Appendix

1 Closed-loop control/PID controller

1.1 What is closed-loop control?

On machines or within systems, variables such as pressure, temperature or flow often need to be set to predefined values. Furthermore these set values should not change even in the event of any disturbances occurring. These functions are assumed by closed-loop control.

Closed-loop control deals with any problems occurring in conjunction with this task.

In order for a variable to be controlled, and to be available to a closed-loop controller in the form of an electrical signal, it first has to be measured and correspondingly converted.

This variable needs to be compared with the specified value or the value pattern in the controller. From this comparison it is then necessary to derive the response required within the system.

Finally, a suitable point must be found within the system, via which the variable can be controlled (e.g. the actuator of a heater). To be able to do so, it is important to know how the system behaves.

Closed-loop control technology tries to establish the generally applicable relationships which universally occur in different technologies. Most textbooks explain this with the help of higher mathematics. This chapter is intended to explain basic terminology and information regarding closed-loop control technology so as to largely dispense with mathematics.

1.1.1 Open-loop control/closed-loop control technology

Open-loop control
The standard IEC 60050-351 defines this as follows: Open-loop control is a process occurring within a system where one or several input variables exert an influence on other variables in the form of output variables according to the specific rules of the system.
The characteristic feature of open-loop control is the open action flow, i.e. the output variable does not have any retroactive influence on the input variable.

Closed-loop control
The standard IEC 60050-351 defines this as follows: Closed-loop control is a process within a system whereby the variable to be controlled (controlled variable) is continuously monitored and compared with the specified value (reference variable). Depending on the result of this comparison, the input variable of the system is influenced in such a manner as to bring about the adaptation of the output variable to the specified value despite any disturbances. This response brings about closed action flow.

1.1.2 Basic terms of closed-loop control technology

Reference variable
The reference variable W is also referred to as the setpoint value of the controlled variable. It specifies the desired value of the controlled variable. The reference variable can remain constant over time; but can also change over time. The desired value of the reference variable is known as the actual value.
In closed-loop control the task is to keep the controlled variable at a desired value or to follow the desired value curve. This desired value is known as the reference variable.

Controlled variable
The aim of closed-loop control is to keep a variable at a specified value or value curve. This variable to be controlled is referred to as controlled variable x.

This problem occurs in systems or on machines of most widely diverging technologies, the variable to be controlled is known as the controlled variable.

Example
Speed of a DC motor (See project 2)
The setpoint and actual value of the speed should be set virtually the same in order to obtain optimal motion behaviour.

– Examples of controlled variables are:
  - The pressure in an air reservoir
  - The pressure in a hydraulic press
  - The temperature in an electroplating bath
  - The flow of coolants in a heat exchanger
  - The concentration of a chemical in a stirring vessel
  - The speed of a feed motion in machine tool using an electric drive
  - The speed of a motor

Manipulated variable
Closed-loop control can only be effected if there is a possibility of intervening in a machine or system in order to change the controlled variable.
The controlled variable can be influence in any system by means of intervention. This intervention alone allows the controlled variable to be set such that it corresponds to the specified value. The variable which effects such intervention is known as the manipulated variable y.

– Examples of manipulated variables are:
  - The setting of an exhaust air restrictor on an air reservoir
  - The setting of a hydraulic pressure regulating valve
  - The voltage applied to the electric heating element of an electroplating bath
  - The setting of a flow control valve in a coolant feed line
  - The setting of a valve in a chemicals feed line
  - The voltage on the armature of a DC motor

Disturbance variable z
Disturbances occur in any controlled system and these are what make closed-loop control a matter of necessity. The effects of such disturbances are known as disturbance variables z.

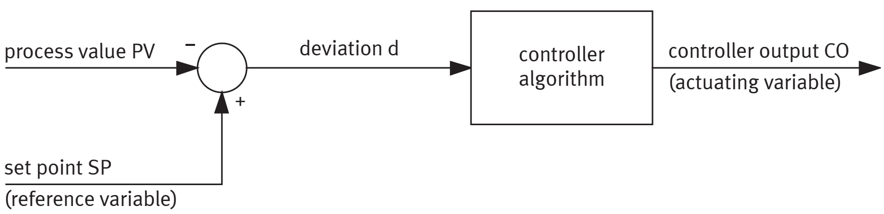
The controlled system is the part of a machine or system where the controlled variable is to be adjusted to the specified value and where the manipulated variables adjust the disturbance variables. A controlled system consists not only of the manipulated variable as an input variable, since disturbance variables also occur as input variables.

System deviation x_d
The comparison of reference and controlled variable is knows as system deviation x_d. It is calculated from the difference:
$x_d = e = W - x$

Control response
The control response indicates how the controlled system responds to changes to the input variable. Determination of the control response is the aim of closed-loop control technology.

Closed-loop controller
The task of the closed-loop controller is to keep the controller variable as near as possible to the reference variable. The controller constantly compares the value of the controlled variable with the value of the reference variable.

From this comparison and the control response, the controller determines and outputs the value of the manipulating variable.

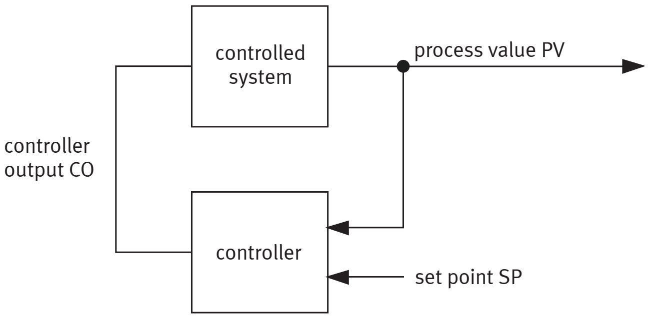


Final control element and actuator
The final control element adjusts the controlled variable. The final control element is normally actuated by a special actuator. An actuator is always required in cases where it is not possible for the closed-loop controller to actuate the final control element directly.

Measuring element
In order to make the controlled variable accessible to the controller, it must be measured by a measuring element (sensor, transducer) and converted into a physical variable that can be processed by the controller as an input.

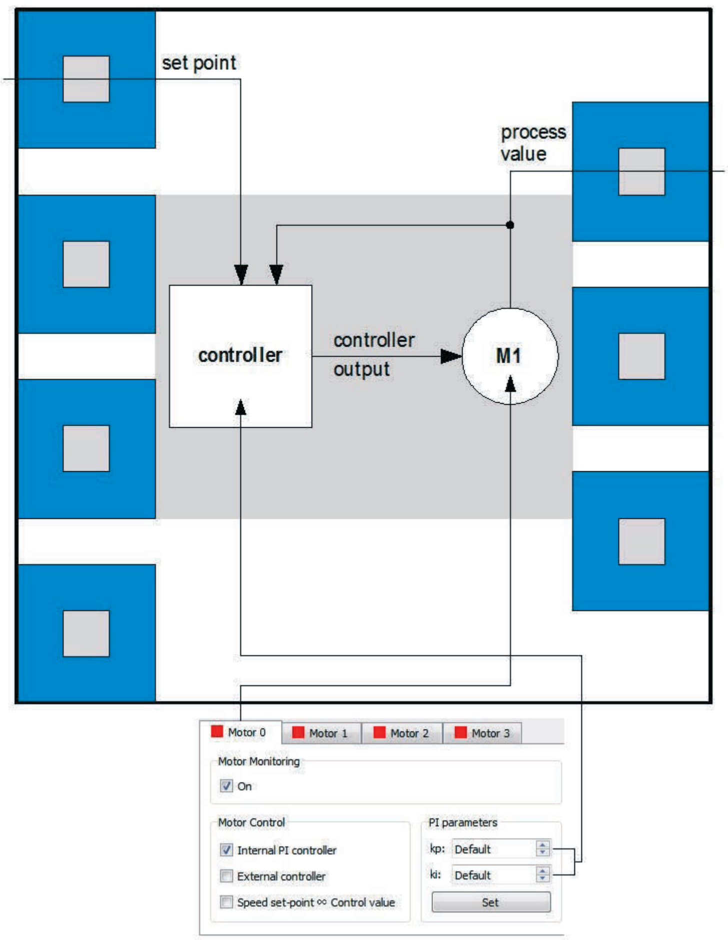
Closed loop

The closed loop contains all components necessary for automatic closed-loop control.



Example -Robotino®

The function block **Motor** comprises a software controller to adjust the speed of the motor.

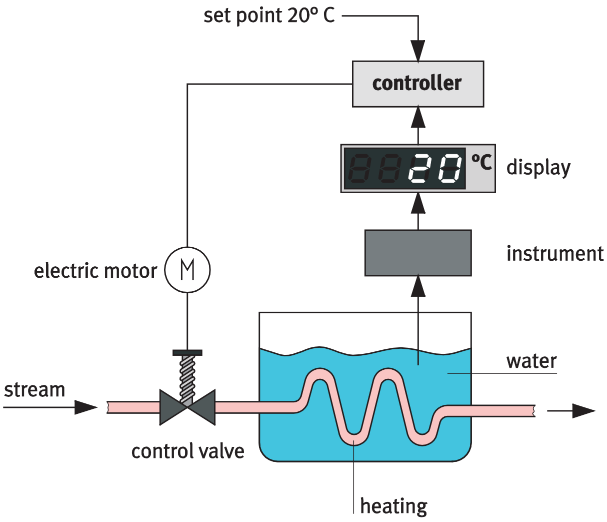


The reference variable W of the closed-loop controller is thus identical to the setpoint speed x of the motor.

- Controlled variable = Actual value of motor speed
  Measurement is effected via the motor encoder.
  The task of a closed-loop controller is to minimise the system deviation, i.e. the deviation of the actual value from the reference variable.

Example

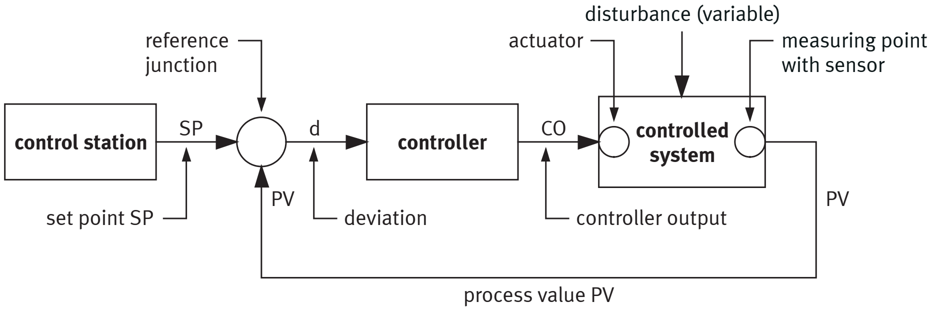
Dependent on the system deviation, the closed-loop controller supplies a signal to the final control element. If the system deviation is mainly in the negative direction, i.e. the measured value of the volumetric flow rate is greater than the present value (the reference variable), the valve is further closed. If the system deviation is mainly in the positive direction, i.e. the measured value is lower than the present value, the valve is further opened.



Generally it is not possible to optimally follow-up the output variable:

- If intervention is too quick or sudden, the system is too heavily activated at the input. The consequence is a fluctuating response at the output.
- If intervention is slow or weak, the output variable will only approximately follow the desired response.

Moreover different systems, i.e. different controlled systems, also require different control strategies. Systems which involve long delays need to be controlled with care and foresight. This briefly outlines the problems of closed-loop control technology and the task facing the control engineer.



The following steps are required if closed-loop control is to be designed for a variable within a system:

- Defining the manipulated variable (this defines the controlled system),
- Determining the response of the controlled system,
- To establish the control strategy for the controlled system (response of the "controller" system),
- Select suitable measuring and final control elements.

Controlled systems
Complex relationships exist between the manipulated variable and the controlled variable. This relationship results from the physical interdependence of the two variables. The part of the control that describes these physical processes is called the controlled system.

The controlled system is the part of the machine or system in which the controlled variable is to be adjusted to the specified value and where the manipulated variables adjust the disturbance variables. A controlled system not only comprises the manipulated variable as input variable, since disturbance variables also occur as input variables.

Before a controller can be defined for a controlled system, the behaviour of the controlled system must be known. The control engineer is not interested in the technical processes within the controlled system, but only in the system behaviour.

Time response of a system
Of particular importance in closed-loop control technology is the time response of a system (also known as dynamic response). This is the time characteristic of the output variable (controlled variable) for changes in the input variable. Particularly important is the response when the manipulated variable is changed.
The control engineer must understand that nearly every system has a characteristic dynamic response.

