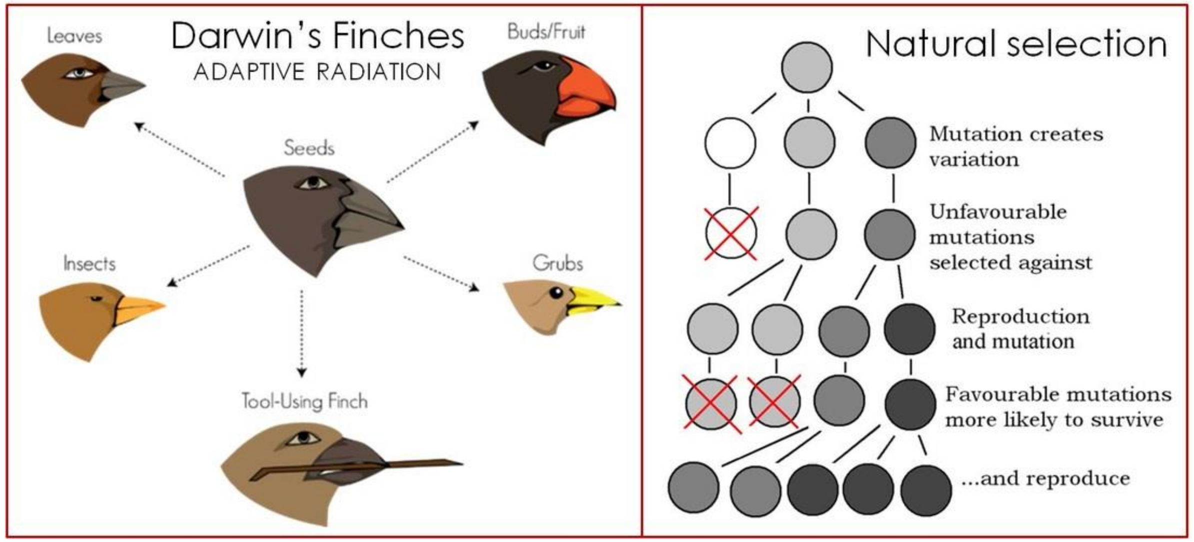


ALTIVAR-58
Schneider
Electric

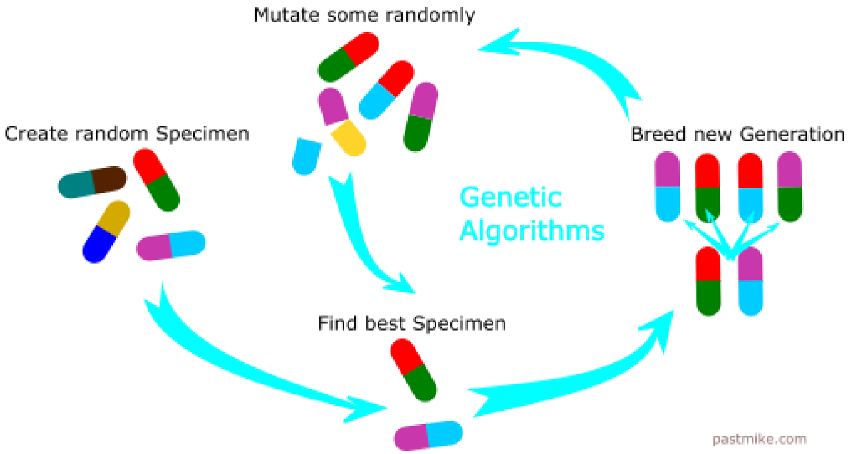




TUNING A CONVENTIONAL SPEED CONTROLLER BY GENETIC ALGORITHMS

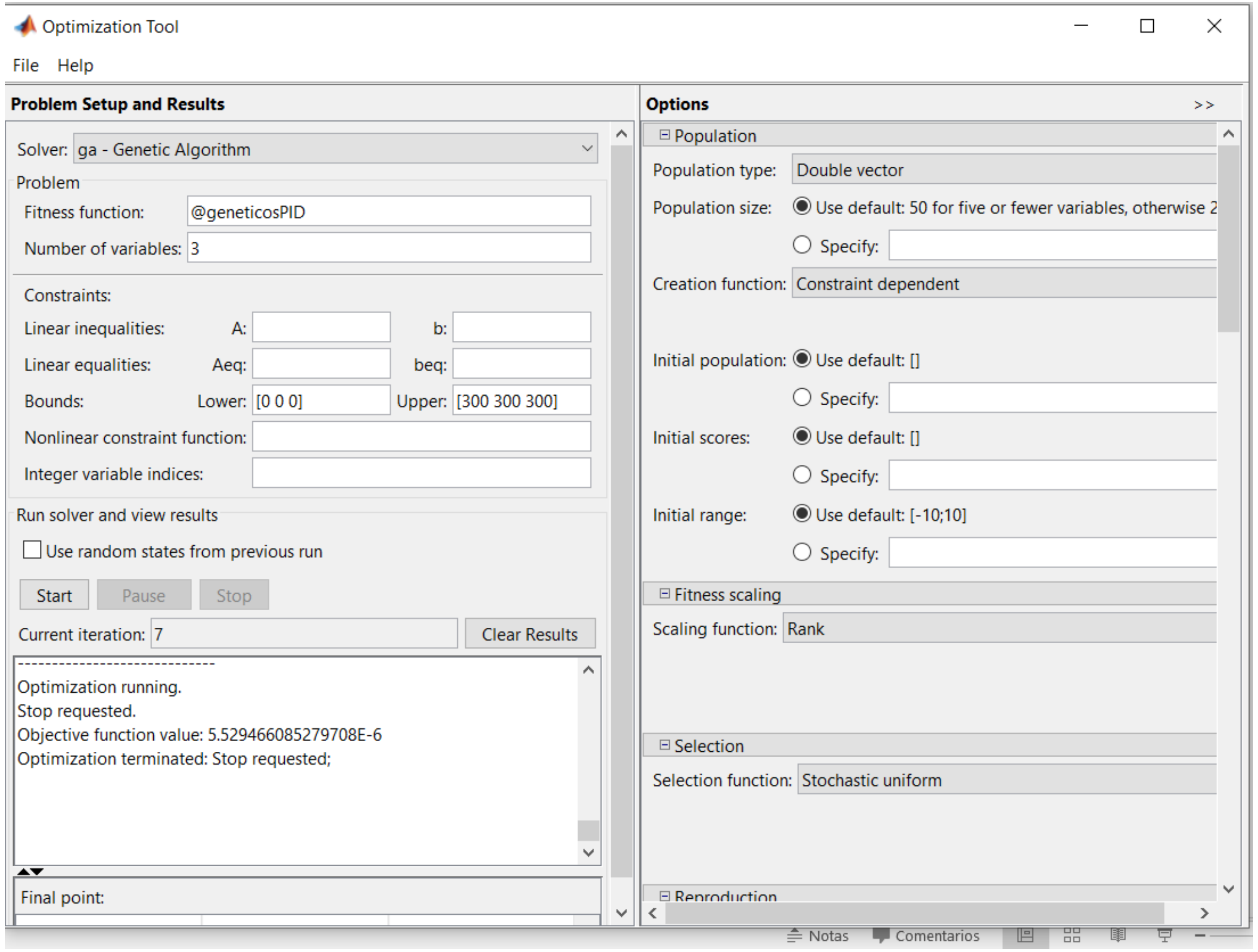


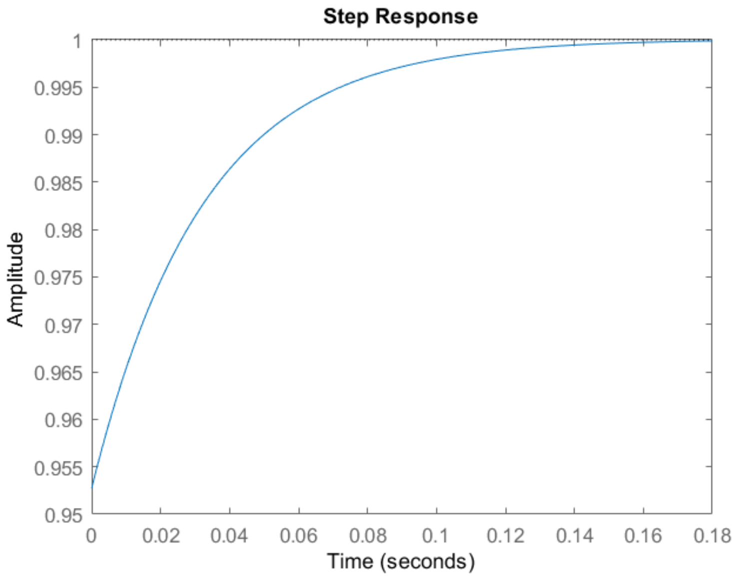
http://loretocollegebiology.weebly.com/evolution--natural-selection.html



https://pastmike.com/what-is-a-genetic-algorithm/

GENETIC ALGORITHM SOLVER (OPTIMIZATION TOOL)

