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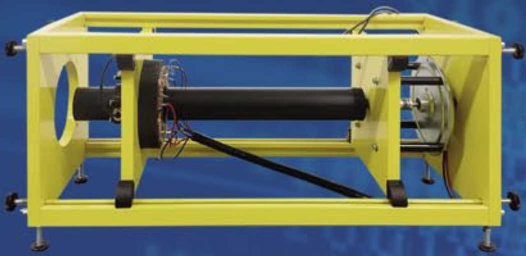
Study control algorithms using INTECO systems

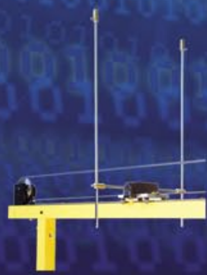


Magnetic bearing

Two-wheeled unstable transporter

Tower Crane

Modular Servo



Pendulum & Cart

Anti-Lock Brake

Multi Tank

Aerodynamical Rotors

Magnetic Levitation

3D Crane

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INTECO

Company profile and its customers

INTECO provides educators and researchers with innovative, cost-effective training systems in the fields of automation, robotics, instrumentation and process control. INTECO is the leader in the design and manufacture of mechatronic systems for the real-time control design and implementation. The company employs highly qualified staff and maintains close links with the industrial and educational world. Many product designs originate from universities. A majority of fabrication is exported. These systems are a mainspring to automatic control laboratories and become essential equipment for lecturers and researchers at universities and technical schools.

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Two-Wheeled Unstable Transporter

Autonomous real-time control of a mobile vehicle

Two-Wheeled Unstable Transporter is an example of quite a complex control system. It is obliged simultaneously meet two control algorithms. The first one is a master regulator. It is responsible to maintain the transporter in the upper unstable equilibrium point. The second one has to follow the predetermined trajectory of the vehicle. Linear quadratic regulators in various forms serve in both control algorithms. To achieve the stabilization goal we need to measure the angle of the transporter pin deviation from the vertical position. This angle is measured due to the combined sensors on the single ADIS device containing an accelerometer and a gyroscope. To stabilize the inherently unstable system it is required the measurement of the deviation of the system from the vertical and the measurement of angles of rotation of both wheels on an ongoing basis. The rotation angles are obtained from the encoders.

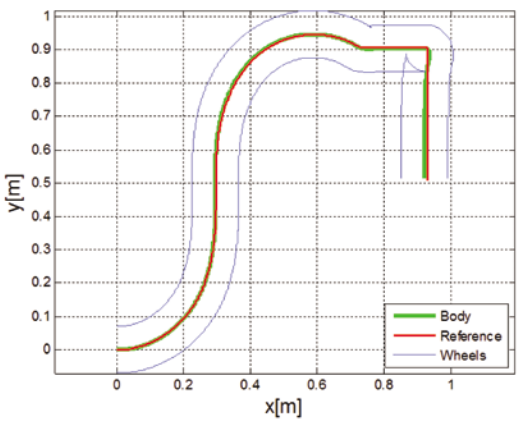
To actuate the transporter the wheels are driven by the PWM signals generated by a notebook or a PC controllers. In principle, systems manufactured by INTECO are based on the same educational approach. At the beginning, control algorithms are built as models, at MATLAB/Simulink or other platforms. Fig.1. The figure on the left shows a simulation trajectory of the transporter model.

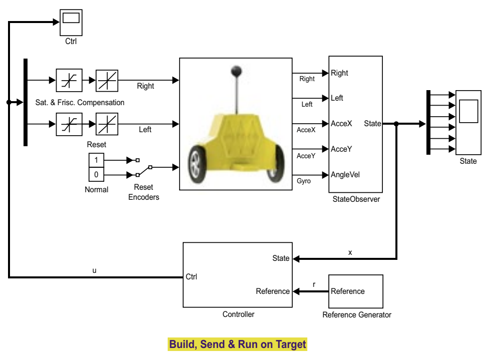
Finally, the simulated controller is transferred to the real-time system. Fig.2. The figure on the right illustrates the real real-time driver. The same controller is applied that has been previously simulated. The special “Built Send & Run on Target” button activates the real-time control procedure. To control in real-time several steps are required: the FPGA of the board RT-DAC/PCI-D has to be reconfigured to communicate with the ADIS device to conform its SPI protocol; the interface has to be built in a form of S-function to get access to measurements and control signals.

Hardware:

- Autonomous unit, wireless communication with the command input computer and trajectory visualization output computer, battery powered
- 2 DC motors equipped with gears PWM controlled

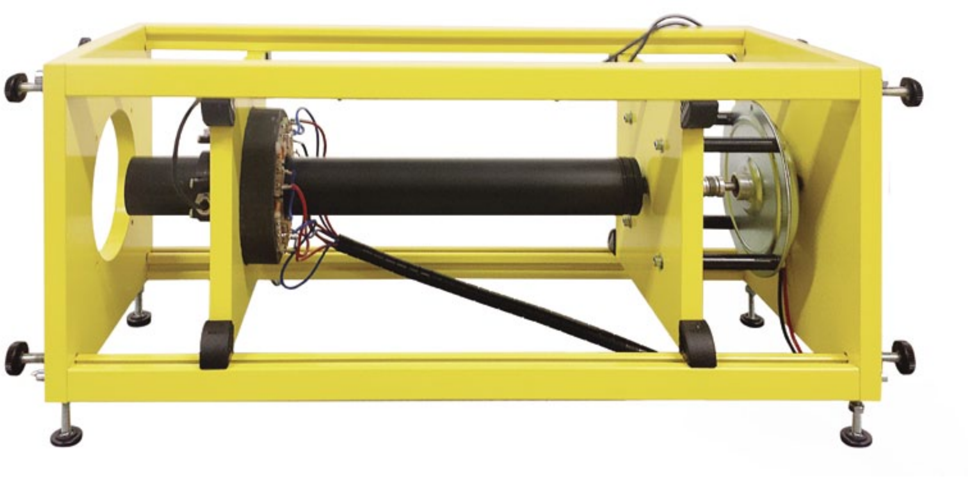
Dimensions: 440x350x600 mm





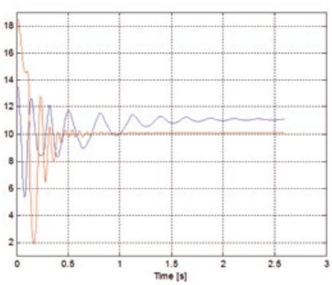
Magnetic Bearing

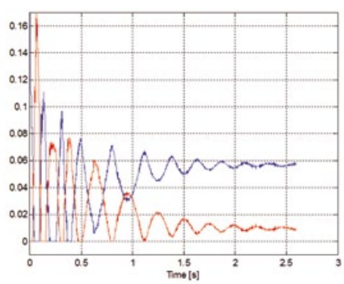
Demonstration of a gap adjustment among the shaft and bearing

