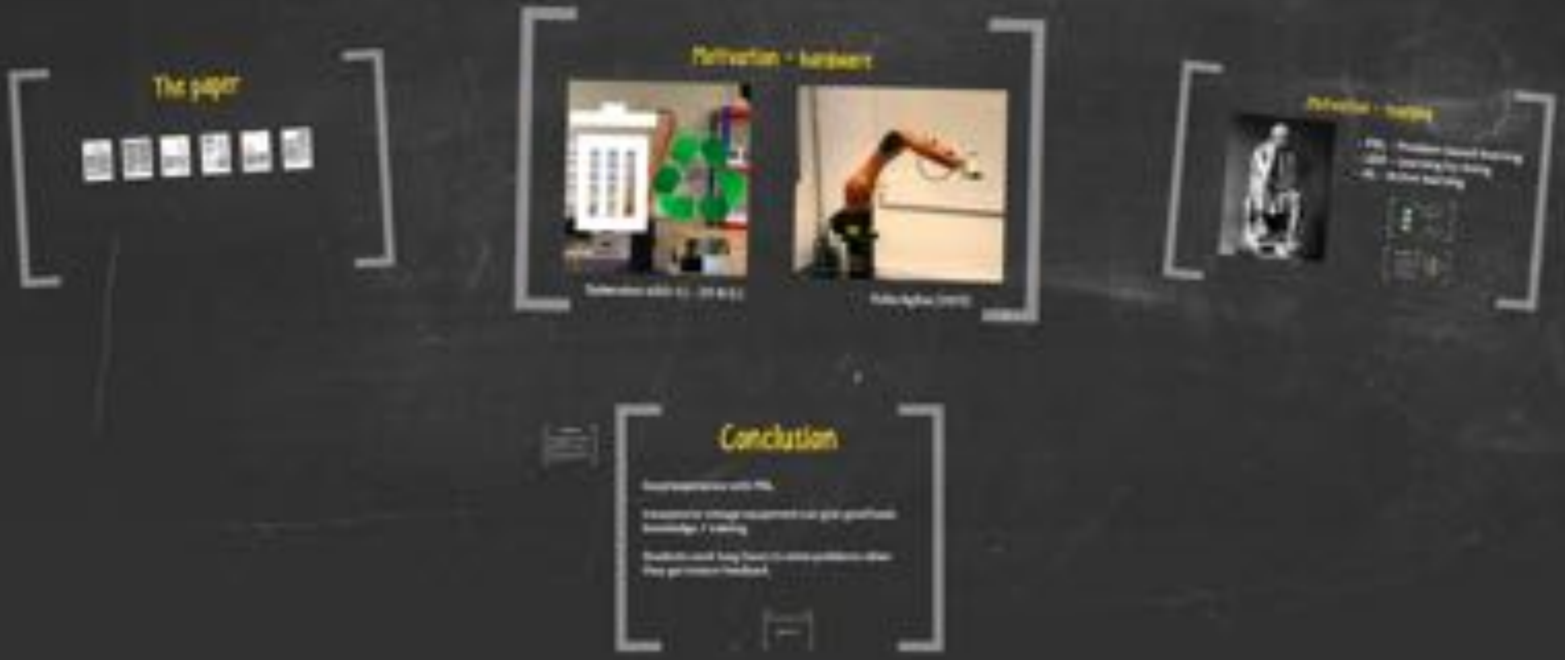
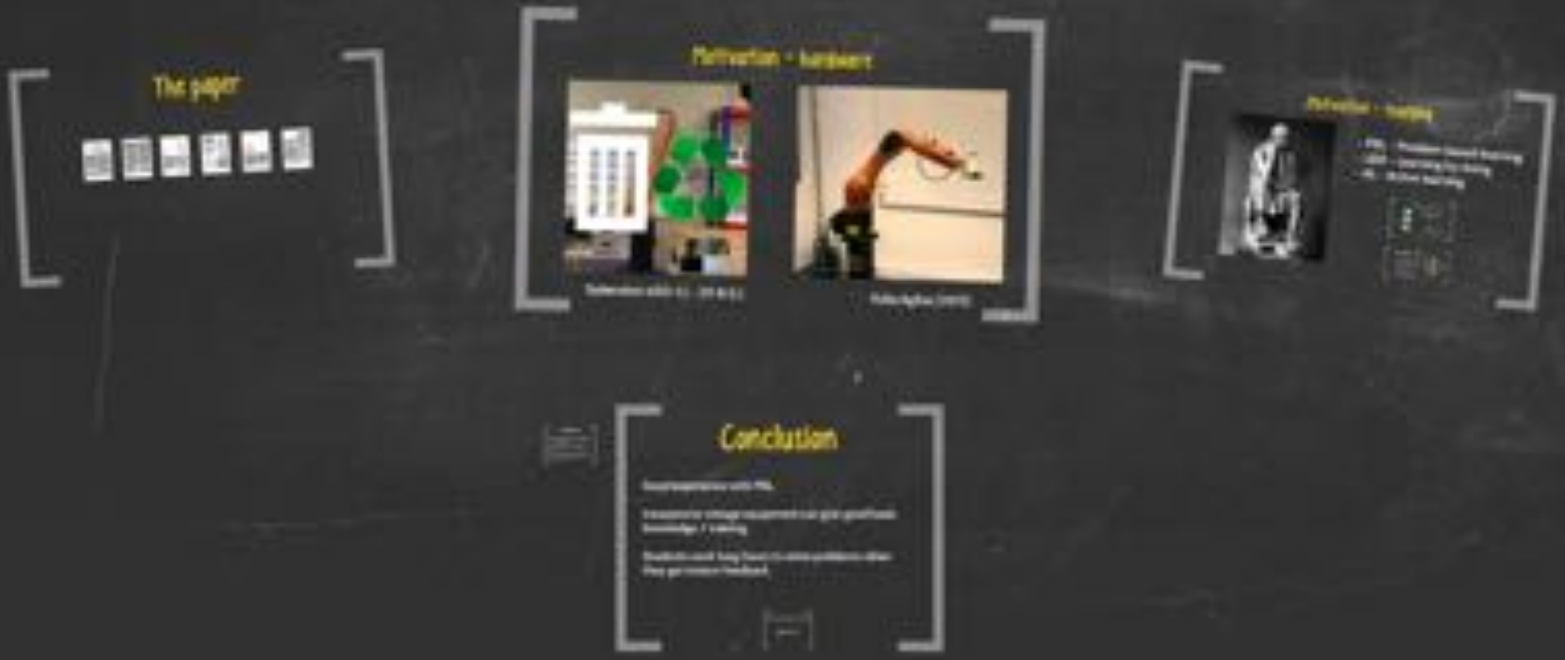
RECYCLING A DISCARDED ROBOTIC ARM, A PEDAGOGICAL PERSPECTIVE



RECYCLING A DISCARDED ROBOTIC ARM, A PEDAGOGICAL PERSPECTIVE



The paper

RECYCLING A DISCARDED ROBOTIC ARM FOR AUTOMATION ENGINEERING EDUCATION

Filippo Sanfilippo[1], Ottar L. Osen[2] and Saleh Alaliyat[1]
[1]Department of Maritime Technology and Operations, Aalesund University College,
Postboks 1517, 6025 Aalesund, Norway. Email: fisa@hials.no
[2]Department of Engineering and Natural Sciences, Aalesund University College
Postboks 1517, 6025 Aalesund, Norway.

