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Robotics Practical

DOF BOX II:
Building a robot with several degrees of freedom (DOF)

Winter 2010

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2. Practical Presentation

You will be using what you learned in classical automation and mechanics classes and you will familiarize yourself as to how to best manage a robot with several degrees of freedom. Students will work in groups and will learn how to share the workload.

The project entails imagining, building and making a moveable robot with several degrees of freedom work. The robot must be able to move across a flat surface. As part of the project, you will program the robot to accomplish a simple task, namely to horizontally push a mass forward.

Students will be given 6 DDL modules (DOF BOX II). Each module contains 1 degree of motorized freedom, independently controllable and each module can be connected to one or several other equivalent modules.

Each student group will receive the following:

- One pack of 6 DOF BOX II modules.
- One I2C-RS232 translator making it possible to connect the system to a PC.
- A Power supply.
- Some tools (screw-driver, etc).

Task One: you will define the module and its control.
Task Two: you will analyze and synthesize the regulator for each DOF.
Task Three: you will build the robot, make it move and characterize its trajectory.

At the end of the practical, the robot will be photographed and a short demonstration will be filmed.

Preparation of the Practical:

You must have read the chapter entitled, “Preparation of the Practical”, prior to attending the first practical session.

Work submission:

The report and the codes of your practical have to be turned in – at the latest - one week after the last practical. You will have to upload your pdf report and a zip filed on moodle at a minimum one week after the last practical. The zip file has to contain all of your robot’s programming codes.

Evaluation:

You will be graded based on your report and on the video, and according to the global evaluation method of the class.

3. Presentation of the DOF BOX II

3.1. Generalities

The DOF Box II is a modular robot with one degree of motorized freedom as well as some motorized, electrical and communications connections that make it possible to connect the robot to one or more similar modules.

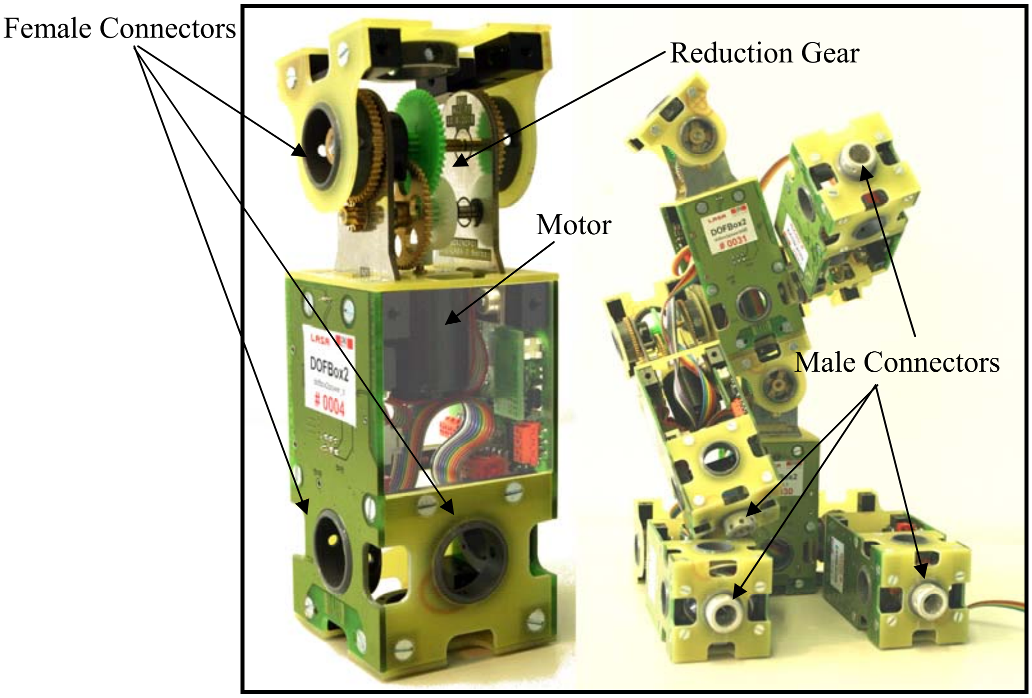

Figure 1: DOF BOX II mounted in a "Dog" shape.

The DOF Box II was created to test other differently assembled robots using as base a unique structure.

One DOF Box II contains:

- one DC motor
- a reduction gear
- a frame with several fixation points for other modules
- a logical electronic circuit for motor control
- a power electronic circuit for motor supply

3.2. Mechanics

3.2.1. Mechanical characteristics

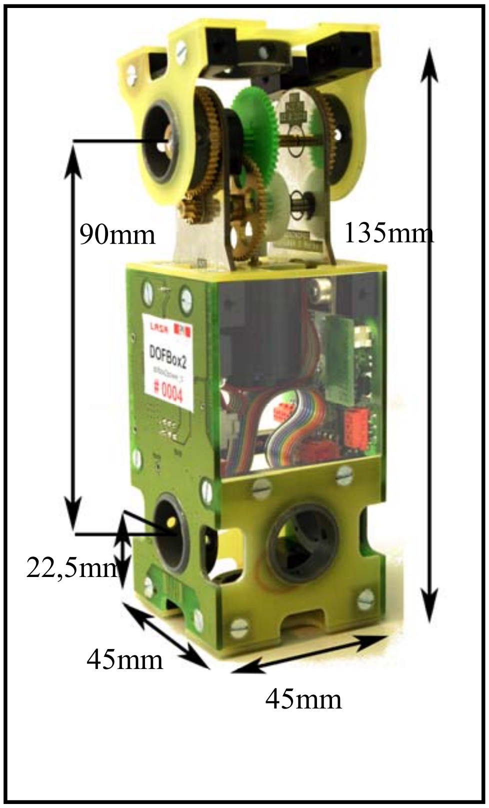

Figure 2: DOF BOX II

Mass:	180 g
Male connector's mass:	6 g
Maximum admissible torque:	~1 Nm
Height:	135 mm
Width:	45 mm
Center of gravity:	70 mm (in z)
Distance between connectors of the same plane:	90 mm
Rotation of the DOF:	+/- 90°

3.2.2. The motor

A **Faulhaber 2224012SR** motor is used in each DOF Box. The motor requires a continuous current and is powered by 12V.