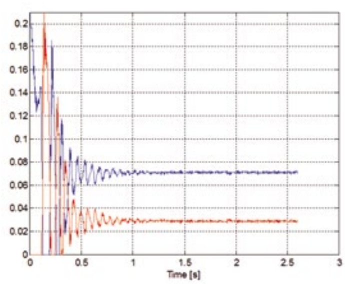


The Software for the magnetic bearing is dedicated to two hardware platforms: FPGA and Real-Time.
FPGA supports measurements of the following sensors:
-the position of the shaft relative to the magnetic bearings,
-the angular position of the shaft.
FPGA generates also six PWM signals to control the following actuators:
-four coils of the bearing,
-the DC motor driving the shaft,
-the disturbance (a change in the shaft imbalance).
The imbalance measured in [µm] is shown in the figure on the left. The initial 14 µm gap at x axis is reduced to 11 µm gap. Similarly at y axis the initial 18.5 µm gap is reduced to 10 µm gap.
If shaft is loaded (disturbed) it can be adjusted in a few seconds. The rotor dynamics is configurable due to the active magnetic bearing control. In fact, the shaft is actuated by the magnetic field generated by four control currents. The two control currents are flowing into two coils associated with the x-axis (see the figure in the middle). The other two currents are flowing into two coils associated with y-axis (see the figure on the right). The time diagrams in both figures are scaled in volts; however these signals are proportional to the currents of the coils.
The main control algorithm runs on the RT platform. There are also procedures for monitoring and / or data acquisition process. Magnetic bearing control is carried out in the MATLAB / Simulink environment using toolboxes that enable the automatic generation of real-time tasks.

Hardware:
-frame equipped with the magnetic bearing and an ordinary bearing, rotating shaft, DC motor and coupling
-power interface
-RT-DAC I/O internal PCIe board
Dimensions: 200x230x590 mm







Multi Tank

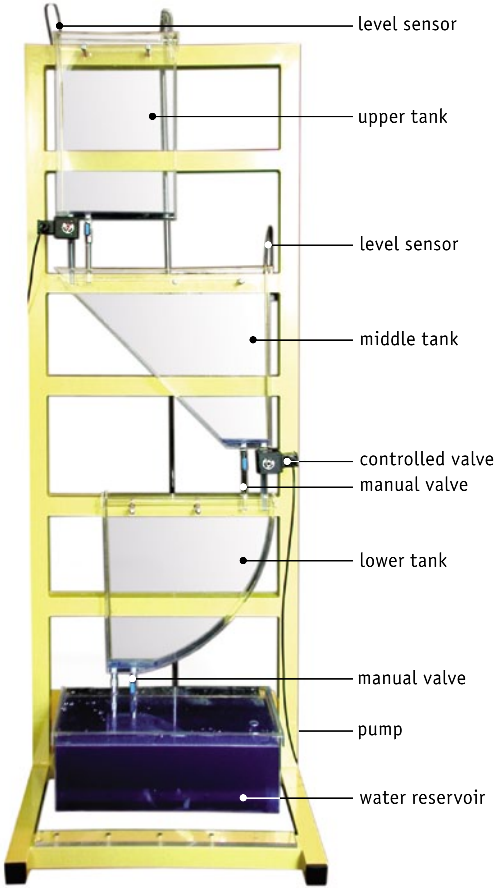
Practical verification of advanced linear and nonlinear control methods

The Multitank System comprises a number of separate tanks fitted with drain valves. Two of the tanks have varying cross sections. These introduce nonlinearities into the system. A variable speed pump is used to fill the upper tank. The liquid outflows the tanks due to gravity. The tank valves act as flow resistors. The area ratio of the valves is controlled and is used to vary the outflow characteristics. Each tank is equipped with a level sensor.

The general objective of the control is to reach and stabilize the level in the tanks by an adjustment of the pump operation or/and valves settings. This control problem can be solved by a number of level control strategies ranging from PID to adaptive and fuzzy logic.

The Multitank System is designed to operate with an external PC-based digital controller. The computer communicates with the level sensors, valves and pump by a dedicated I/O board and the power interface. The I/O board is controlled by the real-time software which operates in the MATLAB/Simulink environment.

A dedicated library of controllers and Simulink models support the Multitank system.



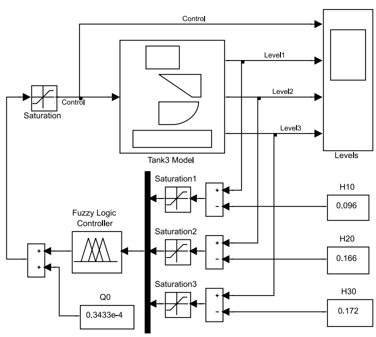
Hardware:

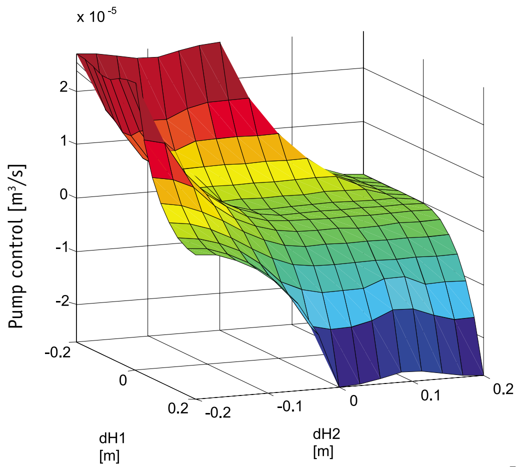
- -3 tanks made of acrylic glass
- -2 controlled valves
- -3 manual valves
- -pump: variable flow, driven by 12 V DC motor
- -3 level sensors, piezoresistive
- -interface and power supply unit
- -RT-DAC I/O internal PCIe or external USB board (the PWM control and encoder logics are stored in a XILINX chip) or the single board RIO or a PLC

Dimesions: 700x600x1650 mm

The fuzzy Simulink control model and fuzzy surface generated as the control result are shown in the figures below.

