RT 121 – RT 124 TEACHING SYSTEMS FOR FUZZY METHODS IN AUTOMATION

RT 121 *Fuzzy Control: Ball-on-Beam*

RT 122 *Fuzzy Control: Inverted Pendulum*

RT 123 *Fuzzy Control: Ball-on-Plate*

RT 124 *Fuzzy Control: Carrier Vehicle with Inverted Pendulum*

INTRODUCTION TO FAST, DIGITAL REAL-TIME CONTROL BASED ON FUZZY METHODS

Fuzzy methods and microcontrollers have gained greatly in importance in automation over recent years. This has also increased the need for specific training. With its RT 121 to RT 124 systems, GUNT offers clearly laid-out and well-conceived teaching systems specially-developed for this future-oriented field.

Fuzzy methods are particularly suitable for systems that mathematics cannot describe adequately or easily. These include, in particular, multivariable systems, and non-linear or time-variant systems. Fuzzy methods are based on fuzzy logic. In fuzzy logic there is not only **right** or **wrong**, as in conventional logic, but there are also less sharply defined concepts such as **almost right** or a **little wrong**.

This special characteristic of fuzzy methods is similar to the workings of the human mind. Consequently, fuzzy methods are particularly well suited to the automation of processes in which manual control is to be replaced by automatic control.

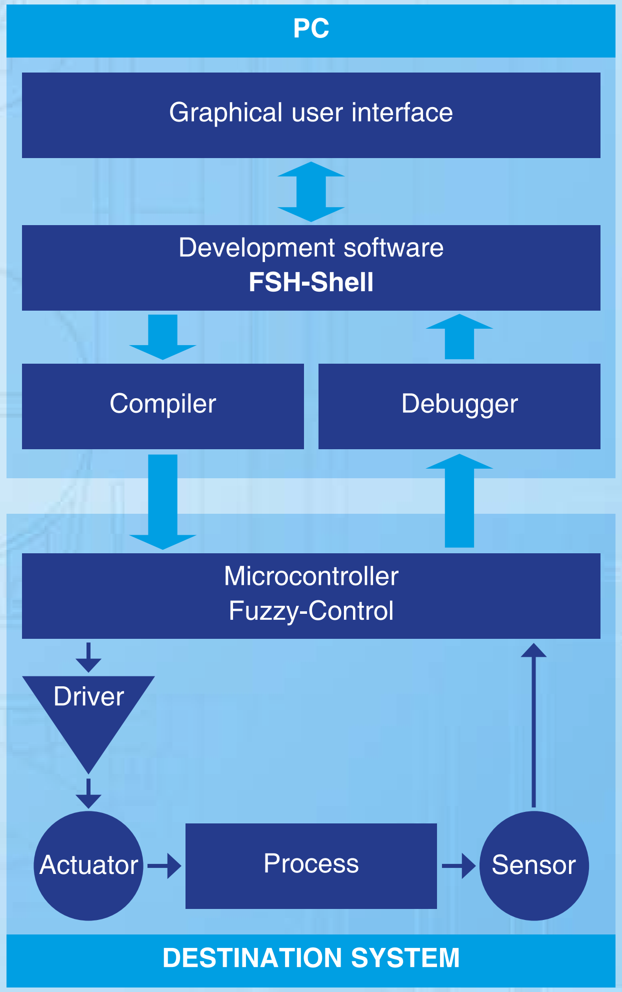
The advantage lies in simple process descriptions based on linguistically defined terms and rules. No complicated mathematical description is necessary.

Four different training systems of increasing complexity

The training systems offer a clearly structured introduction to the design process for microcontroller-based process control systems which are of special relevance to industrial applications. As well as the application of fuzzy methods, they also permit other topics in the field of microcontroller systems to be covered.
The training systems have been produced in close co-operation with **Professor Dr. Kramer from the Department of Automation and Information Technology at the Harz University of Applied Studies and Research**, where the teaching concept and the **FSH-Shell** development software were also developed. The training content and experimentation instructions contained in the training systems are graded by difficulty according to educational/didactic criteria, and have been successfully deployed in practical teaching at the University.

- Easy familiarisation based on user-friendly development software **FSH-Shell** with graphical user interface
- Rapid implementation of the solution into the mechatronic system based on online compiling and downloading to the destination controller
- Test support by Fuzzy Debugger to visualise selected instrumentation and control variables
- Code- and time-optimised software development based on the special **FSH-Shell** compilation concept

Each training system comprises a mechatronics experimental unit (destination system) with the associated hardware (microcontroller, amplifier, sensors, actuators), the FSH-Shell development software and well structured instructional material.



Structure of the training system

BASIC KNOWLEDGE

FUZZY CONTROL

Fuzzy control is nowadays an important branch of control engineering. Conventional approaches have not been displaced but have been enhanced considerably in some fields of application.

Until now, the fuzzy controller has achieved its greatest success in the industrial and commercial application of fuzzy methods.

