IIoT based Efficiency monitoring of a Pick&Place Robot

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Summary

- Identify and compare IoT, IIoT and Industry 4.0
- The role of Industrial Ethernet
- Energy efficiency monitoring. A case study.

Definition of Internet of Things (IoT)

The IoT (Internet of Things) describes a global network infrastructure, linking physical and virtual objects interacting among them.
IoT includes the existing Internet network PLUS any intelligent (smart) physical object and related services, as long as they can communicate.

Properties of IoT Objects

- **Identification (unique address, localization, state)**
- **Interaction (sensing, metering, actuating)**
- **Data processing**
- **Communication**

Added properties of Industrial Internet of Things (IIoT)

IIoT brings IoT in the Idustrial context by including specific requirements necessary, in addition to the standard Internet protocols, so as to comply with the Industrial Control.

- ❑Determinism
- ❑Real time operation (according to the industrial process dynamics)
- ❑Robustness
- ❑Integration of functions and services
- ❑Reliability
- ❑Security and Integrity

Design principles for Industry 4.0

Industrie 4.0 is a project in the high-tech strategy of the German government (April 2013)

1. ***Interoperability***: the ability of **Cyber-Physical Systems, CPS** (i.e. work piece carriers, assembly stations and products), humans and Smart Factories to connect and communicate with each other through **Open standards**.

2. ***Virtualization***: a virtual copy of the Smart Factory created by linking physical sensor data and virtual plant; simulation models to monitor physical processes.

3. ***Decentralization***: the ability of CPS within Smart Factories to make decisions on their own. Reduced role of the central control.