KEYWORDS

PLC, automation engineering education, robotic arm.

ABSTRACT

Robotics and automation technology instruction is an important component of the industrial engineering education curriculum. As manufacturing technologies become much more widespread within manufacturing environments and also become more integrated with manufacturing line operations, industrial engineering and automation departments must continuously develop and update their laboratory resources and pedagogical tools in order to provide their students with adequate and effective study plans. While acquiring state-of-the-art manufacturing equipment can be financially demanding, a great effort is made at Aalesund University College to provide the students with an improved hands-on automation integration experience without major capital investment. In particular, a strategy that consists of recycling electronic and robot disposals is adopted. Students are engaged in a real reverse engineering process and then challenged to find new possible applications and uses.

By adopting a pedagogical perspective, this paper introduces the design and implementation of a robot control system on a hardware platform based on a *Programmable Logic Controller* (PLC). In particular, the controlled robot is a *Schonbot 600-5* manipulator with five degrees of freedom (DOF) that was disposed of by the industry several years ago as electronic waste. By using the *Modbus* protocol, a master-slave architecture is set up with the controller acting as the master and the PLC as the slave. The control software is fully developed on a commercial PLC system, using its standard programming tools and the multi-tasking features of its operating system.

INTRODUCTION

Automation engineering education is a multidisciplinary field of study that involves different types of knowledge and skills. This educational field applies the discipline of mechanical systems, electronic systems, computers and control systems to the integration of product design and automated manufacturing processes. Since industrial applications are becoming increasingly complex and demanding, industry needs experts with skills that cross a variety of disciplines and problem-solving abilities.

The Automation engineering program at the Faculty of Engineering and Natural Sciences and the Product and System Design program at the faculty of Maritime Technology and Operation, at Aalesund University College (AAUC), Norway, provide courses leading to Bachelor's and Master's degrees. These two study programs have several common topics concerning automation engineering subjects.

A common teaching strategy of these programs involves the ideas of Learning by Doing (LBD) (Nguyen & Gnarie 2001), the approaches of Problem Based Learning (PBL) (Albanese & Mitchell 1993) and the concepts of Active Learning (AL) (Martin et al. 2010). In fact, one of the most effective ways of teaching students how to perform a useful task consists of actively involving them and letting them do it. The LBD method is not a new instructional theory, it is exactly what it sounds like. Aristotle stated: "*One must learn by doing the thing, for though you think you know it, you have no certainty until you try*". Similarly, Confucius declared: "*I hear and I forget. I see and I remember. I do and I understand*". More recently, John Dewey, born in 1859, became one of the strongest proponents of the LBD approach. In (Dewey 1997), Dewey argued: "*Education is not preparation for life; it is life itself*".

At AAUC, during their study courses, students are involved with realistic problem settings and scenarios that reflect real application perspectives. Very often, students are divided into groups that stimulate their teamwork skills and critical thinking abilities. From a social point of view, group dynamics are also relevant. In order to prepare the students for their working life, the preferred method of putting groups together is randomly, with a random leader. This method is perceived as fair by the students. Moreover, normal working conditions are simulated in which the average team member is usually unable to select their own team. In addition, this approach also establishes new social networks in the classroom. Our experience is that the students perform better when they know each other well. This probably has to do with the fact that they feel safer in the learning environment and are less afraid of possibly embarrassing situations. However, in generating random groups, an attempt is made to break up the existing frozen social ties, thereby forcing the students into new roles. As such, an industry like

YCLING A DISCARDED ROBOTIC FOR AUTOMATION ENGINEERING EDUCATION

Filippo Sanfilippo*, Ottar L. Osen† and Saleh Alaliyat†
*Department of Maritime Technology and Operations, Aalesund University College,
Postboks 1517, 6025 Aalesund, Norway. Email: `fisa@hials.no`
†Department of Engineering and Natural Sciences, Aalesund University College
Postboks 1517, 6025 Aalesund, Norway.

KEYWORDS

ation engineering education, robotic arm.

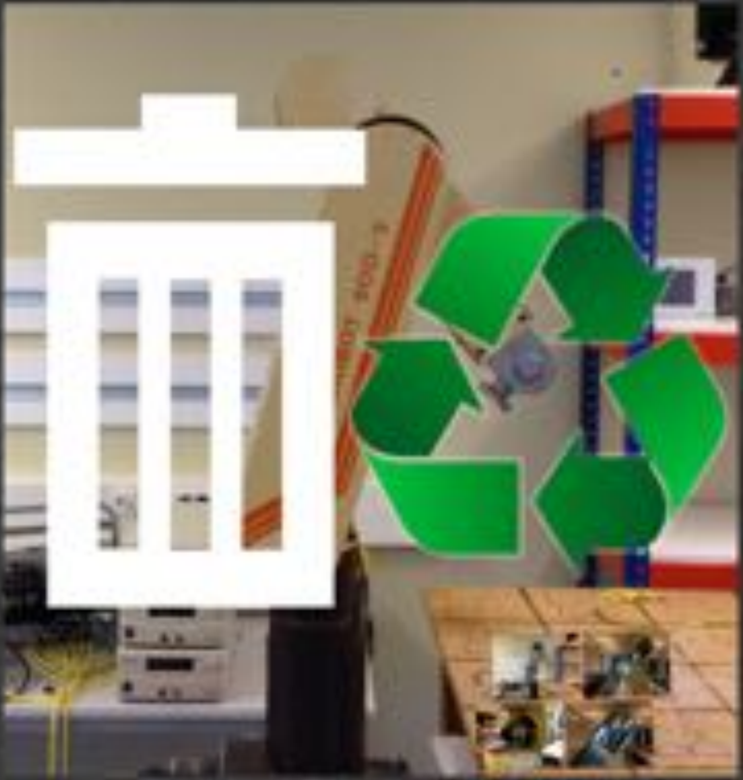
ABSTRACT

d automation technology instruction is an im-
ent of the industrial engineering education
manufacturing technologies become much
d within manufacturing environments and also