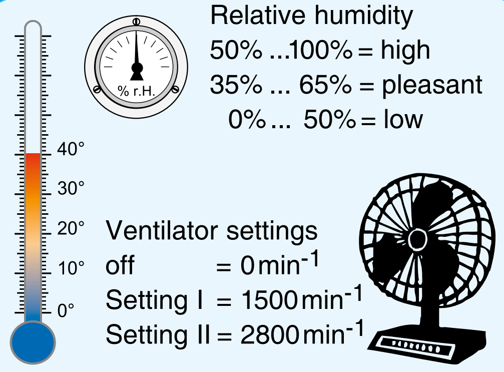
Fuzzy controllers are non-linear controllers. Any non-linearity in the controlled system can be compensated for by an appropriate choice of membership functions and by establishing a rule base. Membership functions are the mathematical models for linguistic terms, such as triangular function, trapezoidal function or Gaussian function.

Like a conventional controller, the fuzzy controller transforms input variables into output variables that then act upon the process or the controlled system. Various input and output variables are linked together to allow complex systems to be easily controlled. The input and output values are crisp values in the form of signals. The fuzzy values that are typical of fuzzy methods only play a role within the controller.

Three processing steps take place within a fuzzy controller: fuzzification, inference and defuzzification.

The design of a fuzzy controller involves the selection of the input/output variables, the determination of the membership functions and the establishment of a rule base.

This simple example shows how a ventilator is used to affect room temperature and air quality. Different ventilator power settings are used depending on room temperature and humidity. The model illustrates the processes within a fuzzy controller and makes no claim to be a realistic implementation.



Room temperature
20°C ... 40°C = hot
10°C ... 30°C = pleasant
0°C ... 20°C = cool

Relative humidity
50% ...100% = high
35% ... 65% = pleasant
0% ... 50% = low

Ventilator settings
off = 0 min^{-1}
Setting I = 1500 min^{-1}
Setting II = 2800 min^{-1}

Sensor

Measured variables

Controlled system (the room)

Actuator (ventilator)

Crisp output value
Speed = 2800 min^{-1}

Reference variable

Crisp input values
Room temperature = 28°C
Relative humidity = 40% r.h.

FUZZY CONTROLLER

The **rule base** contains all the rules in the form "IF a set of conditions is satisfied, THEN a series of consequences follow".
1. Rule **IF** room temperature = tending towards hot **AND** humidity = tending towards pleasant **THEN** ventilator setting II
2. Rule **IF** room temperature = pleasant **AND** humidity = tending towards high **THEN** ventilator setting I
Additional rules...

Processing step: fuzzification

The crisp input values are transformed into fuzzy linguistic terms using mathematical models known as membership functions.

Crisp input value: 28°C ➜ Fuzzy quantity: between pleasant and hot, tending towards hot
Crisp input value: 40% r.h. ➜ Fuzzy quantity: between pleasant and low, tending towards pleasant

Fuzzy input quantities

Processing step: inference

This is the step in which the fuzzy quantities are linked and compared with the individual rules. The result of the inference is a fuzzy output quantity, a fuzzy quantity for the manipulating variable.

1. Rule satisfied ➜ ventilator setting II

Fuzzy output quantity

Processing step: defuzzification

The fuzzy output quantity is transformed back into a crisp output value.

Ventilator setting II ➜ Speed 2800 min^{-1}

Membership function (mathematical model for linguistic terms)

Advantages of fuzzy controllers

- Multivariable control systems can be realised quickly, problem-oriented and comprehensible. This is particularly true if there is no model of the controlled system, or if the model displays an unfavourable non-linear structure.
- The response of a system is described in linguistically defined terms and is therefore simpler to understand than a mathematical one.
- The rule base and the definition of the fuzzy quantity can be added to or modified retrospectively.

Limits of fuzzy controllers

- In conventional control engineering, the controlled system is first modelled. This model is then used to design the controller. By contrast, a fuzzy controller is designed directly from the experiences gained from existing controllers or human input. Errors made during the creation phase are therefore very difficult to correct later.
- As the complexity of the system increases, the amount of work required to develop a fuzzy controller increases superproportionately.
- It's very difficult to find the right defuzzification method. The calculation of the crisp output value is either:
  a) complicated, slow and good
  or
  b) fast, but with a poor result

DIDACTIC RECOMMENDATION

COMPLETE FUZZY CONTROL COURSE

The method of fuzzy control is taught in gradual requirements and the learning content is systematically intensified using the units of the series RT 121 to RT 124. The experimental units are mechatronic systems in which the desired positions and angular positions can be reached as quickly and as exactly as possible. The position or angular position that is reached is held constant against disturbances and any deviations are compensated for.

RT 121 *Ball-on-Beam*

Level 1 – basics: linear, one-dimensional single-variable model

RT 121 provides an introduction to fuzzy control. The knowledge gained with RT 121 is required for further experiments with the other units of this series.

