Application Note DK9322-1109-0009

TwinCAT Supplement 'TwinCAT Kinematic Transformation'

Keywords
supplement
TwinCAT
Kinematics
robot integration
robot controller
transformation
delta kinematics
robot kinematics

Merger of Motion Control, PLC and robotics on one CPU

The TwinCAT Supplement 'TwinCAT Kinematic Transformation' is presented in this application example. This supplement makes it possible to compute robot kinematics together with the PLC and Motion Control on one PC-based CPU. Analogous to the TwinCAT Motion Control package (integration of the drive control in the controller), a robot kinematics is configured and parameterised with the 'Kinematic Transformation' in the TwinCAT system. The advantages of this are the elimination of interfaces between the CPUs, the system-congruent programming and of course the saving of CPUs. The following kinematics are currently integrated in the supplement: 2-D parallel kinematics, 3-D delta, shear kinematics, SCARA, Cartesian portals, crane and roller kinematics.

Glossary of important terms

SCARA	Selective Compliance Assembly Robot Arm
TCP	Tool Centre Point
G-Code	Programming language for NC and CNC machines according to DIN 66025
PCS	Piece Coordinate System
MCS	Machine Coordinate System
ACS	Axis Coordinate System
P&P	Pick-and-Place, sorting and placing process
NC I	TwinCAT module for axis interpolation in three dimensions
NC PTP	TwinCAT module for point-to-point axis positioning
PLC	Programmable Logic Controller

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What does the term ‘kinematics’ mean?

Kinematics (from the Greek ‘kinema’, motion) is the study of the movement of points and bodies in space, described by the variables:

– path s (change of position coordinates),
– velocity v and
– acceleration a,

without considering the causes of a movement (forces). In the context of robotics, the term ‘kinematics’ refers to the different movement possibilities. Since the structure and number of axes determine the workspace of the robot, this workspace is concretely dependent on many parameters: arm lengths, angular range, centre of gravity, maximum load, etc. The arrangement of the arms and joints determine the kinematic structure, which is divided into two main categories:

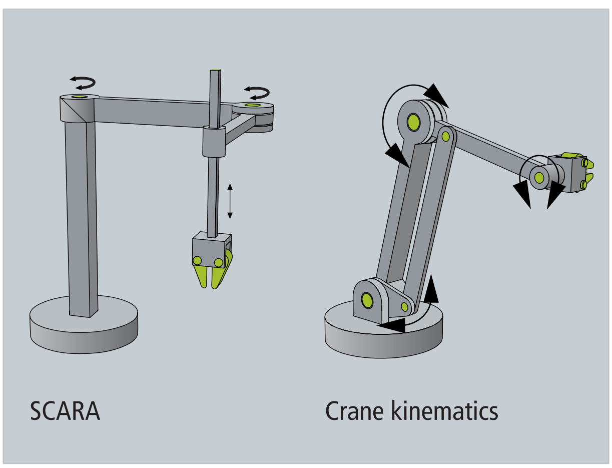

Fig. 1 Examples of serial kinematics: SCARA and crane kinematics

Serial kinematics:

The current position of any axis is always dependent on the position of the preceding axes; i.e. all axes are arranged in succession.

Examples: SCARA, crane kinematics (see fig. 1)

Parallel kinematics:

All axes engage via a single kinematics in the work platform. All drives must be driven in order to perform a defined movement of the TCP.

Examples: Delta kinematics, shear kinematic (see fig. 2)

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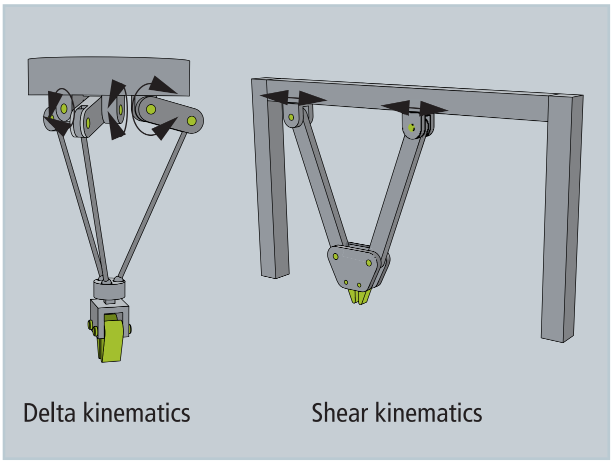

Fig. 2 Examples of parallel kinematics: Delta and shear kinematics

Coordinate systems

Coordinate systems are required in order to describe the positional behaviour of a system. These coordinate systems are laid in the individual active joint axes. Cartesian coordinate systems, for example, can be used for this. These are then linked to the individual bodies in a way that a rotation or translation takes place around or in the direction of the coordinate axes.