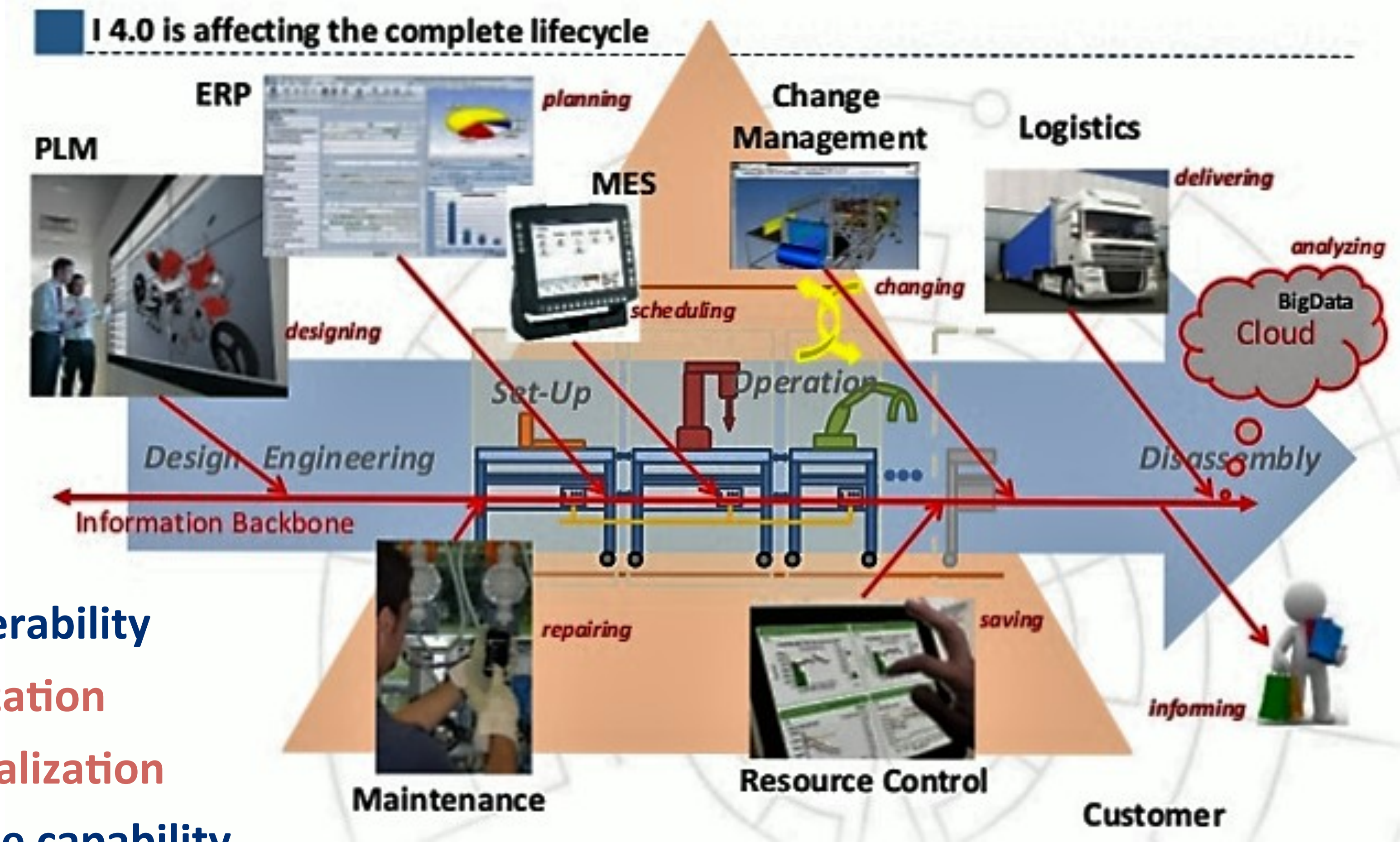
Design principles for Industry 4.0

4. ***Real-Time Capability***: to collect and analyze data and provide the derived insights immediately. Data acquisition, evaluation and control in real time.

5. ***Service Orientation***: offering of services (of CPS, humans or Smart Factories) made available also to other participants, by sharing their facilities through the network as a web service.

6. ***Modularity***: flexible adaptation of Smart Factories to changing requirements by replacing or expanding modules. New modules are identified automatically and can be utilized immediately.

IIoT and Industrie 4.0



- ❑ Interoperability
- ❑ Virtualization
- ❑ Decentralization
- ❑ Real time capability
- ❑ Service orientation
- ❑ Modularity

From IoT to IIoT: Industrial Ethernet

Standard Ethernet is based on an ungoverned network access mechanism (possible collisions, delays, stochastic timing).

INDUSTRIAL Ethernet provides a dedicated time access through switches **(Switched Ethernet).** This **confines the data** traffic in specific areas and guarantees short, deterministic time responses in signal distribution.

The **upper application levels** of Industrial Ethernet offer **interoperability**, based on typical industrial profiles, including **heritage** toward existing technologies.

Industrial Ethernet Solutions

POWERLINK (2001, B&R) (Application level, CANopen) Interfaces UDP/IP. Up to 100 Mb/s.

EtherCAT (2003, Beckhoff) (2nd level ISO-OSI) Interfaces with any TCP/IP and UDP. Up to 100 Mb/s.

EtherNet/IP (1990, Rockwell) (Application level, CIP) Interfaces with any TCP/IP and UDP. Up to 100 0Mb/s.

PROFINET (2003) TCP/IP (Tc 100 ms). Real Time (RT) (Tc up to 1 ms). Isochronous Real Time (IRT) (Tc < 1 ms).

Sercos III (2003) (Livello Ethernet). Cyclic transmission (up to 31,5 μs) and acyclic. *Sercos Energy Profile*

Added values of IE and IIoT for Industry 4.0

General advantages (all levels interconnection)

- Smart factories allows for **individual customer requirements satisfaction**
- **Dynamic business and engineering processes**
- **Optimised decision-making**
- **New ways of creating value** and **novel business models**.

Field level specific advantages

- The direct connection with the machine operation allows for a **faster control, monitoring and production fexibility**.
- **All the process physical variables are at disposal** on the network, thus making it possible to increase resource productivity and efficiency gains.