Its principal characteristics are:

Nominal voltage:	$U_0 = 12$ V
Terminal resistance :	$R_{mot} = 8{,}71\ \Omega$
Torque constant :	$k_M = 14{,}5$ mNm/A
Rotor inductance:	$L = 200\ \mu H$
Rotor Inertia :	$J_{mot} = 2{,}7\ gcm^2$

The motor and the electrical control and power mechanisms are mounted on the main part of the frame. The reducer is mounted on this portion of the frame and it supports the center of the frame's 2nd part which is made up by 3 female connectors.

The motor module feeds the motor and receives the recorded values as well as all the PC initialization values via an I2C line (I2C bus). The module is doubly fed as it uses a 5 V line for the logic and a 9V line for the amplifications attacking the motor.

3.2.3. The reduction gear (r=192)

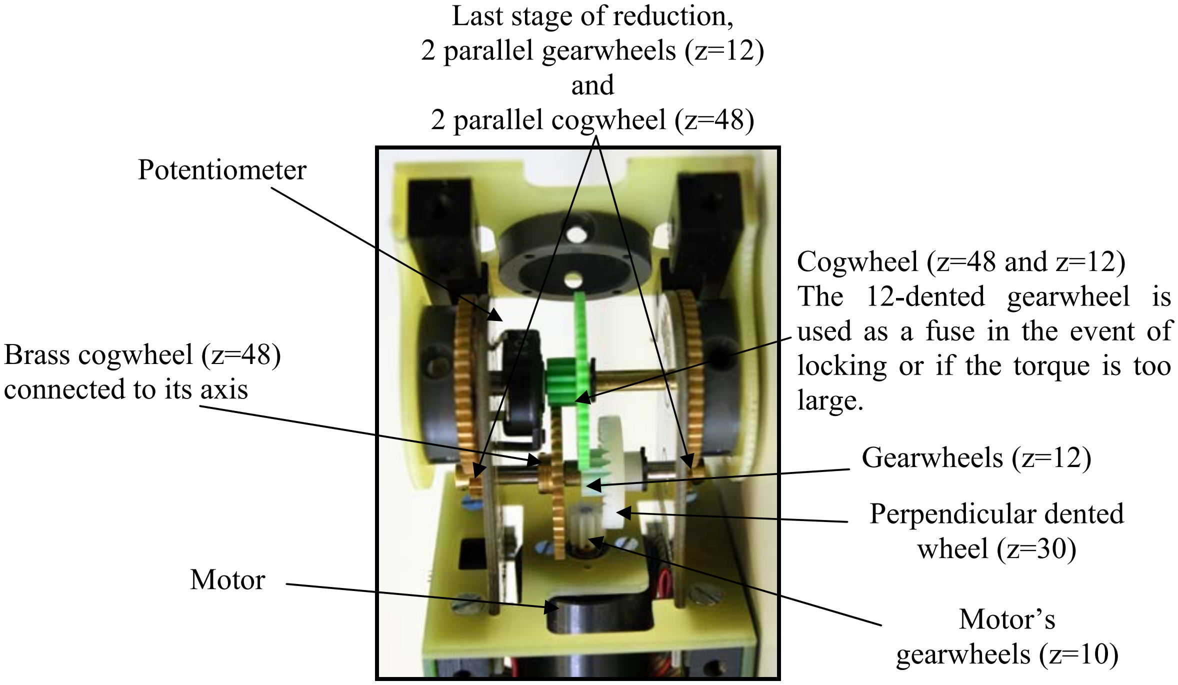

Figure 3: Reduction gear

3.2.4. The power bus and its connectors

Each DOF BOX II has 2 power connectors (Micromatch 4 SMD poles, female) and has to be fed. One or several flat cables (with 4 threads) with male connectors have to cover the robot to feed each module.

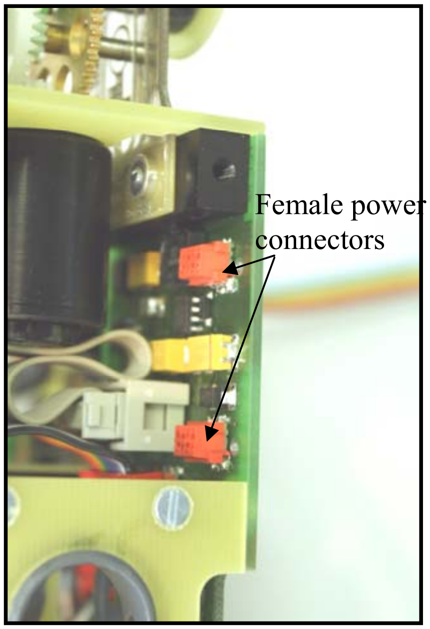

Figure 4: Female power connectors

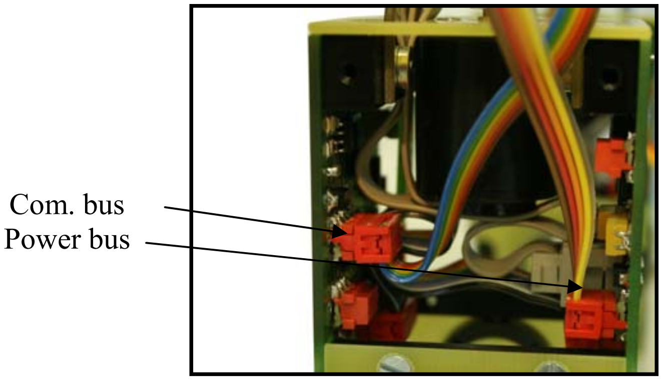

Figure 5: Connections of the power and communications buses

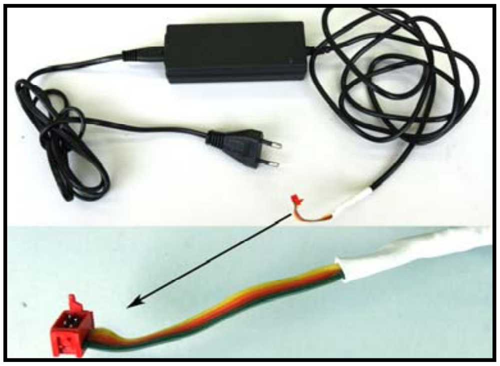

Figure 6: Continuous maximum feed 12V, 5A and its connector

A continuous external power supply of 12V feeds everything by connecting it to one of the power switches of one of the modules (anyone).