1.2 Description of the time response of control systems

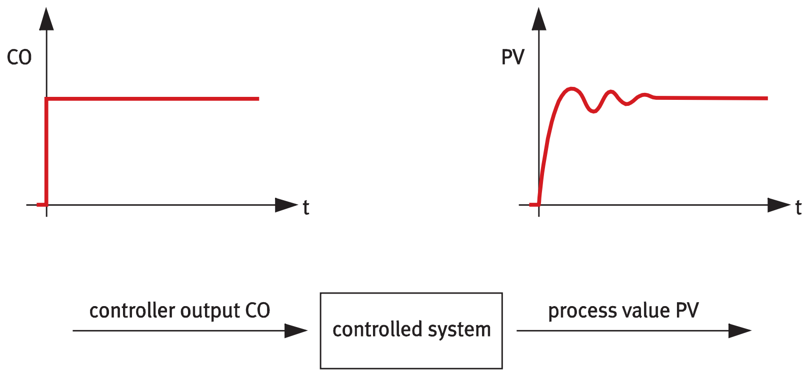
Step response or transient function

The response of a system to a sudden change of the input variable is called the step response or transient function. Every system can be characterised by its step response. The step response also allows a system to be described using mathematical formulas.

Dynamic response

This description of a system is also known as dynamic response. The illustration below demonstrates this correlation. Here the manipulated variable y is suddenly increased (see diagram below).

The step response of the controlled variable x is a settling process with transient overshoot.



Steady state

Another description of a system is the behaviour in the steady state of the system, the static behaviour.

Static behaviour

The static behaviour of a system is reached when none of the variables change with time. The steady state is therefore reached only when the system has settled. This state can be maintained for an unlimited time.

The output variable is still equally dependent on the input variable. This dependence is shown by the characteristic of a system.

1.3 Closed-loop controllers

The previous section dealt with the controlled system - the part of the system which is to be controlled by a controller. This sections looks at the closed-loop controller.

The controller is the device in a closed-loop system that compares the measured value (actual value) with the desired value, the setpoint value, and then calculates and outputs the manipulated variable.

The above section showed that controlled systems can have very different responses. There are systems which respond quickly, systems that respond very slowly and systems with storage properties.

In the case of each of these controlled systems, changes to the manipulated variable y must take place in a different way. For this reason there are various types of controller each with its own control response. The task of the control engineer is to select the controller with the optimal control response for the controlled system.

Control response

Control response is the way in which the closed-loop controller derives the manipulated variable from the system deviation.

PID control for motor control

Standard linear controllers are most commonly used in industry. The transmission ratio of these controllers can be ascribed to the P-, I- and D components which represent the three basic linear forms.

The PID controller is the most important standard controller since it combines the good characteristics of other controller types and is very fast and accurate. This controller combines proportional, integral and differential behaviour. If a step occurs in a signal, the controlled variable initially exhibits PD behaviour, the D-action then drops off while the I-action increases as a function of time. The characteristics are those of the individual control units:

- Kp - the proportional-action component of the PID controller upstream of the motor
- Ki - the integral-action component of the PID controller upstream of the motor
- Kd - the differential-action component of the PID controller upstream of the motor

1.3.1 Proportional controller

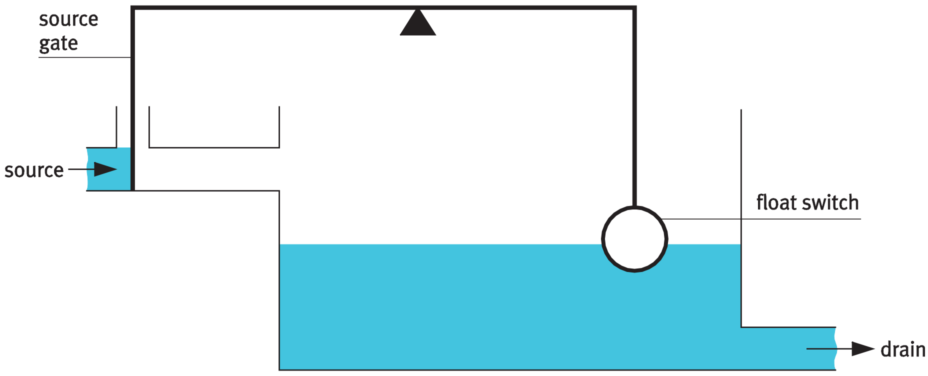
In the case of the proportional controller, the control signal is calculated proportional to the system deviation. If the system deviation is large, the value of the manipulated variable is also large. If the system deviation is small, the value of the manipulated variable is small. The time response of the P controller in the ideal state is exactly the same that of the input variable. The advantage is that the controller intervention is very fast and without delay.

Example level control

Water flows into a container via an inlet and forces the float upwards. The float acts on the gate valve via a lever. If water consumption is high, the gate valve has to be correspondingly opened. If consumption is low, the gate valve opens only very slightly.

This means that, if water consumption is high, the level of water in the tank is also lower than if consumption is low. This is the disadvantage of a proportional controller: Depending on the disturbance variable Z, the level of water in the tank varies.

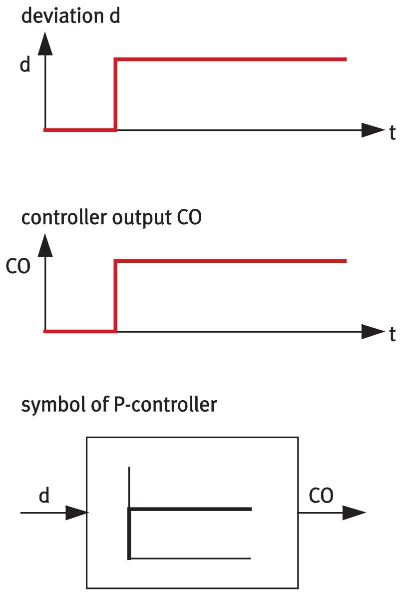
These controllers are generally realised electronically.



Area of application

Proportional-action controllers are used wherever the requirements for control precision are minimal. The P controller converts a step in the input signal directly into a step in the output signal. It has fast response behaviour.

- Advantages
  The advantages of a proportional controller are its speed and simple design.
- Disadvantage
  The disadvantage is that control loops using proportional controllers exhibit residual system deviation. The controlled variable (actual value) never reaches the reference variable (setpoint value).



Time response of a P controller: With a P controller the response of the manipulated variable y is proportional to the system deviation e

1.3.2 Integral-action controller

The effectiveness of an I controller increases over time. Even a slight system deviation results in a high output signal if it exists for a sufficiently long period. This controller converts input signal jumps into ramp-type output signals by means of continuous integration.
This means that changes in manipulated variables are continuous and considerably slower than in the case of a proportional-action controller.

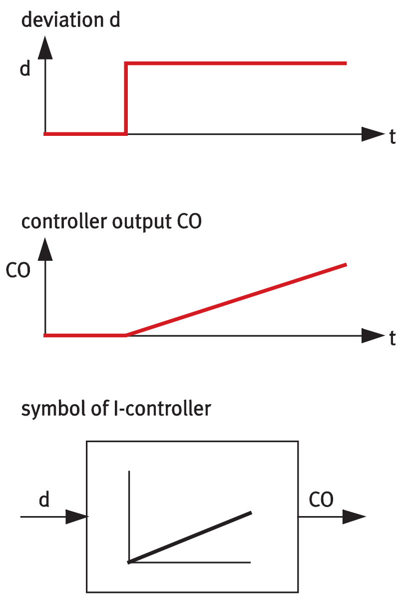
If a constant signal is applied at the input of an integral-action controller, the output changes continuously until the system deviation is compensated. The manipulated variable of an integral-action controller is proportional to the system deviation-time-area.

The greater the system deviation and system deviation over time, the steeper is the increase in the manipulated variable. In the case of an I controller, the system deviation and manipulating speed of the manipulated variable are proportional, i.e. the greater the system deviation, the faster the final control element is changed.

Pure integral-action controllers are rarely used since they tend towards instability and respond too slowly to fast changes.

Area of application

I controllers are frequently used to eliminate the disadvantage of a proportional controller of not being able to fully compensate the system deviation. This is why they are often used in combination with proportional controllers in practice.



Time response of an I controller: With an I controller the manipulated variable responds proportional to the area of the system deviation and time

1.3.3 Differential-action controller

In some controlled system major disturbance variables can rapidly become apparent. The controlled variable deviates greatly from the reference variable within a short time. Deviations such as these can be compensated with a D controller.

The output variable of a D controller is proportional to the temporal change in system deviation. A sudden change in system deviation therefore creates an infinitely large manipulated variable at the controller output.

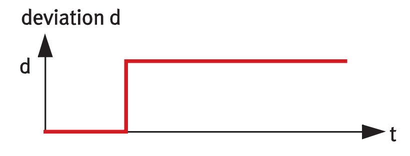
Area of application

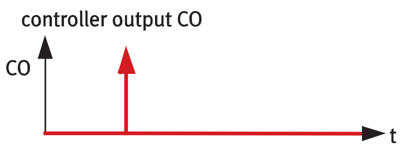
Since a D controller responds solely to the change in system deviation, it is not used on its own. It is therefore always used in combination with a P or PI controller.

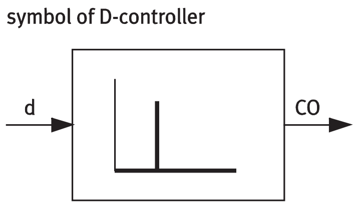
A differential-action controller cannot adjust a residual system deviation and is therefore rarely used in industry.

Differential-action controllers are used in combination with a proportional-action or integral-action controller.

The faster the change in system deviation occurs, the more effective a differential-action controller becomes.





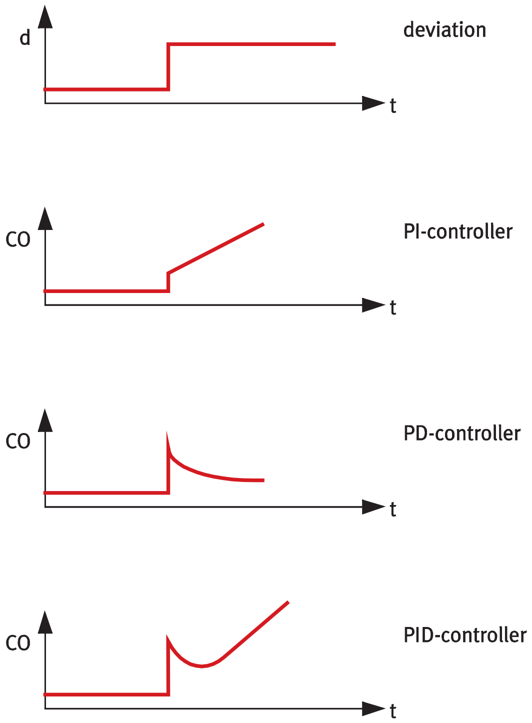


Time response of a differential-action controller: With a D controller, the manipulated variable is proportional to the change in system deviation

1.3.4 Combined controllers

Since the various types of closed-loop controller often do not exhibit the desired response for a particular control task, these are often combined. However, not all combinations of the three controller types are practical. The most frequently used combinations are:

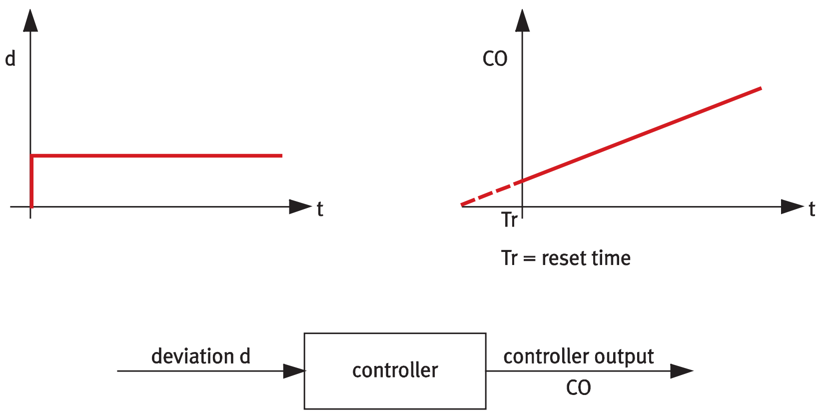
- PI controller
- PD controller
- PID controller



PI controller

A PI controller combines the behaviour of the I controller and P controller whereby the advantages of both controller types are to be used: fast response of the integral-action controller and compensation of the residual system deviation of the proportional-action controller. A PI controller can therefore be used in a large number of controlled systems.