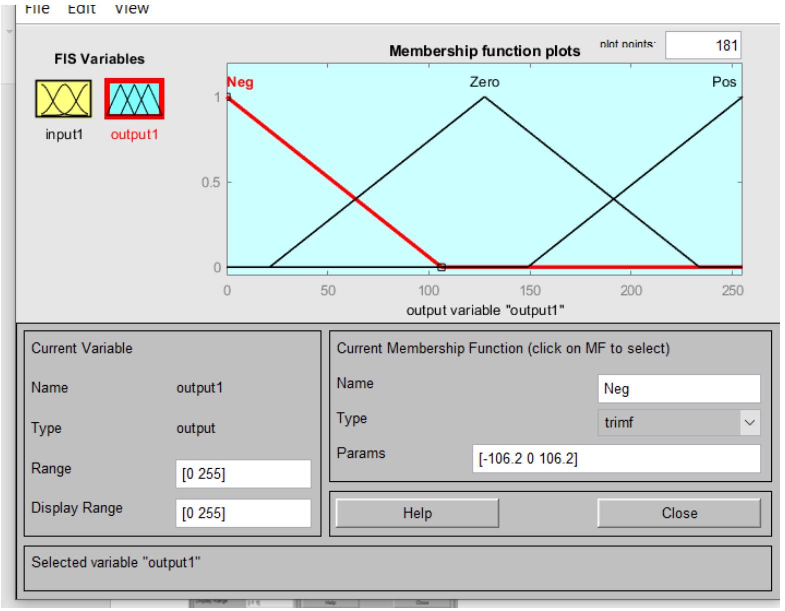


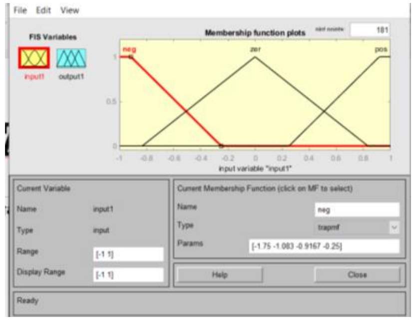


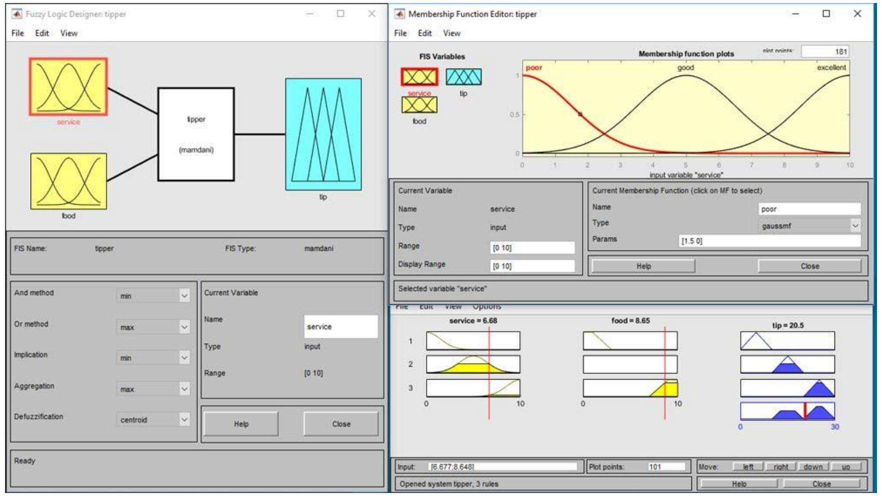
FUZZY LOGIC TOOLBOX

Fuzzy Logic:

“Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true". Wikipedia:

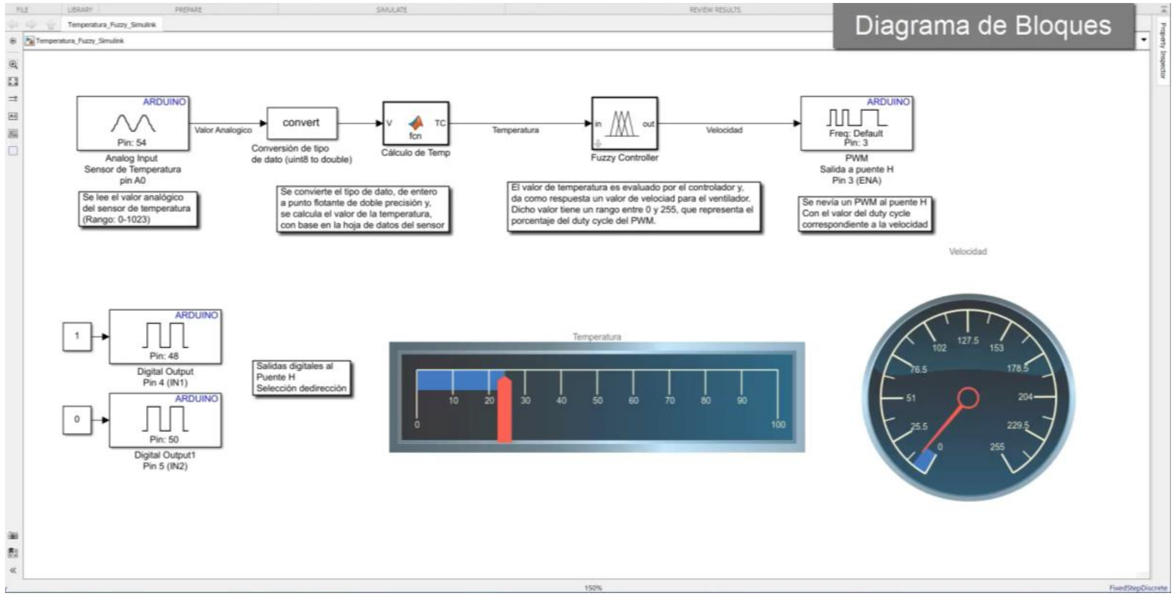


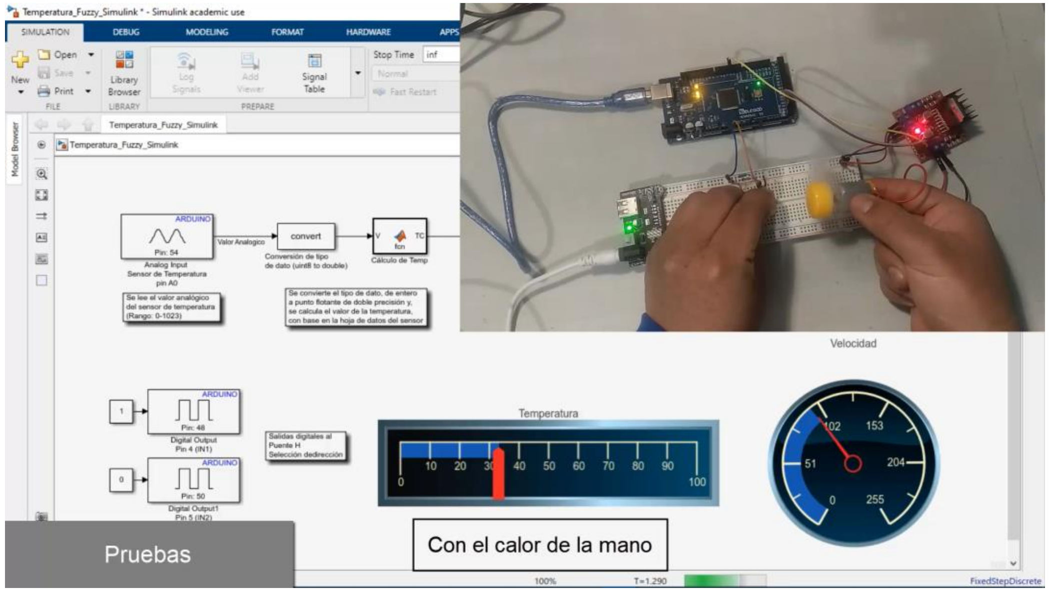




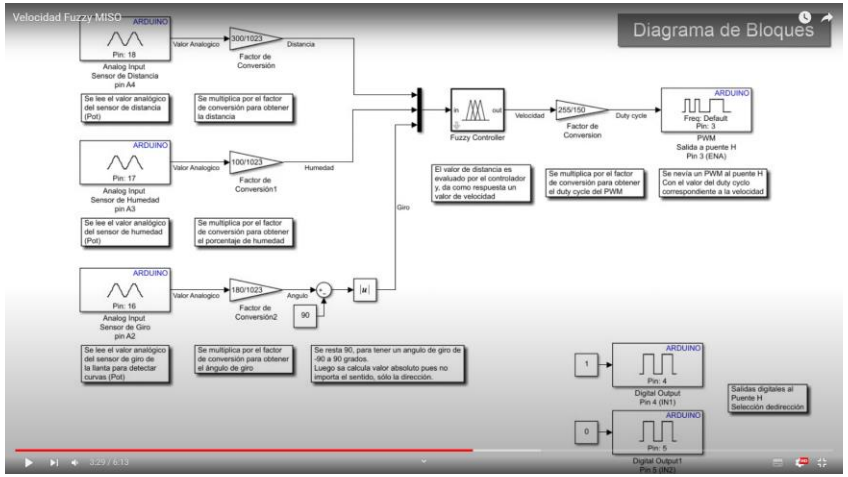
https://www.mathworks.com/products/fuzzy-logic.html#