Openings are found at the each end (boundary) of the robot as well as through the PCB which supports the motor. Power buses (flat 4-cabled wires) and communication buses (flat 6-cabled wires which are reviewed in the following chapter) run through theses openings. Thus the cables are invisible and do not block the robot's movements.

3.2.5. The communication bus and its connectors

The communication bus is made up out of a flat 6-cabled wire fitted with male 6-poled Micromatch connectors. The connection is the same as for the power bus. The communication bus is connected to translator which is, in turn, connected to a PC control port. Please **be aware** that the two I2C connectors are on the same side as the power connectors. The 6 pole connector which is used for the UART bus is on the opposite side.

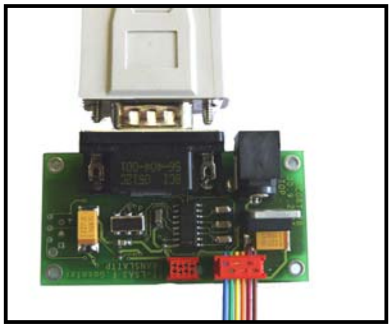

Figure 8: Translator between the PC socket and the I2C bus

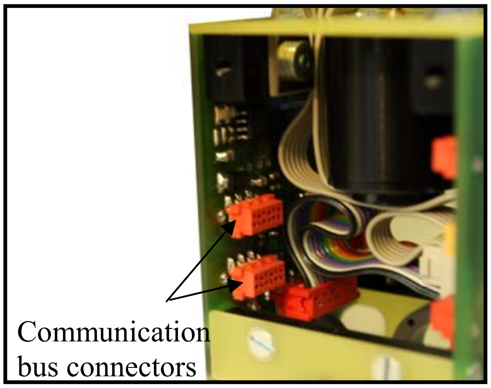

Figure 7: Female communication connectors

3.2.6. Cable openings

Several openings are built onto the sides of the DOF BOX II for the power and communications buses. Thus, the cables thread their way through the robot's internal structure, thereby not interfering with it movements.

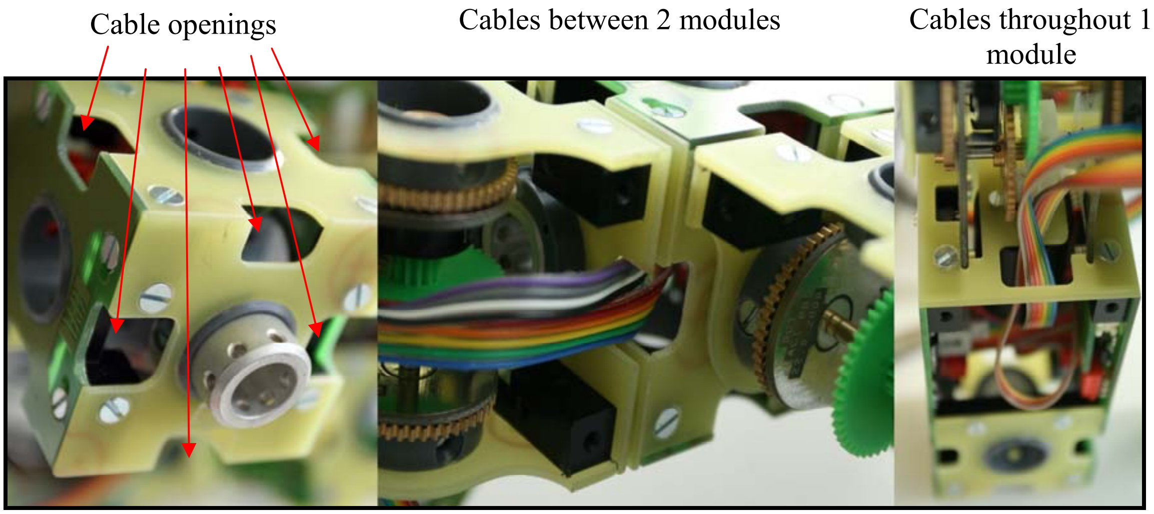

Figure 9: Openings for the communication and power buses

3.2.7. Mechanical connections

The modules have female connectors which are made out of a band containing 2 radial holes.

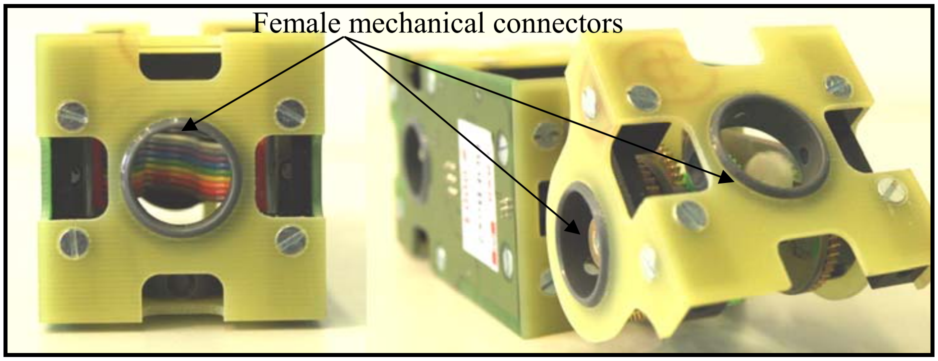

Figure 10: View of the mechanical female connectors

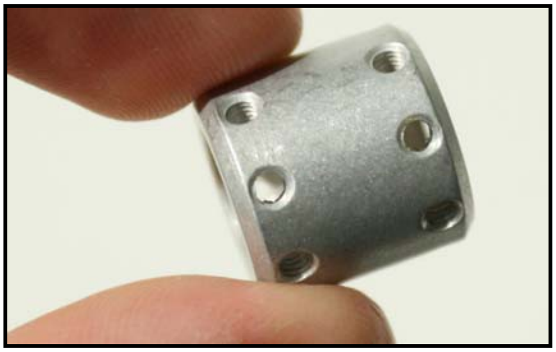

Figure 11: double male connecter

The double male connectors made out of aluminum tubes which hold (contain) radial tappings (M2,5) are placed between 2 female connectors.