In addition to proportional gain, a PI controller has a further characteristic that indicates the behaviour of the I component: the integral-action time which provides a measure of how fast the controller resets the manipulated variable in addition to the manipulated variable generated by the P-action to compensate a residual system deviation. The reset time is the period by which the PI controller is faster than the integral-action controller.



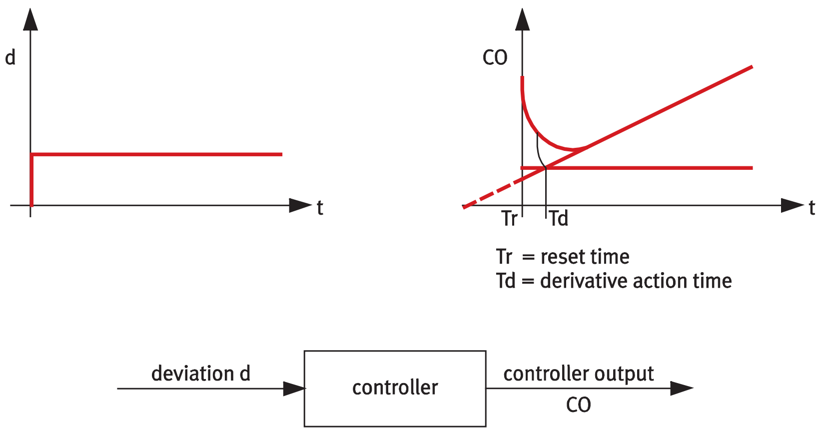
PID controller

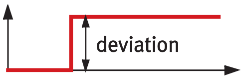
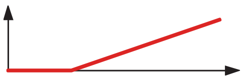
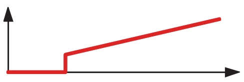
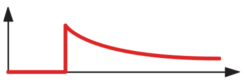
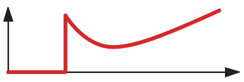
In addition to the properties mentioned of a PI controller, a PID controller also includes the derivative-action component. This takes into account the rate of change of the system deviation.
If the system deviation is large, the D-component ensures a momentary extremely high change in the manipulated variable. While the influence of the D-component drops off immediately, the I component increases slowly. If the system deviation is slight, the behaviour of the D-component is negligible.

- Advantage
  This behaviour has the advantage of faster response in the event of changes or disturbance variables and system deviations are therefore compensated more rapidly.
- Disadvantage
  The disadvantage is that the control loop is much more prone to oscillation and the correct setting of the controller is therefore more difficult.

Derivative-action time

As a result of the D-action, this controller type is faster than a P or a PI controller. This manifests itself in the derivative-action time T_v. The derivative-action time is the period by which the PID controller is faster than the PI controller.



Summary **Controller type**	**Time response**	**Characteristics**
		
P controller		For minimal requirements regarding reference variable. It is fast, but not able to fully compensate a system deviation.
I controller		Slow response; a system deviation can be fully compensated. In the event of large changes in the disturbance variable, the integral-action tends to oscillate.
D controller		Responds only to changes in system deviation. Is not used on its own.
PI controller		Proportional-action controllers are often provided with a small integral-action component, which allows the system deviation to be fully compensated. This is a frequently used combination.
PD controller		This combination is rarely used. It is suitable for closed-loop control where fast response is required to large changes in the disturbance variable.
PID controller		Used for high requirements of closed-loop control systems. The P component effects fast closed-loop control, the I-component ensures high accuracy and the D component increase the speed of closed-loop control.

1.3.5 Structuring and parameterisation of controllers

Closed-loop control forms a components part of automated systems whose main function consists of process stabilisation. They are used with the aim of

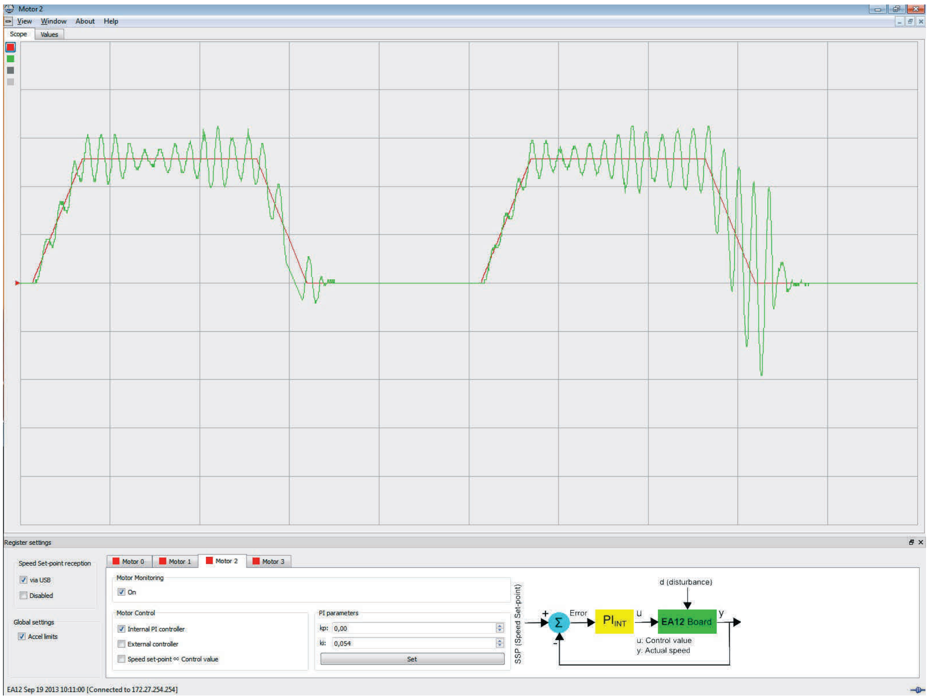
- Bringing about and automatically maintaining certain process states (modes of operation)
- Eliminating disturbances in process sequences and
- Preventing the unwanted linking of subprocesses within the technical process.

Sizing by means of trial

This method of sizing the individual components is particularly suitable in this instance since we are dealing with a simple system. In our case the Kd component is not affecting Robotino's® driving behaviour. Therefore only Kp and Ki components are used and need to be roughly tuned. This is achieved by selecting the smallest possible Kp component and tuning the Ki component to zero (Kp=small, Ki=0).

The Kp component (gain) is now slowly increased until poor damping is obtained.

Example Robotino® View



Tuning of the PID controller

In Robotino® View (with the help of EA09 View), the adjustment of the speed of a DC motor can be easily realised. The sizing of the components kp, ki can be effected by means of adjusting the slides.

Poor damping

Poor damping is obtained if oscillation is reduced ➔ Displacement of oscillation.

However if a tendency to oscillate is to occur, the Kp component must be adjusted slightly lower. The I component is then added and increased and tested in steps until the result virtually coincides. If the result is still not satisfactory, the D component can also be added. This component enables closed-loop control to become more stable. If this is the case, the Kp and Ki components can be increased once more. This is repeated until the result is absolutely satisfactory.

This very practice-oriented and commonly used method of determining controller parameters does not always provide optimum results; this result is however adequate in the case of this system.

Other methods of tuning controller parameters are,
Sizing according to:

- Tuning rules
- The oscillation method
- Sep response
- Bode diagram

2 Robot subsystems: Drive

Industrial robots consist of various subsystems that fulfil different function. The table below provides a schematic representation of these subsystems and subfunctions. The table also provides you with the relevant references as to where these subsystems and subfunctions are described in the technical documentation, data sheets or in this training package.

Subssystems	Subfunctions	Description in documentation regarding Robotino®	
Kinematics	Establishing the spatial relationship between workpiece/tool and production device	Appendix Exercises and solutions	Freedom of movement of a system in the plane and within a space Project 6 and 7
Drive	Conversion and transfer of the required energy to all axes of motion	Appendix Exercises and solutions	Omnidirectional robot, multidirectional wheels, omnidirectional drive Project 2 and 3 Technical documentation and data sheets regarding the topics:"DC motor, gear units, transmission, toothed-belt drive and multidirectional wheels"
Displacement encoder	Measurement of the position and speed of the individual axes of motion	Exercises and solutions	Project 2 and 3 Technical documentation, data sheets: Incremental encoders
Open-loop/ closed-loop control	Storing, controlling and monitoring of the program sequence. Adjustment and control of rotational speeds and velocities	Appendix Exercises and solutions	Closed-loop control technology Projects 2, 3, 4, 8, 9
Sensors	Measurement of physical variables sample and position detection	Appendix Exercises and solutions	Sensors Projects 4 to 8 Data sheets, technical documentation
Grippers	Gripping of workpiece, securing work piece position during travel	As an expansion of Robotino®	

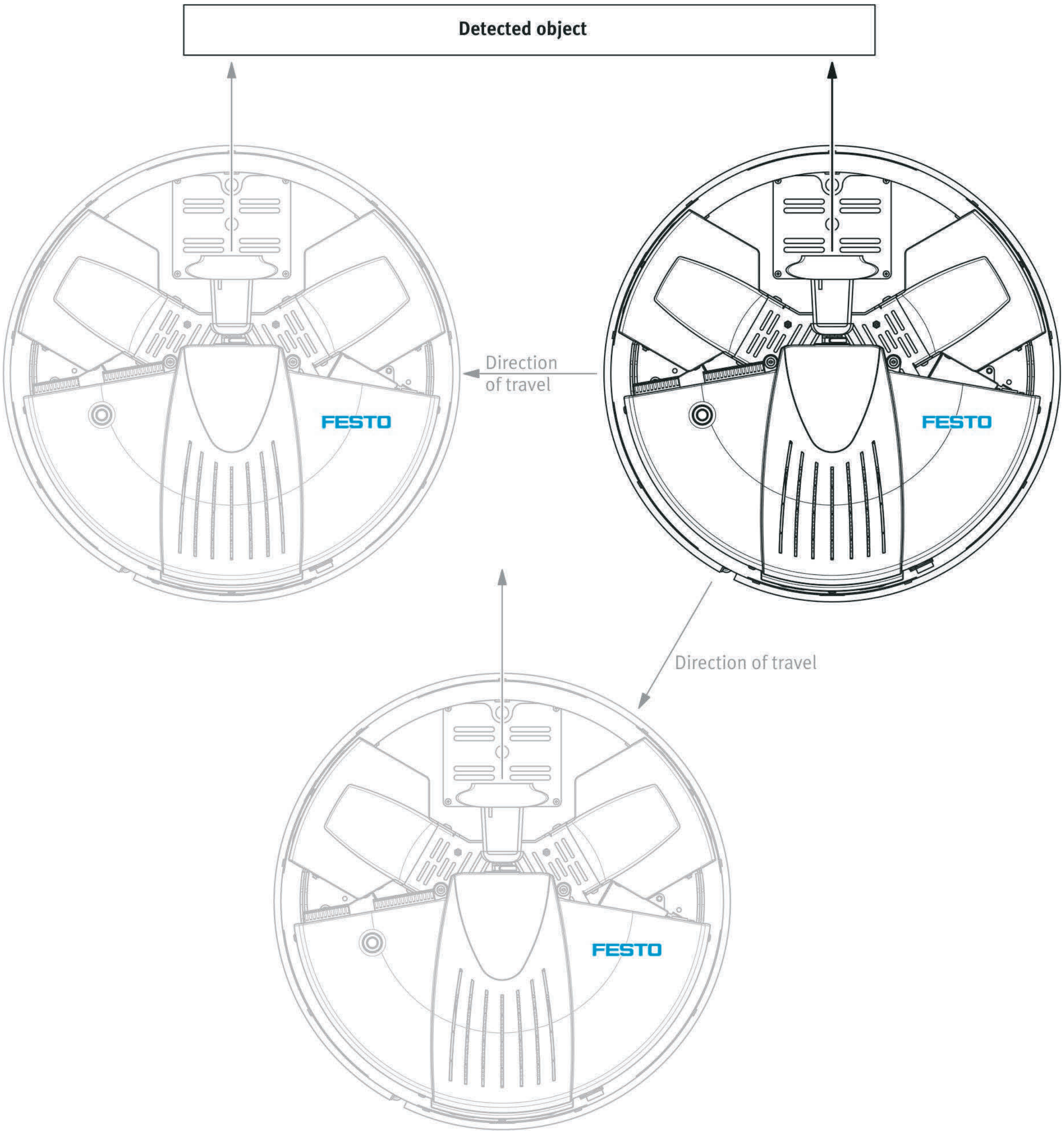
2.1 General information regarding omnidirectional robots

The advantage of omnidirectional driven vehicles is that they can move in any direction without having to rotate.