- Introduction to the basic terms fuzzification, rule base, inference, defuzzification
- Working with the development software FSH-Shell
- Testing of a simple fuzzy control on a slow single-variable system
- Optimisation of parameters and online debugging

RT 122 *Inverted Pendulum*

Level 2a:
non-linear,
one-dimensional
single-variable model

- Design of a fuzzy control for an unstable single-variable system with two separate rule bases for the outputs
- Two separate outputs with strong coupling
- Mastering of non-linearities on the actuator side
- More stringent system optimisation requirements

RT 123 *Ball-on-Plate*

Level 2b: linear, two-dimensional multivariable system

- Design of a fuzzy control for a multivariable system without coupling
- Method using two separate fuzzy controls for both directions
- Improved control characteristics by adopting the strategy of coupling both fuzzy control systems

RT 124 *Carrier Vehicle with Inverted Pendulum*

Level 3: non-linear, one-dimensional multivariable system with a strong coupling

- Design of a fuzzy control for an unstable multivariable system with a strong coupling
- Superposition of pendulum stabilisation and position of the vehicle
- Very high real-time demands
- Develop a strategy to decide what to do in case of conflicting requirements

Increasing problem complexity

FUZZY CONTROL: SOFTWARE

The individual processing steps of the fuzzy controller are shown using the fuzzy control for the ball-beam system (RT 121) as an example.

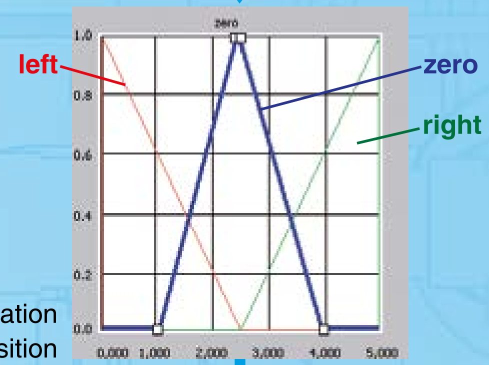
Fuzzification
The crisp input values for the position and velocity of the ball are assigned to linguistic terms. Mathematical models such as triangular and trapezoidal functions are used for this purpose.

Inference
The fuzzy input quantities are linked using a rule base and a result is determined.

Defuzzification
Finally, a triangular function is used to transform a fuzzy result back into a crisp output value. This output value is the manipulating variable for the actuator. In the case of an RT 121, the crisp output value is the speed for the motor. This motor changes the inclination of the beam.

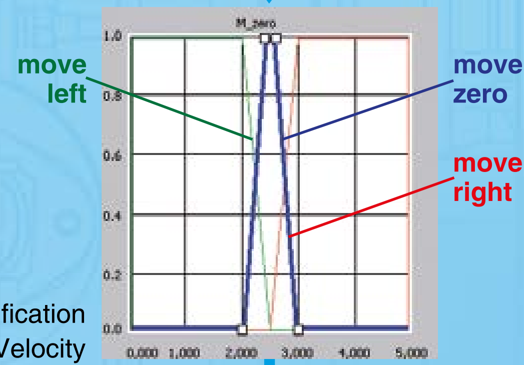
FUZZIFICATION

Crisp input value: position



Fuzzification Position

Crisp input value: velocity



Fuzzification Velocity

INFERENCE

Fuzzy input quantity: position

Fuzzy input quantity: velocity

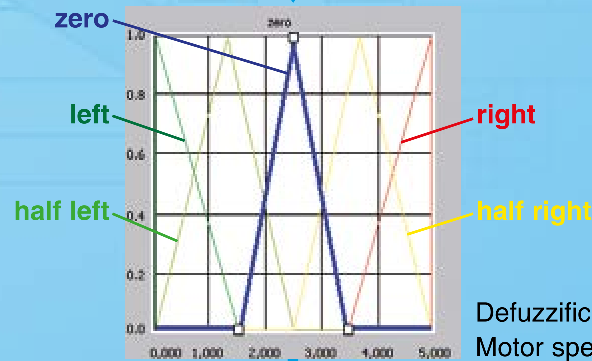
Rule base

	FUZ_BALL_POS		FUZ_BALL_VELO		DEFUZ_MOTOR
1 - IF	LEFT	AND	MR	THEN	HR
2 - IF	LEFT	AND	ZERO	THEN	R
3 - IF	LEFT	AND	ML	THEN	R
4 - IF	ZERO	AND	MR	THEN	HL
5 - IF	ZERO	AND	ZERO	THEN	zero
6 - IF	ZERO	AND	ML	THEN	HR
7 - IF	RIGHT	AND	MR	THEN	L
8 - IF	RIGHT	AND	ZERO	THEN	L
9 - IF	RIGHT	AND	ML	THEN	HL

MR = move right
ML = move left
R = right
HR = half right
L = left
HL = half left

Fuzzy output quantity: speed

DEFUZZIFICATION



Defuzzification Motor speed

Crisp output value: speed

RT 121 Fuzzy Control: Ball-on-Beam

*** Linear, one-dimensional single-variable system with one input and one output**

*** Fast, real-time control using microcontroller**

*** Implementing fuzzy algorithms**

*** Microcontroller-based development process for process control systems**

Technical Description

Fuzzy methods are particularly suitable for systems that mathematics cannot describe adequately or easily. Fuzzy algorithms can offer major advantages, as the control strategy is developed not on the basis of exact mathematical modelling, but on a linguistic description of the process. Additional input variables and the rule base can be easily added.

This experimental unit forms part of a series of teaching systems developed in collaboration with the **Department of Automation and Information Technology at the Harz University of Applied Studies and Research**.

The RT 121 provides an introduction to fast, digital real-time control by fuzzy methods. A ball-beam model acts as a mechanical single-variable system. A fuzzy control is used to attempt to hold the ball in a specific position by tilting the beam, even when the position of the ball is modified by external influences.