Cartesian coordinate system:

- right-handed
- direction of rotation always positive (anticlockwise)

Different coordinate systems can be used as a basis for programming:

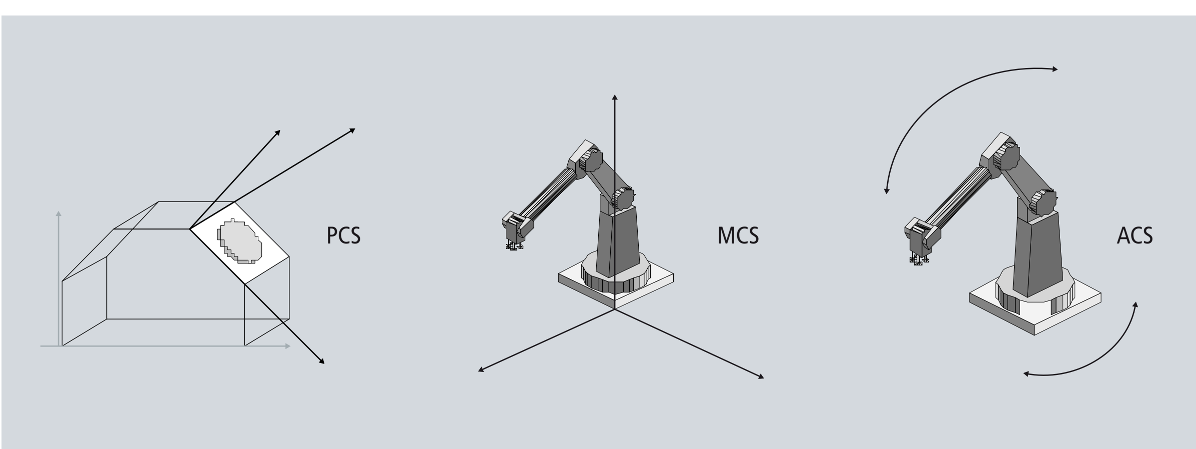

Fig. 3 Coordinate systems that can be used as a basis for programming

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The piece coordinate system (PCS) is independent of the kinematics used and is preferentially applied. The machine coordinate system (MCS) is also independent of the kinematics used. The axis coordinate system (ACS) depends on the kinematics used and is employed for referencing or homing.

The robot is often programmed in the PCS or MCS, since both systems are very clear due to the Cartesian structure. In addition, the type of kinematics in these systems need not be considered, since the corresponding movement sequences are calculated by a transformation. As opposed to this, when programming in the ACS, it is essential to take into account the structure of the axes, since the movement commands for the axes must be programmed directly. Therefore, this type of programming is used only in exceptional cases, such as for homing.

Transformation

Kinematics describes the investigation of the possible movements of the individual members of the robot relative to each other. It takes into account the velocities and accelerations that occur during the movement of the joints, but not the forces that occur or the type of drive of the joint (active/passive). A different arrangement of joints and members can produce identical TCP movement paths (see fig. 4).