Added values for smart factories

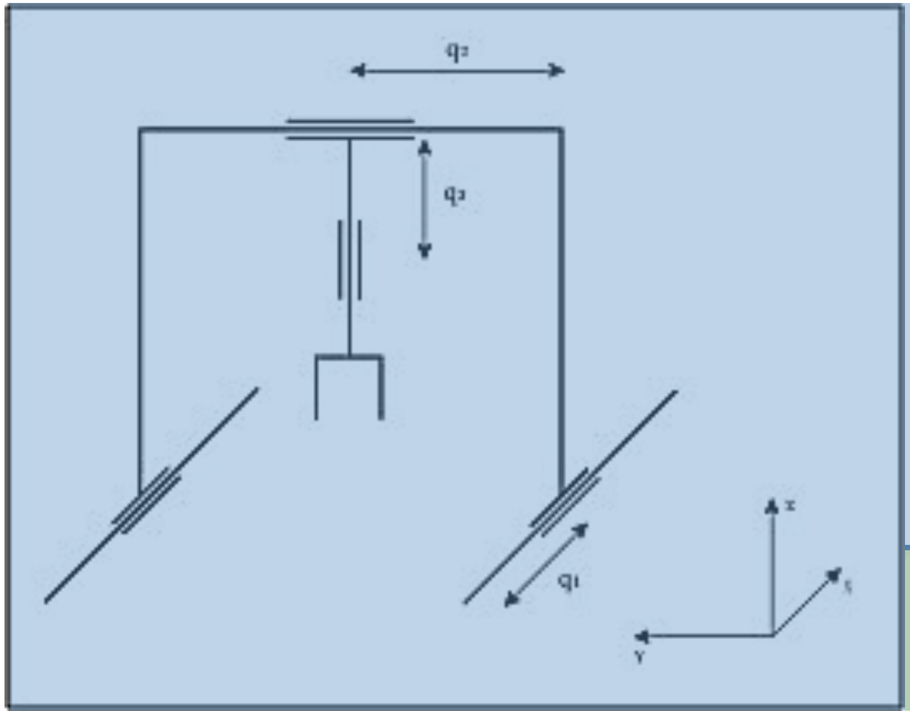
MONITORING AND CONTROL OF THE ENERGY EFFICIENCY IN MACHINE TOOL MOTION CONTROL AND LOGISTIC DISPLACEMENT

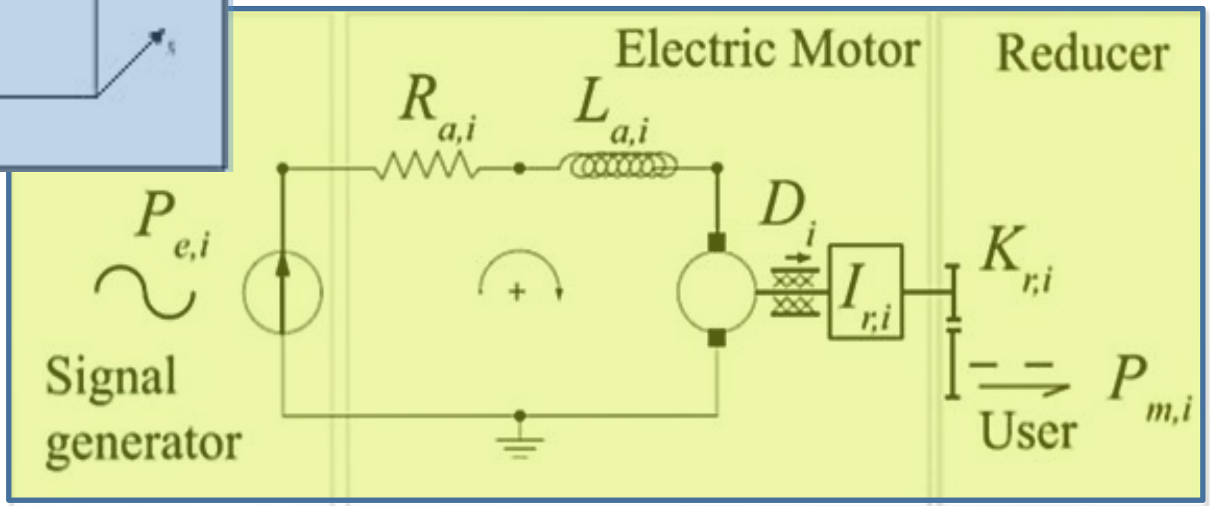
Variables available on the network tunneling trough IE:
-***Electrical variables: voltage, current, electric power***
- Mechanical variables: position, speed, acceleration (torque)