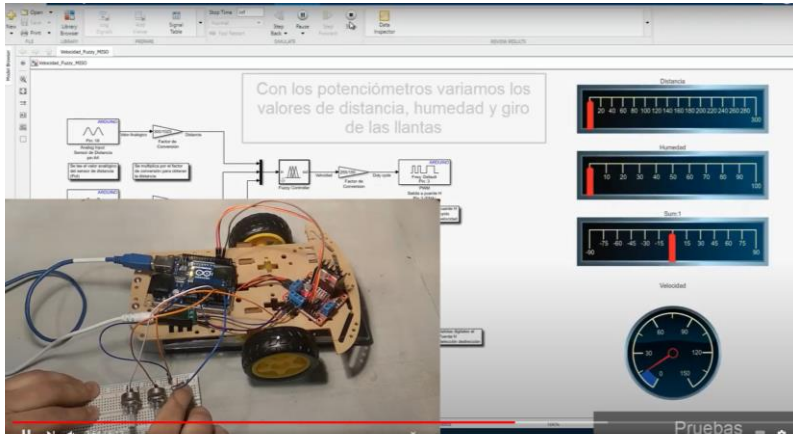
FUZZY LOGIC CONTROLLER – (TEMPERATURE CONTROLLER)

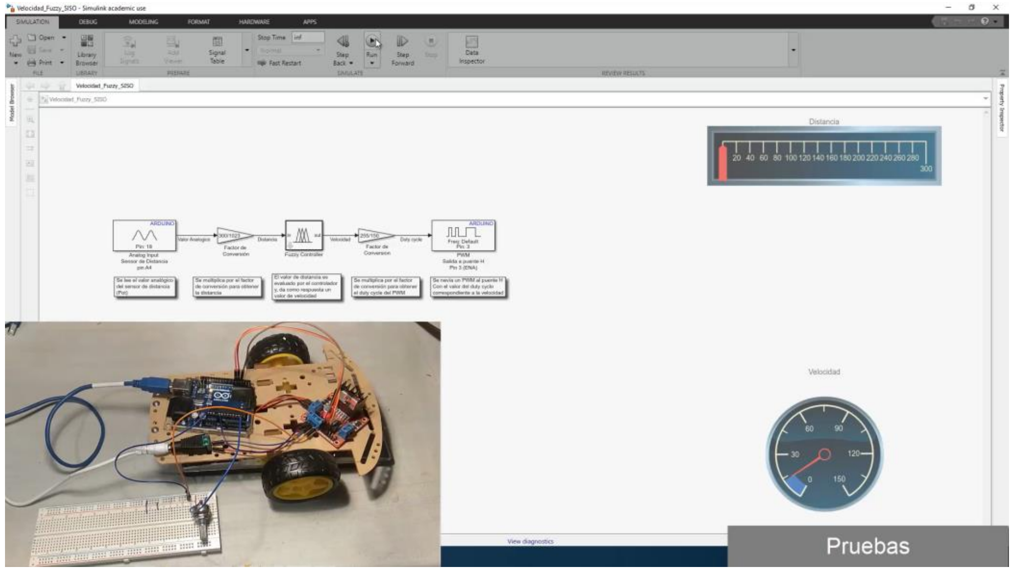




FUZZY LOGIC TYPE 1 AND 2- (MISO AND MIMO)



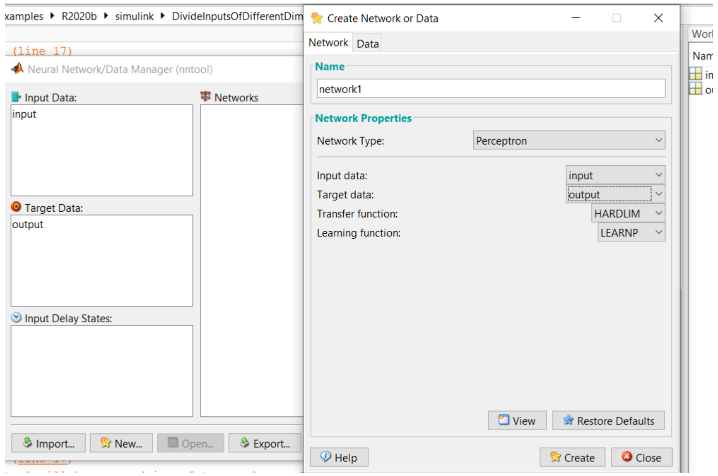


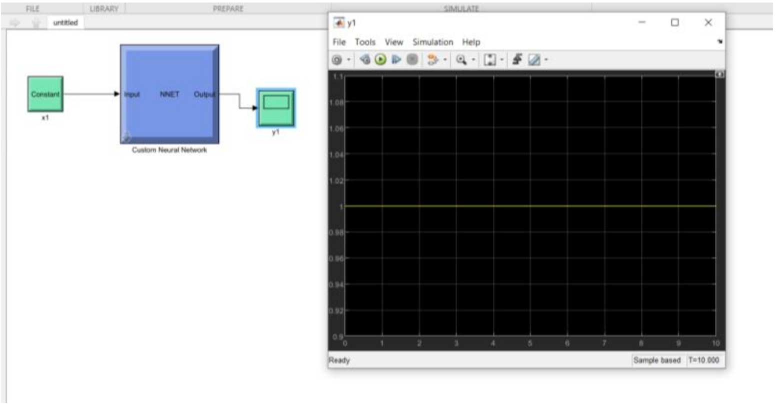


MATLAB DEEP LEARNING TOOLBOX

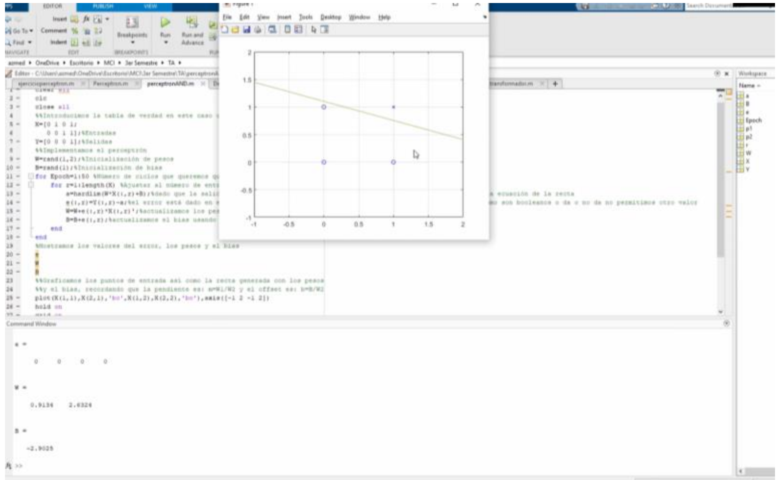
Neural Networks:

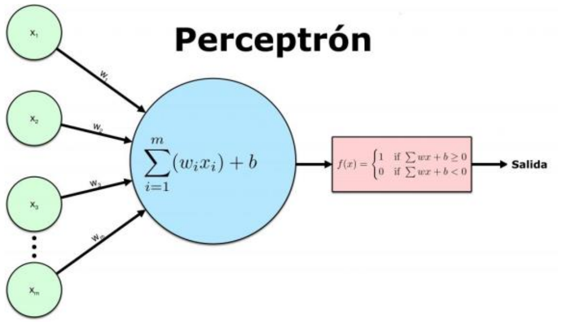
"A **neural network** is a network or circuit of biological neurons, or in a modern sense, an artificial neural network, composed of artificial neurons or nodes". Wikipedia.