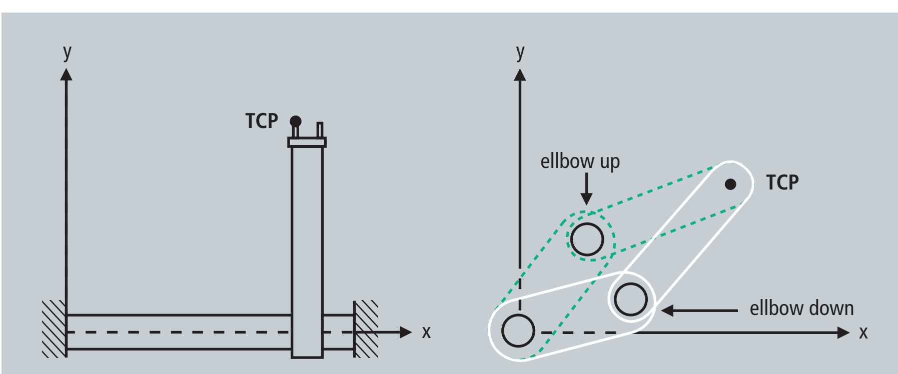

Fig. 4 Identical TCP movement implementable with different mechanisms

Transformation describes, in the context of kinematics, the calculation necessary in order to change from one coordinate system to another. There are basically two problems in considering the kinematics of robots. The direct kinematic problem (KP), also called forward transformation, deals with the calculation of the position of the Tool Centre Point (TCP) in spatially fixed coordinates from the axis-specific joint coordinates of the robot. The inverse kinematic problem (IKP), also called inverse transformation, is the reverse relationship, in which the axis-specific joint coordinates are to be determined from the TCP position. The task of a transformation is to change the position and orientation of the objects relative to one another so that the TCP traverses the desired movement path.

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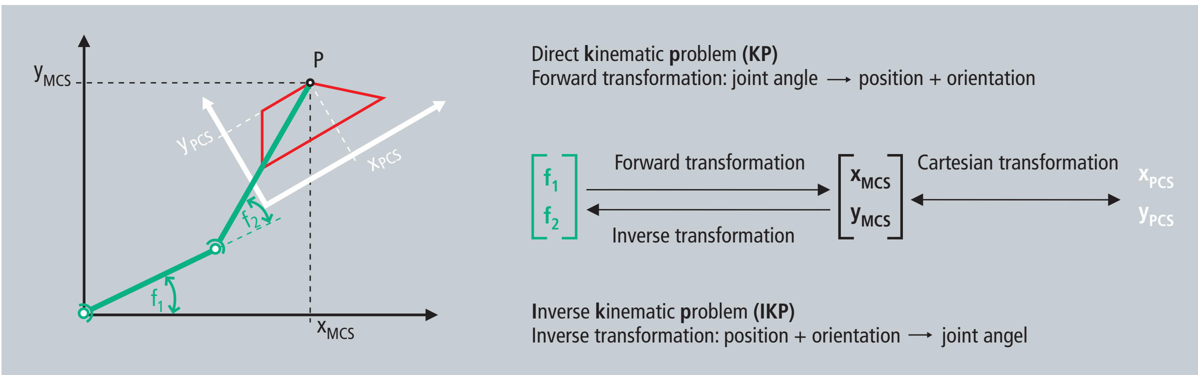