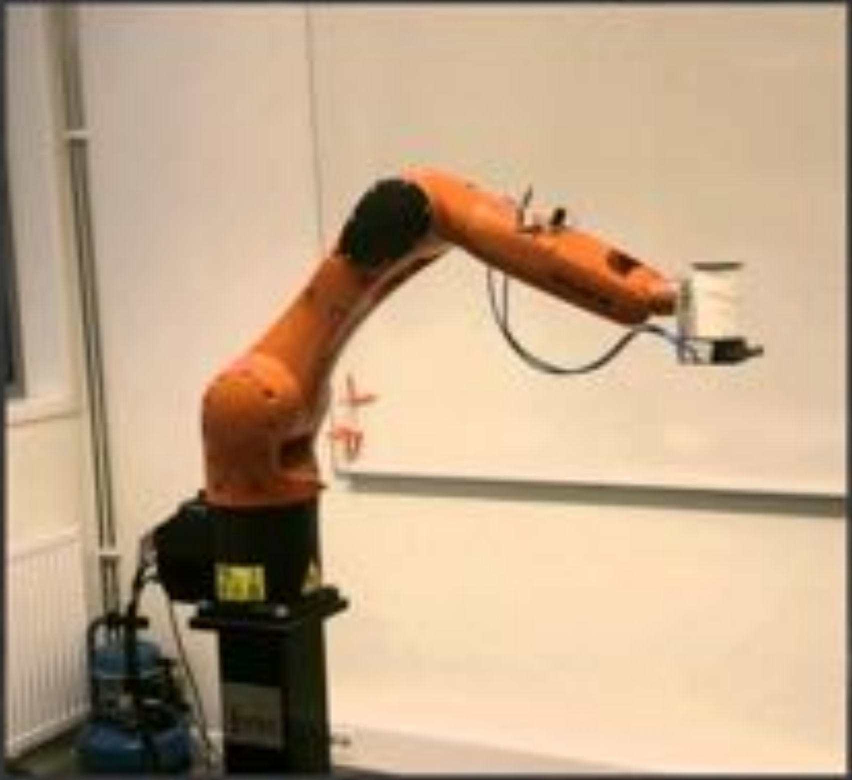
with skills that cross a variety of disciplines
solving abilities.

The Automation engineering program at
Engineering and Natural Sciences and the Proc
Design program at the faculty of Maritime T
Operation, at Aalesund University College (A
provide courses leading to Bachelor's and M
These two study programs have several comm
cerning automation engineering subjects.