The position of the ball is determined using a resistive measuring system. A potentiometer detects the inclination of the beam. These sensors supply crisp signals to the fuzzy controller, where the signals are transformed into fuzzy input values and inferenced before being transformed back into a crisp output value. A servo motor equipped with a drive rod modifies the inclination of the beam and acts as an actuator.

The control algorithms are initially written in the user-friendly development software FSH-Shell and then compiled to generate microcontroller code. The control strategy can be optimised at a later date.

A joystick can be used to control the system manually. This allows the degree of difficulty of the control process to be estimated very accurately.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- introduction to the fundamentals of fuzzy control and microcontroller technology
- working with the development software FSH-Shell
- development of a simple fuzzy control for a single-variable system using the elements
  * fuzzification, rule base, inference, defuzzification
- implementation of fuzzy algorithms in the mechatronic system using microcontrollers
- optimising the algorithms on the mechatronic system using the online debugger

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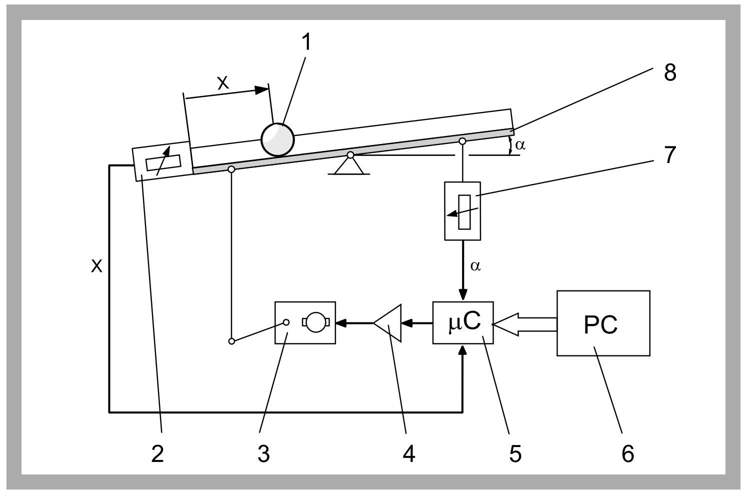
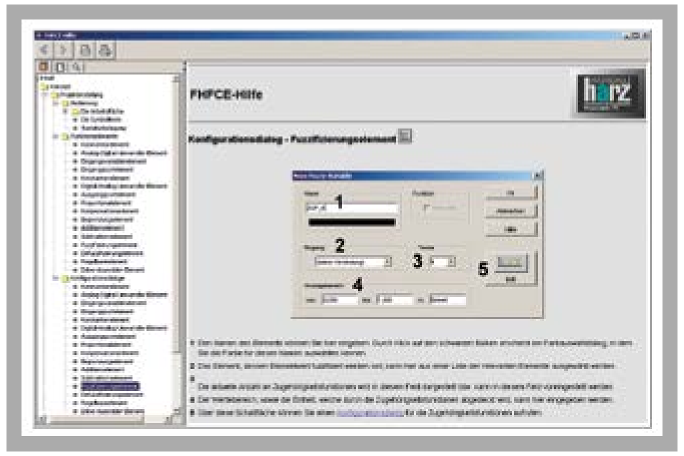
RT 121 Fuzzy Control: Ball-on-Beam



1 ball, 2 ball position sensor, 3 servo motor for beam drive, 4 amplifier, 5 microcontroller, 6 PC with development software, 7 beam inclination sensor, 8 beam

FSH-Shell development software: structure of a fuzzy control



FSH-Shell development software: help function

Specification

[1] introduction to fuzzy control and microcontroller technology
[2] ball-beam as mechanical single-variable system, SISO (Single Input - Single Output)
[3] switchable between fuzzy and manual mode
[4] servo motor for beam drive as actuator
[5] microcontroller with USB port as fuzzy controller
[6] FSH-Shell development software for design and optimisation of the fuzzy controller
[7] resistive measuring system with film potentiometer as ball position sensor
[8] potentiometer as beam inclination sensor
[9] part of the structured teaching concept: level 1 - basics

Technical Data

Beam, U-profile
- length: 500mm
- material: aluminium

Ball
-diameter: 25,4mm
- weight: 66g

Servo motor
- operating voltage: 5,0V
- actuation torque, interpolated: 206Ncm
- actuator velocity, interpolated: 0,18s/60°

Microcontroller
- 8bit microcontroller Zilog Z8Encore
- 12-fold ADC 8bit

Software: FSH-Shell, runs under Windows Vista or Windows 7

Film potentiometer
- resistance value: 12,5kΩ +/-30%
- electrical path: 500mm

Dimensions and Weight

LxWxH: 600x520x330mm
Weight: approx. 20kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz/CSA, 1 phase

Scope of Delivery

1 experimental unit
1 USB cable
1 FSH-Shell development software
1 set of instructional material

Order Details

080.12100 RT 121 Fuzzy Control: Ball-on-Beam

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RT 122 Fuzzy Control: Inverted Pendulum

* Non-linear, one-dimensional single-variable system with two actuators
* Inverted pendulum with one input and two outputs
* Fast, real-time control using microcontroller
* Implementing fuzzy algorithms
* Microcontroller-based development process for process control systems

Technical Description

This experimental unit forms part of a series of teaching systems developed in collaboration with the **Department of Automation and Information Technology at the Harz University of Applied Studies and Research**.