Fig. 5 Different kinematic problems

Typical kinematics

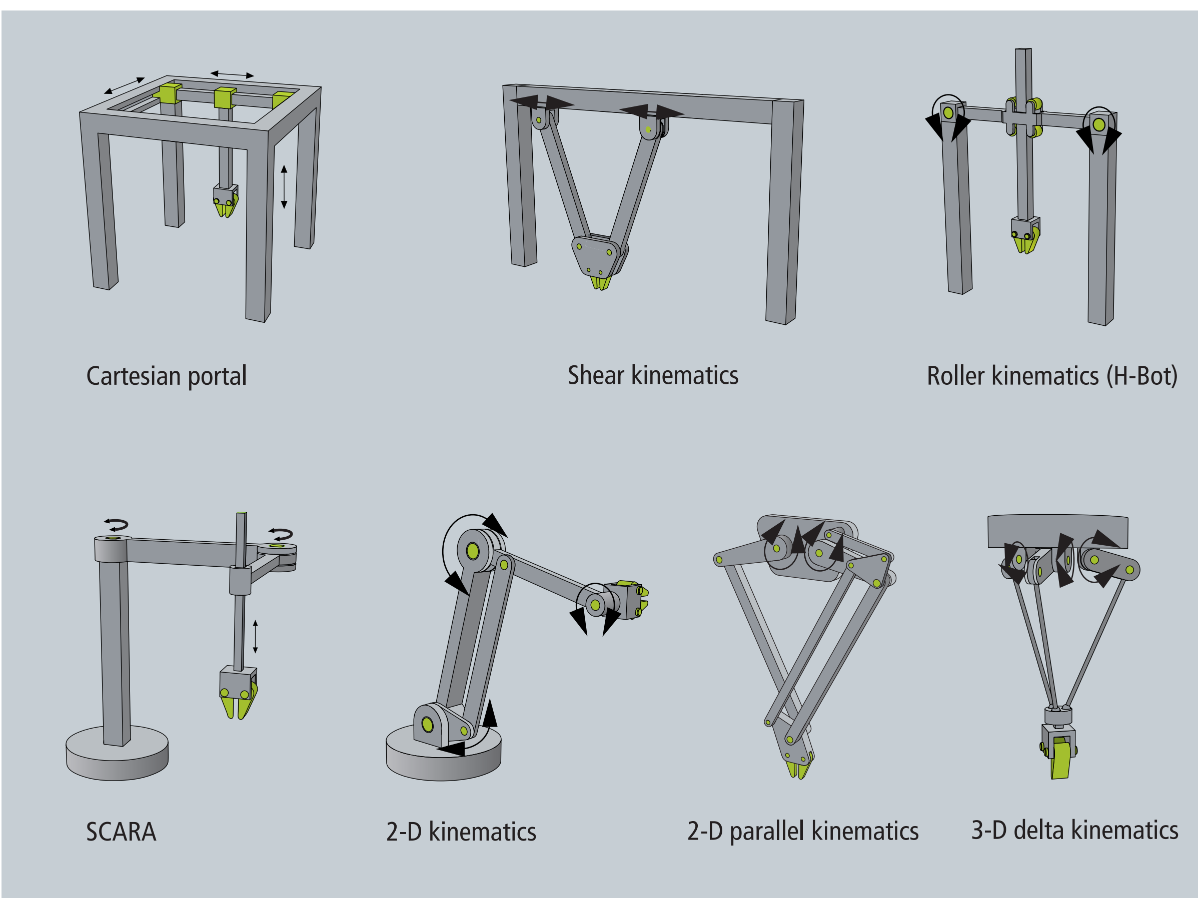

Fig. 6 Overview of the kinematics#

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'Kinematic Transformation' supplement

The supplement uses TwinCAT NC I for interpolating movements and G-Code (DIN 66025) as a basis and has been developed primarily for P&P applications. In addition, standard PTP and cam plate applications can be realised. All NC PTP characteristics, such as 'cam plates', 'flying saw' and NC I can be combined as desired with the robot motion. The target coordinates are programmed conveniently in the Cartesian coordinate system. In order to calculate the following error and the oscillation tendency, a current pre-control variable is calculated from the dynamic module. All forward and inverse transformations are performed by the TwinCAT Kinematic Transformation module.

The product currently supports a variety of parallel and serial kinematics and is therefore suitable for the most diverse fields of application. The kinematic system can be selected conveniently in the TwinCAT System Manager. The kinematic channel is used to parameterise the type (e.g. delta) and the bar lengths and their offsets. Masses and inertias must be specified for current pre-control.
In order to illustrate the synchronicity and dynamics of robot applications, Beckhoff showed a 3-D delta kinematics in action during the product presentation of the supplement at the Hanover Fair 2009.

http://www.beckhoff.com/TwinCAT-Kinematic-Transformation

Fig. 7 Presentation of the supplement at Hanover Fair 2009 with 3-D delta kinematics

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The presented robot is equipped with standard components from the Beckhoff product range; installed are Servo Drives from the AX5000 series. Motors and gears are also Beckhoff components. On the software side, the robot is based on the TwinCAT NC I package in combination with the Kinematic Transformation supplement. The dynamic properties of the robot allow a wide field of use for P&P applications: with path velocities of up to 7 m/s and accelerations of up to 9 g, the robot synchronises itself to a cam plate, drives along corresponding paths there and decouples itself again. However, the supplement reflects the versatility of industrial robot integration and is therefore suitable not only for P&P.

Practical example of a P&P application: 3-D delta robot | vision system – synchronisation with conveyor belts

A P&P application is a typical application for delta kinematics. Parts are to be removed from a conveyor belt and placed on another conveyor belt. A vision system recognises the position and orientation of the parts. The prerequisite is, of course, that the two conveyor belts are both within the robot's workspace. The direction of movement of the belts is arbitrary: they can be moving in the same or in opposite directions.
Separators can often be dispensed with if flexible vision systems are used – pre-sorting is eliminated. The vision system is placed in front of the robot and determines the position and orientation of the material. The determined coordinates are forwarded to the controller. The pick-up and set-down positions of each individual object are determined from these coordinates. The 'flying saw' algorithm now calculates the synchronous position at which the robot and the part coincide.