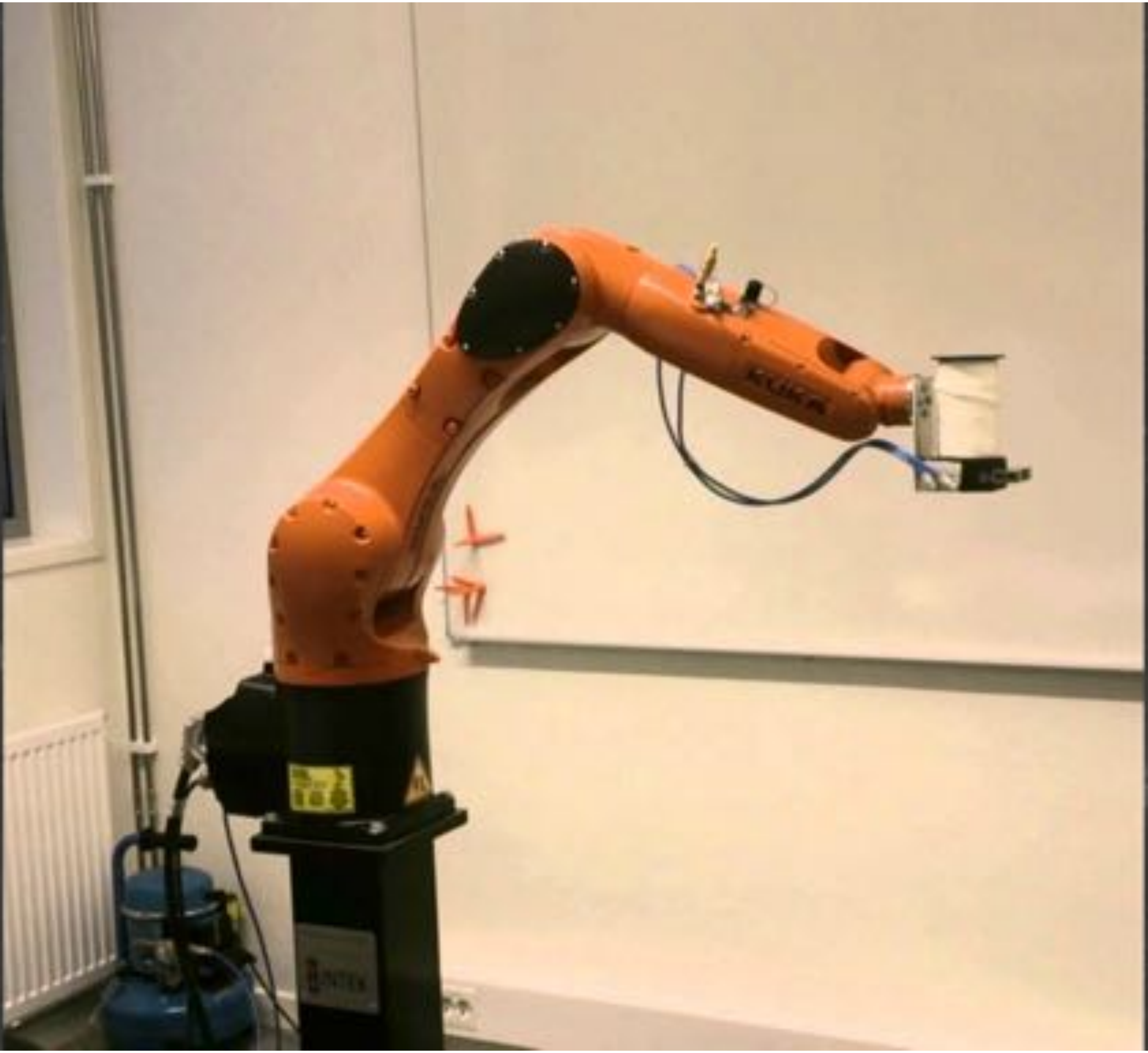
Motivation - hardware

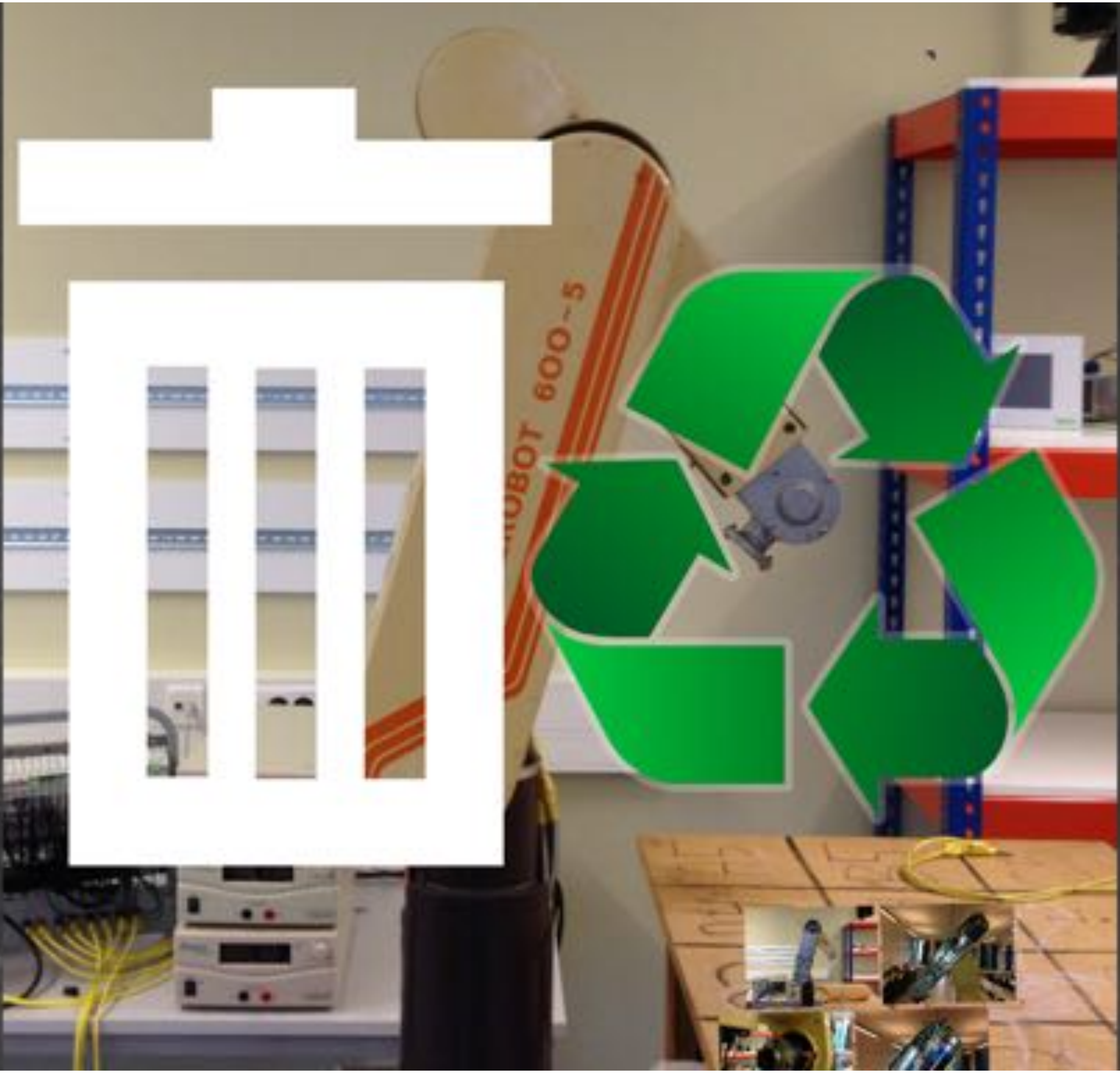


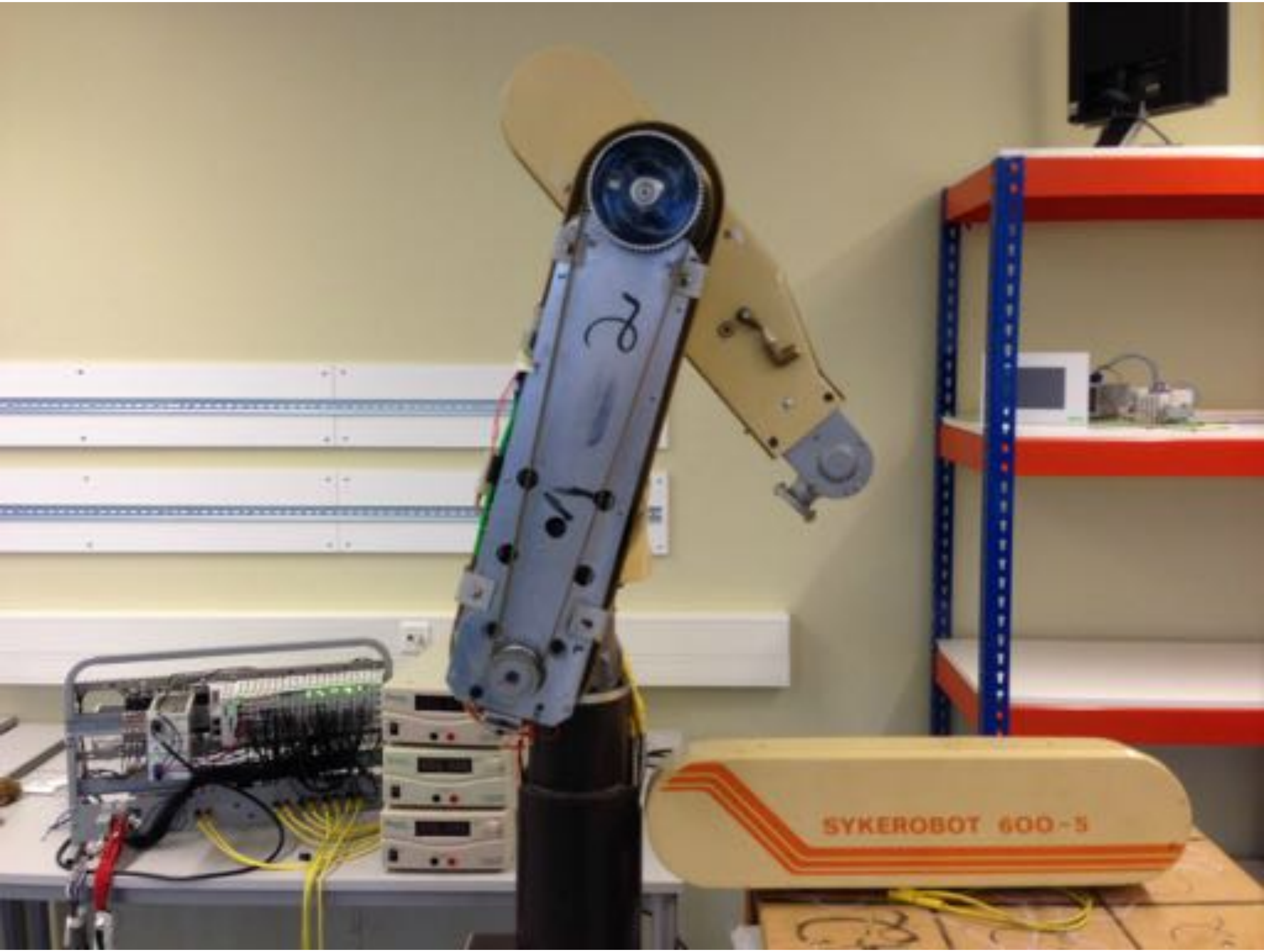
Sykerobot 600-5 (~20 B.G.)