The unstable "inverted pendulum" system acts as a mechanical single-variable system. The upright position of the pendulum is adjusted by two independent propeller drives and should be achieved quickly and if possible without overshooting. A fuzzy control will be developed and optimised for this purpose.

The inclination of the pendulum is measured by a potentiometer. The sensor supplies a crisp signal to the fuzzy controller, where the signal is transformed into a fuzzy input value and inferenced before being transformed back into a crisp output value. This output value controls the actuators, two propeller drives.

The learning contents of the experimental unit RT 121 are extended by RT 122 that is more complex because of its two independent drives. Conducting the experiment makes high demands on the system optimisation, as the two independent drives have to be tuned.

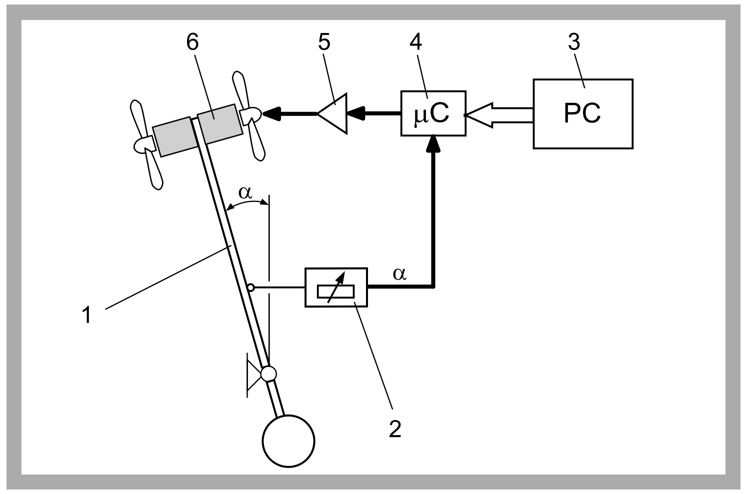
The control algorithms are initially written and simulated in the user-friendly development software FSH-Shell and then compiled to generate microcontroller code. The control strategy can be optimised at a later date.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

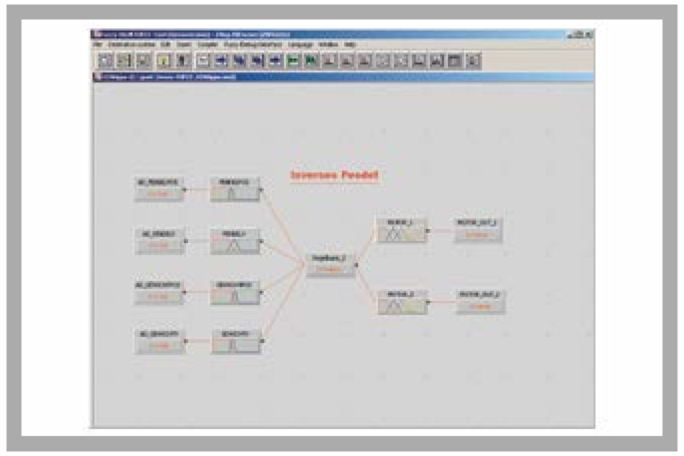
Learning Objectives / Experiments

- design of a fuzzy control for the unstable single-variable system: inverted pendulum (fundamentals from RT 121 required)
- working with the development software FSH-Shell
- activating of two independent actuators that are coupled via the system
- mastering of non-linearities in the system: inverted pendulum
- mastering of non-linearities in the propeller drive
- optimisation of
  * fuzzification
  * rule base
  * defuzzification with respect to stability
  * velocity
  * control quality

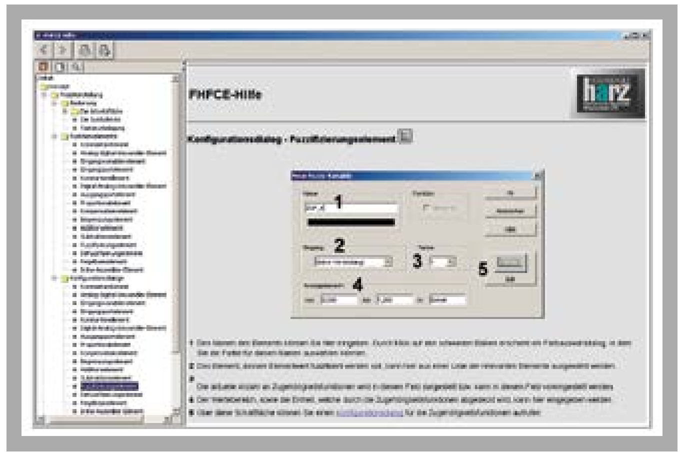
RT 122 Fuzzy Control: Inverted Pendulum



1 inverted pendulum, 2 pendulum inclination sensor, 3 PC with development software, 4 microcontroller, 5 amplifier, 6 drive motors with propellers