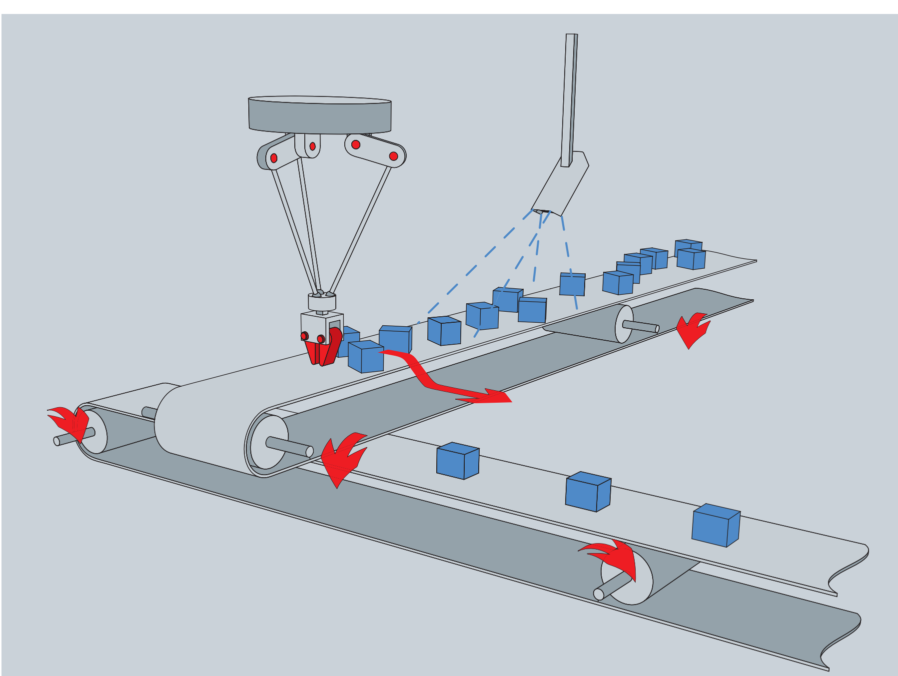

Fig. 8 **Separation: the parts are re-sorted from a 'chaotic' arrangement from one conveyor belt to another for further processing**

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The task of the product presented here is to calculate the movement command from the positions and velocities of the conveyors and the data from the vision system, so that the robot grips the object precisely, traverses the specified path and places the object once again precisely on the other conveyor. To do this, the robot synchronises itself with the conveyor belt drive and moves together with the conveyor belt in order to reach the optimum pick-up position. As soon as the robot has picked up the object, it decouples itself from the conveyor belt drive in order to change to the other conveyor belt. Setting-down follows the same principle: The position is specified by the controller, the robot synchronises itself, moves with the belt and positions the object optimally for placing. The smoother the coordination of the individual components to one another, the quicker the process can be executed.

Another area of application of delta robots is the filling of gaps in object carriers after quality checking.
Not completely filled packages with 3 x 3 parts are to be filled by a robot in conjunction with a vision system, so that the packages are complete. The robot receives the coordinates at which no part is present via the position detector. From a chaotic arrangement of supplied objects, the robot picks one up, synchronises itself to the conveyor belt and places it in the gap according to the coordinates.