Fuzzy Controller





ABS Antilock Braking System

The automotive engineering system to control the wheel slip

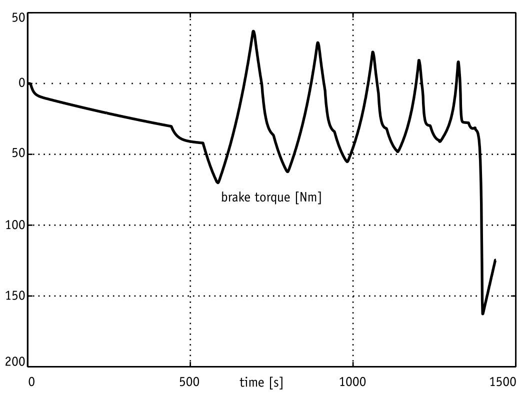
Antilock Braking Systems are designed to optimize braking effectiveness while maintaining car controllability. The ABS model is driven by a flat DC motor steered from a PC.
There are two encoders measuring the rotational angles of two wheels. At the beginning of an experiment the wheel simulating the relative road motion is accelerated to an assumed threshold velocity. The car wheel accelerates following the rotational motion of the imitating road wheel. If the threshold velocity is achieved a braking procedure starts. If the car wheel becomes motionless it means that it remains in slip motion (the car velocity is not equal to zero) or it is absolutely stopped. The less the slip the better is car control.
One of the pre-programmed slip control algorithms can be applied. The results of this experiment are shown in the figures below.

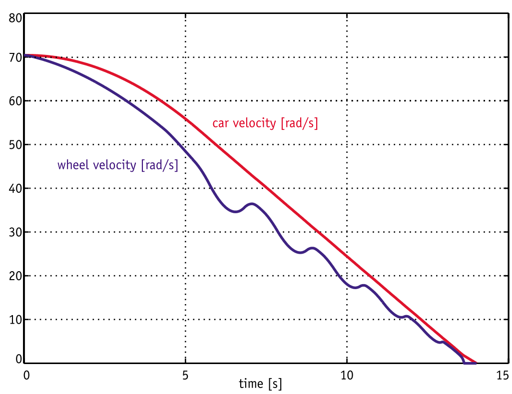
Hardware:

- mechanical unit: rigid frame, double wheel, DC high-torque flat motor, electromechanical brake and shock absorber
- position sensors: incremental encoders
- interface and power supply unit
- RT-DAC I/O internal PCIe or external USB board (the PWM control and encoder logics are stored in a XILINX chip) or the single board RIO or a PLC

Dimensions: 480x370x540 mm

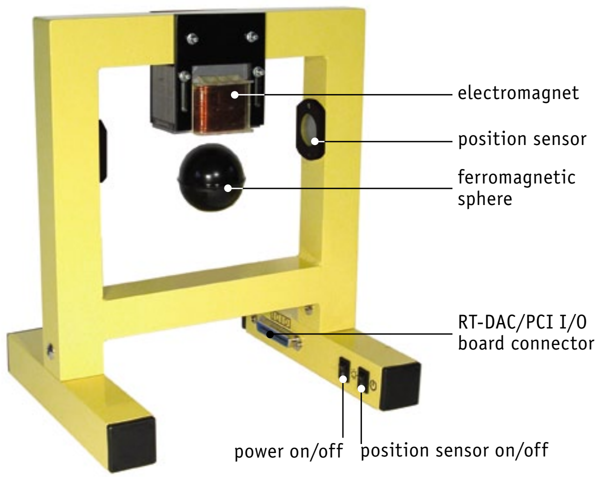
Result of experiment; slip=20%; bang-bang control





Magnetic Levitation Systems

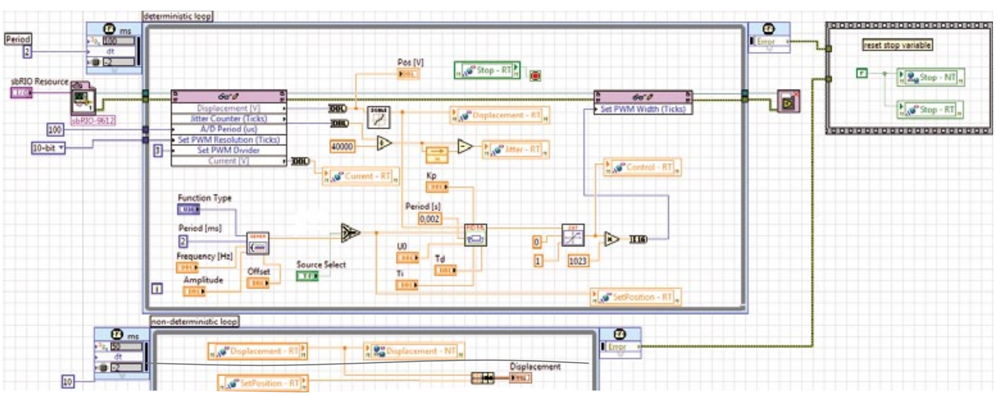
The frictionless electromagnetic control systems



The Magnetic Levitation System (MLS) is a nonlinear, open-loop unstable, time varying and frictionless, dynamical system. The basic principle of MLS operation is to apply the voltage to an electromagnet to keep a ferromagnetic sphere levitated. Moreover, the sphere can follow a desired position value varying in time. The coil current is measured to examine identification and to perform control strategies. To levitate the sphere a real-time controller is required. The equilibrium stage of two forces (the gravitational and electromagnetic) is maintained by the controller to keep the sphere in a desired distance from the electromagnet. The system is fully integrated with MATLAB/Simulink and operates in the real-time in MS Windows. This feature extends MLS application and is useful in robust controllers design. In the case of two electromagnets the lower one can be used for an external excitation or as a contraction unit. Alternatively, a PC equipped with Single Board RIO of National Instruments with the power interface can be used. A fragment of the LabVIEW controller is shown in the figure below.