PROCESS DIAGNOSTICS
-**Process and sensor variables coming from all sensors and actuators**
-**Devices activities and status**

Efficiency in the Automation Industry

The case with a Pick & Place Portal (Robot) operation





Overall Energy required by the Robot operation

$$E = E_d + E_{km} + E_{gm} + E_{kl} + E_{gl}$$

Where

- E_d is the energy dissipated through the armature resistance and through the mechanical viscous friction
- E_{km} is the kinetic energy stored in the manipulator inertial field
- E_{gm} is the gravitational potential energy due to the manipulator masses
- E_{kl} is the kinetic energy delivered to the user
- E_{gl} is the variation of the workpiece potential energy

The consumption of the energy during pick and place operations however, considering **a cycle time where the handled object is picked up and delivered at zero velocity**, is simplified by assuming:

$$E = E_d + E_{gl}$$

The case with a Pick & Place Portal (Robot) operation

Torque dynamic model
(Euler-Lagrange)

$$\tau = D(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q)$$

Power developed by the actuator (motor)

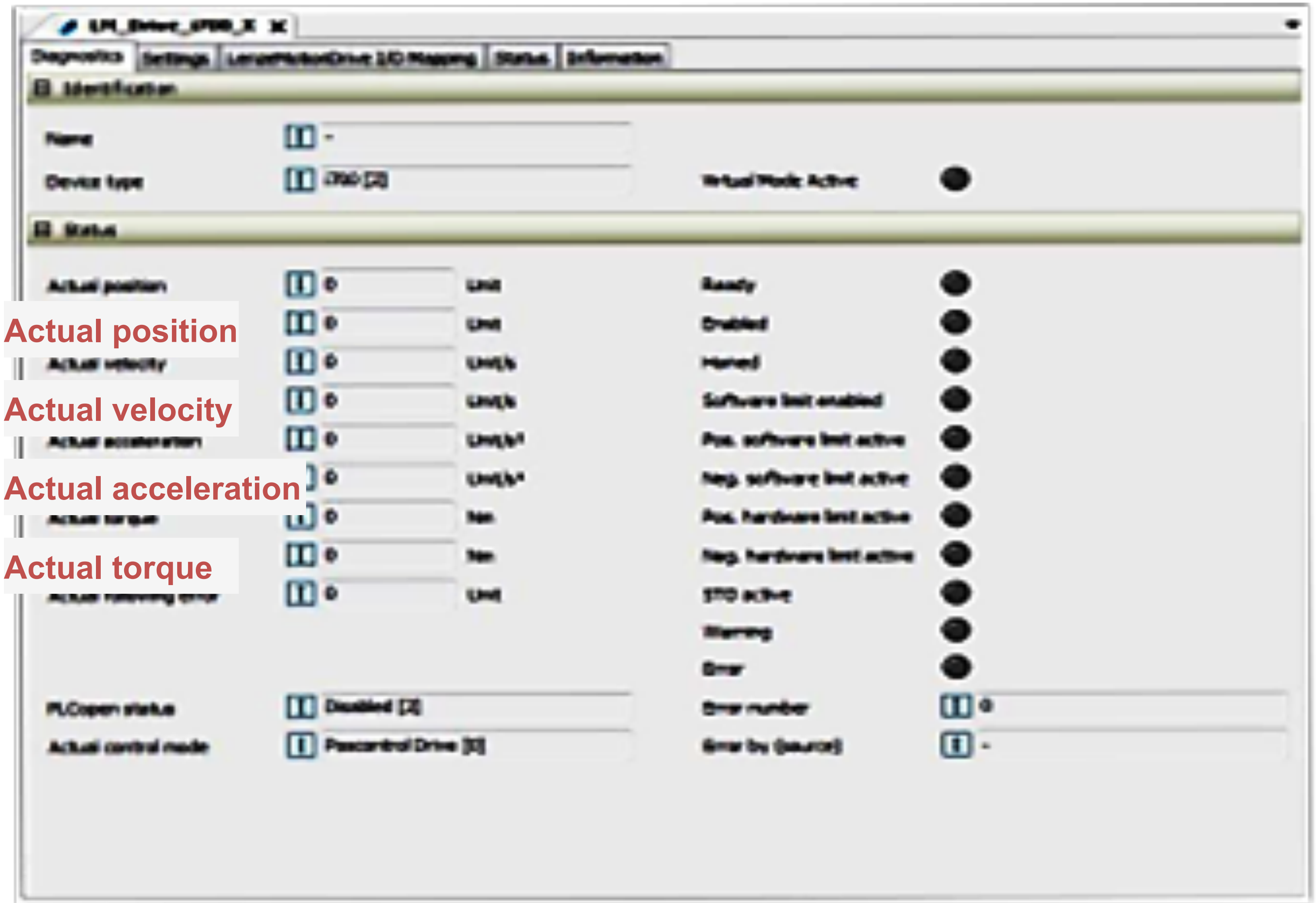
$$P = \frac{\tau_{av} \times v_{av} \times 2\pi}{60 \times 1000} \; [kW]$$