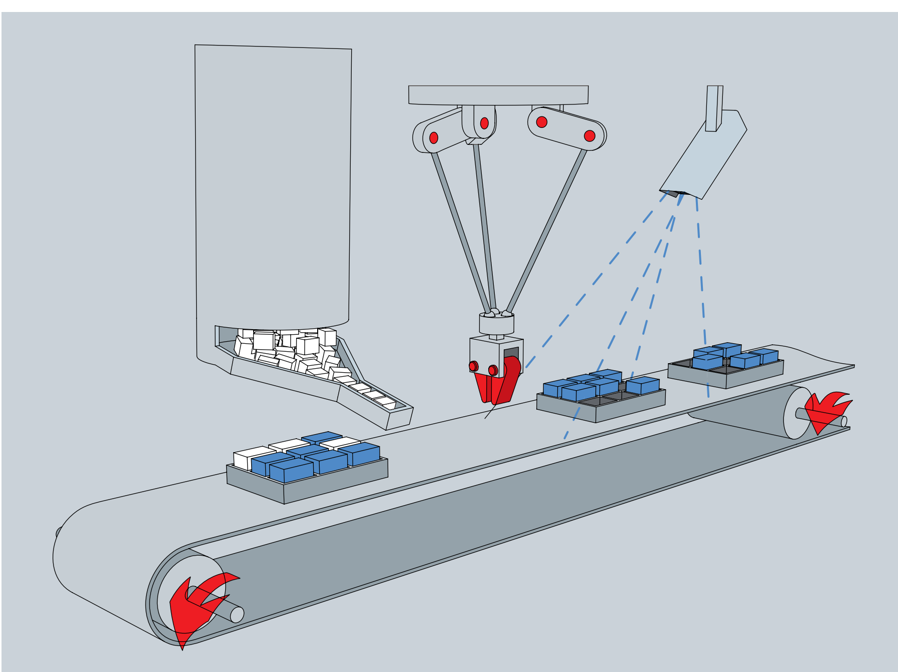

Fig. 9 Detection and filling up of missing parts

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The robot must place three parts; therefore, a processing sequence must be determined in order to ensure that the object carrier is completely filled within the robot's workspace. The robot picks up an object, synchronises itself and places it.

Application advantages

With the 'Kinematic Transformation' supplement integrated in the TwinCAT automation suite, it is possible to realise various robots directly in software. This can simplify a manufacturing process considerably. A separate CPU for controlling the robot becomes redundant. The configuration and programming is carried out in the tools of the standard controller: in TwinCAT. No separate programming and configuration tool needs to be learnt. This reduces engineering costs significantly. Analogous to the approach in Motion Control, a kinematic channel is created and programmed via the familiar TwinCAT software environment after selecting the appropriate presets. The result is a uniform, complete system.

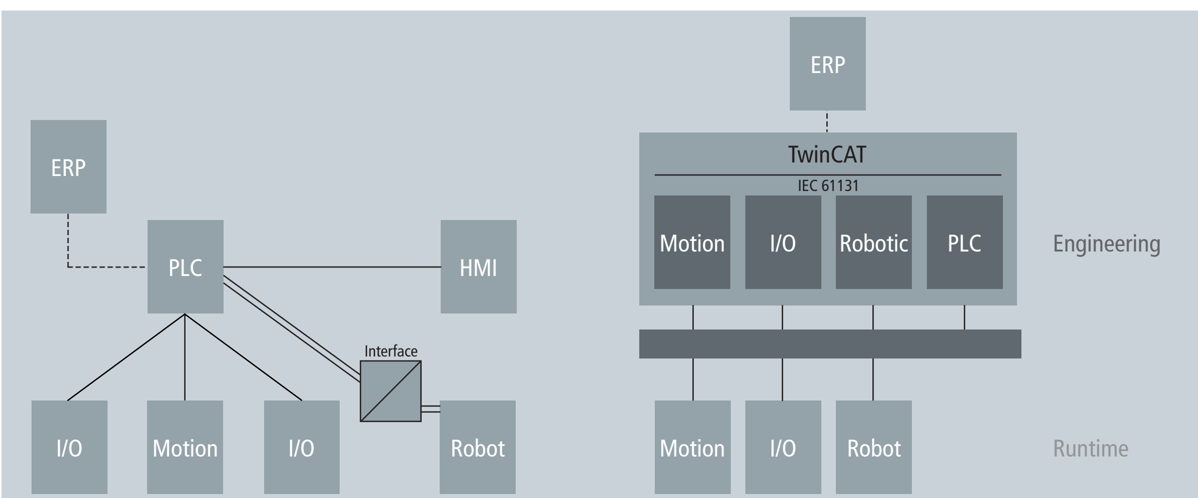

Fig. 10 Merging of the individual functions in TwinCAT

The application is improving in qualitative terms, and the product with it, because inefficiencies due to interoperation of different CPUs for PLC, motion and robots can be avoided. In practical use, combining programmable logic controller (PLC), Motion Control and the kinematic implementation of movement sequences (robotics) in a single controller brings about a reduction in engineering costs and a shortening of cycle times in the manufacturing process. In addition to the elimination of interfaces and components, the merging of PLC, robotics and Motion Control into one application makes the system homogeneous. For the user, therefore, there is no apparent difference in the treatment of the individual functions.

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– PLC and Motion Control on the PC **www.beckhoff.com/TwinCAT**

– Optional TwinCAT software packages **www.beckhoff.com/supplements**

– Realises kinematic transformations for TwinCAT PTP or TwinCAT NC I **www.beckhoff.com/kinematics**