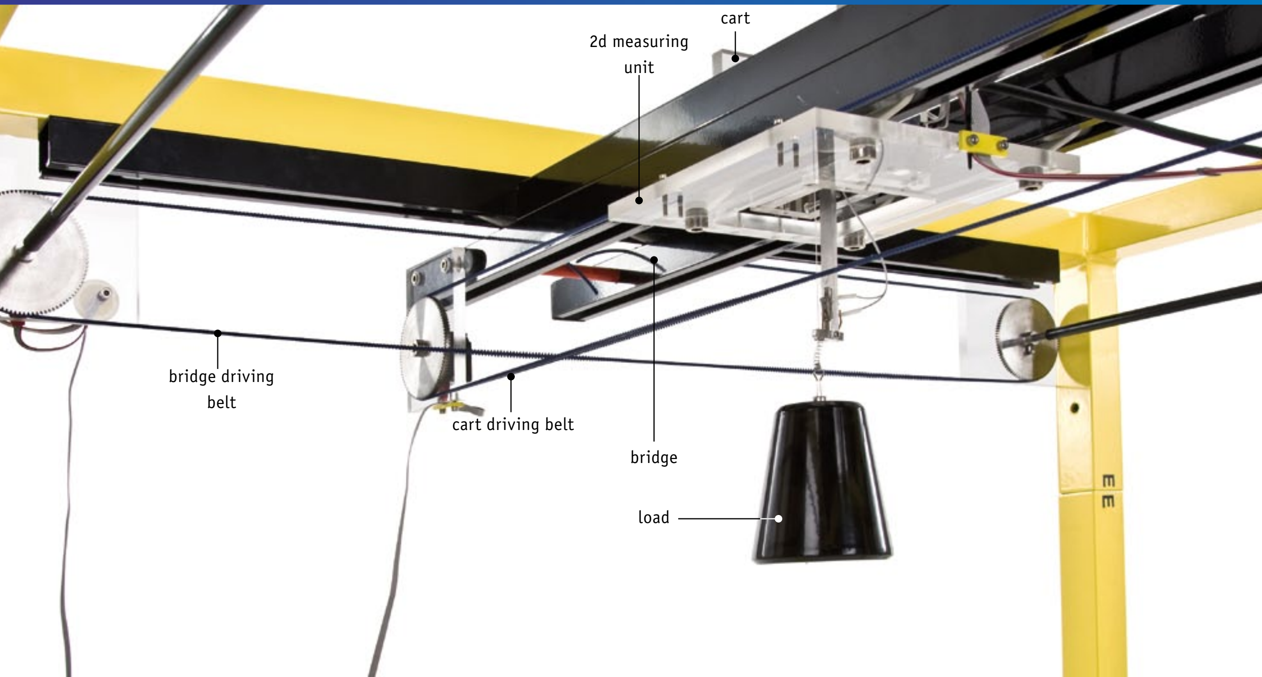
Hardware:
- -electromagnet
- -ferromagnetic sphere
- -position sensor
- -current sensor
- -power interface
- -the single board RIO (the PWM control and encoder logics are stored on the board) or RT-DAC I/O internal PCIe or external USB board (the PWM control and encoder logics are stored in a XILINX chip) or a PLC

Dimensions: 280x280x390 mm



3D Crane

Laboratory model of industrial gantry crane controlled from PC

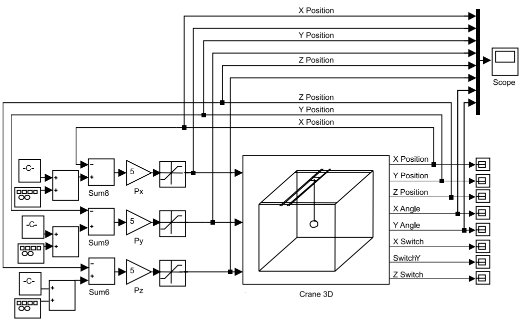


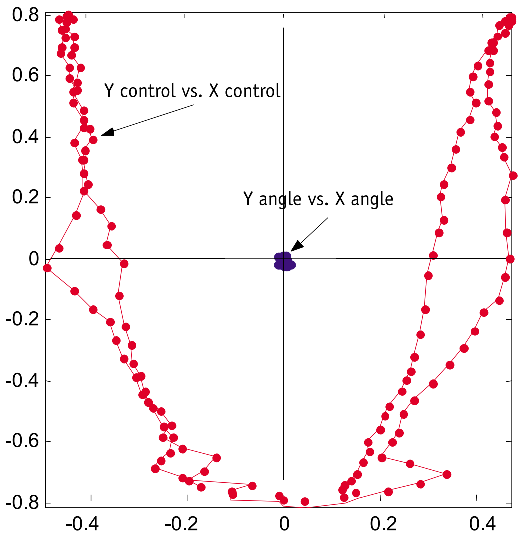
The three-dimensional model of industrial crane is a highly nonlinear MIMO system equipped with a dedicated system of sensors – the unique 2D angle measuring unit. The system is integrated with MATLAB/Simulink and operates in the real-time. The software enables rapid prototyping of real-time control algorithms. The C-code writing is not required. 3D Crane is delivered with the library of basic controllers. The model has three controlling DC motors and five angular position measuring encoders. An example of the 3D P controller is shown in the left figure.
The figure on the right shows the effect of the P control stabilized motion.