FSH-Shell development software: structure of a fuzzy control



FSH-Shell development software: help function

Specification

[1] design and optimise fuzzy control systems using microcontroller technology
[2] inverted pendulum as mechanical single-variable system, SIMO (Single Input - Multiple Outputs)
[3] 2 independent motors for propeller drive as actuators
[4] microcontroller with USB port as fuzzy controller
[5] FSH-Shell development software for designing and optimising the fuzzy controller
[6] rotary potentiometer as pendulum inclination sensor
[7] part of the structured learning concept: level 2a

Technical Data

Inverted pendulum
 - length: 780mm
- counterweight: 1,89kg
2 drive motors: 7,2V / 23A
Microcontroller
- 8bit microcontroller Zilog Z8Encore
- 12-fold ADC 8bit
Software: FSH-Shell, runs under Windows Vista or Windows 7
Rotary potentiometer
- resistance value 5kΩ +/- 20%

Dimensions and Weight

LxWxH: 600x520x1200mm (with upright pendulum)
Weight: approx. 36kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz/CSA, 1 phase

Scope of Delivery

1 experimental unit
1 USB cable
1 FSH-Shell development software
1 set of instructional material

Order Details

080.12200 RT 122 Fuzzy Control: Inverted Pendulum

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RT 123 *Fuzzy Control: Ball-on-Plate*

*** Linear, two-dimensional multivariable system with two actuators**
*** Ball-plate model with two inputs and two outputs**
*** Fast, real-time control using microcontroller**
*** Implementing fuzzy algorithms**
*** Two fuzzy controllers with weak coupling**
*** Microcontroller-based development process for process control systems**

Technical Description

This experimental unit forms part of a series of teaching systems developed in collaboration with the **Department of Automation and Information Technology at the Harz University of Applied Studies and Research**.

A ball-plate model acts as a weakly-coupled mechanical multivariable system. A fuzzy control is used to move the ball to a specific position quickly and with as little movement of the plate as possible, even when the position of the ball is modified by external influences.

The position of the ball is measured without feedback using a touch panel and the crisp signals sent to the fuzzy controller, where the signals are transformed into fuzzy input values and inferenced before being transformed back into a crisp output value. Two servo motors act as actuators during this process. The inclination of the plate is modified by the movements of the respective motors; these movements are transferred to the plate by the drive rod.

The learning contents of RT 123 are based on the fundamentals of RT 121. The RT 123 is a multivariable system with two separate fuzzy controllers, which can also be coupled. Optimisation of the system by fine tuning the parameters will be looked at in a later exercise.

The control algorithms are initially written in the user-friendly development software FSH-Shell, simulated and then compiled to generate microcontroller code. The control strategy can be optimised at a later date.

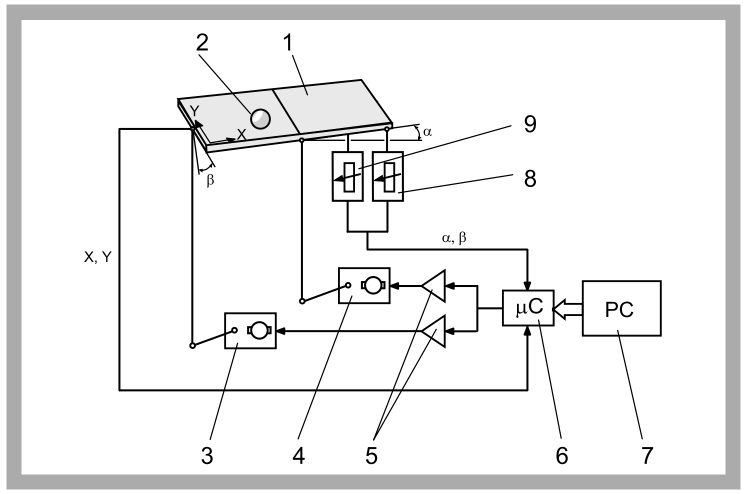
A joystick can be used to control the system manually. This allows the degree of difficulty of the control process to be estimated very accurately.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

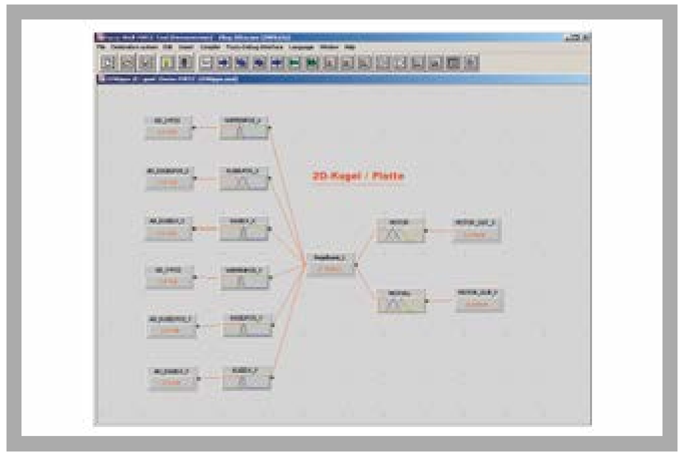
Learning Objectives / Experiments

- design of a fuzzy control for a decoupled multivariable system (fundamentals from RT 121 are required)
- development of a model with two separate fuzzy controllers for each axis
- effect of the position and velocity of the ball on the control characteristic
- optimisation of control characteristic by additional coupling of the fuzzy controllers
- comparison of a fuzzy control with a manually controlled system