Energy consumed in a work cycle

$$E_{wc} = \int_0^{T_{wc}} \frac{P}{3600} \, dt \;\; [kWh]$$

Efficiency in the Automation Industry

Energy calculation from EtherCAT variables (DSD-Lenze)



The Working Cycle time

Energy consumption of the motor has been calculated by using the above mentioned variables.

The operation work cycle time **Twc** has been varied by using a scaling method.

At first a reference work cycle time **TwcREF** has been chosen; based on this criteria, the optimal trajectory parameters have been calculated.

Then a number of different simulations have been executed, by assuming a scaled **αTwcREF** work cycle, where **α <1** implies that an accelerated process is considered, while **α >1** is for slower ones.

EtherCAT Architecture (DSD-Lenze)

EtherCAT line : Master
Inverter 1: feed 2 Motors (x and y axes): Slave
Inverter 2: feed 1 Motors (z axis): Slave

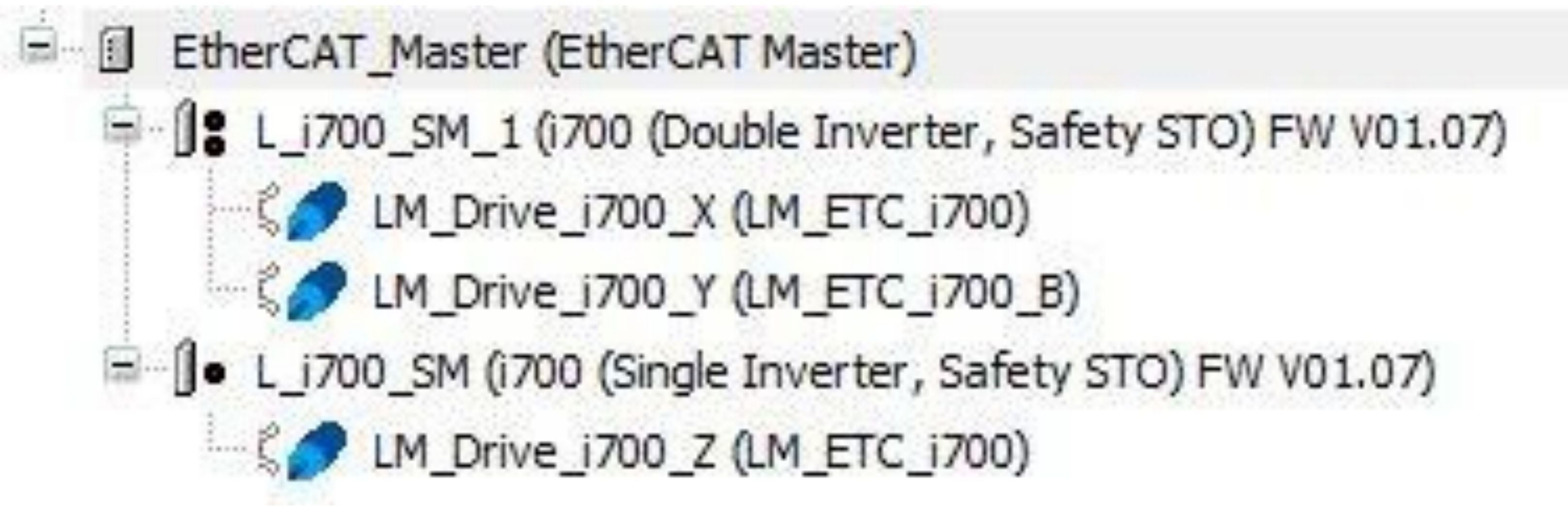


Fig. 4 – Sub-slave structure

Energy calculation from EtherCAT variables (DSD-Lenze)

SCALING FACTOR	0,543	1,000	1,228	1,455	1,683	1,910	2,138
v_z [m/s]	0,230	0,125	0,102	0,086	0,074	0,065	0,058
v_x [m/s]	0,163	0,088	0,072	0,061	0,053	0,046	0,041
v_y [m/s]	0,163	0,088	0,072	0,061	0,053	0,046	0,041