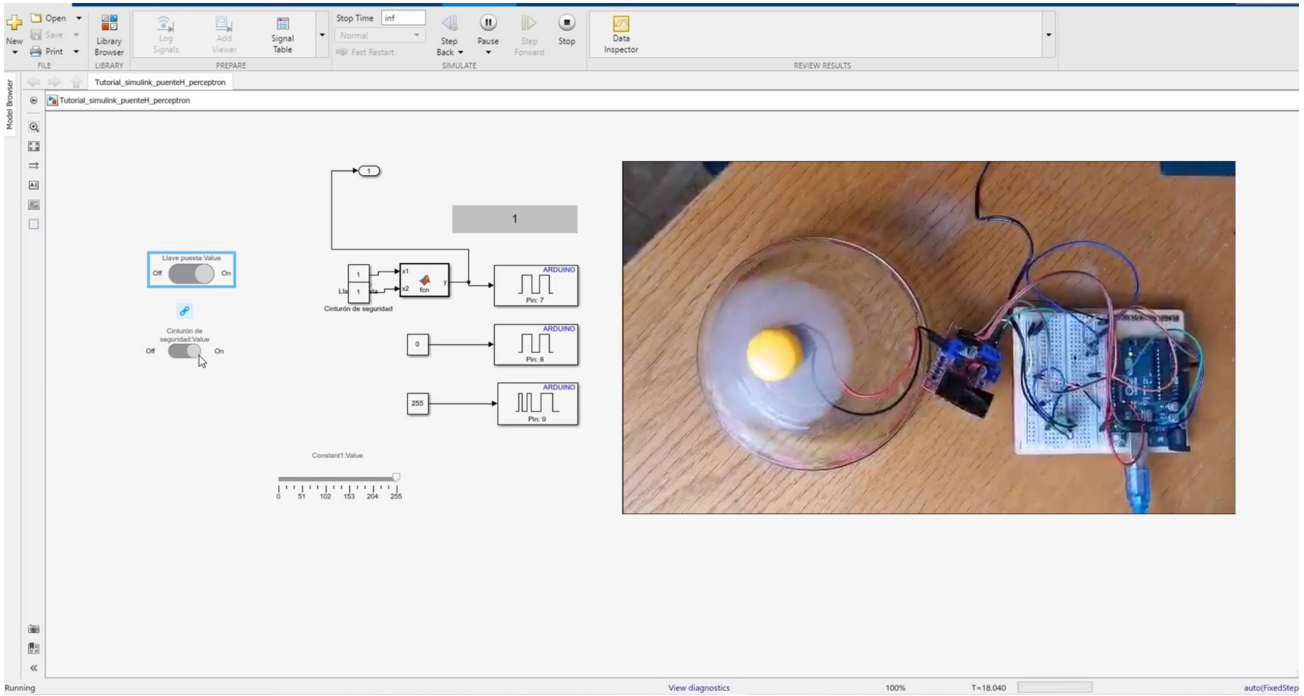


THE ESSENTIAL ELEMENT, THE PERCEPTRON, PROGRAMMED IN *MATLAB* THEN MOVED TO Simulink-Arduino

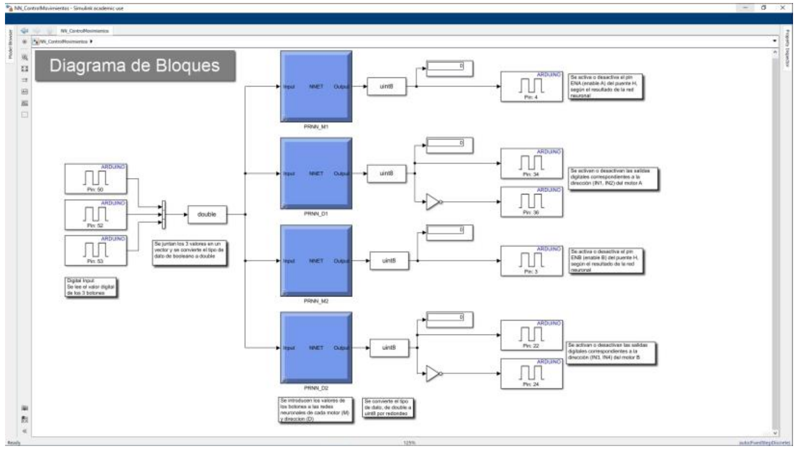


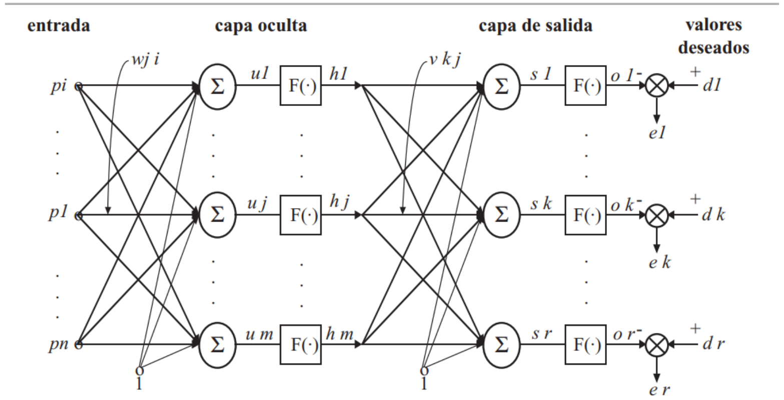


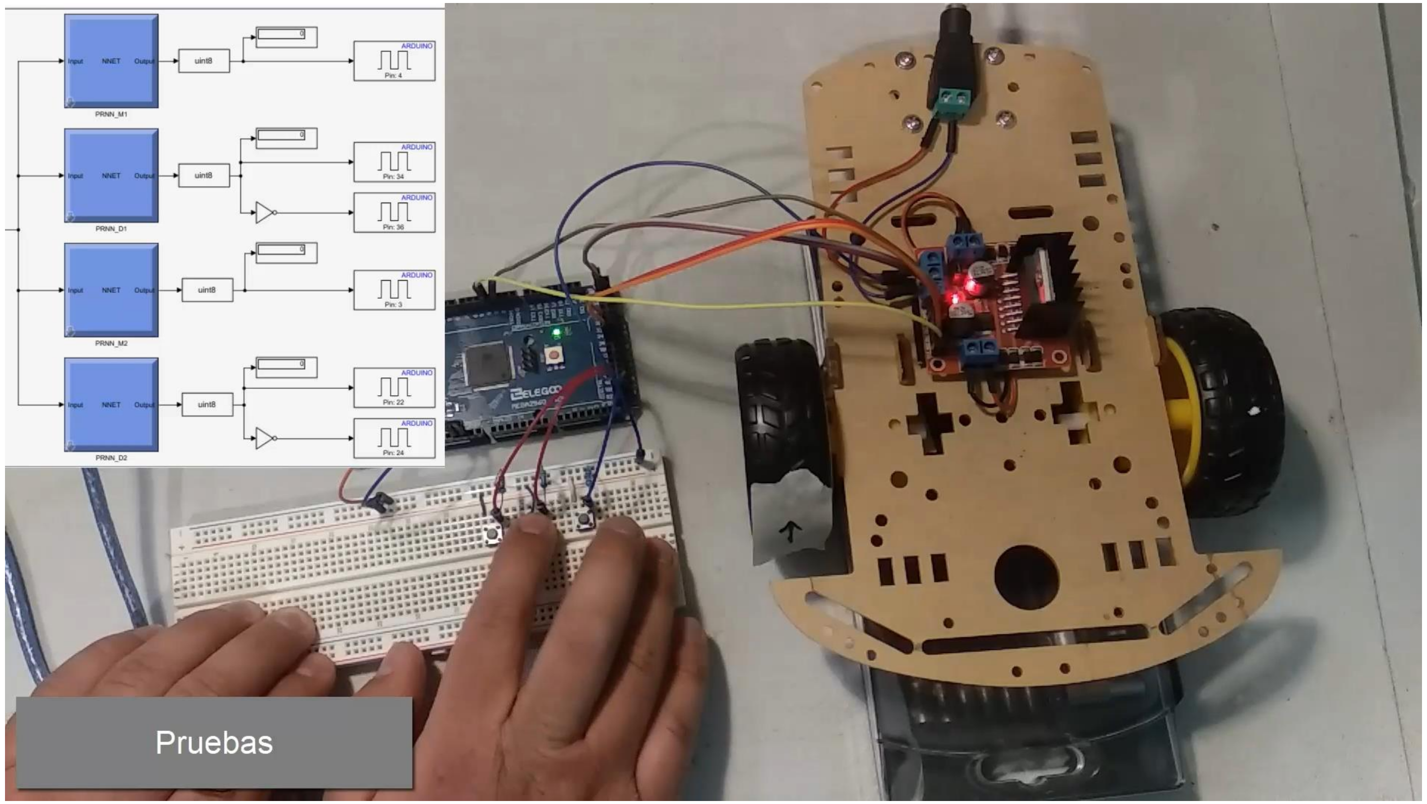
http://blog.josemarianoalvarez.com/2018/06/10/el-perceptron-como-neurona-artificial/