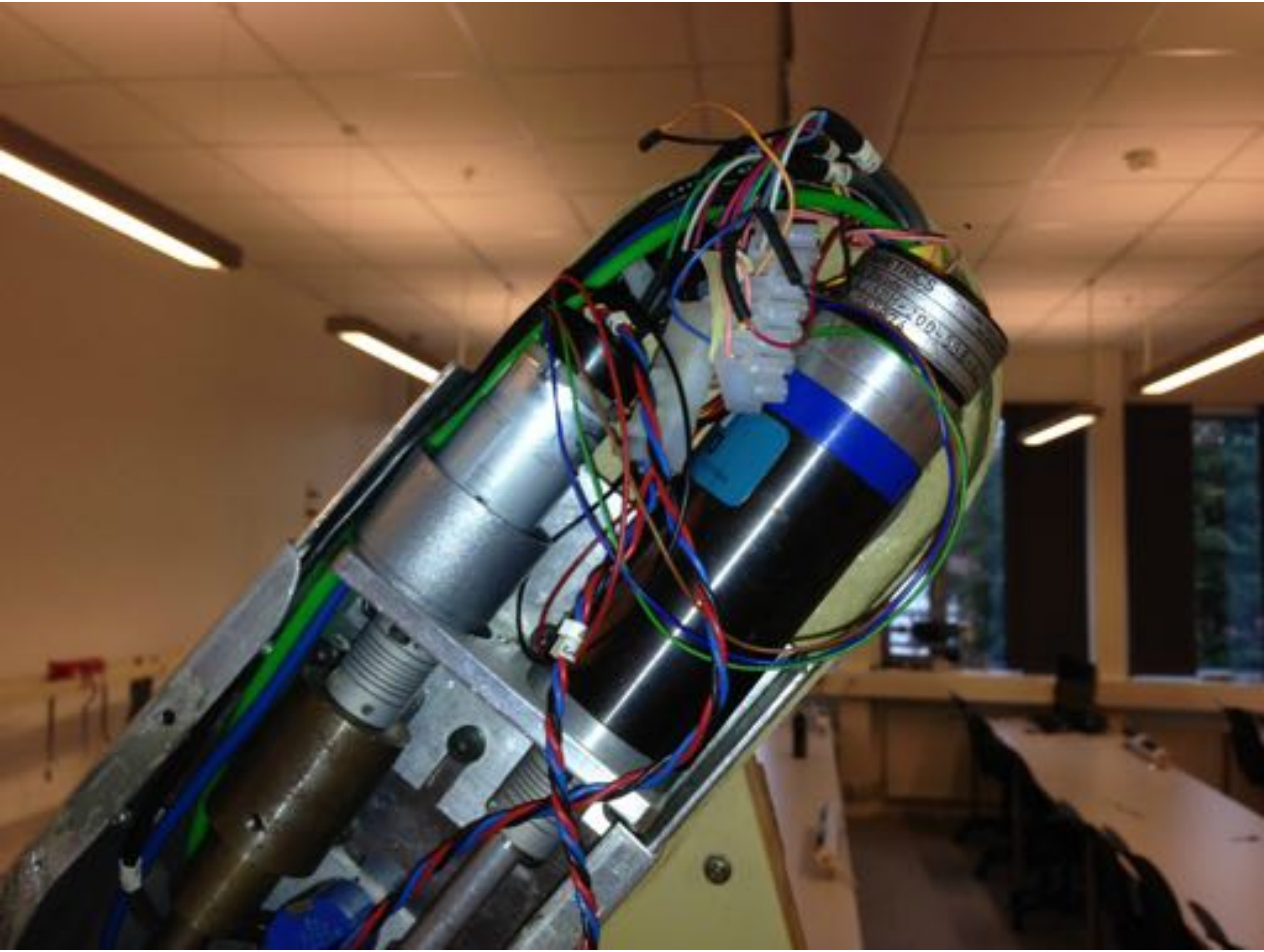


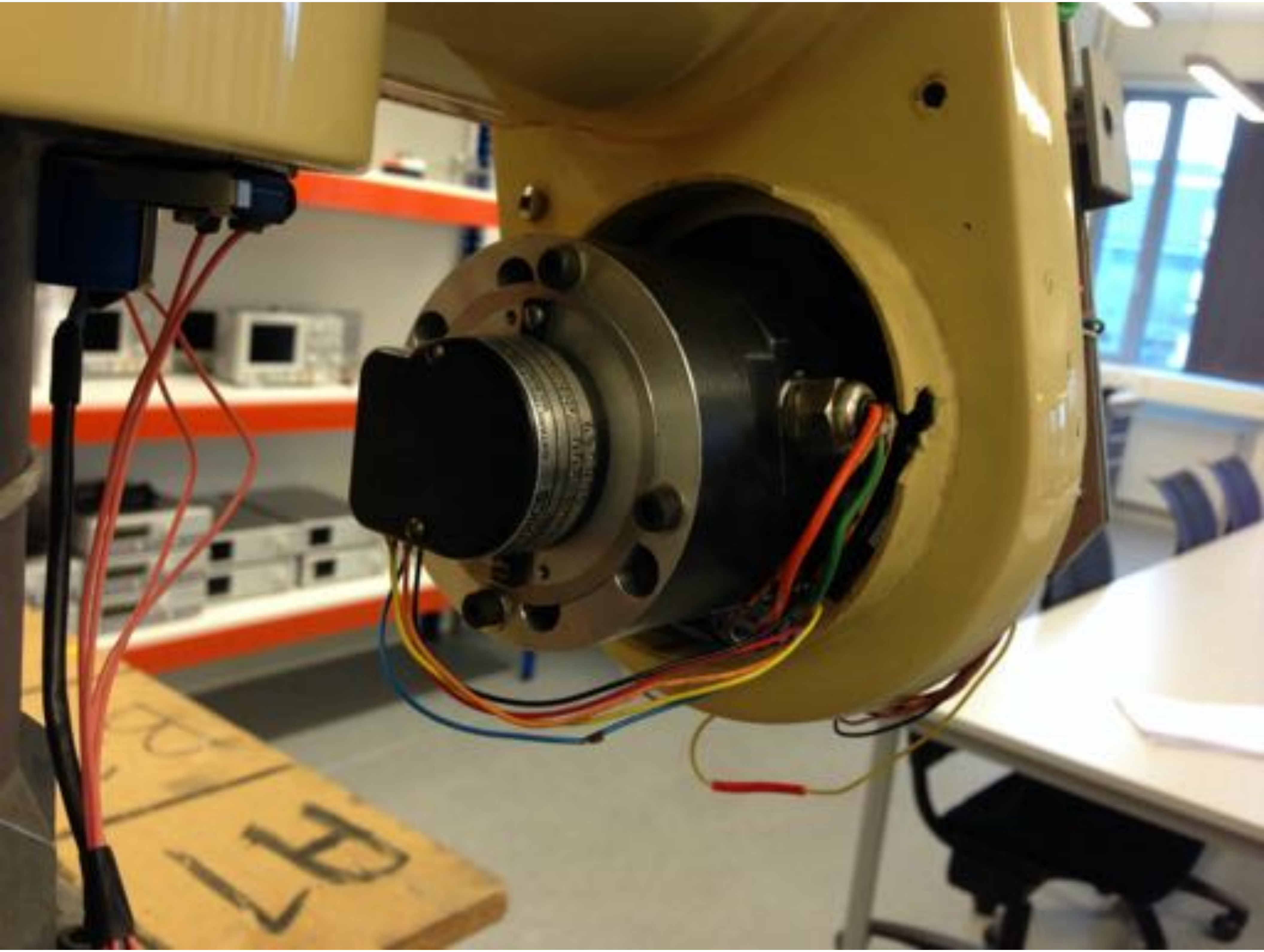
Kuka Agilus (2013)


KUKA


ROBOT 600-5


SYKEROBOT 600-5





Motivation - teaching

- PBL - Problem based learning
- LBD - Learning by doing
- AL - Active learning

Our approach - projects

"One must learn by doing the thing, for though you think you know it, you have no certainty until you try."
-- Aristotle

"I hear and I forget. I see and I remember. I do and I understand."
-- Confusius

"Education is not preparation for life, it is life itself."
-- Dewey

Closed loop learning / Hardware in the loop

The closed loop learning process give:

- Immediate feedback
- Objective feedback

"Anything is easy if you can assimilate it to your collection of models"
-- Papert

Doing creates new models that is added to a growing collection of models. A large collection of models will ease assimilation of new knowledge in the future also.