The core element of an omnidirectional drive is a so-called omnidirectional wheel or multidirectional wheel or caster, also known as omniwheel. Usually barrel-shaped, these wheels are attached to the revolving surface of the main wheel, whose axes of rotation are at a right angle to the axis of rotation of the main wheel (see illustration).

Multidirectional wheels can be actively driven via the motor and also passively roll laterally via the casters integrated in the wheel.

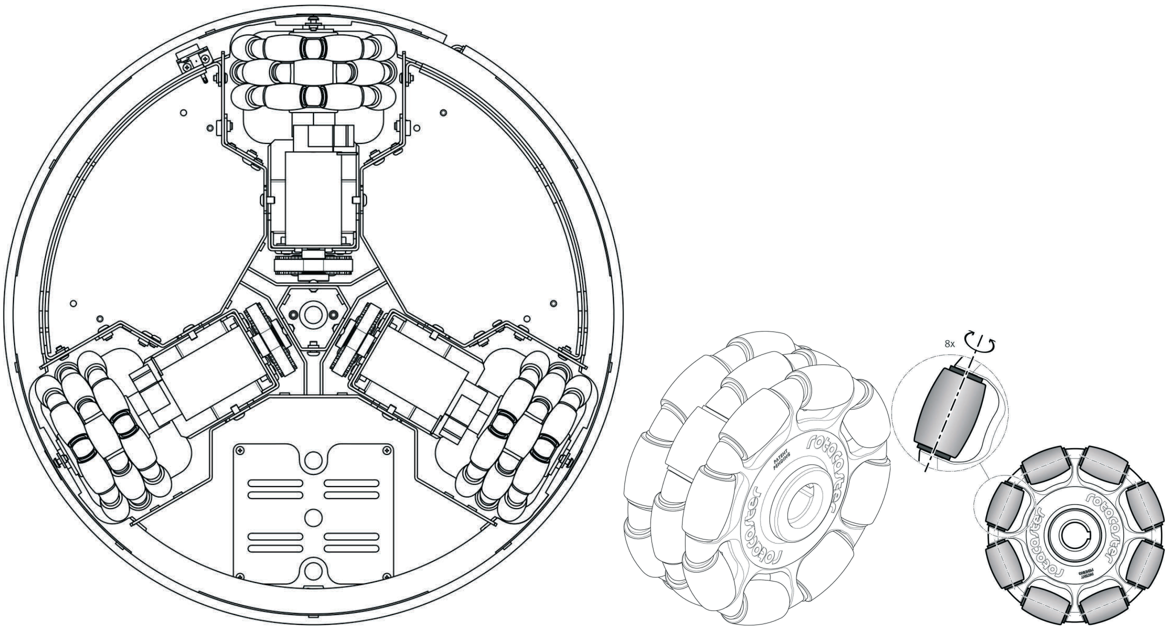
A robot does not need to turn away from the object monitored; it retains its line of vision.



Moving with rotating (see also project 2, positional sketch)

2.2 Multidirectional wheels

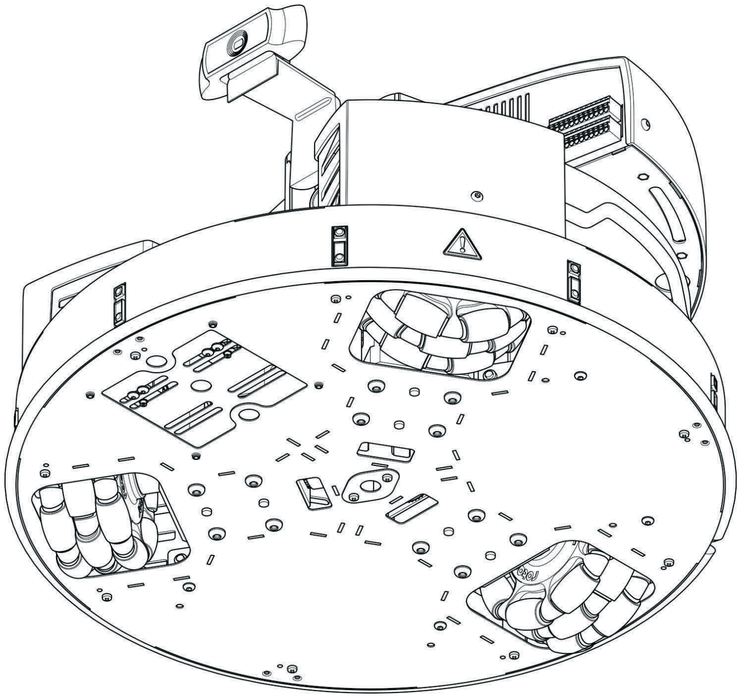
A multidirectional caster is moved in one direction via its drive axis and in addition can roll in any direction by means of the other casters. Through interaction with the other two drive units, it is therefore possible to generate a direction of motion which deviates from that of the direction of actuation.



Omnidirectional drive

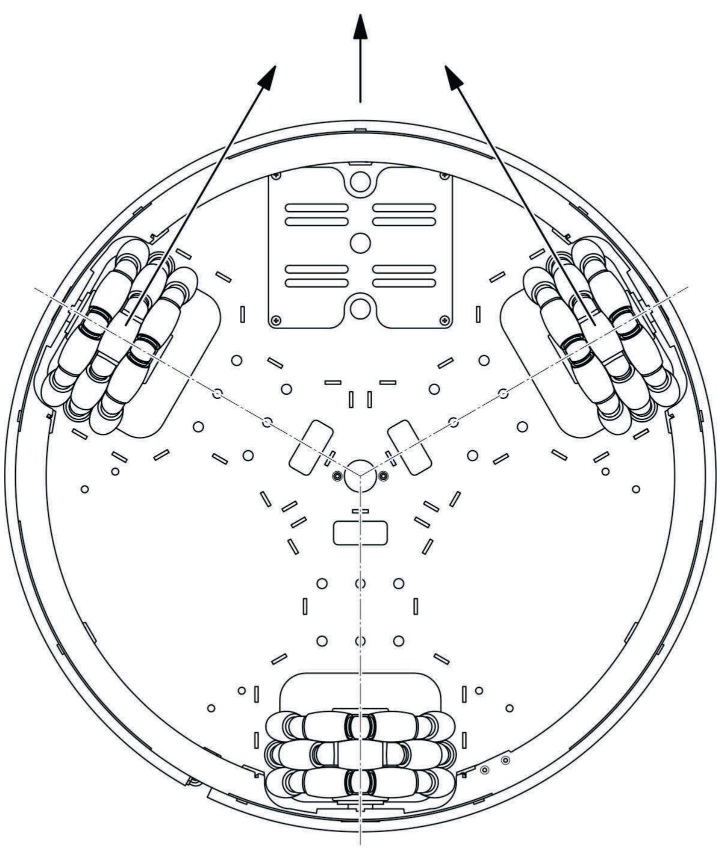
If the main wheel is driven, the two auxiliary wheels lock and act as the running surface of the main wheel. If the drive is stopped and the vehicle moved into another direction, for example via a second omniwheel attached at a right angle, the auxiliary wheels rotate and thus minimise the frictional resistance of the wheel. This type of design allows fast locomotion at virtually any angle to the direction of travel of the main wheel.

On a symmetrical drive, the wheels (multidirectional wheels or casters) are attached 120° apart.



Wheels 120° apart

The wheels on an omnidirectional drive are actuated such as to rotate together.



Direction of motion

Multidirectional wheel – advantages and disadvantages
The advantage of this system is that, owing to the different speed control of the motors, the robot is able to travel in any direction without the need for turning.
Additional advantages are:

- An omnidirectional vehicle is able to turn when stationary
- The turning circle on these vehicles is equal to zero, no need for shunting
- The weight of the entire robot is distributed across three wheels and system balance is therefore improved
- No steering mechanism required
- Mechanically simple and sturdy.

One disadvantage is that power consumption is relatively high in the case of forward travel, since there is a large number of rolling surfaces and greater rolling resistance is generated due to increased frictional resistance.

Different wheel types
Different wheel types are used in the field of omnidirectional robots. This is always dependent on the surface on which the robot is to travel. Transverse casters made of soft plastic or polyurethane, are particularly suitable for hard and smooth surfaces such as glass or tiles. Hard transverse casters are more suitable for soft surfaces such as carpets or cardboard. A further difference with multidirectional wheels is the number of transverse casters used. As can be seen in the illustration on page 26, multidirectional wheels have three transverse casters per wheel. Multidirectional casters of this type originate from the materials handling sector where three transverse casters are adequate.

2.3 Freedom of movement of a system in the plane and space

2.3.1 Degrees of freedom
The freedom of movement of a system in a plane or spatial direction is known as degrees of freedom.
Degrees of freedom are the flexibility of movement of bodies in a plane or space.
Various possibilities are available to move a body within a space:

Translatory movements	x-coordinate
	y-coordinate
	z-coordinate

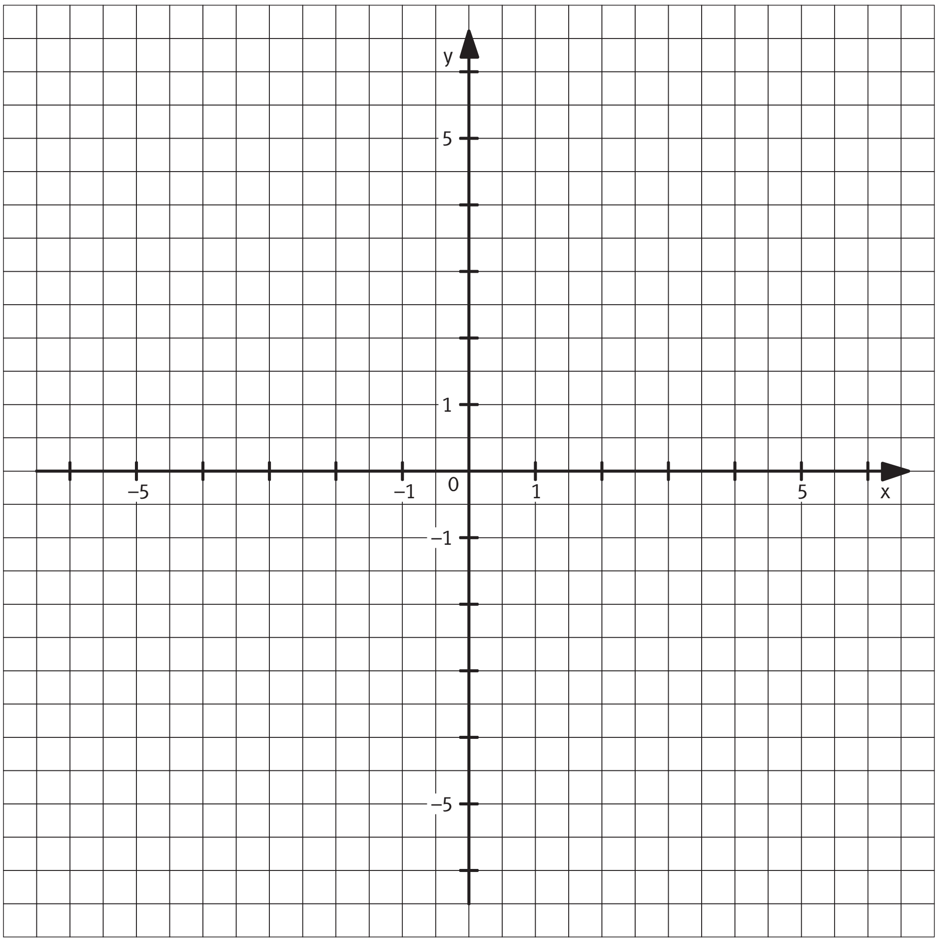
These degrees of freedom relating to such spatial displacement within a space are known as translatory degrees of freedom.

In addition, one two or three rotational degrees of freedom apply in the case of rotating, rigid bodies, depending on whether the body moves around one, two or three of its rotational axes.

Rotatory movements: Rotation around	x-axis
	y-axis
	z-axis

2.3.2 Coordinate system

In order to represent the position and degrees of freedom of a body, the rectangular Cartesian coordinate system is used (Cartesian according to R. Descartes, 1596 to 1650).
The purpose of a coordinate system is to indicate the position of points of bodies within a space.
The position in the space is uniquely determined using the selected coordinate system by indicating numerical values, i.e. the coordinates. Specific objects (lines, curves, distances, areas, bodies), can then be specified by means of individual points.