Hardware:
- PWM controlled 3 DC motors
- interface and power supply unit
- RT-DAC I/O internal PCIe or external USB board (the PWM control and encoder logics are stored in a XILINX chip) or the single board RIO or a PLC

Dimensions: 1000x1000x800 mm

3D P Controller

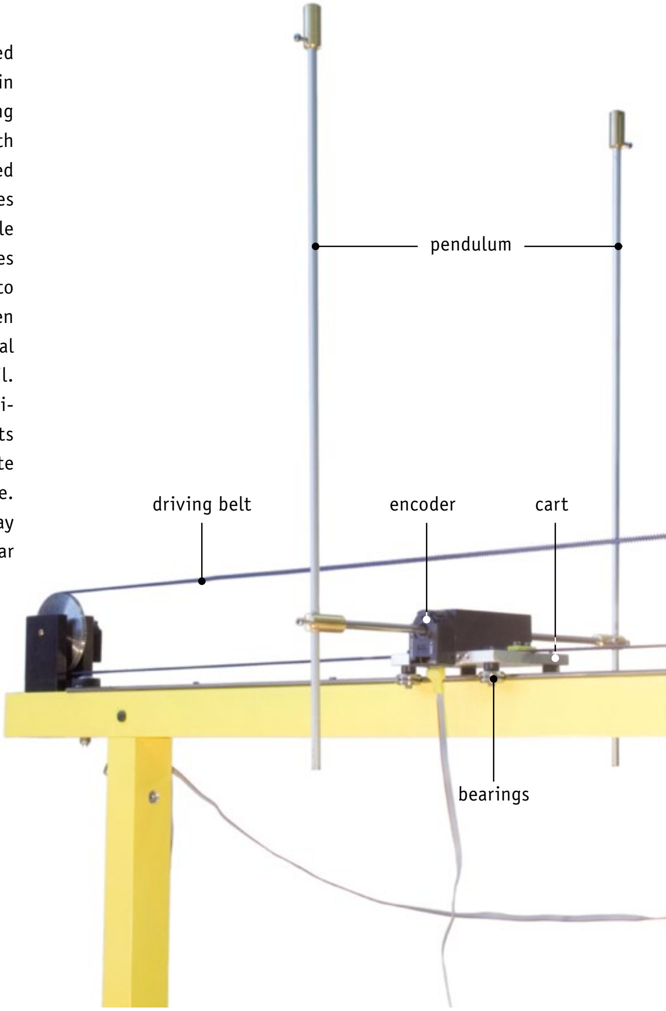




Pendulum & Cart Control System

The fourth order, nonlinear and unstable real-time control system

Pendulum & Cart Control System consists of a pole mounted on a cart in such a way that the pole can swing freely only in the vertical plane. The cart is driven by a DC motor. To swing and to balance the pole the cart is pushed back and forth on a rail of a limited length. The purpose of the inverted pendulum control algorithm is to apply a sequence of forces of the constrained magnitude to the cart such that the pole starts to swing with increasing amplitude and the cart does not override the ends of the rail. The pole is swung up to achieve a vicinity of its upright position. Once this has been accomplished, the controller is maintaining the pole vertical position and is bringing the cart back to the centre of the rail. The system operates directly in the MATLAB/Simulink environment. The user obtains ready preprogramed experiments in the real-time using the Real Time Windows Target to create code with the Simulink Coder code generation software. The user own controller can be generated in an easy way using Simulink and library of drivers. Moreover, the nonlinear and fourth order mathematical model of the system is included. MATLAB/Simulink control requires RT-DAC I/O internal PCI or external USB module (PWM control and encoder logics are stored in a XILINX chip). Besides the MATLAB or LabVIEW control environments all our systems can be also controlled from any PLC, e.g. SIEMENS SIMATIC S7-1200 PLC In the first figure below the simulated snapshots of the pendulum during a rulebased control are shown. In the second figure on the right the time-optimal control and corresponding pendulum trajectory are shown.



Hardware:

-Pendulum & Cart mechanical system driven by 12V DC flat motor

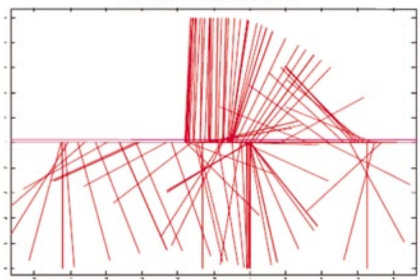
-PWM control generated in a PC or a notebook or in a PLC

-signal conditioning interface and power supply unit

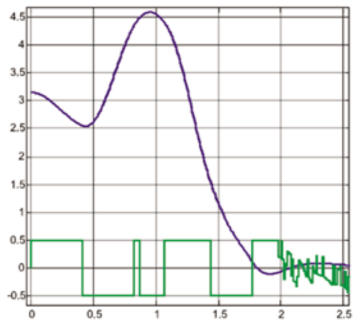
-linear bearings

Dimensions: 2200x500x850 mm

Animation in MATLAB

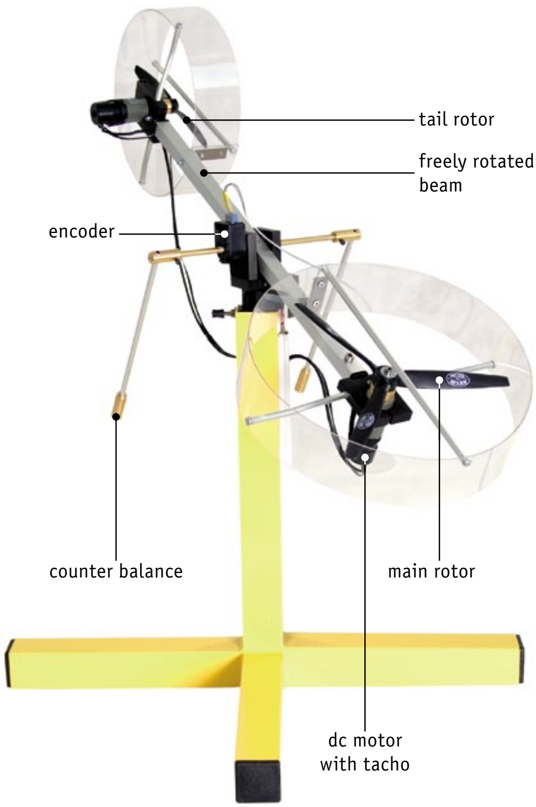


Pendulum angle [rad] vs. time [s] (blue line)
Control [PWM] (green line)



Two Rotor Aerodynamical System

The Multi Input Multi Output (MIMO) strongly cross-coupled control system



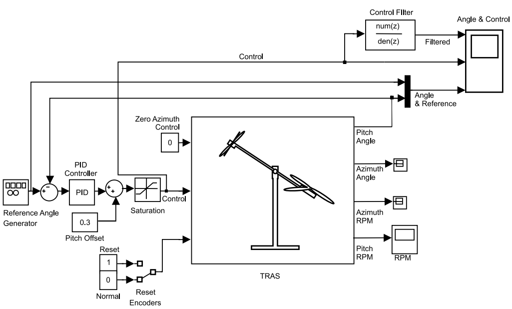
Two Rotor Aerodynamical System (TRAS) is a set-up designed for control experiments. In certain aspects its behaviour resembles that of a helicopter. From the control point of view it exemplifies a high order nonlinear system with significant cross-couplings.