Figure 12: Insertion of the male connector

The strength of the mechanical bond (linkage) is guaranteed by the 2 tight screws (M2,5) placed at 90 degrees (radially to the connectors).

Figure 14: Fastening of the male connector with a screw

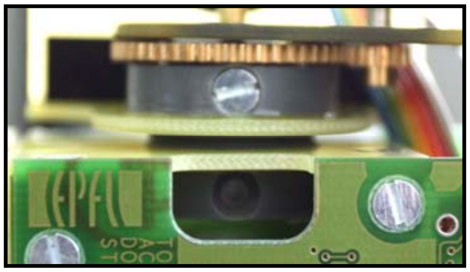

Figure 13: Double male connector between 2 female connectors

3.3. Control diagram

The DOF BOX II has a control system within its module. The box is controlled via a PID and the user can choose the ratio. One can control the box's position, speed and momentum (torque for a good quality DC motor). Several ranges are available to the user given him/her various options such as the frequency of the control samplings, measuring positions, control types, and desired position or velocities, etc.

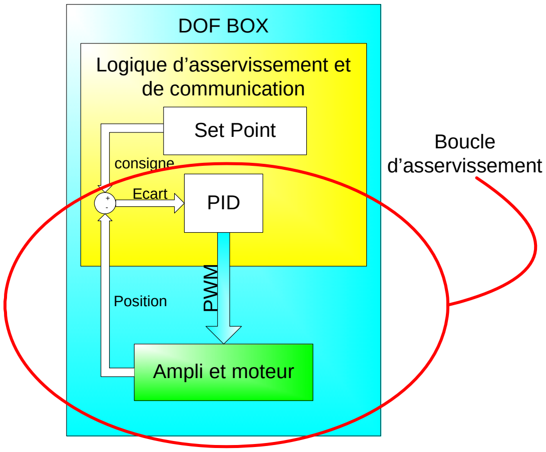

Figure 15: Schematic of the control diagram

Each module is connected to a communication bus I2C and to a power bus that provides the power needed by the system (for the system to run).

More complex controls, such as the creation (production) of the trajectory and possible referential changes are made by the PC that controls the system. The PC communicates with the system via a translator connecting the PC and the robot's I2C power line.

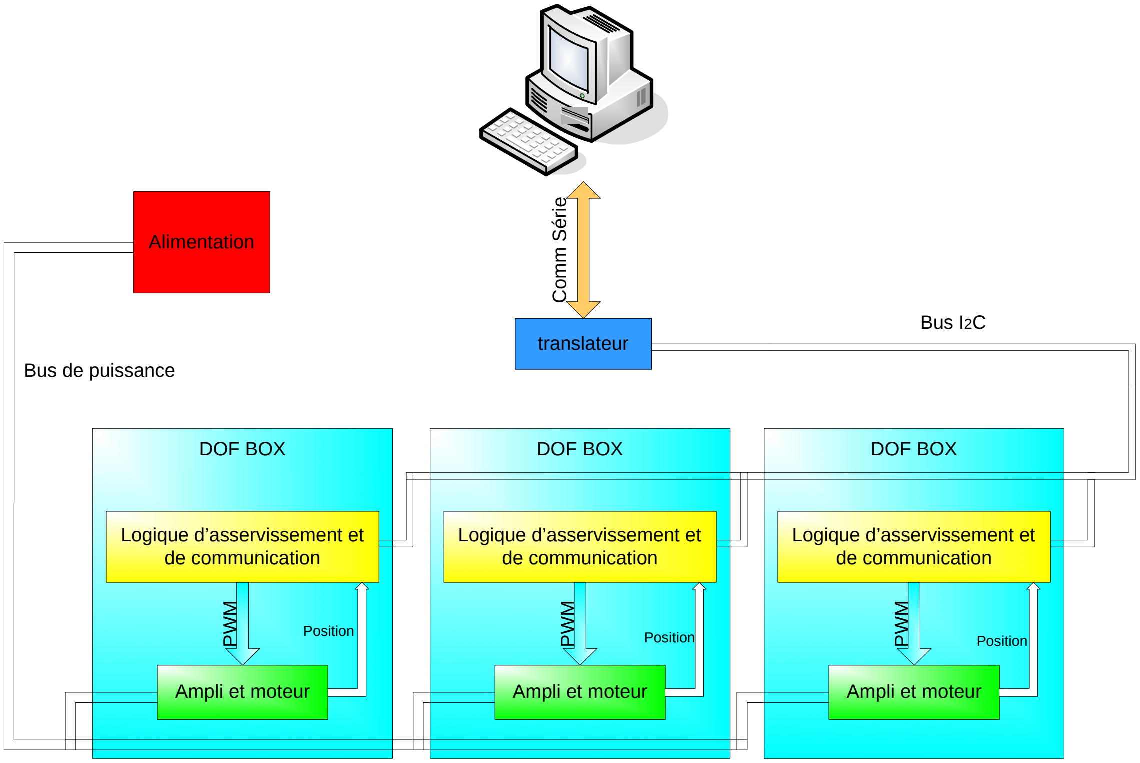

Figure 16: System's configuration diagram

Once the system is initialized and the control mechanisms are reviewed, one has to update the placement, speed and torque settings following the calculated trajectories.

4. Preparation of the Practical

4.1. To prepare for the first session

Please be sure to have reviewed the following prior to the first practical

- Exercise 1: Measurement of the reducer’s efficiency
- Exercise 2: Measurement of the reducer’s backlash
- Exercise 3: Determining the resolution of the encoder’s potentiometer
- Exercise 4: Computing the transfer function of DOF Box
- Exercise 5: Controller design
- Exercise 6: Evaluation of the controller performance

4.2. To prepare for the 2nd session

Please be sure to have the following completed prior to the 2nd practical

- Exercise 5: Controller design
- Exercise 6: Evaluation of the controller performance
- Exercise 7: Design the robot
- Exercise 8: Design a trajectory in the joint angle space.
- Exercise 9: Imagine and develop the robots’ different movement sequences
- Exercise 10: Evaluating the robot’s performance

Exercise 11 is bonus, and has maximum 5% of the total score.

!!!! BEWARE !!!!!

A torque higher than 1 NM can be generated by the DOF BOX II, which can be dangerous if used incorrectly. A wrong order or technical problem can make the robot behave/move unexpectedly and seriously harm the users. Please take all necessary precautions in order to avoid injuries.