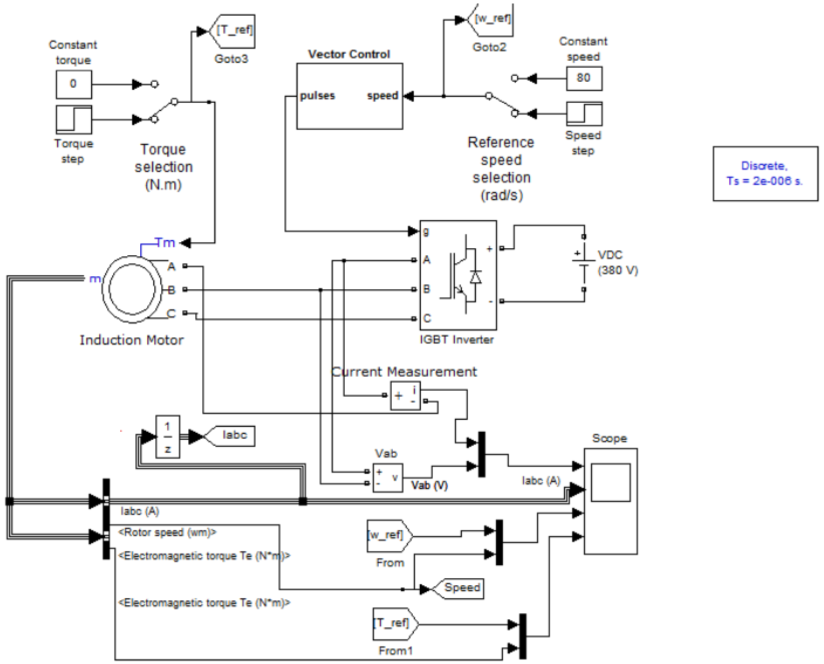
A MULTILAYER STRUCTURE FOR CONTROLLING A PROTOTYPE OF AN ELECTRIC CAR



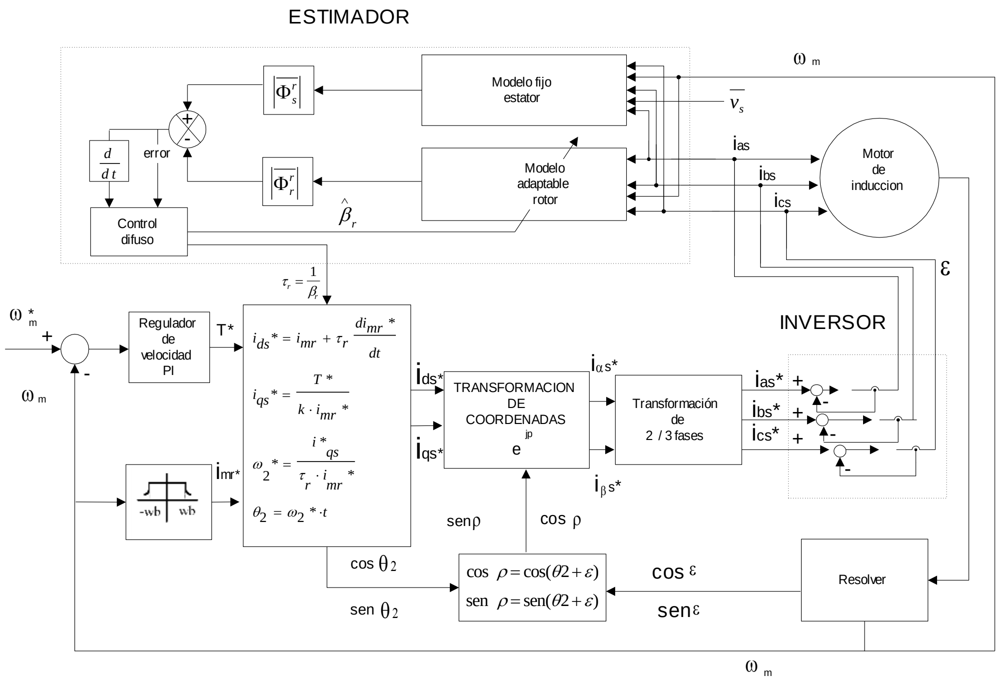




VECTOR CONTROL OF INDUCTION MOTORS

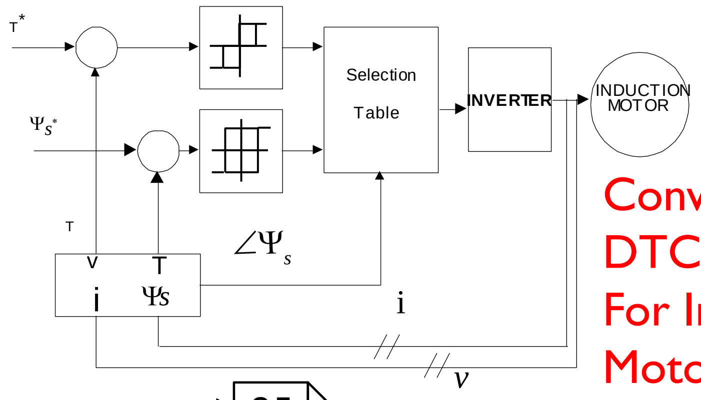


Conventional Vector Control
Structure For Induction Motors

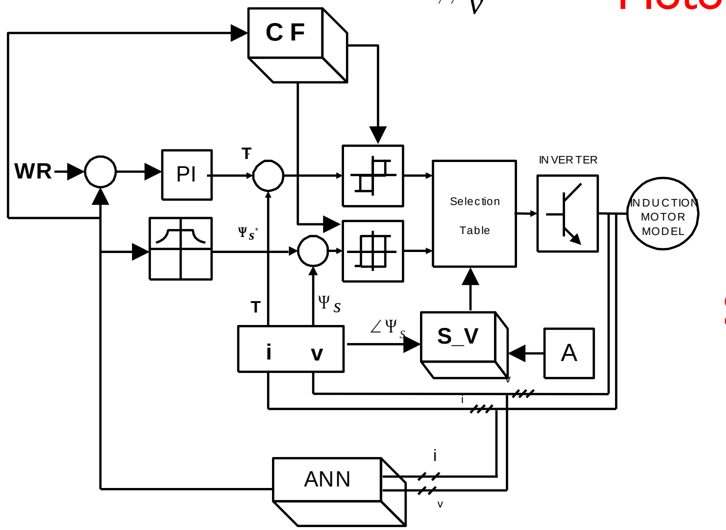


Proposed Vector Control
Structure For Induction Motors

DIRECT TORQUE CONTROL OF INDUCTION MOTORS



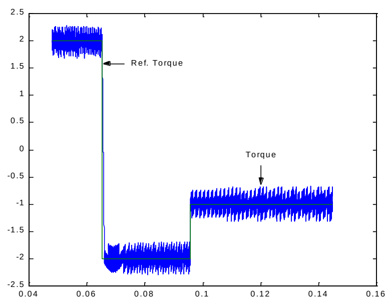
Conventional DTC Structure For Induction Motors

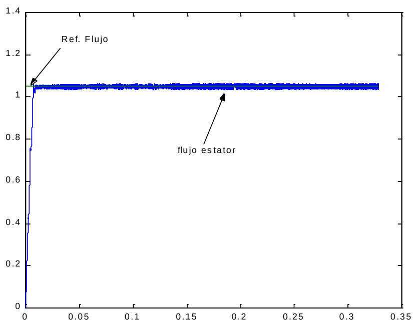


Proposed DTC Structure For Induction Motors

$$T = \frac{3}{2} P \frac{L_m}{L_S L_R} \left|\overline{\psi_R}'\right| \left|\overline{\psi_S}\right| \operatorname{sen}\gamma$$

$$\overline{\psi}_s = \int (\overline{v}_s - \overline{i}_s R_s)$$





$$v_{sd} = R_S i_{sd} + \dot{\psi}_{sd} - \omega_S \psi_{sq}$$

$$v_{sq} = R_S i_{sq} + \dot{\psi}_{sq} + \omega_S \psi_{sd}$$

$$0 = R_r i_{rd} + \dot{\psi}_{rd} - \omega_{slip} \psi_{rq}$$

$$0 = R_r i_{rq} + \dot{\psi}_{rq} + \omega_{slip} \psi_{rd}$$

$$\psi_{sd} = L_S i_{sd} + L_m i_{rd}$$

$$\psi_{sq} = L_S i_{sq} + L_m i_{rq}$$

$$\psi_{rd} = L_r i_{rd} + L_m i_{sd}$$

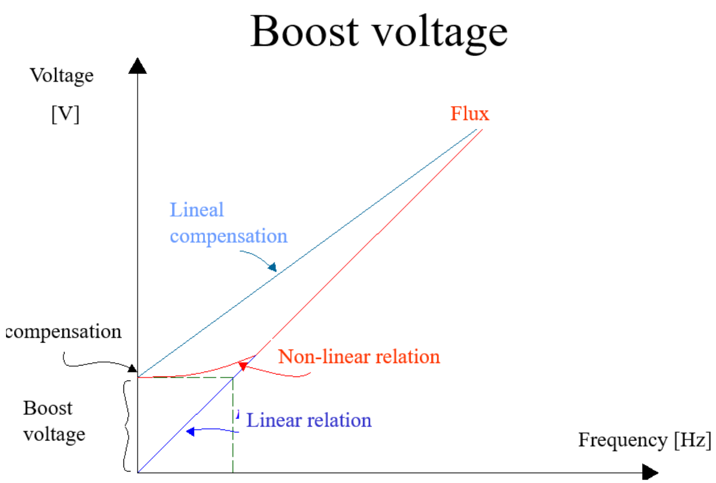
$$\psi_{rq} = L_r i_{rq} + L_m i_{sq}$$

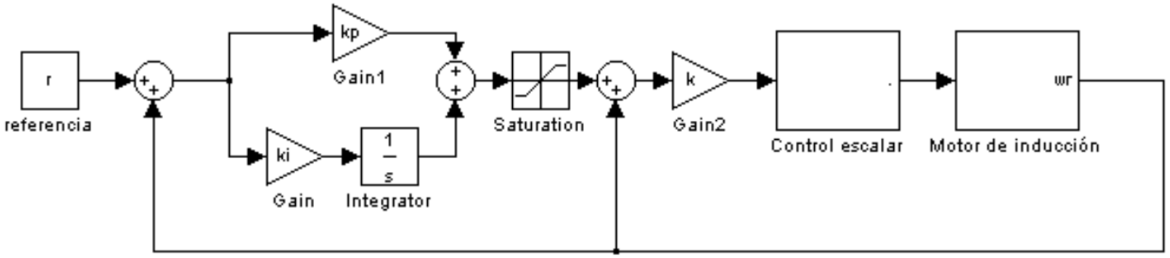
$$T = \frac{3}{2} p \left(\psi_{sd} i_{sq} - \psi_{sq} i_{sd}\right)$$

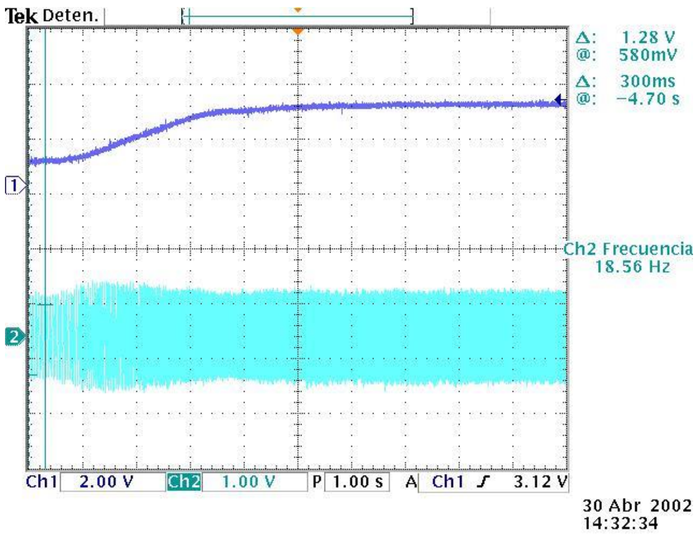
$$\omega_S = \omega_{slip} + \omega_r$$

INDUSTRIAL NEEDS: THE TROLLEY POLE CONTROL TOPOLOGY IN MEXICO CITY

Scalar control is based on the steady-state model of the motor.



