PORTABLE ROBOT SYSTEMS FOR MACHINE TENDING TASKS

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Abstract

Motivated by the need for industrial robot systems that are suitable for temporary and flexible deployment at a variety of machine tending stations, we have developed, built and tested an easy-to-use portable robot system. The main features of the system include integration of all components on a single, easily movable platform, on-board sensory means ensuring personnel safety in the vicinity of the operating system, as well as an intuitive graphical user and programming interface. Small and medium enterprises (SME) often are faced with varying order volumes and irregular scheduling of machine loads, so automation of manufacturing tasks in this environment requires additional flexibility beyond that of conventional fixed robot installations. Our system manages this requirement through its easy adaptation to a range of tasks, handling order peaks as they occur and complementing manual machine tending, potentially leading to nearly full booking of the robot station. Robotic automation of manufacturing tasks in SME thus increasingly becomes an economically viable choice.

Introduction

Supplying machines with work pieces is a production step that still today largely is carried out manually, especially in small and medium-sized enterprises. This is mainly due to the appreciable investment cost for dedicated automation solutions along with insufficient utilization ratios of these systems in a common production environment. In order to open up new potential for highly flexible automation of manufacturing processes especially in SMEs, an innovative and flexible system for material handling and machine tending purposes has been developed and tested in production. The development goes along with the demand for universal robot platforms that can be reused for many different product generations [1].

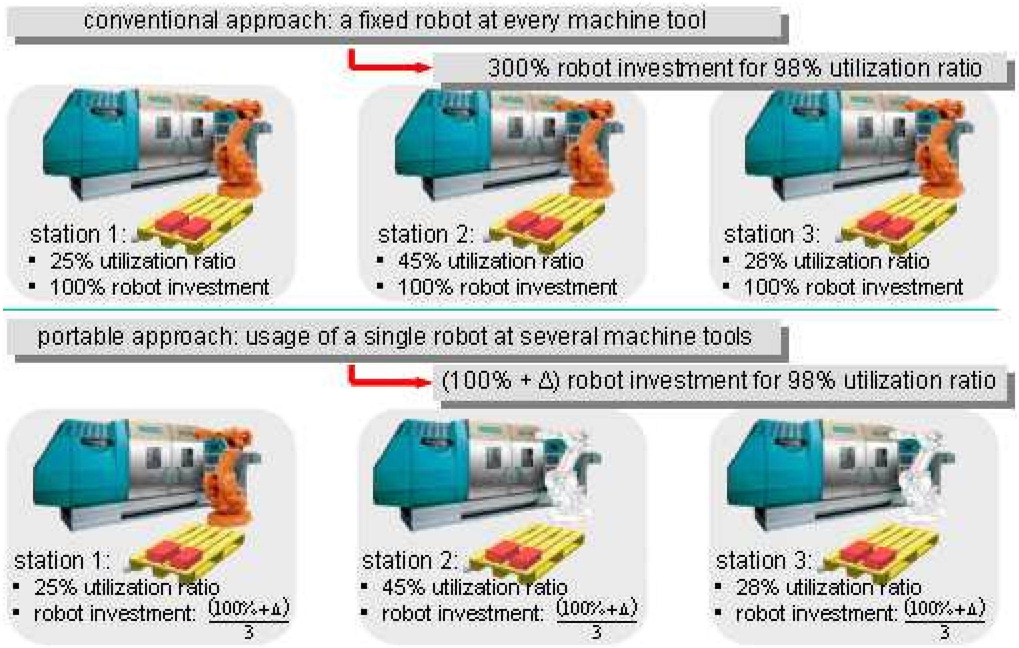


Figure 1: Potential operation scenario for portable robot systems.

Within the project “Porthos” a flexible, easy-to-use and compactly movable, integrated robot system for material handling and machine tending tasks has been developed [2]. This system is easily movable from one machine or station to another, it is intuitively programmed by a graphical user interface and it adapts semi-automatically to new tasks. Safety sensors monitoring intrusions into the working envelope guarantee personnel safety in the vicinity of the system.