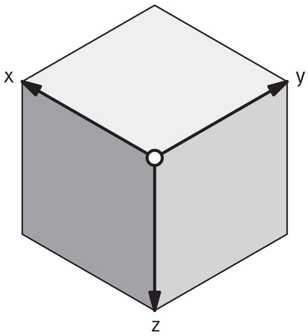
Cartesian coordinate system, two-dimensional

The rectangular planar Cartesian coordinate system consists of two perpendicular real axes. The horizontal line is the x-axis and vertical line the y-axis.

Any point in the plane can be denoted by the associated negative or positive x- and y-values.

Sections along the x-axis are known as the abscissa and along the y-axis as the ordinates. Measurement starts from the intersection (origin).

The three-dimensional spatial Cartesian coordinate system consists of three perpendicular real axes (the vertical axis is the z-axis). These have a common coordinate origin. The system or body is able rotate freely around the coordinate origin. The x- and y axes are horizontal and the z-axis is vertical.



Cartesian coordinate system, three-dimensional

2.3.3 Movement of bodies

Any movement of a body is possible in positive or negative direction. A body moving forward or backward along an axis; for example a rail vehicle. It can move forward or backward along a predefined path and has only one degree of movement.

A robot which is able to move straight ahead in forward or back direction moves along the x-axis in positive or negative direction (one degree of freedom, translation).
A robot moving laterally moves along the y-axis in positive or negative direction.
A robot moving in a straight line (forward, backward, positive of negative within the coordinate system) and laterally (to the right and left, positive and negative within the coordinate system) therefore has two translatory degrees of freedom.)

A robot travelling in a circle rotates around the central axis, the z-axis and therefore has an additional degree of freedom, the rotary degree of freedom. Rotation around the z-axis is possible in two directions.

The Robotino® can move in any direction:

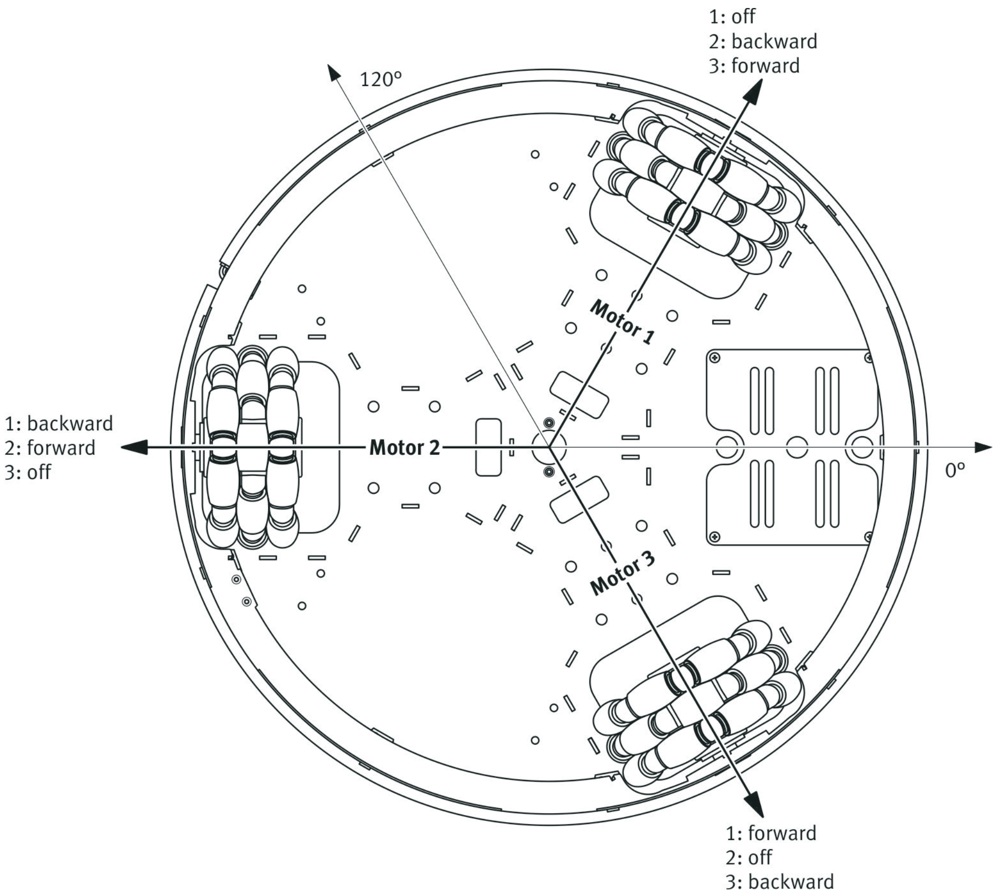
- Forward
- Backward
- Laterally
- In a circle with or without retaining the line of vision

and therefore has three degrees of freedom, two translatory and one rotary degree of freedom.

2.4 Actuation of an omnidirectional drive

The actuation of an omnidirectional drive is fairly complex. With an omnidirectional drive it is only possible to move along by means of three non-steerable wheels. Three drive motors are actuated in the case of an omnidirectional drive. On the assumption that there are three control commands for the actuation of a motor (forward, backward, off), these three possibilities alone result in 27 options for three motors. These 27 control options allow the robot to be controlled in different directions.

A lateral control command, as is possible with the Robotino®, is not dealt with here at this stage.



Actuation of the motors

The table below lists the 27 options possible via the following "commands"

- forwards,
- off,
- backwards

However the various speed levels have not been taken into consideration. Different speed levels would also enable the direction of travel to be changed. Each motor travels at the same speed level.

2.4.1 Actuation and direction of travel

The table above demonstrates how the motors need to be actuated to enable the robot to travel in 300 degree direction as shown in the illustration overleaf.

Motor 1	Motor 2	Motor 3	Direction of travel
Forward	Forward	Forward	Rotation in clockwise direction, while stationary
Forward	Forward	Off	Rotation in clockwise direction with small radius
Forward	Forward	Backward	Rotation in clockwise direction with large radius
Forward	Off	Forward	Rotation in clockwise direction with small radius
Forward	Off	Off	Rotation in clockwise direction with mean radius
Forward	Off	Backward	Travel to 0°
Forward	Backward	Forward	Rotation in clockwise direction with large radius
Forward	Backward	Off	Travel to 300°
Forward	Backward	Backward	Rotation in anti-clockwise direction with large radius
Off	Forward	Forward	Rotation in clockwise direction with small radius
Off	Forward	Off	Rotation in clockwise direction with mean radius
Off	Forward	Backward	Travel to 60°
Off	Off	Forward	Rotation in clockwise direction with mean radius
Off	Off	Off	Stationary
Off	Off	Backward	Rotation in anti-clockwise direction with mean radius
Off	Backward	Forward	Travel to 240°
Off	Backward	Off	Rotation in anti-clockwise direction with mean radius
Off	Backward	Backward	Rotation in anti-clockwise direction with small radius
Backward	Forward	Forward	Rotation in clockwise direction with large radius
Backward	Forward	Off	Travel to 120°
Backward	Forward	Backward	Rotation in anti clockwise direction with large radius
Backward	Off	Forward	Travel to 180°
Backward	Off	Off	Rotation in anti clockwise direction with mean radius
Backward	Off	Backward	Rotation in anti clockwise direction with small radius
Backward	Backward	Forward	Rotation in anti clockwise direction with large radius
Backward	Backward	Off	Rotation in anti clockwise direction with small radius
Backward	Backward	Backward	Rotation in anti clockwise direction, while stationary

Division into degrees

2.4.2 Actuation of the three Robotino® motors

The Robotino® has three drive motors which drive three multidirectional wheels. The rotational speed of an individual wheel can be set irrespective of the rotational speed of the other wheels. In order to move the Robotino® in one direction, the rotation of the individual wheels must be coordinated, since the correct interaction alone generates the desired Robotino® movement.

The motors can be actuated either directly with the help of Robotino View or with the help of the function block "omnidrive". However, the use of the function block "Omnidrive" (Robotino® View) is recommended for all applications.

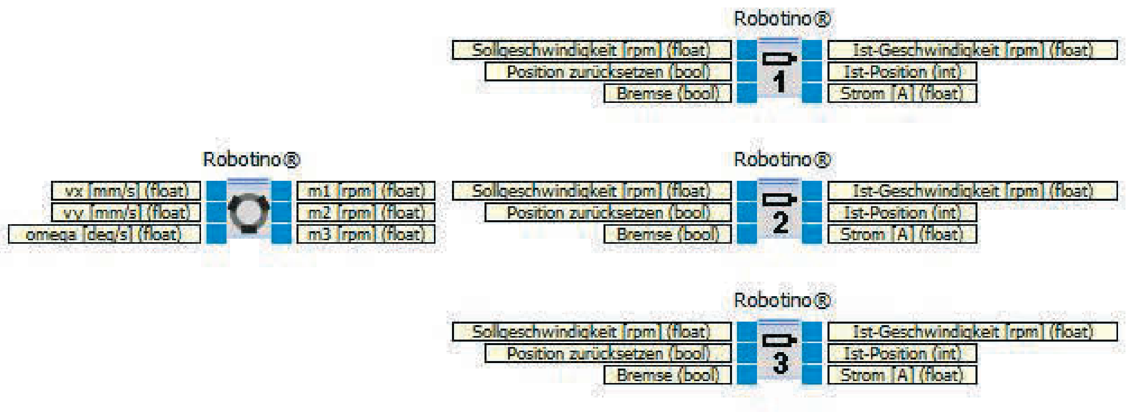
Function block "omnidrive"

The "omnidrive" calculates the setpoint rotational speeds of motors 1, 2 and 3 in x- and -y direction on the basis of a specified setpoint speed. In addition, the actual speed in x- and y-direction and the actual rotational speed are calculated from the actual speed.

The Robotino® has two translatory degrees of freedom, the movement along the x- and y-axis for straight ahead and lateral travel. In addition rotation is possible around the z-axis.
The inputs and outputs of the omni module are correspondingly occupied:

Inputs	Description
vx_float	Set-velocity in x-direction in Robotino's local coordinate system in mm/s
vy_float	Set-velocity in y-direction in Robotino's local coordinate system in mm/s
omega_float	Set-rotational velocity in deg/s

Outputs	Description
m1_float	Speed set-point motor 1 in rpm
m2_float	Speed set point motor 2 in rpm
m3_float	Speed set-point motor 3 in rpm



Omnidrive

The direction (coordinates) and setpoint speed are defined, input and calculated at the input of the function block **"Omnidrive"** and converted into the setpoint values for the respective motor speed (see fig. above).

The setpoint speeds for the three drives are output at the output of the function block **"Omnidrive"**. These setpoint speeds realise the corresponding actual speed in x-, y-direction or the rotational speed.

Under the keyword "omnidrive" in Robotino® View Help, you can find out how the conversion of the setpoint speed vector and the setpoint rotational speed is derived into the setpoint speed of the individual motors.

Note

A small example of applied vector analysis can be found in project 3, linear travelling and positioning of a robot system "travelling a defined distance".

3 Characteristic curve of sensors

A characteristic curve represents the relationship of two values in the form of a line within a two-dimensional coordinate system. In the case of the distance sensors of the Robotino® this is the relationship between the distance of the obstacles and the output values generated in Robotino® View.

3.1 Recording of a characteristic curve

As a rule, a characteristic curve is recorded by means of measuring the two variables and entering these in a corresponding coordinate system or table, whereby the values of the one variable are uniquely allocated to the other. The characteristic curve of the component is obtained if these point-pairs are connected by a line/curve. The accuracy of the curve is improved by increasing the number of measuring points. For a particularly important range of values, it is advisable to record the characteristic curve more precisely.

3.2 Linearisation of a characteristic curve

Characteristic curves are mainly non-linear, but can at least be linearised in sections whereby a simple conversion of sensor values into standard units of measurement can be carried out in those sections. Characteristic curves can be easily determined by means of linearisation via a linear equation.

The formula for a straight line in a coordinate system is (for the distance D and the sensor values X)
$D = MX + B$

whereby
M = Gradient of curve
B = Offset of curve
D = Distance of object
X = Output value of sensor

If the linear equation of the linearisation of a section is to represent the distance characteristic curve of the sensor, then M and B is to determined such that the sensor value X supplies the distance value D.

The constants M and B are determined via two trial measurements: D1 and X1 are the distance and the output value of a measurement (for example at 5 cm). D2 and X2 are the distance and output value of a second measurement (for example at 10 cm).