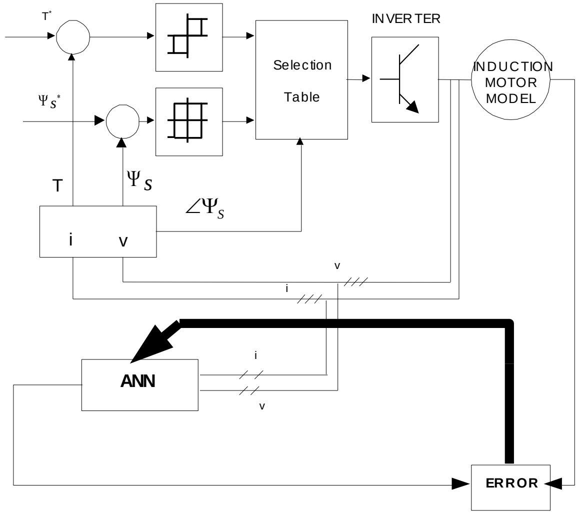


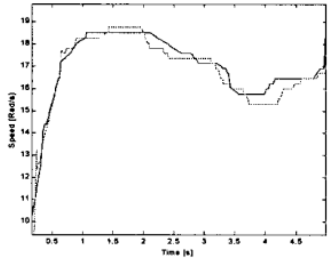


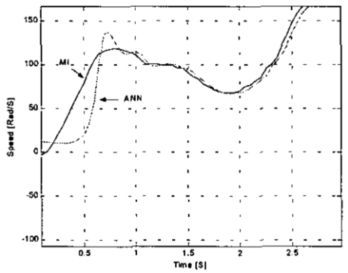
https://lasillarota.com/metropoli/del-auge-a-la-decadencia-trolebus-en-cdmx/254027

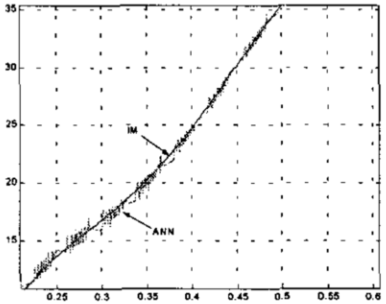
Some projects developed at Tecnologico de Monterrey, Mexico, Based on Electric Drives

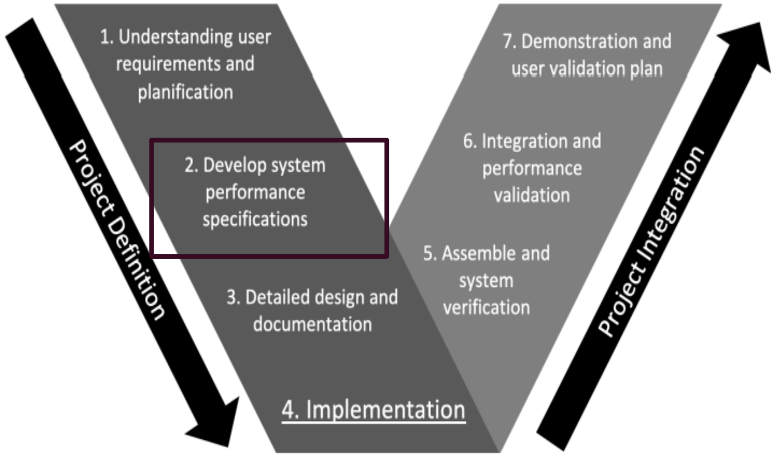
USING ARTIFICIAL NEURAL NETWORKS IN THE INDUCTION MOTOR DTC SCHEME





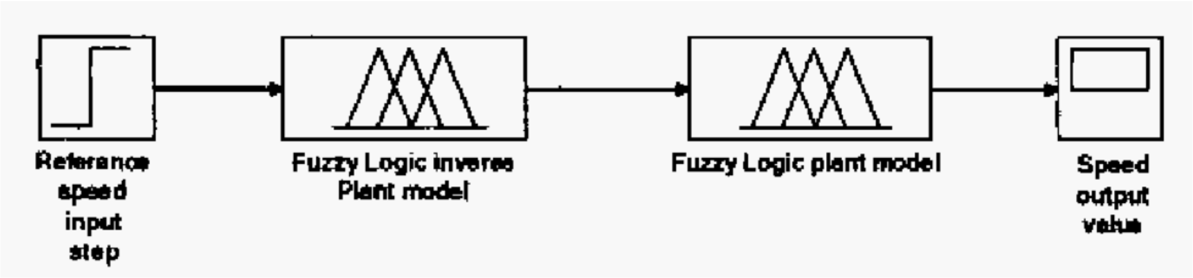


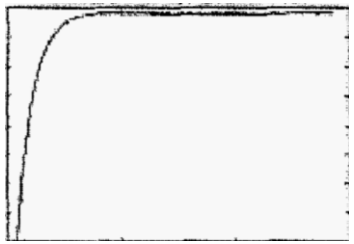


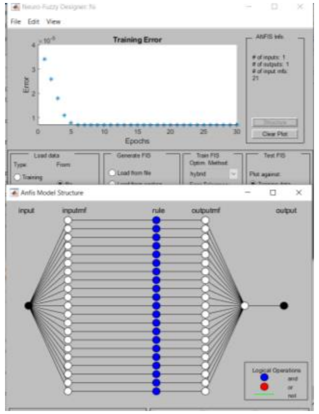


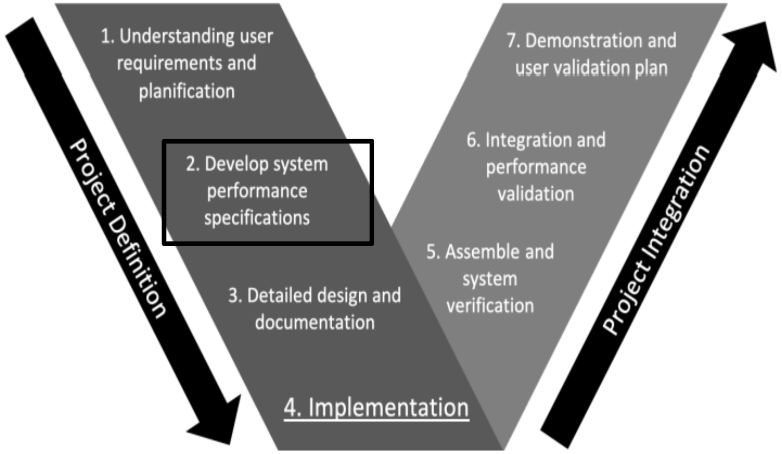
P. Ponce, D. M. Aguilar and A. Monroy, "Using artificial neural networks in the induction motor DTC scheme," *IEEE*

A NOVEL DC DRIVE BASED ON FUZZY LOGIC INVERSE PLANT MODEL OPTIMISED BY ANFIS.









Ponce, P., Blancas, R., Tena, C., & Rana, M. (2004, December). A novel DC drive based on fuzzy logic inverse plant model optimised by ANFIS. In *2004 IEEE International Conference on Industrial Technology*.

REINFORCEMENT LEARNING-DESIGN AND CONTROL OF AN ACTIVE AERODYNAMIC CAR SPOILER

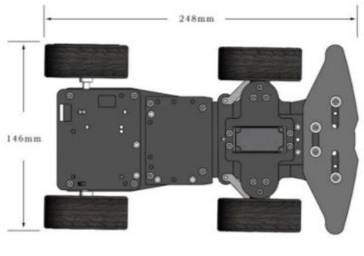
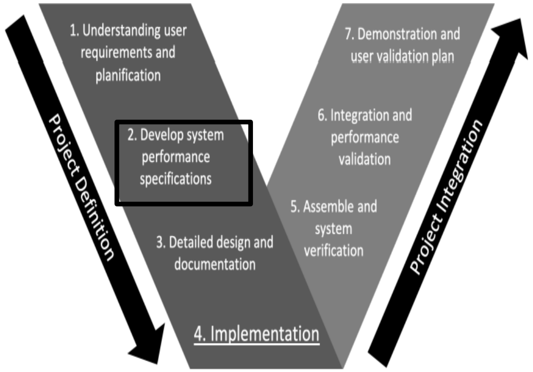
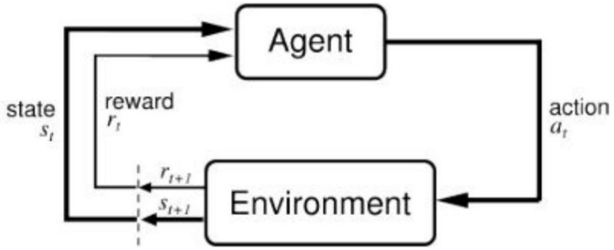
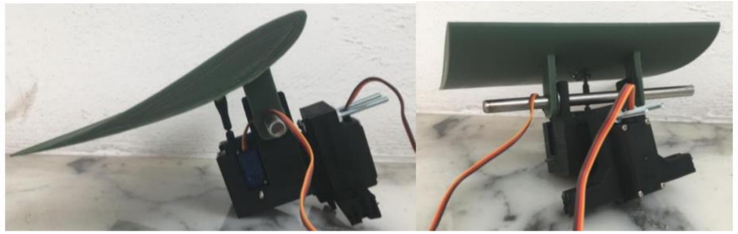