TRAS consists of a beam pivoted on its base in such a way that the beam can rotate freely both in the horizontal and vertical planes. At both ends of the beam there are rotors (the main and tail ones) driven by DC motors.

A counterbalance arm with a weight at its end is fixed to the beam at the pivot. The state of the beam is described by four process variables: horizontal and vertical angles measured by encoders fitted at the pivot, and two corresponding angular velocities. Two additional state variables are the angular velocities of the rotors, measured by speed sensors coupled with the driving DC motors. In a real helicopter the aerodynamic force is controlled by changing the angle of attack. In the laboratory set-up the angle of attack is fixed. The aerodynamic force is controlled by varying the speed of rotor. Significant cross couplings are observed between actions of the rotors. Each rotor influences both position angles. A design of stabilising controllers for TRAS is based on decoupling.

The TRAS system has been designed to operate with an external, PC-based controller. The control computer communicates with the position, speed sensors and motors by a dedicated I/O board and power interface. The I/O board is controlled by the real-time software which operates in the MATLAB/Simulink environment. A preprogrammed library of controllers and Simulink models supports the TRAS system. The diagram below shows the Simulink real-time 1D Pitch PID controller.

1D Pitch PID Control



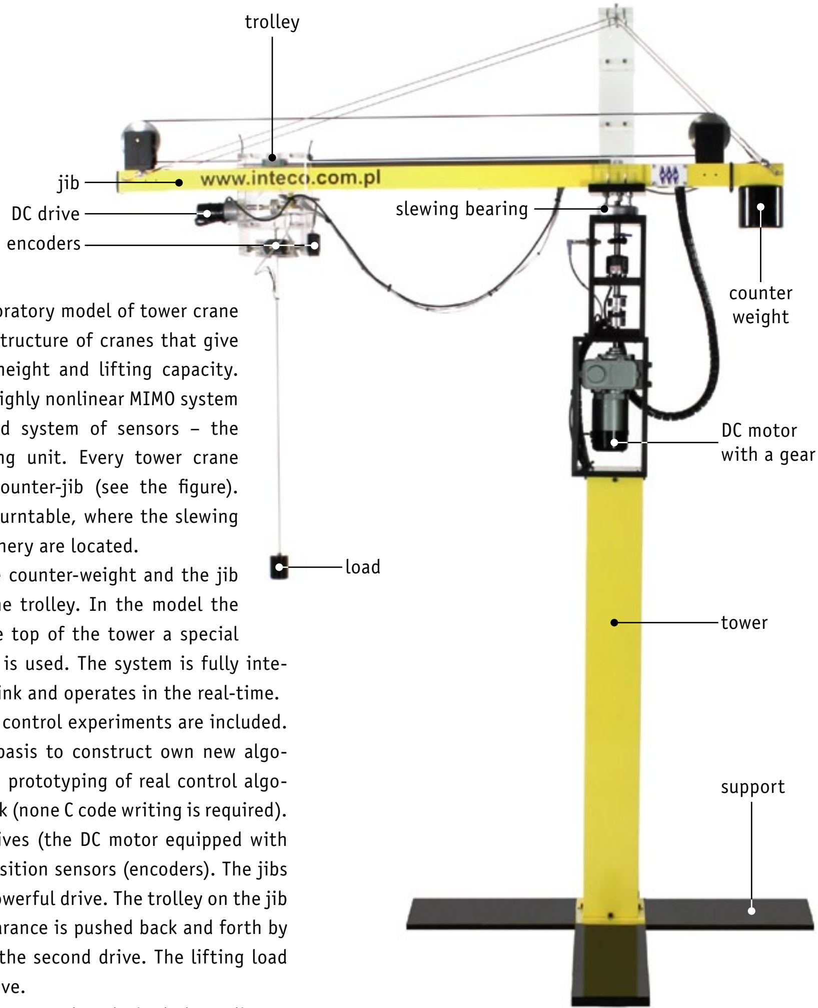
Hardware:

- -motors: 12V DC, PWM controlled
- -beam position sensors: incremental encoders
- -rotor velocity sensors
- -RT-DAC I/O internal PCIe or external USB board (the PWM control and encoder logics are stored in a XILINX chip) or the single board RIO or a PLC

Dimensions: 520x520x650

Tower Crane

The control goal: to track a trajectory and not to swing the load



The three-dimensional laboratory model of tower crane corresponds to a modern structure of cranes that give the best combination of height and lifting capacity. The laboratory model is a highly nonlinear MIMO system equipped with a dedicated system of sensors – the unique 2D angle measuring unit. Every tower crane consists of the jib and counter-jib (see the figure). Both are mounted to the turntable, where the slewing bearing and slewing machinery are located.

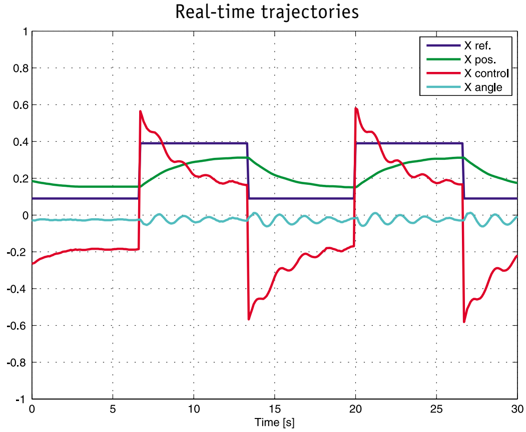
The counter-jib carries the counter-weight and the jib suspends the load from the trolley. In the model the turntable is located at the top of the tower a special plastic-metal slewing ring is used. The system is fully integrated with MATLAB/Simulink and operates in the real-time.

A number of preprogramed control experiments are included. They constitute a proper basis to construct own new algorithms of a user. The rapid prototyping of real control algorithms becomes an easy task (none C code writing is required).