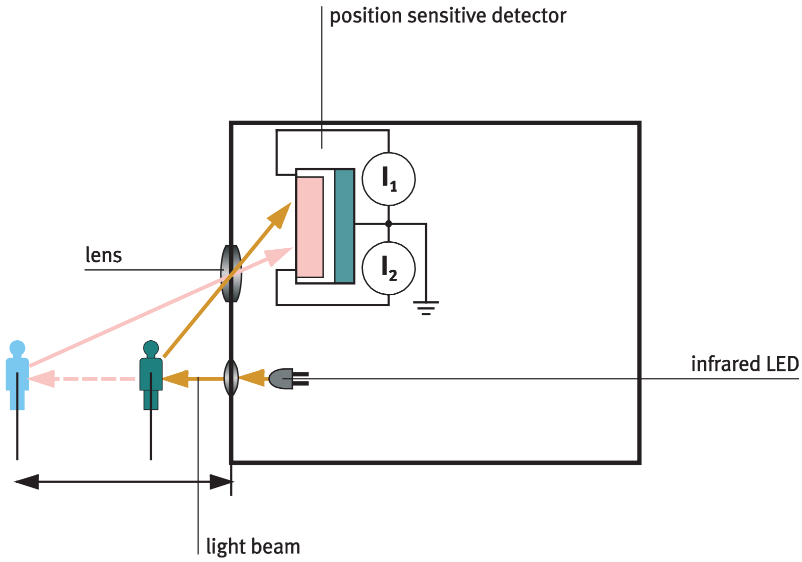
The gradient M of a curve is determined by establishing the relationship between the difference of the distance values and sensors values and calculating a conversion factor from this.
$M = \Delta D / \Delta X$

Inaccuracies occur with this method which can however be disregarded in most cases. It may be advisable to carry out different linearisation for different sections in order to eliminate inaccuracies. A reduction of the linearised section also serves this purpose.

4 Infrared distance sensors

Infrared distance sensors consist of an emitter which emits an infrared light beam, a corresponding receiver and an electronic evaluation unit.

The emitter emits an infrared beam. If this does not impinge on an object, it is not reflected and the receiver therefore does not receive a light beam. However if the light is reflected by an object, the light beam is detected within a certain range of the receiver. Since the photo transmitter and the receiver are located a small distance from one another within the sensor, the emitted and received light beams form a triangle.



Infrared distance sensor: Triangulation method

Depending on the distance, the reflected light beam impinges at a different point on the receiver. The receiver consists of a position-sensitive detector (PSD), which detects the different points of incidence. A signal processing unit converts these into an analogue voltage value.

A PSD is a photo diode of lamellar form. It consists of a light-sensitive and a metallic layer. Metal electrodes are located at the ends of these layers. If a light beam impinges at a point on this light-sensitive layer, this releases charge carriers which generate a current flow towards the two electrodes. The unlit parts of the layer act as resistance. The relationship between the currents on the electrodes is dependent on the position of the point of incidence. The relationship determined between the currents is processed by the evaluation electronics.

The relationship between the currents is independent of the impinging quantity of light; the distance measurement is therefore not dependent on the reflectivity and material of the object.

Diffused light and daylight are eliminated by means of pulsing the emitted light beam. Only signals received via such pulsing are used for evaluation. Continuous light is virtually "ignored".

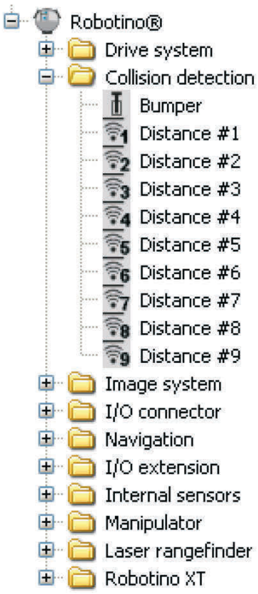
In the majority of cases, emitter, receiver and signal processing are combined into one unit.

Examples of typical areas of application for infrared sensors are parking distance control systems on cars, toilet flushing, door openers or alarm systems.

4.1 Infrared sensors in Robotino® View

The distance sensors in Robotino® View have one output A1, which supplies a voltage value of 0 - 2.55 V. The scaling and conversion of these values within a distance sensor must be carried out by the user.

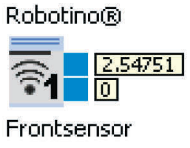
The function blocks for distance sensors are in the function block library **Robotino® Collision detection**.



For easier identification you can also allocate a name to the sensor.

To do so open the window of the function block by clicking the right mouse button and activate **Display name**). Then enter the desired name.

The name of the symbol is changed.



The connection **Value** indicates the current voltage value of the sensor and the connection **Heading** the direction of detection of the sensor, starting with 0° for the sensor.

5 Optical proximity sensors

Optical proximity sensors use optical and electronic means for object detection whereby a red or infrared light is used. Particularly reliable sources for red and infrared light are semiconductor light emitting diodes (LEDs). They are small and sturdy, have a long service life and can be easily modulated. Photodiodes or phototransistors are used as receiver elements. The advantage of red light is that it can be detected by the naked eye when adjusting the optical axes of the proximity sensor used. Also polymer fibre-optic cables can be easily used thanks to their minimal subduing of light in this wave length range.

Infrared (non visible) light is used in applications where increased luminous power is required, for example to bridge greater distances. Furthermore it is less susceptible to interference (ambient light).

In the case of both types of optical proximity sensors additional suppression of external light influences is achieved by means of modulation (pulsing) of the optical signal. The receiver is tuned to the pulse of the emitter. Particularly in the case of infrared light, the use of day-light filters further improves insensitivity to ambient light.

In the case of optical diffuse sensors the switching function works as follows:

- Brightness switching
  The output closes if an object to be sensed enters into the light beam. (normally open output = NO)
- Dark switching
  The output opens if an object to be sensed enters into the light beam. (normally closed output = NC)

5.1 Design of optical proximity sensors

Optical proximity sensors basically consist of two main groups: the emitter and the receiver. Depending on the design and application, reflectors and fibre-optic cables will be required.

The emitter and receiver are either incorporated into one housing (diffuse sensors and retro-reflective sensors), or accommodated in separate housings (through-beam sensors).

The emitter contains a radiant source for red or infrared light which spreads in a straight line and can be diverted, focussed, interrupted, reflected and directed. It is received by the receiver and electronically evaluated.

Usually proximity sensors contain a light emitting diode (LED), which is illuminated when the output switches. The LED display serves as an adjustment aid and can be used for functional testing.

5.2 Operational reserve of optical proximity sensors

Optical proximity sensors may be exposed to contamination such as dust, swarf or lubricants during operation and therefore function may be impaired as a result of contamination. Both contamination of the lenses of the proximity sensor optics or the object to be sensed may be the cause of this.

Heavy contamination within the light beam of through-beam sensors or retro-reflective sensors may cause the light beam to be interrupted. This will then simulate the presence of an object. In the case of diffuse sensors, heavy contamination of the lens system can be evaluated as an object being present, if the optical radiation reflects the contamination on the lens back to the receiver. Heavy contamination of the object itself can result in the evaluation of an object which is not present if less radiation is reflected as a result of contamination.

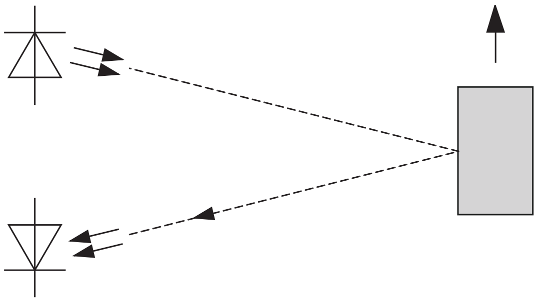
Optical proximity sensors have a certain degree of operational reserve (also known as functional reserve). A flashing indicator on the proximity sensor is a worthwhile means of checking the operational reserve, which becomes active if the minimum operational reserve is inadequate. Designs are for example available which start flashing if the operational reserve factor of = 1.5. This signals that an operational reserve of 50 % is still available.
The flashing indicator can be used as an adjustment aid for the assembly and adjustment of the proximity sensor configuration. It also acts as a contamination display during subsequent operation the functional reserve is gradually reduced due to the effects of contamination.

Inadequate functional reserve may also have causes other than contamination, e.g.:
- Exceeding of reliable operating range or sensing range
- Changes in the material surface of objects sensed
- Incorrect assembly (misalignment)
- Ageing of transmitter diode
- Fracture of fibre-optic cables

Mode of operation

The emitter and receiver are accommodated in the same housing. The object reflects part of the emitted radiation and activates the receiver as a result of this. Depending on the receiver design, the output is then switched through (NO contact function) or switched off (NC contact function). The switching distance is heavily dependent on the radiance factor of the object. The size, surface, shape, density and colour of the object as well as the angle of incidence determine the intensity of the reflected radiation so that only small distances within a range of a few decimetres can generally be monitored.

The background must absorb or reflect radiation; in other words, if no object is present, the reflected radiation must be clearly below the triggering level of the receiver circuit.



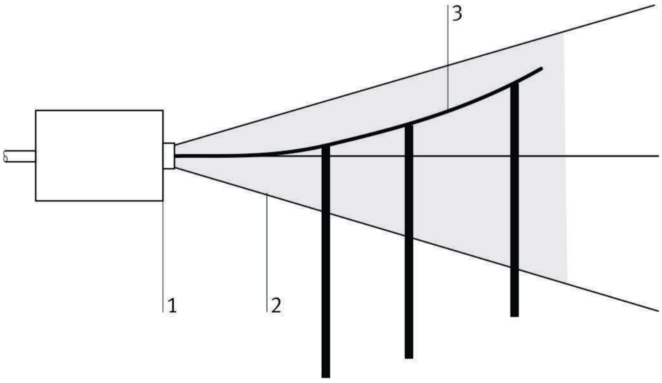
Diffuse sensor (principle)

5.3 Technical characteristics

The tables below list the most important technical characteristics of diffuse sensors. These tabular compilations provide typical data and are merely intended as a general overview.

Parameter	Wert
Object material	Any
Operating voltage	10 - 30 V DC or 20 - 250 V AC
Sensing range	50 mm - 2 m (usually adjustable)
Maximum switching current (transistor output)	100 - 500 mA
Sensitivity to contamination	Sensitive
Service life	Long (approx. 100.000 h)
Switching frequency	20 - 2000 Hz
Designs	Cylindrical or block-shaped
Protection class (DIN 40050)	Up to IP67
Ambient operating temperature	0 - 60 °C or -25 - +80 °C

The sensing range data in the data sheets is usually in relation to white cardboard in that the white rear side of the Kodak grey card CAT 152 7795 from Eastman Kodak is generally used. The white side of this test card has a constant reflection of 90° within the spectral range of approx. 450 - 700 nm. The grey side reflects 18 %.



Emitter/receiver (1)   Transmission range (2)   Response curve (3)

Small distance: No reflecting surface required.
Large distance: Large reflecting surface required.

Response curves of diffuse sensors

5.4 Notes regarding use

Advantages of diffuse sensors

- Since the reflection of the light on the object activates the receiver, no additional reflector is required.
- The object can be diffuse reflecting, specular or diaphanous to transparent provided that a sufficiently high proportion of radiation is reflected by the object.
- Whereas through-beam sensors merely allow the detection of objects at a right angle to the light beam, diffuse sensors allow frontal detection, i.e. in the direction of the light beam.
- Depending on the diffuse sensor setting, objects can be detected selectively against a background.

Disadvantages of diffuse sensors

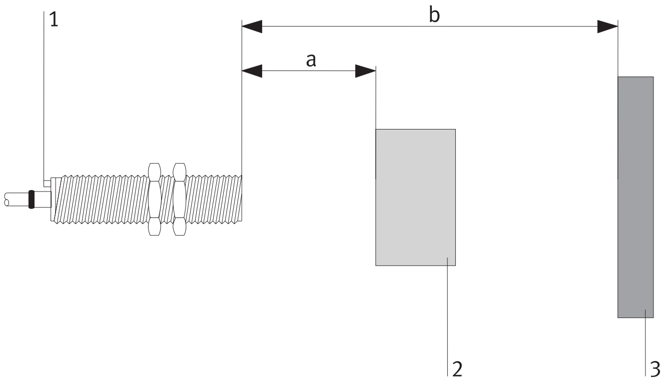
- The response curves at a right angle to the beam spread direction are not exactly linear. Diffuse sensors are therefore not quite as effective as through-beam sensors if precision lateral response is important.