"Anything is easy if you can assimilate it to your collection of models"
-- Papert

Doing creates new models that is added to a growing collection of models. A large collection of models will ease assimilation of new knowledge in the future also.

Our approach – projects

Simulate real world working conditions
- Random groups (appointed by teacher)
- Random leader (appointed by teacher)
- Planning and reporting

Groups of 4 students, 3 is an odd number ;-)
- 4 allows subgroups of 2

Doing, a part of the student evaluation.
- Exam grade *f(project work, knowledge)*

The paper





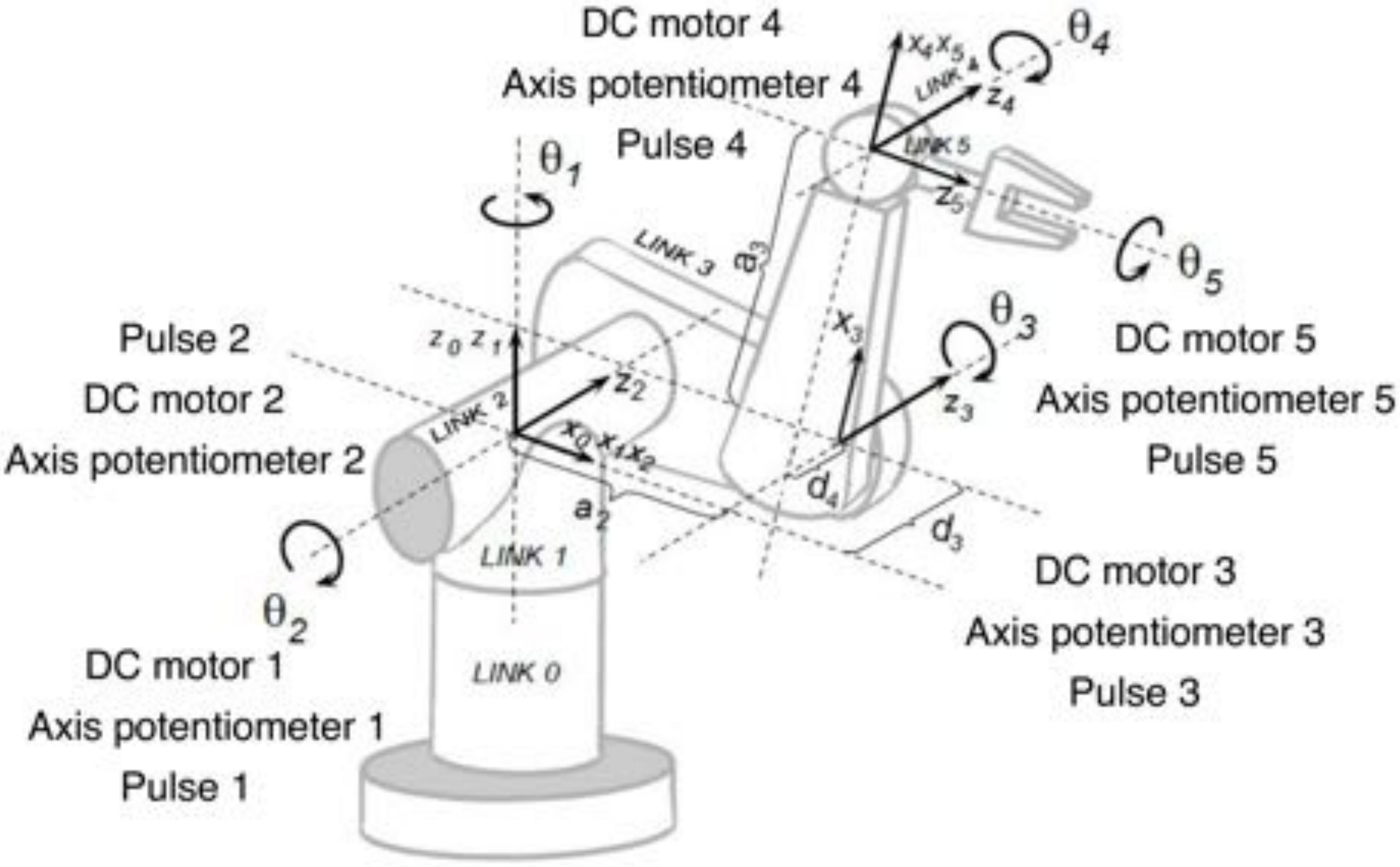
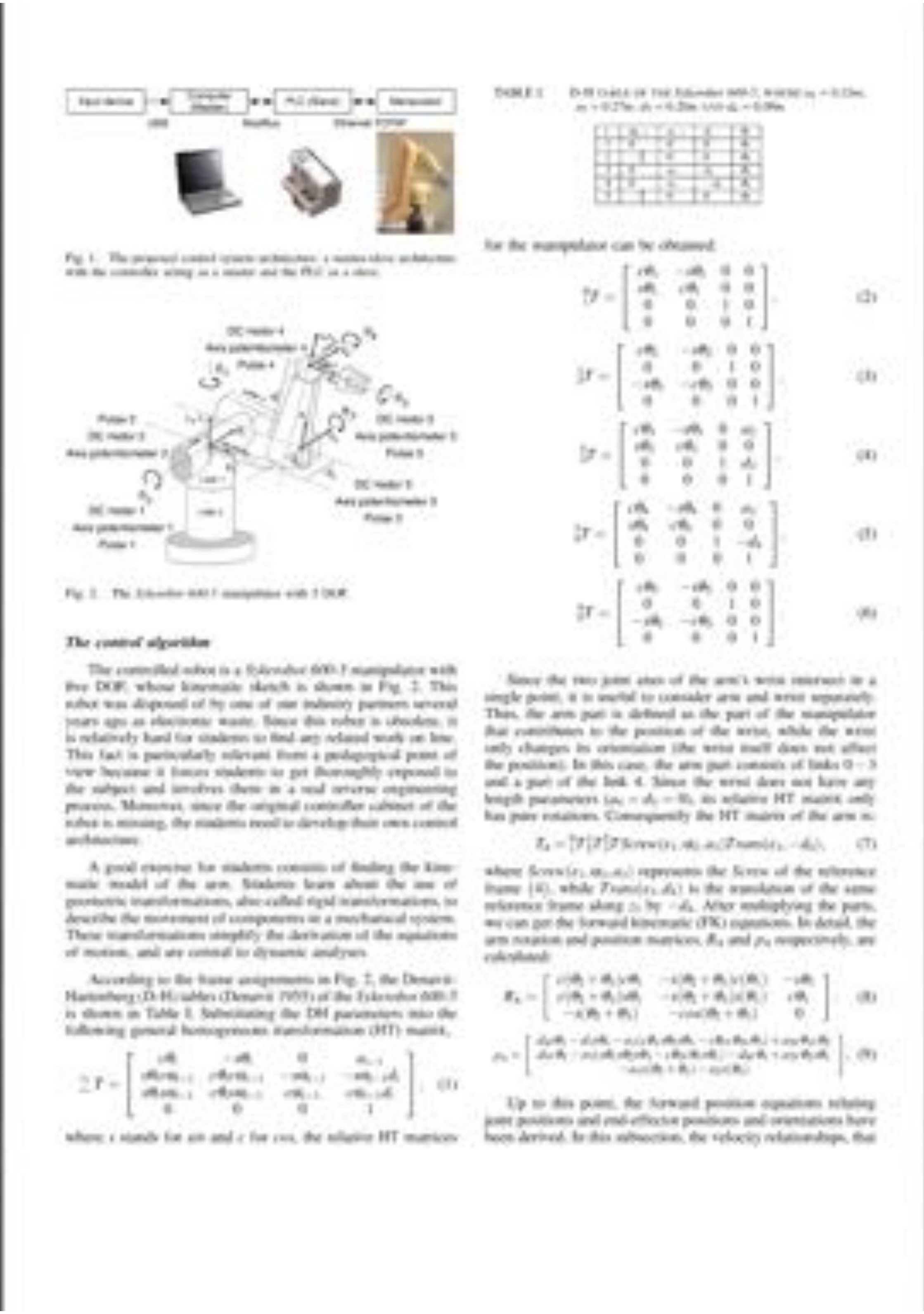