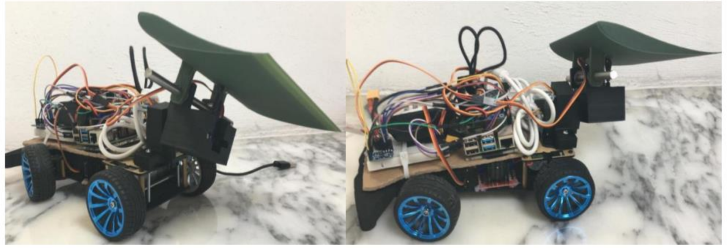
Figure: Down face of the used RC car with measurements.

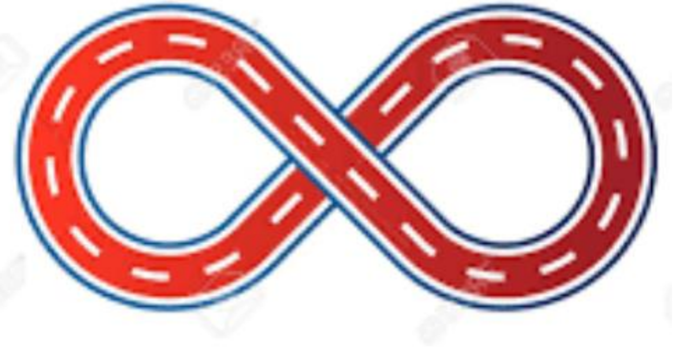
Figures . Top view and side view, of the final construction of the RC car.





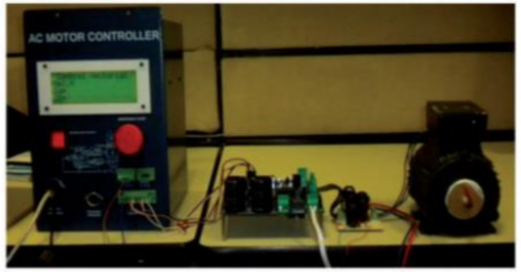


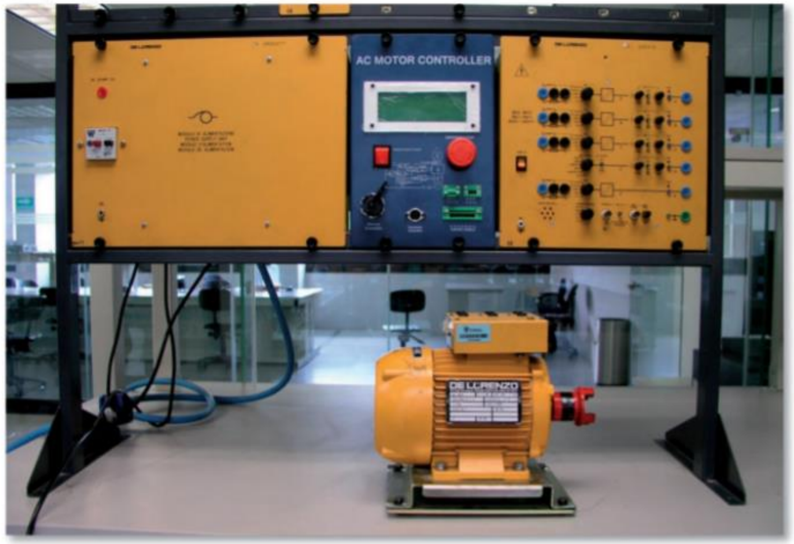


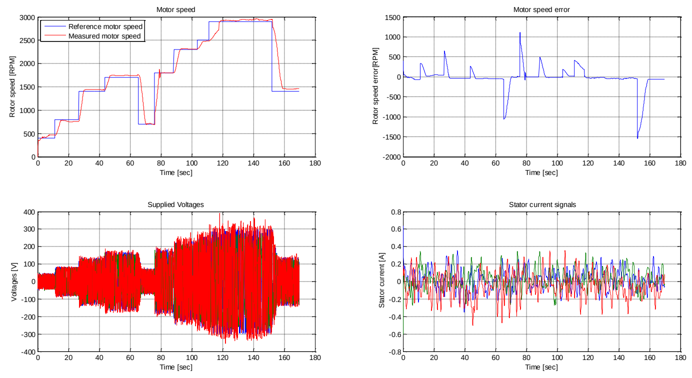


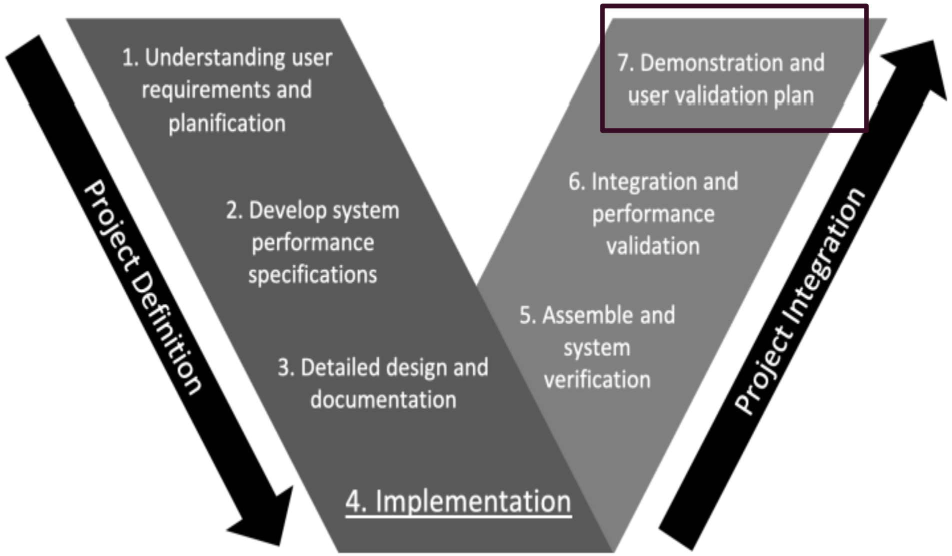
Miguel, V. E. V., Angel, G. G. J., Omar, M. J., Pedro, P., & Arturo, M. (2021, August). Deep Q-learning for Control: Technique and Implementation Considerations on a Physical System: Active Automotive Rear Spoiler Case. In *2021 IEEE International Conference on Mechatronics and Automation (ICMA)* (pp. 818-824). IEEE.