There are three control drives (the DC motor equipped with a gear) and five angular-position sensors (encoders). The jibs rotate driven by the first powerful drive. The trolley on the jib rail with an adjustable clearance is pushed back and forth by the transmission belt and the second drive. The lifting load is operated by the third drive.

The typical control goal is to track a desired three-dimensional trajectory (i.e. operate the load in a desired prescribed manner) simultaneously keeping the load at the minimal amplitude of swinging. This effect is shown in the figure below.

Real-time trajectories



Hardware:

-3 DC motors equipped with gears PWM controlled

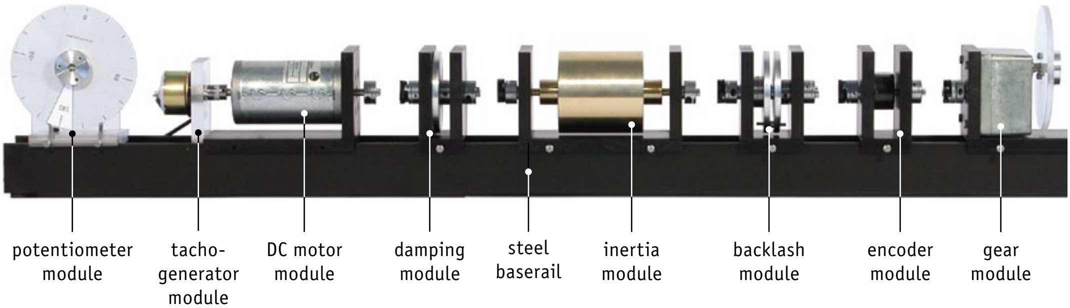
-interface and power supply unit

-RT-DAC I/O internal PCIe or external USB board (the PWM control and encoder logics are stored in a XILINX chip) or the single board RIO or a PLC

Dimensions: 1200x1200x1500 mm

Modular Servo

An easy to reconfigure set-up to demonstrate servo control problems



Modular Servo is designed especially for the study and verification of basic and advanced control methods in practice. It includes demonstration of typical variable factors such as friction, damping and inertia as well as a number of position/speed control methods ranging from PID to LQ and time-optimal control.

DC motor module can be coupled with several other modules. A vast number of linear and nonlinear mechanical modules are designed to demonstrate the influence of backlash, damping, elasticity and friction. The units may be investigated individually before completing the system. Damping module consists of a paramagnetic disc which runs between the poles of a permanent magnet. Inertia module is equipped with a solid metal roll.

A metal base-rail provides firm fixing to the modules, enabling imitation of block schematic diagrams. There are no wired connections. Everything is “connected” via software. No mechanical skills are required to assemble a working system.

Modular Servo operates with a PC-based controller. The PC communicates with the position sensor and motor by the I/O board and the power interface.

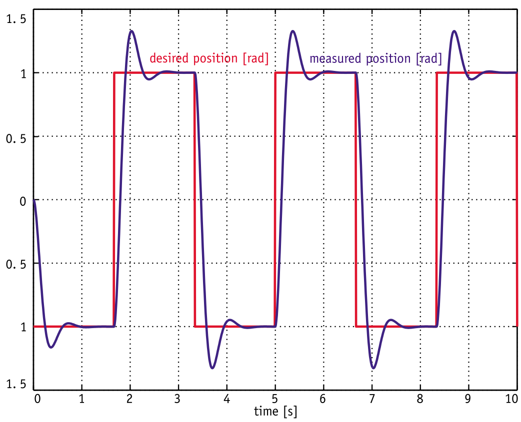
The I/O board is controlled by the real-time software which operates in the MATLAB/Simulink RTW/RTWT environment. The preprogramed library of controllers and models built in Simulink supports Modular Servo.

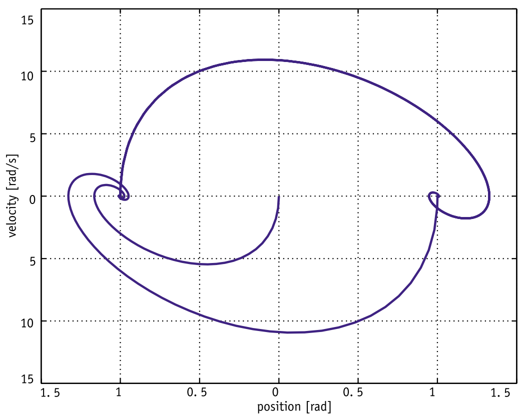
A comprehensive range of experiments may be carried out using Modular Servo and associated software. An example shown in the figure below shows how the servo system tracks the desired position. The time and phase plane diagrams are presented.

Hardware:

-motor: DC, 12V, PWM controlled
-interface and power supply unit
-7 mechanical modules
-position & speed sensors: incremental encoders tacho-generator
-aluminium base-rail
-RT-DAC I/O internal PCIe or external USB board (the PWM control and encoder logics are stored in a XILINX chip) or the single board RIO or a PLC

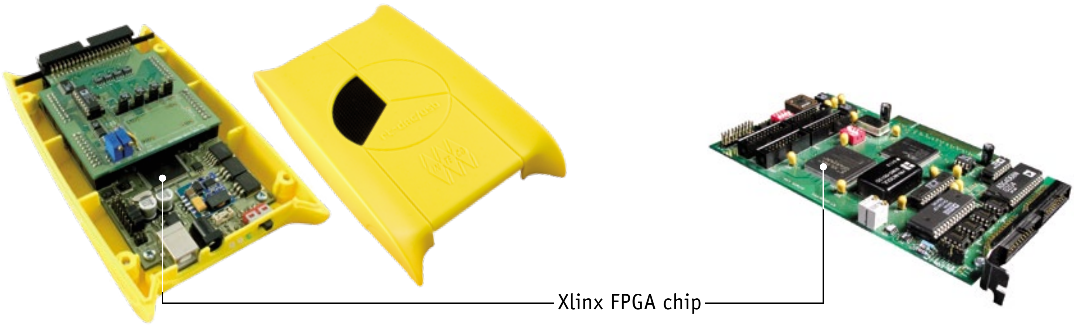
Dimensions: 900x100x145 mm





RT-DAC USB 2.0 I/O Module RT-DAC PCI Board

Hardware reconfigurable by software. Real-time measurements and controls.