Fig. 2. The *Sykerobot 600-5* manipulator with 5 DOF.



The control algorithm

The controlled robot is a [illegible] manipulator with five DOF, whose kinematic sketch is shown in Fig. 2. This robot was disposed of by one of our industry partners several years ago as electronic waste. Since this robot is obsolete, it is relatively hard for students to find any related work on line. This fact is particularly relevant from a pedagogical point of view because it forces students to get thoroughly exposed to the subject and involves them in a real reverse engineering process. Moreover, since the original controller cabinet of the robot is missing, the students need to develop their own control architecture.

A good exercise for students consists of finding the kinematic model of the arm. Students learn about the use of geometric transformations, also called rigid transformations, to describe the movement of components in a mechanical system. These transformations simplify the derivation of the equations of motion, and are central to dynamic analyses.

According to the frame assignments in Fig. 2, the Denavit-Hartenberg (D-H) tables (Denavit 1955) of the [illegible] is shown in Table I. Substituting the DH parameters into the following general homogeneous transformation (HT) matrix,

Since the two joint axes of the arm's wrist intersect in a single point, it is useful to consider arm and wrist separately. Thus, the arm part is defined as the part of the manipulator that contributes to the position of the wrist, while the wrist only changes its orientation (the wrist itself does not affect the position). In this case, the arm part consists of links 0 − 3 and a part of the link 4. Since the wrist does not have any length parameters, its relative HT matrix only has pure rotations. Consequently the HT matrix of the arm is:

Up to this point, the forward position equations relating joint positions and end-effector positions and orientations have been derived. In this subsection, the velocity relationships, that relate the linear and angular velocities of the end-effector (or any other point on the manipulator) to the joint velocities will be derived. Mathematically, the FK equations define a function between the space of Cartesian positions and orientations and the space of joint positions. The velocity relationships are then determined by the Jacobian of this function. The Jacobian is a matrix-valued function and can be thought of as the vector version of the ordinary derivative of a scalar function. The Jacobian matrix is one of the most important pieces of information in the analysis and control of robot motion.

The robot considered presents only spherical joints, therefore, the description of the angular velocity, ${}^{i+1}\omega_{i+1}$, of link $i+1$ can be obtained as:

$$ {}^{i+1}\omega_{i+1} = {}^{i+1}_{i}R\,{}^{i}\omega_i + \dot{\theta}_{i+1}\,{}^{i+1}\hat{Z}_{i+1} \qquad (10) $$

where ${}^{i+1}_{i}R$ is the rotation matrix of frame $\{i\}$ with respect to $\{i+1\}$, ${}^{i}\omega_i$ is the angular velocity of frame $\{i\}$, $\dot{\theta}_{i+1}$ is the angular velocity of joint $i+1$ and ${}^{i+1}\hat{Z}_{i+1}$ is the unit vector of frame $\{i+1\}$. Similarly, the corresponding relationship for the linear velocity, ${}^{i+1}v_{i+1}$, of link $i+1$ is given by:

$$ {}^{i+1}v_{i+1} = {}^{i+1}_{i}R({}^{i}v_i + {}^{i}\omega_i \times {}^{i}P_{i+1}), \qquad (11) $$

where ${}^{i}v_i$ is the linear velocity of frame $\{i\}$ and ${}^{i}P_{i+1}$ is the position of frame $\{i+1\}$ respect to $\{i\}$. Applying these equations successively from link to link, we can compute ${}^{N}\omega_N$ and ${}^{N}v_N$, the rotational and linear velocity of the last link. For the considered arm, we get:

$$ {}^{1}\omega_1 = \begin{bmatrix} 0 \\ 0 \\ \dot{\theta}_1 \end{bmatrix}, {}^{1}v_1 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \qquad (12) $$

$$ {}^{2}\omega_2 = \begin{bmatrix} -\dot{\theta}_1 s\theta_2 \\ -\dot{\theta}_1 c\theta_2 \\ \dot{\theta}_2 \end{bmatrix}, {}^{2}v_2 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \qquad (13) $$

$$ \begin{aligned} {}^{3}\omega_3 &= \begin{bmatrix} -\dot{\theta}_1 c\theta_2 s\theta_3 - \dot{\theta}_1 s\theta_2 c\theta_3 \\ \dot{\theta}_1 s\theta_2 s\theta_3 - \dot{\theta}_1 c\theta_2 c\theta_3 \\ \dot{\theta}_2 + \dot{\theta}_3 \end{bmatrix}, \\ {}^{3}v_3 &= \begin{bmatrix} s\theta_3(a_2\dot{\theta}_2 + d_2\dot{\theta}_1 s\theta_2) - d_2\dot{\theta}_1 c\theta_2 c\theta_3 \\ c\theta_3(a_2\dot{\theta}_2 + d_2\dot{\theta}_1 s\theta_2) + d_2\dot{\theta}_1 c\theta_2 s\theta_3 \\ a_2\dot{\theta}_1 c\theta_2 \end{bmatrix}, \end{aligned} \qquad (14) $$

$$ \begin{aligned} {}^{4}\omega_4 &= \begin{bmatrix} [illegible] \\ [illegible] \\ \dot{\theta}_2 + \dot{\theta}_3 + \dot{\theta}_4 \end{bmatrix}, \\ {}^{4}v_4 &= \begin{bmatrix} [illegible] \\ [illegible] \\ [illegible] \end{bmatrix} \end{aligned} \qquad (15) $$