5. Instructions

5.1. Information about the lecture notes

Required reading

Parts of the lecture notes, provided in annexes and taken from the automation and mechanical classes taught at EPFL are required in order to do the practical, these are highlighted in italics.

The rest of the lecture notes are provided for information purposes, as they contain general and important concepts.

Annexes

In addition to the above, you are provided with a C-code library to allow you to accomplish the required measurements. These are available in a zip file “DOFBox_SourceCode.zip”, which you can find on the class’s website.

Be sure to download and unzip the file. Copy the file into your work folder. Each code for each exercise is located in a separate. Thus, make sure to keep the structure of the folder embedded in the zip file. Should the program generate results, these can be found in the folder “results”.

Your report must contain all the results and the discussions that are indicated in the exercises.

5.2. Notations

P_{red_out}	Power at the output of the reduction gear	$[W]$
P_{red_in}	Power at the input of the reduction gear	$[W]$
μ_{red}	Efficiency of the reduction gear	
ω_{red_in}	Angular speed at the input of the reduction gear	$\left[{rad}/{s}\right]$
ω_{red_out}	Angular speed at the output of the reduction gear	$\left[{rad}/{s}\right]$
M_{red_in}	Torque at the input of the reduction gear	$[Nm]$
M_{red_out}	Torque at the output of the reduction gear	$[Nm]$
r_{red}	Reduction value	
u_{mot}	Motor voltage	$[V]$
R_{mot}	Terminal resistance of the motor	$[\Omega]$

i_{mot}	Motor current	$[A]$
L_{mot}	Rotor inductance	$[H]$
K_M	Torque Constant	$\left[{Nm}/{A}\right]$
Ω_{mot}	Angular speed of the motor	$\left[{rad}/{s}\right]$
M_{mot}	Mechanical torque at the output of the motor	$[Nm]$
M_{mot_el}	Electromechanical torque of the motor	$[Nm]$
M_{pert}	Perturbation torque	$[Nm]$
J_{mot}	Rotor inertia	$[kgm^2]$
J_{ch}	Payload inertia	$[kgm^2]$
J'_{ch}	Payload inertia on the motor output	$[kgm^2]$
θ_{mot}	Angular position of the motor	$[rad]$
θ_{out}	Angular position of the payload	$[rad]$
e	Error between desired value and the current value	Depends on the system
y_c	Desired value	Depends on the system
u	Controller value	Depends on the system
u_i	“Integration” component of the controller	Depends on the system
u_d	“Derivation” component of the controller	Depends on the system
K_p	Proportional gain of the PID controller	Depends on the system
T_i	Time constant of the integration term	$[s]$
T_d	Time constant of the derivation term	$[s]$
h	Time step of the A/D regulator	$[s]$
s	Frequency of the Laplace transform	
K	Transfer function of the controller	Depends on the system
H	Transfer function of the system	Depends on the system
G	Transfer function of the system in closed loop	Depends on the system
k	Discretized time value: $t \approx k \cdot h$	

5.3. First part: Characteristics of the DOF BOX II

The module will be characterized during this first part. The obtained results are needed to accomplish certain tasks from the second part (numerical applications).

5.3.1. Measurement of the reducer's efficiency

The reducer is used to increase (and decrease the speed) the robot's torque at the exit (output). The reducer is made out of 2 cogwheels mounted on 2 axes. The relation of the prongs between each wheel pair provides the reduction ratio of the couple in question. The product of the various reductions provides the total reduction ratio of the reducer. This reduction technique is commonly used but at a price of its efficiency. The prongs rub against each other to produce movement and the cogwheels are mounted on smooth platforms that also rub, thus the efficiency is not perfect. Generally, the larger the reduction efficiency turns out to be, the lower the efficiency will be and the larger the backlash will be and the more rigidity will be. An efficiency lower than 50% means that the system is no longer back-drivable.

In general, the reducer's efficiency is expressed using a constant such as:

$$\mu_{red} = \frac{P_{red\_out}}{P_{red\_in}} = \frac{\omega_{red\_out} \cdot M_{red\_out}}{\omega_{red\_in} \cdot M_{red\_in}} \Leftrightarrow M_{red\_out} = r_{red} \cdot \mu_{red} \cdot M_{red\_in}$$

where M_{red_in} and M_{red_out} are respectively, the entrance and exit torques of the redactor, r_{red} is the reduction value and μ_{red} is the reducer's efficiency. The formula is simplified for in reality the ratio is not constant and is depending upon the position, speed and load.

In addition, in order to make the system move, one usually needs an initial torque due to the static rubbing coefficient which is higher than the dynamic coefficient.

5.3.1.1. Exercise 1 (6%)

Measure the reducer's efficiency for a chosen model contingent on the charge (power) and on the position at a given speed (near motionless movement).

***Remarks**:*

- *The reduction value is 192*
- *You will find information about reducers related equations in the chapter "reducers and reductions' efficiency".*

5.3.1.1.1. Measurement protocol

We are going to try and measure the current used by the motor in order to measure the efficiency of the reducer. Thus we will be able to extrapolate the motor's torque during the vertical movement of a mass attached to a lever connected to the DOF BOX exit.

You are provided with the load – in this case a balanced bar (rod). A mass can be attached to the bar at certain specific points. Comparable loads at the reducer's exits are respectively 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5 Nm.

Please proceed as follows:

- Place the bar on the DOF BOX you wish to test
- Connect the DOF BOX (one time only) to the communication bus and the communication bus to the translator.
- Connect the power supply to the DOF BOX
- Start the "./Debug / Exe1_Reducer_Efficiency.exe" program
- Follow the instructions
- Once you have finished with your measurements and closed the program, start the script "plot_torque_data.m"

Look for the images of the corresponding graphs in the "figure" folder and the data in the "data" folder (in "data.mat" file).

5.3.1.1.2. Points for discussion

- *Insert the graphs that you find appropriate and insert possible comments*
- *Add your personal comments (5 lines at the most)*
- *Is it possible to identify a simple function linking the charge to the reducer's efficiency?*
- *Is it possible to identify a static/dynamic friction value? (5 lines maximum)*
- *Explain the deviations between the measurements. (5 lines maximum)*

Remember the following:

The standard deviation s of a list of numbers $y = [y_1; y_2; \ldots; y_n]$ is:

$$s = \sqrt{\frac{(y_1 - \bar{y})^2 + \ldots + (y_n - \bar{y})^2}{n-1}}$$

where $\bar{y}$ represents the mean value of y.