a_z [m/s^2]	1,694	0,500	0,332	0,236	0,177	0,137	0,109
a_x [m/s^2]	1,198	0,354	0,235	0,167	0,125	0,097	0,077
a_y [m/s^2]	1,198	0,354	0,235	0,167	0,125	0,097	0,077
TET [s]	30,49	56,13	68,90	81,68	94,45	107,23	120,00

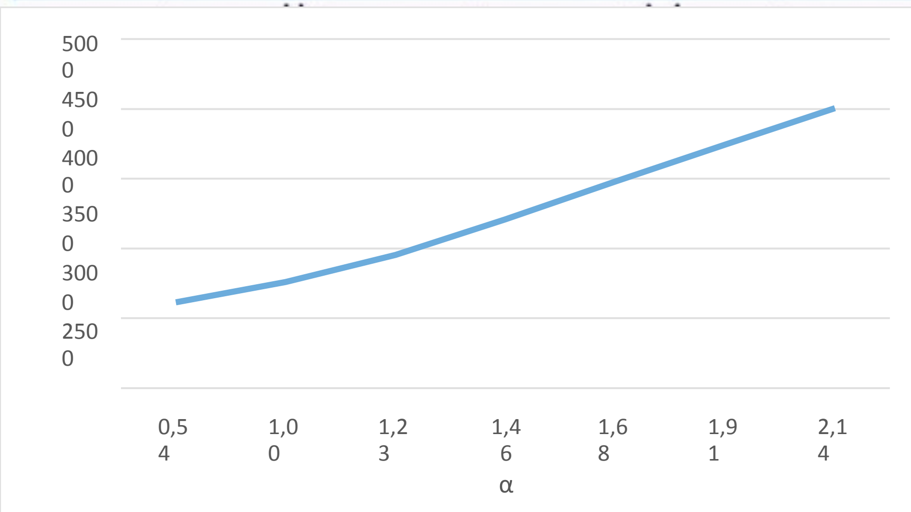


Fig. 6 – Energy related variables values vs Scaling factor

Conclusion

- IIoT and Industry 4.0 offer advantages both at higher architecture level and low field level.

- The paper concentrates on the latter, by showing that a common protocol for supervision and actuation of the drives, offer extra data to be used in parallel with the main process to monitor specific behaviors like energy consumption monitoring and diagnostics.

- A reduced number of sensor devices are requested due to the integration with the control process

Conclusion

- A dynamic model of a Cartesian robot has been considered, and an **application based on EtherCAT** protocol variables has been designed, and partially tested.

- The application calculates in real time the energy consumption as a function of motion parameters, therefore offering to a supervising program a measurement useful to implement energy efficient trajectory tuning.

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