Notes

The size, surface, shape, density and colour of the object as well as the angle of incidence determines the intensity of the radiation reflected so that, as a rule, only small distances within a range of a few decimetres can be monitored. The background needs to absorb or reflect radiation, i.e. in the absence of an object the reflected radiation must be clearly below the triggering level of the receiver circuit.

Failure of the emitter is evaluated as "no object present".

5.5 Background suppression with a diffuse sensor



Adjustable potentiometer (1) Object (2) Background (3)

Distance between proximity sensor and object (a),
Distance between proximity sensor and background (b)

Background suppression with a diffuse sensor

5.6 Adjustable sensitivity

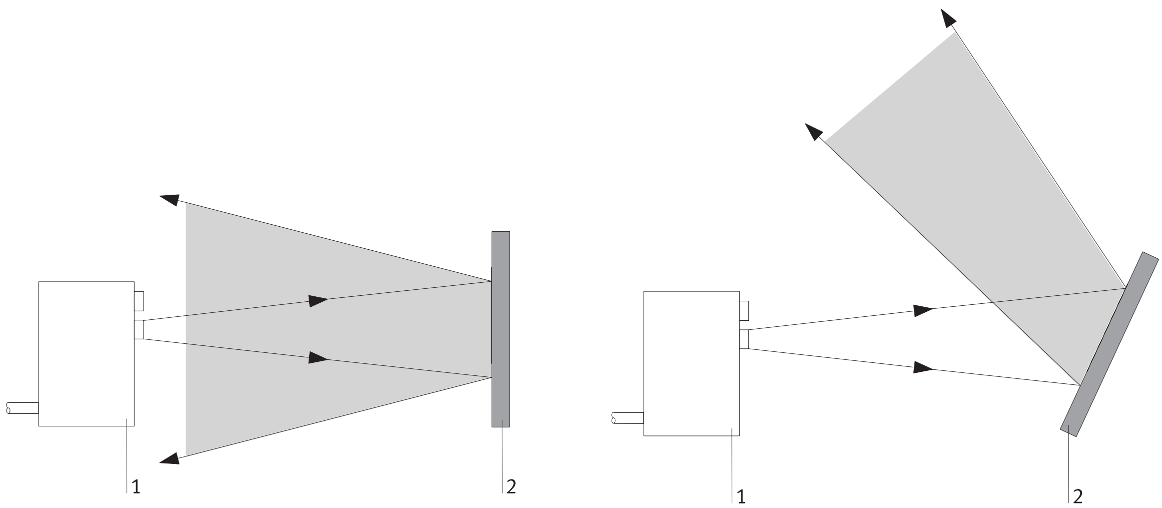
The action of a diffuse sensor is based on the difference in reflection from the object and background. If contrast is only minimal, the triggering level of the circuit can be selected by means of the sensitivity adjustment on the proximity sensor (single-turn potentiometer or multi-turn potentiometer), so that the object is reliably detected even under these less favourable conditions.

However a tolerance range must be allowed in respect of ageing, voltage and temperature fluctuations and contamination. The setting range should therefore not be fully exhausted when making the adjustment.

The careful adjustment of a diffuse sensor using a potentiometer must allow a certain reserve in respect of changes in the quality of the object, contamination of the proximity sensor, dust in the atmosphere, etc. Narrow, only just functioning settings may cause problems.

Some diffuse sensors are equipped with an adjustment aid in the form of a flashing LED to ensure reliable setting. The LED display flashes in the range of uncertainty. The setting is to be made such that, in the case of a proximity sensor with normally open contact, the LED is illuminated without flashing in the active switching status.

5.7 Behaviour of a diffuse sensor in the case of a specular object



Emitter/receiver (1)   Specular surface (2)

Object is detected   Object is not detected

Transparent objects
- Light glass
- Light Plexiglas
- Transparent plastic foil

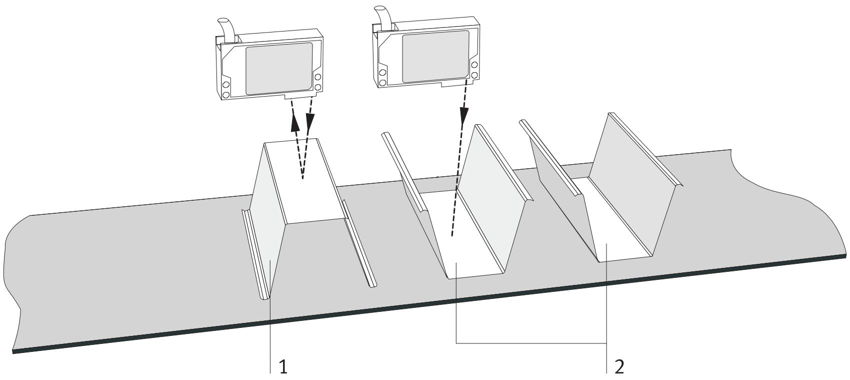
These materials generally have smooth, reflecting surfaces so that a diffuse sensor can be used. The prerequisite is that the object must be vertical to the beam direction.

Objects of minimal reflection

– Matt black plastic
– Black rubber
– Dark materials with rough surface
– Dark textiles
– Burnished steel

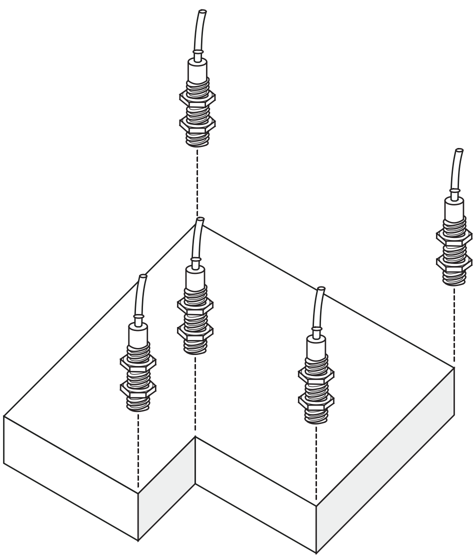
Diffuse sensors do not react to the above materials or only at a very close distance.

5.8 Application examples



Correct (1) Wrong (2)

Monitoring of workpiece position via diffuse sensor



Identity and position checking with diffuse sensors

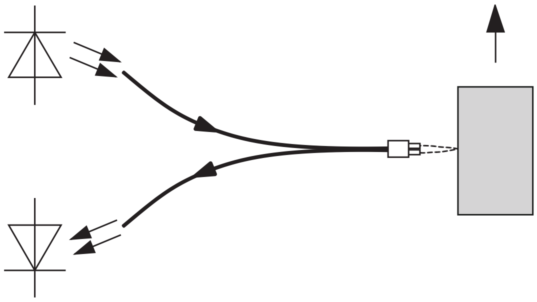
Careful adjustment of the sensitivity on the potentiometer is necessary, whereby tolerances owing to differences in material, contamination, etc. must be taken into consideration.

A connected controller checks whether all sensors respond (the proximity sensor outputs are linked via a logic "AND-operation).

Diffuse sensors with fibre-optic cables are required for high accuracy and small distances from the object.

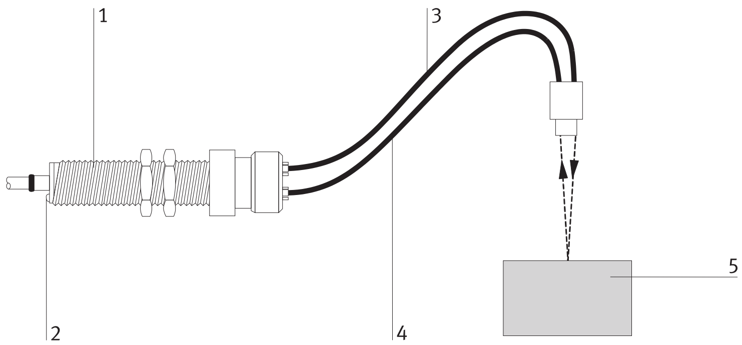
5.9 Optical proximity sensors with fibre-optic cables

Optical proximity sensors with fibre-optic cable attachments are used if conventional devices require too much space. Similarly, the use of fibre-optic cables is of advantage in areas subject to explosion hazards. The position of small objects can be very precisely detected using fibre-optic cables.



Diffuse sensor with fibre-optic cable (principle)

Emitter and receiver fibre-optic cable combined into one unit.



Optical proximity sensor (1)	Emitter fibre-optic cable (3)	Object (5)
LED display and adjusting screw (2)	Receiver fibre optic cable (4)	

Diffuse sensor with fibre-optic cables (sample design)

5.9.1 Notes regarding use

Advantages of fibre-optic attachments on optical proximity sensors

- The detection of objects in difficult to access areas such as through holes.
- Possibilities of offset mounting of the proximity sensor housing (e.g. in hazardous environment: heat, water, interference radiation, explosion hazard).
- Precision detection of small objects.
- Possibility of movable configuration of sensing elements.

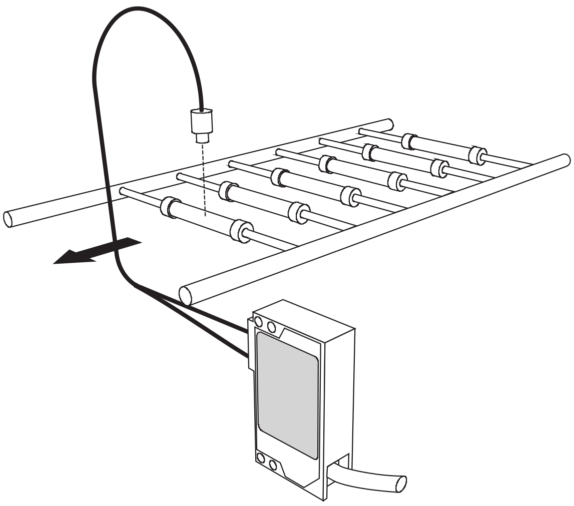
Advantages of polymer-fibre-optic cables

- Mechanically sturdier than glass fibre.
- Possibility of simply cutting to length the sensor-side end using a sharp knife.
- Cost effective.

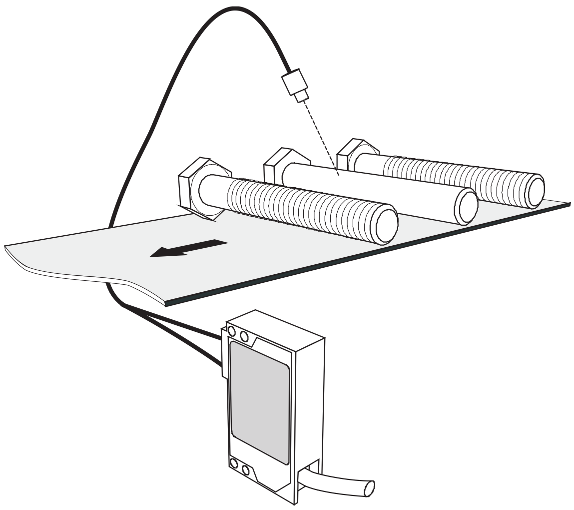
Advantages of glass fibre fibre-optic cables

- Suitable for high temperature range.
- Minimal optical damping with long lengths and within close infrared range.
- High resistance to ageing.

5.9.2 Application examples



Detection of small objects via diffuse sensor with fibre-optic cables



Thread checking

The threaded screws (diffusely) reflect sufficient light to cause the receiver to switch. The light emitted by the emitter is reflected away by the smooth surface.

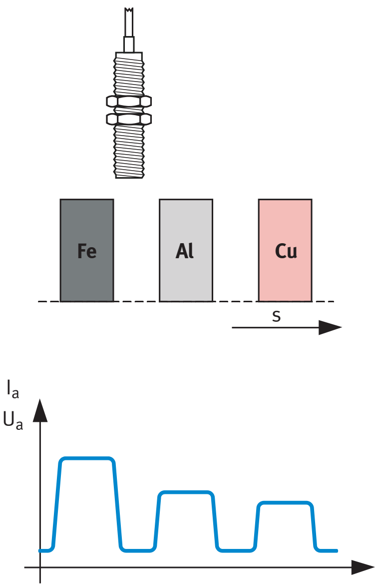
6 Inductive sensor

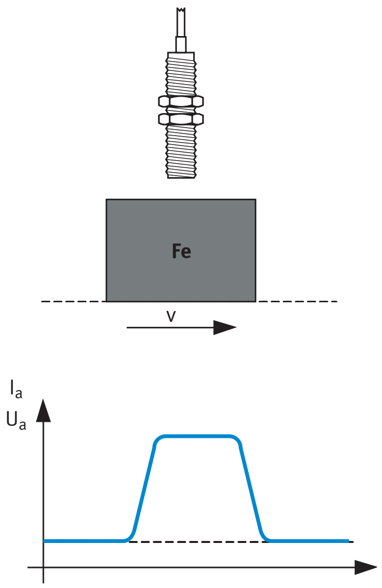
An inductive sensor consists of a coil with ferrite core. Together with a capacitor, the coil forms a resonant circuit thereby creating an electromagnetic field in front of the coil. If an electrically conductive object is present in this field, a voltage is generated within this, which in turn causes so-called eddy currents within the material. The required energy is drawn from the resonant circuit. This is also known as attenuation of the resonant circuit. The output stage is switched via the evaluation stage in accordance with programming. Depending on material or distance, analogue inductive sensors supply an analogue voltage or current intensity signal.