5.3.2. Measuring the backlash

One of the major drawbacks of using a reducer is its backlash. It can be prevented by “tightening the backlash” but in low cost projects such a complex technology is just not feasible.

5.3.2.1. Exercise 2 (6%)

Choose a model and measure the reducer’s backlash as a function of the position of a payload.

5.3.2.1.1. Measurement Protocol

One measures the reducer’s backlash taking as a function of the position of the payload. The motor will be placed in position by the encoder so as not to be dependent upon the backlash of the reducer. Should the regulator increase quite a bit at a low charge, then one can assume that the motor is blocked at a set point.

Steps to follow:

- Place the measurement tool onto the DOF BOX you wish to measure
- Connect the DOF BOX to the communication bus and the bus to the translator
- Connect the power to the DOF BOX
- Open the excel file “./data/Measuring_Reducer_Backlash.xls”
- Start the following program “./Debug / Exe2_Backlash.exe”
- Follow the instructions to increase or decrease the position setting
- Measure the distance at the end of the rod for each measuring position and insert your findings into the excel file.

5.3.2.1.2. Discussion Points

- *Be sure to insert the graph showing the reducer’s backlash as well as your own comments. The backlash takes into account a position at a low charge.*
- *Comment the reducer’s backlash (maximum 5 lines)*
- *Is the backlash dependent on the position – why and for what reason(s)? (maximum 5 lines)*
- *Insert a bar chart of the measured backlash regardless of the position, if logical. Calculate the spread of the values (if logical) and comment on the spread. Explain the points that do not make sense. (maximum 10 lines)*
- *Do your modules all appear to have the same backlash (without making accurate measurements and by comparing your results with those of other groups)? Explain the potential differences. (maximum 5 lines)*
- *Come up with other reduction ratios, compare them to the reducers with cogwheels and come up with an application that better fits them. Should this application work better that the cogwheel reducer? (maximum 10 lines)*

5.3.3. Characteristics of the encoder's potentiometer

Each module's degree of freedom can be measured in 2 ways:

- By placing a potentiometer at the motor's end (at the level of the exit pin)
- By 16 motor-turn encoder

By using a potentiometer one has the advantage of being able to measure an absolute position whereas a measurement using an encoder results in a zero set at the initialization (at the start) and depends upon the reducer's backlash. This is due to the measurement being done upstream (behind) the reducer.

The potentiometer is a measurable resistance and therefore subject to noise, whereas with the encoder one can proceed with incremental measurements. Thus, one can perfectly repeat the measurements after initialization unless a mistake in the count has occurred.

5.3.3.1. Exercise 3 (8%)

- Calculate the theoretical resolution of the encoder
- Measure the potentiometer's resolution measurement based on a specific module's position at a low payload (and with the direction of the payload being continuous)
- Create a graph and show the "position measured by the potentiometer" contingent on the "position measured by the encoder" and calculate the typical margin (deviation) between these two fixed points.

5.3.3.1.1. Measurement protocols

We will use the following method: set the encoder's starting point and then place the measuring bar at a 60^{o} angle before lowering it softly and letting the bar settle onto a previously placed obstacle. Using the obstacle, one is able to determine a set (fixed) position which depends neither on the encoder nor on the potentiometer. As the bar is stopped during its descent, the backlash is the same for each measurement. 10 measurements are carried out at 3 different positions. One will have to calculate the average and the typical deviation (distance) for each position in order to evaluate the precision of each collector.

Steps to follow:

- Place the measurement bar into the DOF BOX's axis that you wish to measure
- Connect the DOF BOX to the communication outlet (one time only) and the outlet to the translator
- Connect the power to the DOF BOX
- Start the following program, "./Debug/ Exe3_Resolution_Pot.exe"
- Follow the instructions

Once you are finished with the procedure, note that the "datam.txt" file contains measurements for the accompanying positions.

5.3.3.1.2. Discussion Points

- *Insert your calculation on the encoder's resolution*
- *Provide the mean and the standard deviation for each sensor and for each position*
- *Itemize in a few words the advantages and disadvantages of these 2 position measurement methods (maximum 5 lines)*
- *How can one initialize the position with an encoder? What are your comments on the security aspects (if applicable) when measuring a position with an encoder? (maximum 5 lines)*
- *Come up with an application for which it would make more sense to use an encoder and one for which it would be better to use a potentiometer and also specify the implementation specifics. Justify your comments (maximum 5 lines)*

5.4. Second Part: Control of one Module

One the robot is assembled, the system which you will be controlling can be viewed as follows:

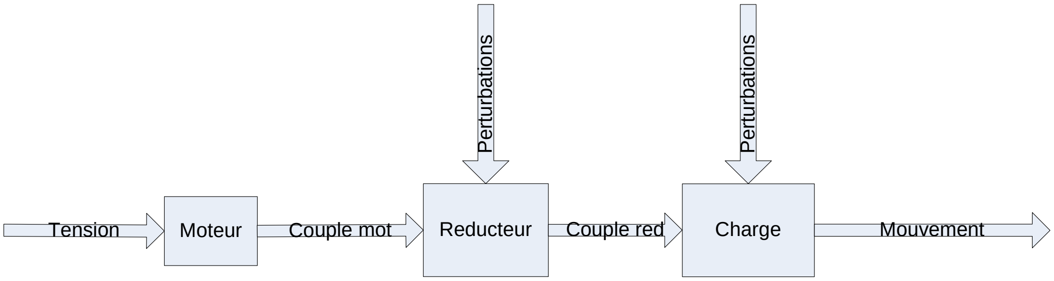

Figure 17: Drawing of the system you want to control

Assuming that:

- All elements are linear
- The charge is constant

By relating the charge's inertia and the perturbations at the motor's level, one comes up with the following linear system:

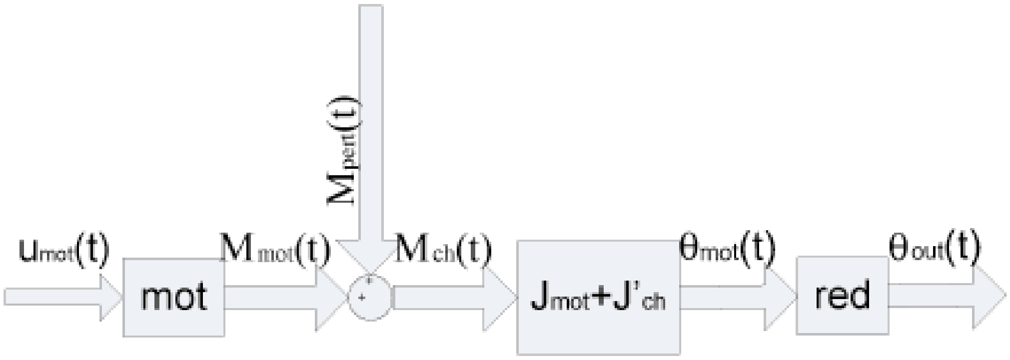

Figure 18: Simplification and linearization of the system one wants to control

5.4.1.1. Exercise 4 (10%)

Calculate the transfer function of this system taking into account that the motor is practically motionless (di/dt = 0) and without taking into account any disturbances. Calculate everything again taking disturbances into account.

5.4.1.1.1. Discussion Points

- *What are the hypotheses done in order to be able to consider the system as a linear system?*
- *Insert the equations and the calculations which will enable you to come up with the transfer function of the system you want to control (*$\frac{\theta_{out}(s)}{U_{mot}(s)}$ *or* $\frac{\theta_{mot}(s)}{U_{mot}(s)}$*).The power of the motor is controlled by the PWM value (-128 to127) and the position at the reducer's exit varies from -90 to 90 on the entirety of the module's range of movement (*180^o*). Infer the transfer function* $\frac{POS(s)}{PWM(s)}$ *where pos is the position coded within the register of the module's positions and PWM is the value of the PWM generated by the module on the power bridge?*
- *How is the dry friction imitated in the transfer function and what does that mean (imply) in terms of regulation? (maximum 5 lines)*

5.4.2. Design of the controller

The measurement and control sampling frequency is 264Hz. One wants to size a PD regulator for the previous system using the following specifics and taking into account that the inertia of the charge is of 5,52 gm^2.

Specifics of the closed loop system in position control

- The cut-off frequency of the closed system is higher or equal to 15 Hz
- An integral term is not wanted (PD and not PID)
- One should not exceed the set point by 15% during a unit jump of the command

5.4.2.1. Exercise 5 (10%)

Size the PD regulator following the specifics below.

Comments:

- Take into account the reduction gear efficiency as a parameter in order to compute the control parameters. You will proceed with a numerical application during the practical using the items measured in exercise 1.
- Chapters 8 and 9 of [1] (Numérisation et synthèse discrète) provide a review on summarization and synthesis in Bode's diagram of an analog reducer.
- A charge of 5,52 gm^2 is provided during the practical

The coded algorithm found in the DOF BOX II box does not include the low-pass filter in the derivator). It also uses the 2nd Euler method for the term integral (please refer to the chapter entitled, “Reminder about the digitalization of an analog regulator”)

$$e(k) = y_c(k) - y(k)$$

$$u_i(k) = u_i(k-1) + \frac{h}{T_i} e(k)$$

$$u_d(k) = \frac{T_d}{h} \cdot (e(k) - e(k-1))$$

$$u(k) = K_p \cdot (e(k) + u_i(k) + u_d(k))$$

The value of KP, KD, KpDivpos and KdDivPos ranges that are considered as parameters for the PID on the DOF BOX II can be deduced from the following equations:

$$K_p = KP \cdot 2^{-KpDivPos}$$

$$K_d = KD \cdot 2^{-KdDivPos}$$

$$K_d = K_p \cdot T_d$$

5.4.2.1.1. *Discussion Points*

- Discuss how you identified the parameter values Kp and Td of your regulator and be sure to pin-point the parts of the text-book helped you.
- Calculate the values of the Kp, KpDiv, Kd and KdDiv of the module remembering that the PID calculation in the DOF BOX was conducted over 16 bits according to the method explained earlier.
- Insert the calculations (or reasoning) that enabled you to find the closed loop dynamics of your control system as well as the dynamics of its controller.

5.4.2.2. Exercise 6 (10%)

- Calculate the closed-loop dynamics
- Measure the closed-loop dynamics
- Calculate the deviation of the position
- Measure the deviation of the position
- Show and explain the observed/noted differences

Question: defend why you chose a particular cut-off frequency for the closed-loop system.

5.4.2.2.1. Measurement Protocol for Exercise 6

We are going to analyze the dynamics of the closed loop system by measuring the response of the system to step inputs in position instead of performing harmonic tests, assuming that the system is functioning well.

Steps to follow:

- Pin the load you want to measure onto the DOF BOX
- Connect the DOF BOX to the communication outlet (one time only) and the outlet to the translator
- Connect the power to the DOF BOX
- Start the following program, « ./Debug/Exe6_Dynamics.exe»
- Follow the instructions
- Launch the "plot_step.m" script once you have closed the program and finished with your measurements

The graphic images can be found in the "figures" folder and the data in the "data" folder (the data is found in a data.mat file)

5.4.2.2.2. Discussion Points

- *Insert your graphs of step responses.*
- *Interpret the above mentioned graphs. How does one deduct the band-pass of the closed loop system (taking into account a hypothesis that the closed loop system is like a first order system). What happens when one has large amplitude differences? How does one interpret these differences according to the modelization of the linear system that is controlled? Complete the system you want to control by inserting blocks that will help you take into account what you have observed (10 lines maximum).*
- *Does the system you have measured match your predictions? What are the differences and where do they come from (5 lines max).*

5.5. 3rd Part: Building a Robot

You will design, build, control and describe a robot in this 3rd and last part of the practical. The robot will be able to do the following:

- Move forward and backwards
- Be able to move an object or be able to apply a horizontal pressure of 1N on an exterior object

5.5.1. Steps to Follow

5.5.1.1. Exercise 7 (7%)

Design a robot able to follow the 'Scope Statement' listed above. Refer to the chapter entitled "Presenting the DOF BOX II"

5.5.1.1.1. Discussion Points

- *Explain what you did to conceptualize your robot*
- *Insert a photo of your robot*

5.5.1.2. Construction

Build your robot. This entails:

- Building your robot
- Correctly connect the power and communication cables/joints
- Connecting the communication bus to the translator
- Connecting the PC cable to the translator
- Connecting the power to one of the robot's outlets

5.5.1.3. Exercise 8 (7%)

Design a trajectory in the joint angle space.