To find these velocities with respect to the non-moving base frame, they can be rotated by using the rotation matrix R_4:

$$ \begin{aligned} {}^{0}_{4}v &= R_4\,{}^{4}v_4 = \begin{bmatrix} {}^{0}_{4}v_{1,1} \\ {}^{0}_{4}v_{2,1} \\ {}^{0}_{4}v_{3,1} \end{bmatrix}, \\ {}^{0}_{4}v_{1,1} &= [illegible] \\ {}^{0}_{4}v_{2,1} &= [illegible] \\ {}^{0}_{4}v_{3,1} &= -a_2\dot{\theta}_2 c\theta_2 - a_3\dot{\theta}_2 c(\theta_2 + \theta_3) - a_3\dot{\theta}_3 c(\theta_2 + \theta_3). \end{aligned} \qquad (16) $$

As such, the time derivative of the kinematics equations yields the Jacobian matrix of the arm, which relates the joint rates to the linear and angular velocity:

$$ \begin{aligned} J &= \begin{bmatrix} J_{1,1} & J_{1,2} & J_{1,3} \\ J_{2,1} & J_{2,2} & J_{2,3} \\ J_{3,1} & J_{3,2} & J_{3,3} \end{bmatrix}, \\ J_{1,1} &= [illegible] \\ J_{1,2} &= [illegible] \\ J_{1,3} &= [illegible] \\ J_{2,1} &= [illegible] \\ J_{2,2} &= [illegible] \\ J_{2,3} &= [illegible] \\ J_{3,1} &= 0, \\ J_{3,2} &= -a_2 c\theta_2 - a_3 c(\theta_2 + \theta_3), \\ J_{3,3} &= -a_3 c(\theta_2 + \theta_3). \end{aligned} \qquad (17) $$

PLC

Since the discarded robot is missing the controller cabinet, students are encouraged to develop their own control system on a PLC architecture. A PLC is a type of digital computer that is generally used in automation for electro-mechanical processes, typically for industrial use. A PLC can be controlled by a simulation program designed on a computer and it is equipped with a set of Digital Inputs (DI), Digital Outputs (DO), Analog Inputs (AI) and Analog Outputs (AO) or Pulse-width modulation (PWM) outputs. This kind of I/O interface is typically conform to strict industrial quality standards with protected inputs (often galvanically separated from the PLC by optocouplers) and outputs. The operating range is commonly at 24V or 4-20mA signal levels. These characteristics are relevant from a didactic point of view, giving the students the opportunity of experience a typical industrial architecture setup. Moreover, a PLC can be logically programmed in different forms, such as a ladder diagram, a structural text and a functional block diagram and stored in memory. These different programming possibilities give students the chance to learn different programming techniques and approaches. A PLC is an example of a hard real-time system since output

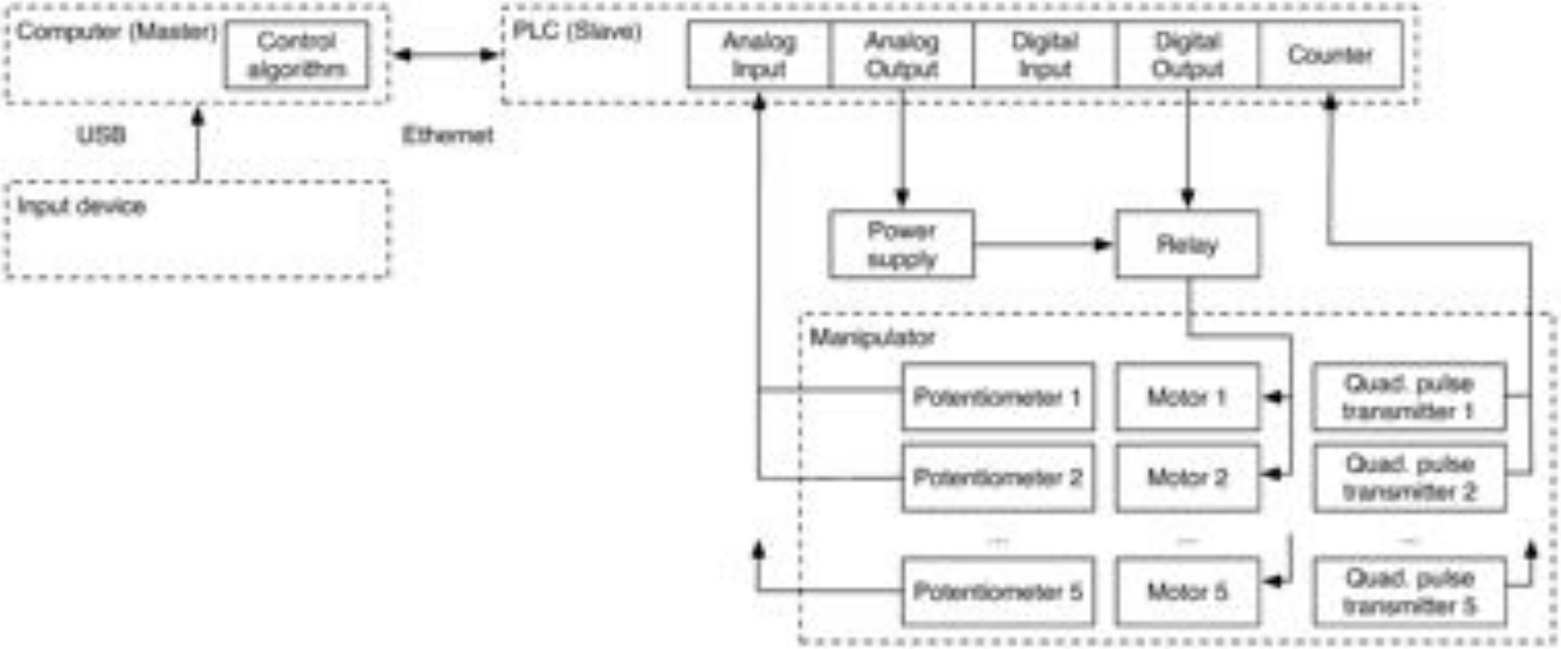


Fig. 3. The proposed control system architecture.

Fig. 4. A detailed photo of the potentiometer and of the quadrature pulse transmitter from one of the manipulator joint.

results must be produced in response to input conditions

Fig. 5. The *omega.7* haptic device from *Force Dimension* that was used as an input device.

Conclusion

Good experience with PBL

Inexpensive vintage equipment can give good basic knowledge / training.

Students work long hours to solve problems when they get instant feedback.

Thank you for your attention!

Questions?

REFERENCES

Callaghan, M., Harkin, J., Scibilia, G., Sanfilippo, F., Mc- Cusker, K. & Wilson, S. (2008), Experiential based learning in 3d virtual worlds: Visualization and data integration in second life, in ‘Remote Engineering & Virtual Instrumenta- tion, (REV 2008)’, REV.

Liu, C., Sanfilippo, F., Zhang, H., Hildre, H. P., Liu, C. &
Bi, S. (2012), Locomotion analysis of a modular pentapedal walking robot, in ‘Proceeding of the European Conference on Modeling and Simulation (ECMS)’, pp. 441–447.

Rekdalsbakken, W. & Sanfilippo, F. (in press), Enhancing undergraduate research and learning methods on real-time processes by cooperating with maritime industries, in ‘Pro- ceeding of the European Conference on Modeling and Simulation (ECMS 2014)’.

Thank you for your attention!

Questions?