6.1 Use

Inductive sensors are for example used

- to differentiation between various metallic materials
- to measure distances
- for monitoring assembly

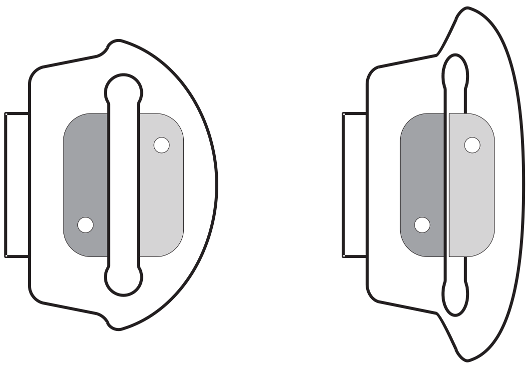




7 Sensitive edge, collision detection

The collision protection sensor of the Robotino® consists of a so-called sensitive edge. This sensitive edge consists of a polymer profile of different shape with integrated switching chamber. Two separate conductive areas are located within the chamber that short-circuits if pressure is applied to the sensitive edge thereby generating a signal for the evaluation unit. The sensitive edge on the Robotino® operates according to the quiescent current principle so that a potential cable fracture can be detected and the Robotino® stopped.

Quiescent current is an electrical current which continuously flows within a circuit even if this is not active. If the current is not flowing then this is due to a cable fracture or a damaged sensitive edge.



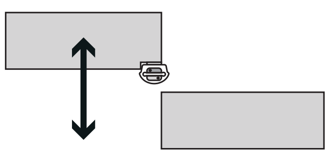
Function of collision protection sensor

7.1 Areas of application

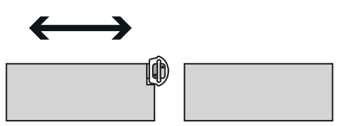
Sensitive edges are used predominantly in safety technology in order to eliminate injury to persons or damage to machinery or materials as a result of crushing or shearing. In medical engineering, they are used on diagnostic equipment, radiation devices and movable protective covers in order to protect patients and personnel.

They are also in use on lift doors, bus doors and electrical skylights to protect fingers.

Protection shear point



Protection - crushing point

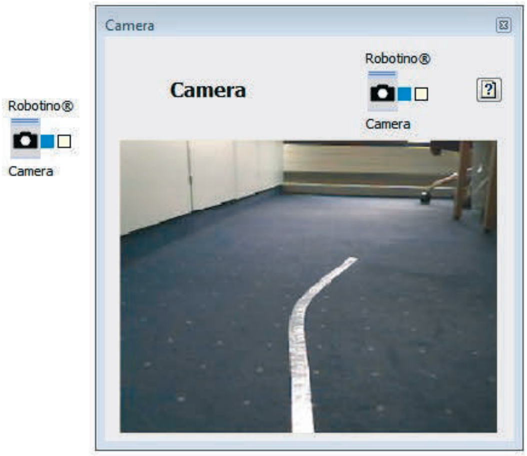


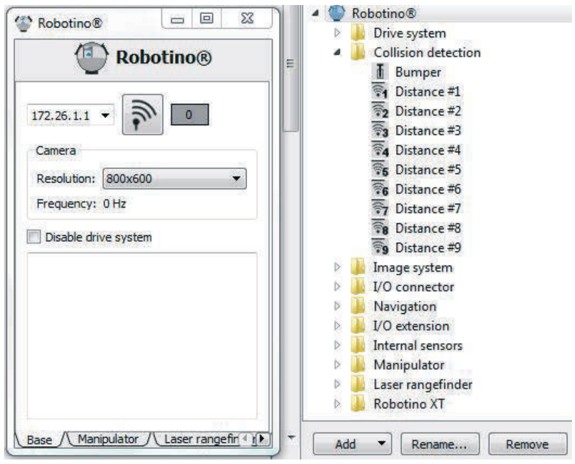
7.2 The bumper in Robotino® View

The bumper is available in Robotino® View in the Robotino® hardware folder and does not need to be parameterised. It supplies a 1-signal upon contact and is used mainly to stop the Robotino® in the event of a collision.

8 Webcam

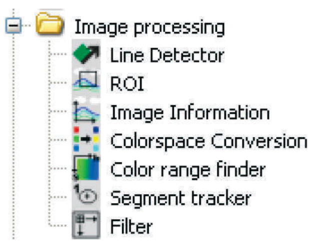
The camera provides a live image of the momentarily detected situation. The camera is connected to the command bridge via one of the six USB plugs. The camera function block in Robotino® View allows the user to access images from the camera mounted on Robotino®.





Resolution settings can be adjusted in the **Robotino® device dialogue** (see figure). One of two different resolutions can be selected (320 x 240, 640 x 480, 800 x 600). In the case of colour detection, the lower resolution is usually better because fewer different colour data are then included in the image. This makes it easier for the software to detect contiguous colour areas.

Robotino® View offers a variety of function blocks for image processing.



9 Learning potential provided by Robotino® for modern vocational training

Excerpts from the expert opinion of PD Dr. Alfred Riedl, Chairman of the Pedagogic Department at the Technical University in Munich

9.1 Targeted goals for modern vocational training

Reorganisation of the metalworking and electrical vocations as of 1987 was the first considerable structural reaction to massive changes in the fields of technology and economy. The second followed with the introduction of general syllabi oriented towards specific fields of learning by the conference of the ministry of education and cultural affairs of the German states (KMK) in 1996. Both measures are targeted at comprehensive, vocational empowerment which expresses itself in terms of capabilities for independent planning, execution and monitoring of work activities. And thus a change from the more emphatically stressed knowledge orientation in previous curricular syllabi to an orientation towards competition has taken place in the classroom. In addition to technical content, the imparting of key qualifications is becoming more and more important in the educational structure. This necessitates an instructional concept which is action oriented, offers diverse opportunities for self-directed learning and allows for constructivist learning.

Current trends such as setting up schools as competence centres, school autonomy, quality development and evaluation, learning location cooperation, team development and the implementation of syllabi oriented towards specific fields of learning are becoming apparent at vocational schools. The vocational school as an independent learning location is improving its quality by means of technical specialisation, and especially by placing emphasis on certain skilled vocations or training content. In the field of automation technology, the technical requirements are becoming more demanding due to the great innovative potential of this sector which is very important for Germany. Vocational training in the fields of electrical engineering and mechatronics is most likely to do justice to requirements concerning content and didactic approach if vocational schools, and their educational experts, have learning environments at their disposal which are well equipped both technically and with regard to media. This makes a constructivist approach to instruction possible, which develops theoretical knowledge with reference to actual vocational practice in vocationally relevant settings which are aligned to systematic practice.

9.2 The Robotino® learning system as a constituent of modern vocational training

With the broad-based incorporation of fields of learning into the general syllabi of the KMK as of approximately 2000, additional curricular tasks have evolved for teachers involving concrete implementation of extremely open exercises for specialised and non-specialised educational goals for instruction. The Robotino® learning system, including didactically prepared proposals for direct use in instructional settings, significantly simplifies curricular work, as well as the work of the teacher during instruction for the incorporation of a wide variety of syllabus content for automation technology. For learning situations with durations of several hours in which students are able to learn in a self-directed fashion to a great extent, prepared proposals are available for suitable learning situations in the field of automation technology, which are typical of the respective vocation, are adequately complex and highly authentic, and can be prepared as complete learning activities. This is highly relevant for vocations in the fields of electrical engineering and metalworking technology.

General infrastructure conditions are an important influencing factor for complex and realistic vocational training situations in actively oriented instruction. As a rule, an integrated, specialised classroom is required to this end. The Robotino® learning system can significantly extend the scope of equipment in existing specialised classrooms, and contribute to the provision of top quality facilities thanks to the system's technical layout. Robotino® is compatible with existing automation equipment systems such as programmable logic controllers and other typical automation components. One of Robotino's® special strengths is the fact that this complex technical system can also be used in an autonomous manner outside the setting of an integrated, specialised classroom, i.e. in any classroom at all. The only requirement is a PC used for control purposes. Outside of the meticulously organised learning environment of the specialised classroom as well, complex, vocation-relevant exercises can be implemented at nearly any training location as an accompaniment to theoretical learning content at a very sophisticated level.

Diverse and highly demanding requirements faced by teachers in laying out action-oriented teaching and learning processes necessitate of a great deal of technical confidence, as well as comprehensive methodical and didactic skills. Becoming familiar with the Robotino® learning system, as well as planning and development of the learning arrangement including the creation of necessary instruction materials, takes a great deal of time. The Robotino® workbook places the knowledge required for instruction with the learning system at the disposal of the teacher on the basis of eleven different projects for easy self-study, and makes it possible to work with the learning system quickly in a technically confident manner. Existing backup materials (teaching automation technology in an innovative, learning-field oriented fashion) generate impetus for the didactic incorporation of Robotino® into constructivist instruction. They greatly simplify integration of this system into one's own existing instruction, and offer innumerable suggestions for school-specific development of new learning arrangements.
...

During instruction with Robotino®, the learning activities can be shifted extensively to the learners themselves. The teacher provides support, gives advice and stimulates the learning activities. Learners can become actively involved in a self-directed manner for the entire duration of instruction with technical, automation learning subject matter with great relevance for their vocation both now, as well as in the future. This has a positive influence on their motivation and interest, which are thus able to stabilise and evolve.

Constructivist learning makes it necessary to take the learners' existing base of knowledge and experience into consideration, and to allow associated interpretation to ensue. Robotino® provides innumerable, broad ranging points of contact from simple electronics fundamentals right on up to extremely complex and challenging automation technology problems. These individually adaptable ranges of content and degrees of difficulty allow for highly differentiated instruction.
...

In action-oriented learning situations, a great deal of the responsibility for learning is transferred to the learners. Consequently, the teacher does not function as an imparter of knowledge for the most part, but rather much more as an advisor and supporter for the learning process. When students have questions, the teacher encourages them to solve problems independently, while supporting learners in the development of their own problem solving concepts. Not only are correct sample solutions provided for programming tasks encountered in the learning situation, but rather numerous, technically acceptable solution variants as well.

An important didactic concept for instruction of this sort involves technical discussions, which have special significance for instruction, and in which learners take on the role of the doer to a great extent. During the course of technical discussions, the teacher can relate to the subject matter as well as the learning process, and offer communicative help in a dialogue regarding content with the learners. In addition to situations involving technical discussion in small groups, learning of this sort also necessitates instructional support with the entire group, in order to counteract ineffective learning and demanding too much from individual learners.

Robotino® provides a comprehensive, vocation-related range of subject matter for the field of automation technology. The tasks which are processed during instruction are only loosely pre-structured, and are not reductionistically simplified. Errors which may occur, as well as the need for optimisation of control solutions along the way, offer further learning potential. Technical discussions entered into to this end make it possible to talk about and correct solutions arrived at by the students, and are capable of promoting better understanding. For teachers, providing this type of support to learners involved in an individualised learning process results in a significant role change as compared with traditional teaching methods. In addition to changing pedagogical requirements, they are usually confronted with very high demands from a technical standpoint as well. Robotino® helps meet these demands.

9.3 Conclusions

The Robotino® learning system provides extremely diverse, potential content in accordance with the state-of-the-art for the development of vocational competence in the field of automation technology. Furthermore, in addition to comprehensive technical content, key qualifications can be imparted within a self-guided learning environment with a corresponding didactic concept. Robotino® is suitable for numerous learning goals and content from syllabi for vocational schools which are oriented towards specific fields of learning. Beyond this, the learning system opens up a wide variety of content and methodical learning approaches for automation technology to facilities which offer continuing vocational training.