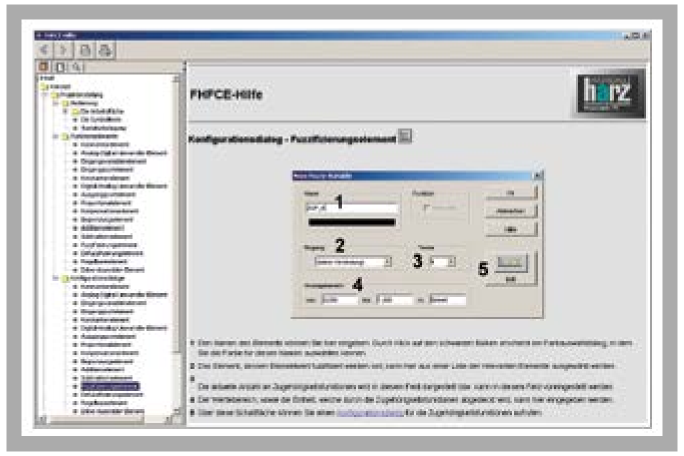
RT 123 *Fuzzy Control: Ball-on-Plate*



1 swivelling plate with touch panel to measure ball position, 2 ball, 3 swivel drive y-axis, 4 swivel drive x-axis, 5 amplifier, 6 microcontroller, 7 PC with development software, 8 plate inclination sensor y-axis, 9 plate inclination sensor x-axis



FSH-Shell development software: structure of a fuzzy control



FSH-Shell development software: help function

Specification

[1] develop parallel fuzzy controls using microcontroller technology
[2] two-axis ball-plate system as mechanical multivariable system, MIMO (Multiple Inputs - Multiple Outputs)
[3] switchable between fuzzy and manual mode
[4] 2 servo motors used as actuators to swivel the plate
[5] microcontroller with USB port as fuzzy controller
6] FSH-Shell development software for designing and optimising the fuzzy controller
[7] resistive analog touch panel as ball position sensor
[8] potentiometer as plate inclination sensor
[9] part of the structured learning concept: level 2b

Technical Data

Plate: LxW: 378x303mm
Ball
- diameter: 35mm
- weight: 174g
2 servo motors
- operating voltage: 5,0V
- actuation torque, interpolated: 206Ncm
- actuator velocity, interpolated: 0,18s/60°
Microcontroller
- 8bit microcontroller Zilog Z8Encore
- 12-fold ADC 8bit
Software: FSH-Shell, runs under Windows Vista or Windows 7
Touch panel
- operating voltage: 5,5V
- active area: 378,5x303mm

Dimensions and Weight

LxWxH: 600x520x300mm
Weight: approx. 24kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz/CSA, 1 phase

Scope of Delivery

1 experimental unit
1 USB cable
1 FSH-Shell development software
1 set of instructional material

Order Details

080.12300 RT 123 Fuzzy Control: Ball-on-Plate

RT 124 Fuzzy Control: Carrier Vehicle with Inverted Pendulum

* **Non-linear, single-dimensional multivariable system with strong coupling**
* **Complex, mechanical system with two degrees of freedom**
* **Fast, real-time control using microcontroller**
* **Implementation of fuzzy algorithms**
* **Microcontroller-based development process for process control systems**

Technical Description

This experimental unit forms part of a series of teaching systems developed in collaboration with the **Department of Automation and Information Technology at the Harz University of Applied Studies and Research**.

A vehicle with an inverted rod pendulum acts as a mechanical multivariable system. A fuzzy control moves the rod pendulum to the centre position, where it is held in position, and at the same time controls the position of the vehicle.

A rotary encoder determines the position of the vehicle from the rotation of its wheels. A rotary potentiometer detects the inclination of the pendulum. These sensors supply crisp signals to the fuzzy controller, where the signals are transformed into fuzzy input values and inferenced before being transformed back into a crisp output value. This in turn activates an actuator, the drive motor on the vehicle. The control process is made more difficult by the fact that the vehicle can only move to a limited extent from its original position.

The RT 124 completes the learning contents from the RT 121 - RT 123 series. This experimental unit is very complex, as the controller has to activate an actuator using two input variables. The overall solution also has to be fine tuned properly.

The control algorithms are initially written and simulated in the user-friendly development software FSH-Shell and then compiled to generate microcontroller code. The control strategy can be optimised at a later date.

A joystick can be used to control the system manually. This allows the degree of difficulty of the control process to be estimated very accurately.