5.5.1.3.1. Discussion Points

- Design and represent (drawings) the different movement sequences of the robot that are used for the displacement.

5.5.1.4. Exercise 9 (16%)

Code a short program in C (or C ++) with which one can control the robot. The robot should be able to move over one dimension as well as forwards and backwards. Be aware that your final grade will include the code you created, taking into account its focus, modularity, observations, interface, etc) as well as the video showing the robot's movement.

Comments: You will find everything you need in the "Code_Example" folder which is located on the class's website, (lasa.epfl.ch). In addition, you can find an example that can be used for a "doggie" robot.

5.5.2. Characteristics of the robot

5.5.2.1. Exercise 10 (10%)

- Measure how fast the robot moves traveling further than 50 cm (in one direction and back and forth), measuring only the average speed.

- Measure how far the robot travels and, on a graph, depict (show) several repetitions of the same movement. Create a bar chart showing your results and be sure to comment. Also create a chart showing the distance vs. the traveled distance (be sure to depict the mistake) and be sure to comment.

5.5.2.1.1. Discussion Points

- *Insert a bar chart showing how fast your robot traveled over 50 cm and comment on the results (5 lines maximum).*
- *Create a bar chart showing how far your robot moved according to a specific movement sequence (10 repetitions minimum).*
- *Provide the average distance traveled as well as the typical difference (gap).*
- *Can odometry be used to localize the position of the robot? Explain why and if not, come up with a different positioning method suited to your robot's geometry. (5 lines max).*

5.5.3. Movements of a mass

Several masses are available and the purpose of this section is to determine the maximum mass/load a robot is able to move.

5.5.3.1. Exercise 11 (10%)

Use what you were given to figure out how heavy a load a robot can move.

5.5.3.1.1. Discussion points

- *What is the maximum mass/load a robot is able to move? Is the robot suited to move a load?*
- *Come up with an equation which shows the robot's ability to move a load. The equation will be based upon your robots mechanical measurements (known or measured). Provide your comments. (5 lines max)*

The End

Congratulations

A short video, showing your robot in movement will be done.

6. Reminder about reduction gear and reduction coefficient:

Reduction coefficient:

$$r_{red} = \frac{\omega_{red\_in}}{\omega_{red\_out}}$$

Charge inertia at the motor level:

$$J'_{ch} = \frac{J_{ch}}{r_{red}^2}$$

Comparisons between torques (hypothesis: zero friction)

$$M_{red\_out} = r_{red} \cdot M_{red\_in}$$

With the hypothesis of a constant dry friction:

$$\mu_{red} = \frac{P_{red\_out}}{P_{red\_in}} = \frac{\omega_{red\_out} \cdot M_{red\_out}}{\omega_{red\_in} \cdot M_{red\_in}} \Leftrightarrow M_{red\_out} = r_{red} \cdot \mu_{red} \cdot M_{red\_in}$$

7. Reminder about DC motors:

Voltage of a DC motor:

$$u_{mot}(t) = R_{mot} \cdot i_{mot}(t) + L_{mot} \cdot \frac{di_{mot}(t)}{dt} + K_M \cdot \Omega_{mot}(t)$$

In quasi-static mode, one has

$$u_{mot}(t) = R_{mot} \cdot i_{mot}(t) + K_M \cdot \Omega_{mot}(t)$$

The motor torque is:

$$M_{mot\_el} = K_M \cdot i_{mot}(t)$$

With the hypothesis that viscous friction and other mechanical loss of the motor are negligible, one has:

$$M_{mot} \approx M_{mot\_el}$$

8. Reminder about digitization of a analog controller

The PID is usually digitally implemented, whereas the system one wishes to control is analog. What one normally does is to design an analog regulator prior to digitalizing it. There are several digitization methods and have both advantages and disadvantages (ease of implementation, computation speed, stability, etc). The following method is simple and intuitive and can be used to make simple checks. What follows derives from [1].

The PID analog regulator is of the following form:

$$K(s) = K_p \cdot \left(1 + \frac{1}{T_i s} + \frac{T_d s}{1 + \frac{T_d}{N} s} \right)$$

The regulator contains a filter in the derivation term Td/N. N is normally between 3 and 20 and can also be disregarded during the synthesis. One normally sees the following case, where N ->∞ (thus without filter).

The standard form of the proportional controller with the 2nd Euler method and with the integrator of the first Euler method is:

$$K(z) = K_p \cdot \left(1 + \frac{\frac{h}{T_i}}{z - 1} + \frac{N \cdot (z - 1)}{\left(1 + N \frac{h}{T_d} \right) \cdot z - 1} \right)$$

The algorithm now ready to be implemented as follows:

$$\begin{aligned}
e(k) &= y_c(k) - y(k) \\
u_i(k) &= u_i(k-1) + \frac{h}{T_i} e(k-1) \\
u_d(k) &= \frac{T_d}{T_d + Nh} \cdot \left(u_d(k-1) + N \cdot \left(e(k) - e(k-1) \right) \right) \\
u(k) &= K_p \cdot \left(e(k) + u_i(k) + u_d(k) \right)
\end{aligned}$$

The algorithm coded in the DOF BOX II does not include a low pass filter and uses the 2nd Euler method for the integral term

$$
\begin{aligned}
&e(k) = y_c(k) - y(k) \\
&u_i(k) = u_i(k-1) + \frac{h}{T_i} e(k) \\
&u_d(k) = \frac{T_d}{h} \cdot \left(e(k) - e(k-1)\right) \\
&u(k) = K_p \cdot \left(e(k) + u_i(k) + u_d(k)\right)
\end{aligned}
$$

9. Bibliography

[1] Longchamp, R. (1995). Commande numérique de systèmes dynamiques. Presse Polytechnique et universitaires romandes. Lausanne.
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[3] Daidié, D (2005) Création d’un robot mobile à plusieurs DDL. LASA, Ecole Polytechnique Fédérale de Lausanne.