This is an omnipotent functionality that conforms to a given application. The RT-DAC family of PCI boards has A/D, D/A converters and digital I/O lines. All the I/O functions are realisable by hardware due to the on-board programmable logic FPGA chip. The OMNI board equipped with an EEPROM memory is used to store the ready-to-use or user-defined logic. Once installed in the computer the board suits to a number of applications that require different types and numbers of I/O channels. It is not necessary to change the board for a new application. Only the board's logic is replaced. The OMNI board behaves like an omnipotent I/O device.

RT-DAC/PCI (general) consists of 16 boards.

RT-DAC/PCI-OMNI is the most potent among the general boards in the family. The default board functions can be replaced by a new logic structure that implements new functions.

Specification:

-16 analog inputs, 12 bits resolution, 1.8µs conversion time per channel, input range +/-10V
-analog amplifier 1, 2, 4, 8 and 16 V/V
-4 analog outputs; 8/12-bit resolution, output
-ranges +/-10, -10-0, 0-10 V
-32 general purpose digital I/O signals, changeof-
-state (COS) interrupt from selected digital inputs
-4 PWM outputs, 8/12 bits resolution, frequency
-range from 0.15Hz to 156kHz
-4 incremental encoder inputs, 32-bit counters
-2 32-bit timers, 25ns resolution
-2 32-bit counters
-2 digital signal generators, selectable duty cycle, maximum output frequency 20MHz
-interrupt controller, interrupt source timer, COS of digital inputs, 2 dedicated interrupt input signals

RT-DAC/USB is a portable version of the RT-DAC I/O boards. This real-time control and measurement module transfers signals between a computer and a process or a plant. Therefore RT-DAC/USB is a perfect device to be plugged-in to a laptop and to be connected to sensors and/or actuators of the process constituting a portable control and measurement stand.

FPGA technology:

Reconfigurability of the digital I/O according to user requirements

Software:

-Compatible with MATLAB/Simulink
-RTCON (if MATLAB/Simulink are applied)
-RT-DAC/USB may operate directly from MS Excel sheets
-Affected OS: MS Windows

Digital USB module:

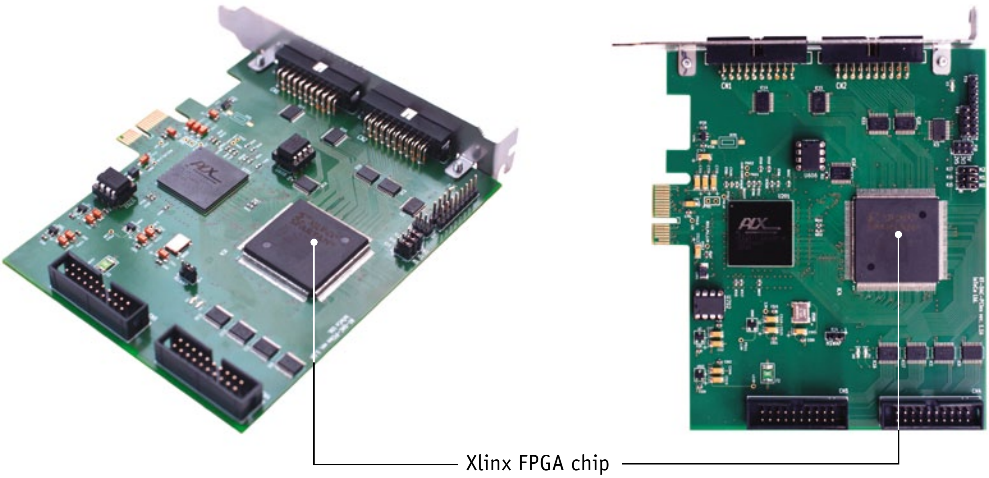
-26 digital I/O signals
-4 PWM channels: 8/12 bits resolution (4 DO shared with 4 digital I/Os)
-digital generators: 1 channel, dedicated trigger and gating signals (1 DO and 2 DI shared with 3 DI/O)
-encoders: 4 channels, optional index signal, defined active level of the index signal (12 DI shared with 12 DI/O)

Analog USB module:

-ADC: 12 bits, +/-10V, 16 channels software programmable gains: 1, 2, 4, 8, 16 Noise (input grounded at connector) for gain = 16: 1.0 LSB
-Throughput: 100 kSample/sec (data acquisition mode), 1 kSample/sec (close-loop control mode)
-DAC: 12 bits, 4 channels.

Digital RT-DAC PCI Express Board

Similar in operation to the RT-DAC board but for the PCI Express bus



PCI Express includes the freely reconfigurable FPGA chip of a flexible functionality. Board functions implemented in the hardware can be adjusted to the specific requirements of the target application. Moreover, the board hardware configuration can be changed repeatedly in a programing way.

A unique feature of the board is the ability to configure the FPGA for direct hardware implementation of certain portions of control algorithms, which typically are implemented by a software way. Reliability, speed and high accuracy of the durations of time intervals – a perfect jitter - are provided. The period of the most rapid samples can be several tens nanoseconds!

The architecture of measuring and control boards uses the PCI Express bridges. They are connected from one side to the PCI Express bus on the other side offer a local bus. The last one is connected to the reconfigurable FPGA devoted to input / output functions of the board.

The digital board has signal conditioning modules in the form of the card with galvanic isolation circuits to be imposed on the board. Dedicated board configurations often contain common combinations of channels input / output: digital inputs and outputs with an optional interrupt generation "change of state interrupt", incremental quadrature encoders with the index, PWM wave generators, counters, frequency-meters and chronometers.

We provide three hardware and software options: MATLAB, LabVIEW, and any PLC, e.g. a SIEMENS PLC

www.inteco.com.pl

Software Real-time control in MATLAB and Simulink, alternatively LabVIEW alternatively any PLC software, e.g. TIA PORTAL.

Manuals Installation Manual, User's Manual (rich in pre-programmed experiments).

Controllers A PC with the PCIe I/O board from INTECO or a laptop with the external USB 2.0 I/O module from INTECO, alternatively a PC with the Single or Compact Board RIO from National Instruments, alternatively any PLC, e.g. SIEMENS PLC.

INTECO Sp. z o. o. Katowicka 36, 31-351 Krakow, Poland
tel./fax: +48 12 430 49 61
e-mail: inteco@inteco.com.pl