VECTOR CONTROL FOR AC MOTORS

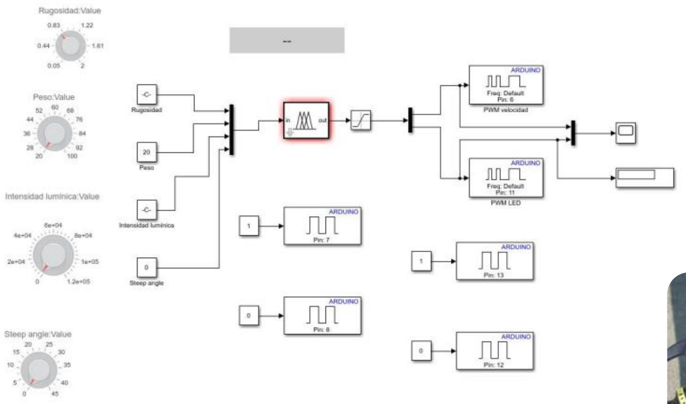


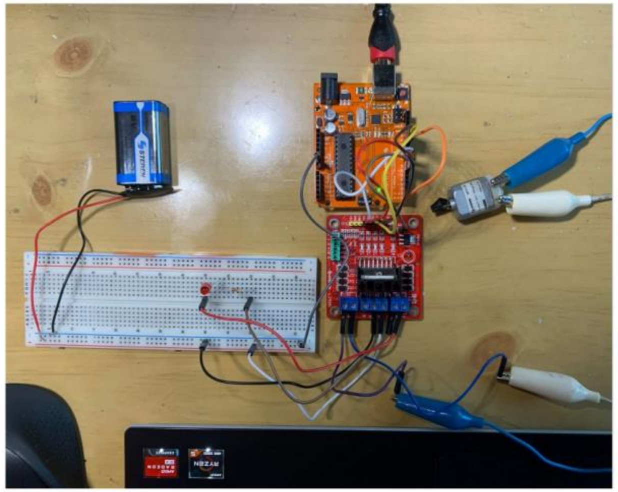


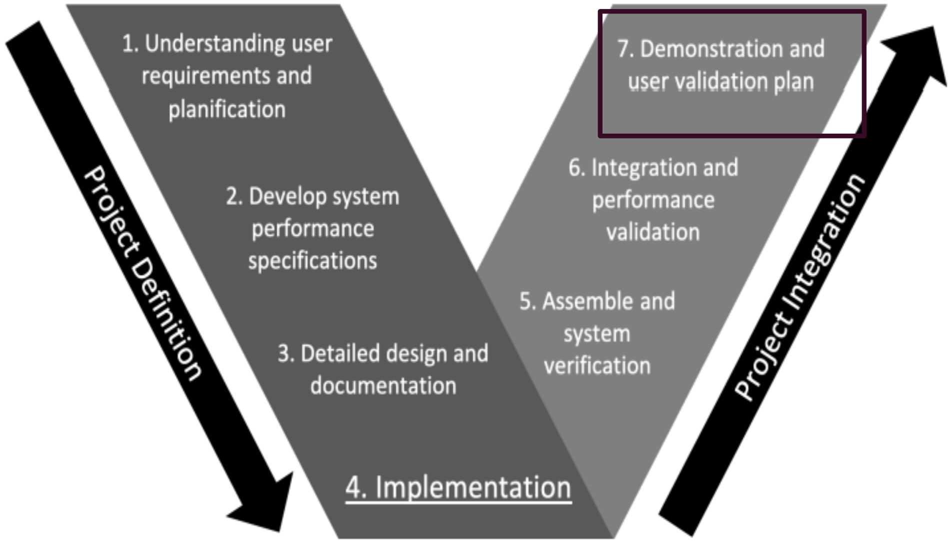




ELECTRIC BICYCLE DESIGN

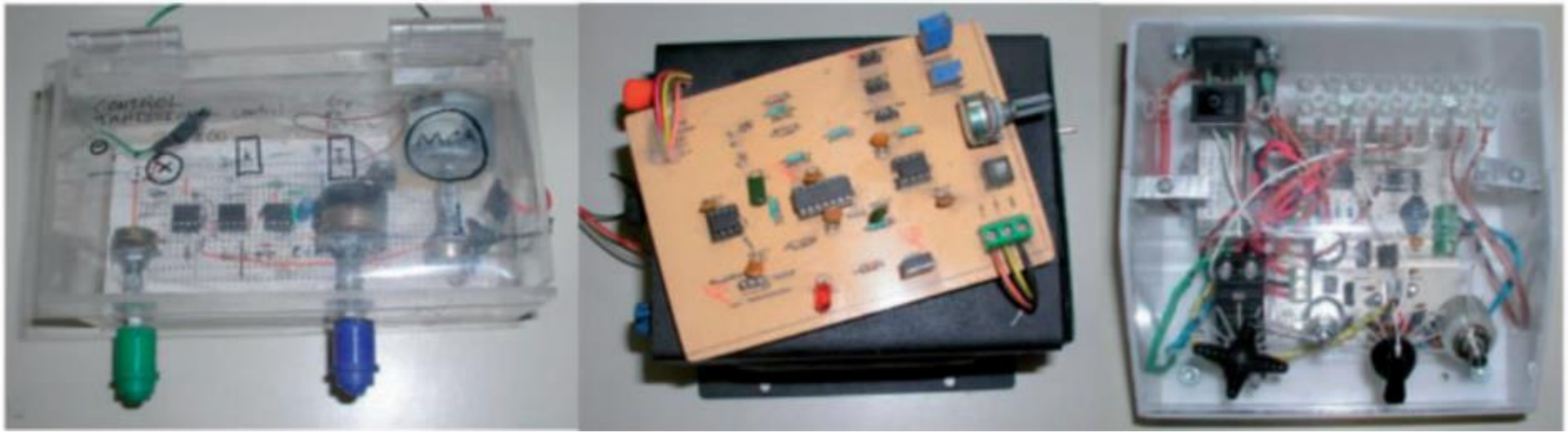


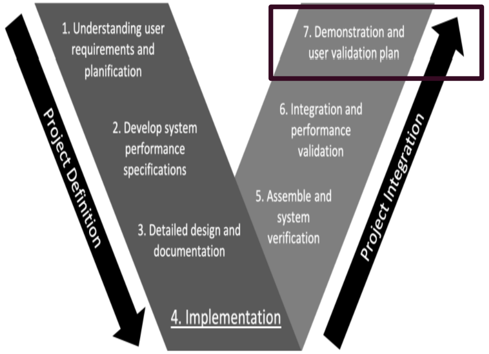




Students: Huerta Emanuel, Segura Daniel,
Ochoa Andrés, Zúñiga David , Jiménez Jaime

EDUCATIONAL MODULE (VIRTUAL LEARNING)





Low-cost educational module

Portable- AC power source 120 V 60Hz

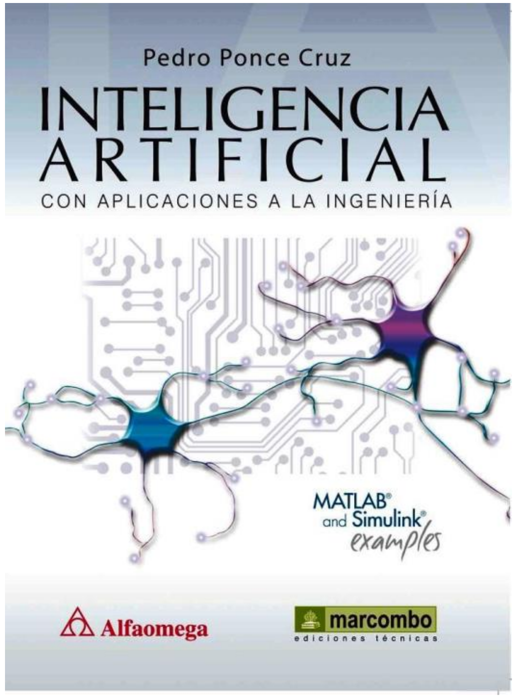
DC Motor coupled with a load (spring)

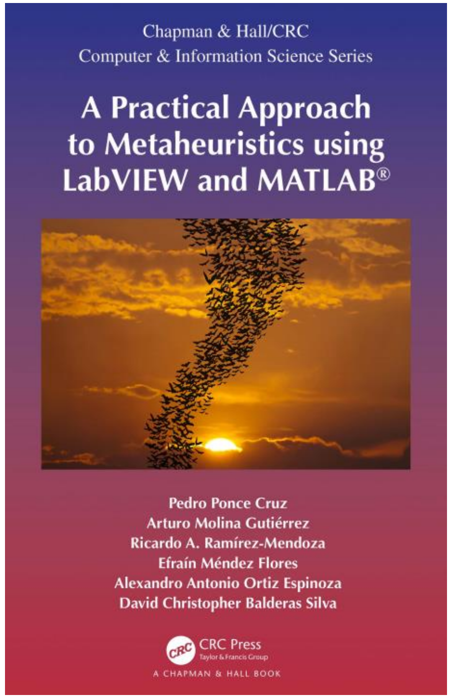
Position sensor

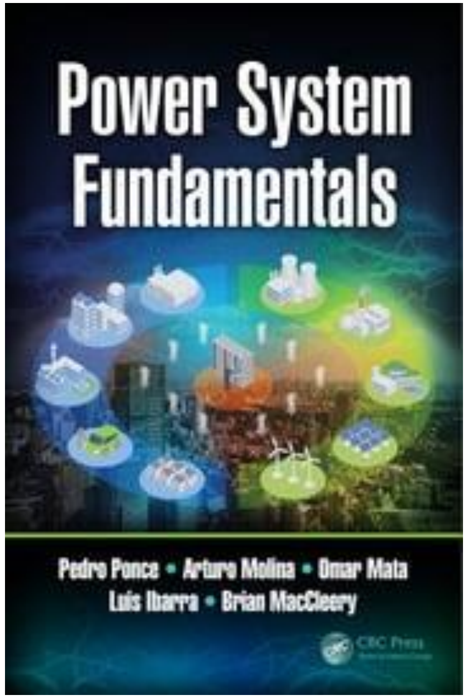
Inputs and outputs (digital and analog)

First and second order (RLC combination for system identification)

BOOKS USING *MATLAB* AND **Simulink**







THE MAIN CONCLUSIONS

- **Nowadays, engineering students must be equipped with a solid theoretical and experimental background to develop the required competencies and skills to propose innovative and creative solutions for real-world problems.**

- **Since there are no specific instructions to solve real-world problems, advanced theoretical and experimental concepts must be connected by complex thinking.**

- **As a result, the educational model Tec 21, the industrial V model, and MATLAB/Simulink give a unique opportunity to learn those concepts in a friendly manner accomplishing exceptional results.**

ADDITIONAL, CONCLUSIONS

- Tec 21 model and V model encourage critical thinking in which engineering students can understand complex concepts, create original ideas, and develop experimental approaches
- Creativity and innovations must be part of the educational loop in engineering classes when students are solving complex problems
- Students can propose novel ideas and design prototypes using low-cost hardware and advanced software tools
- MATLAB and Simulink help students to understand theoretical concepts and solve complex problems in real scenarios
- Professors play a new role in this era, creating new didactic material
- When the industry is connected with the engineering classes, students can be motivated with industrial challenges

“The value of an idea lies in the using of it.“

Thomas Edison (1847 – 1931), Inventor

Q&A

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