The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Learning Objectives / Experiments

- design of an demanding fuzzy control for an unstable, coupled multivariable system (fundamentals from the experiments with the units RT 121 - RT 123 are required)
- superposition of pendulum stabilisation and position control of the vehicle
- comparison of different controller structures
- optimisation of rule base
- development of a strategy to decide what to do in case of conflicting requirements
- demanding optimisation of control response

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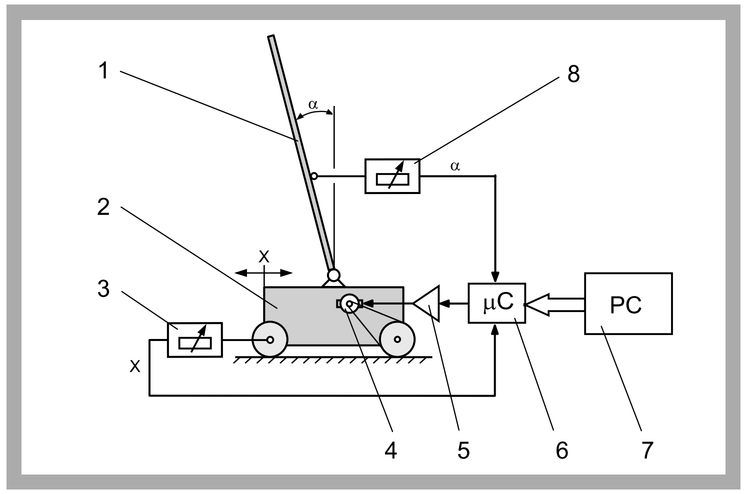
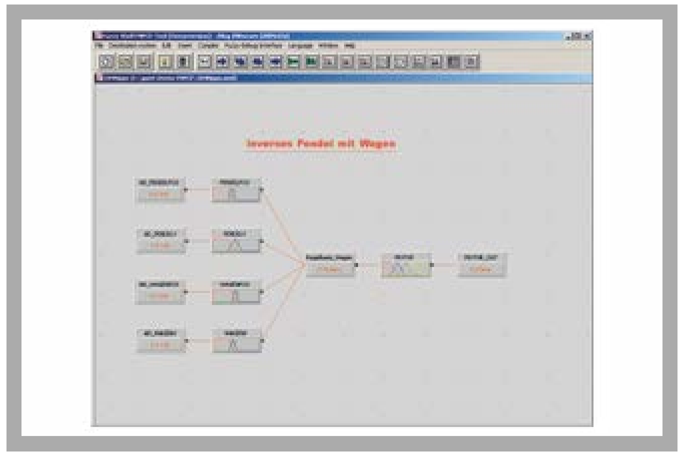
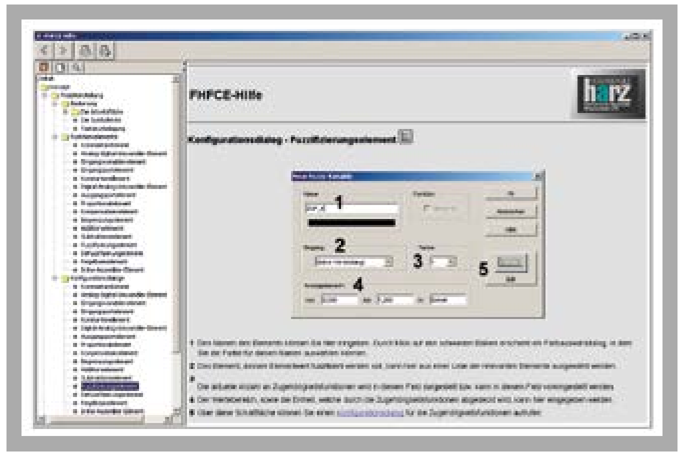
RT 124 Fuzzy Control: Carrier Vehicle with Inverted Pendulum



1 rod pendulum, 2 vehicle, 3 vehicle position sensor, 4 drive motor, 5 amplifier, 6 microcontroller, 7 PC with development system, 8 pendulum inclination sensor



FSH-Shell development software: structure of a fuzzy control



FSH-Shell development software: help function

Specification

[1] fine tuning of a fuzzy control system with strong coupling and use of microcontroller technology
[2] inverted rod pendulum with vehicle as mechanical multivariable system, MISO (Multiple Inputs - Single Output)
[3] switchable between fuzzy and manual mode
[4] motor to drive the vehicle as actuator
[5] microcontroller with USB port as fuzzy controller
6] FSH-Shell development software for designing and optimising the fuzzy controller
[7] rotary potentiometer as pendulum inclination sensor
[8] rotary encoder as vehicle position sensor
[9] permitted route of vehicle relative to starting position: adjustable
[10] part of the structured learning concept: level 3

Technical Data

Vehicle
- max. tensile force: 12N

Rod pendulum
- length: 990mm
- weight: 0,1kg

Drive motor: 12V
Microcontroller
- 8bit microcontroller Zilog Z8Encore
- 12-fold ADC 8bit

Software: FSH-Shell, runs under Windows Vista or Windows 7
Rotary potentiometer
- resistance value 5kΩ +/- 20%

Rotary encoder
- diameter of sensor wheel: D=40mm
- impulses per revolution: 50
- resolution: 2,51mm / impulse

Dimensions and Weight

LxWxH: 600x520x190mm (control unit)
Weight: approx. 20kg
LxWxH: 350x290x1080mm (vehicle)
Weight: approx. 2kg

Required for Operation

230V, 50/60Hz, 1 phase or 120V, 60Hz/CSA, 1 phase

Scope of Delivery

1 experimental unit
1 USB cable
1 FSH-Shell development software
1 set of instructional material

Order Details

080.12400 RT 124 Fuzzy Control: Carrier Vehicle with Inverted Pendulum

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