Such a flexible system lifts the constraint of installing specific automation solutions at each of the stations one plans to automate [3], [4]. This opens the prospect of using a single portable material handling system at any number of machine tools, according to where the production bottleneck might be at the moment (see Figure 1). The result is a very high degree of utilization of the portable material handling system. Additionally, the key to acceptance by the workforce will be the simplification of operating the system through the graphical user interface. In many cases these two points will decisively influence the economic viability of an automated material handling solution.

Requirements on a Portable Robot System

Nowadays industrial robots cannot be applied for handling small lot sizes in a profitable way because of the high investment costs and installation efforts. In order to open up this new market for industrial robots, their flexibility must be increased in several respects:

- Improved portability of robot systems,
- Intuitive user interface providing guidance to the operator and supporting fast generation of robot programs,
- Flexible work piece handling by multi-functional grippers and interfaces for sensor integration
- Sensor-based monitoring of the robot’s workspace to ensure personnel safety.

The portability of the robot system allows the operator to deploy the robot at different machine tool stations, according to demand. Transportation of the system must be possible by means of a hand truck or forklift. The attachment to the floor must be simple and can rely on mechanical elements on the portable platform that can be locked to matching anchors that are fixed in the floor. The connection between the robot and the floor optionally can be fitted with self-centering elements. Without this option the exact position of the robot must be calibrated with appropriate sensors each time the system is repositioned.

Whenever the system is not installed at a given location, dust cover screws must cover the anchors level with the floor, so that they are not subjected to dirt and do not pose a tripping hazard or form an obstacle for other vehicles or objects to be moved on the shop floor. Standard connectors must be used to realize connections for power, media such as compressed air, control or data interface to the machine tool and factory network. Generally only two additional connections will need to be installed at the machine tool. It must be connected to the robot controller in order to join both emergency stop and safety interlock circuits and to synchronize the handling and machining tasks, i.e. to operate doors and chucks or to start the machining process. Before initial installation at a machine tool, its PLC must be prepared for communication with the robot controller via digital inputs and outputs (IOs).

The work and time required for the initial commissioning of the system, for moving it between locations, or for varying the handling task must be reduced significantly compared to traditional approaches in order to keep the production downtime to a minimum. A portable platform allows for an easy reinstallation in front of another machine tool. After anchoring to the floor, the calibration and programming of the robot system shall be carried out, assisted by intuitive graphical tools provided as part of the integrated system. In the case of first-time applications at new machines, a ramp-up procedure must be carried out to assure the quality of the production task. As SMEs often lack staff with sufficient experience in the field of robotics, all steps in the ramp-up procedure need to be comprehensible and intuitive.

The reinstallation of the system at locations and for tasks for which it has already been commissioned should be tasks realistically handled by the machine operator. He can reuse old, adapted programs or create new definitions of handling applications in a task-oriented way. Thus we must describe the workflow in an abstract, generally understandable way (e.g. “Place work piece in machine tool” or “Pick work piece from pallet”).

Ease-of-use and system portability also requires an innovative solution for personnel safety. Traditional safety equipment is permanently fixed to the floor and physically separates the working area of the robot from the operators. This approach would require safety fences around each application site of a portable robot system. The result would be a loss of flexibility and additional costs for several fences. A sensor-based solution installed on the portable platform, based on laser scanners to monitor the borders of the working area and stop the robot as soon as an intrusion is detected, maintains the flexibility of deployment to various locations, since the scanner fields can be adapted to the details of each location.

In the research project Porthos, we have developed a robot system that meets these demands that are typical of SMEs. A more detailed description of each of the aspects of the Porthos system is given in the following sections, focusing particularly on the version of the system set up for pilot production tests at WMF AG.

Realization of Mobility

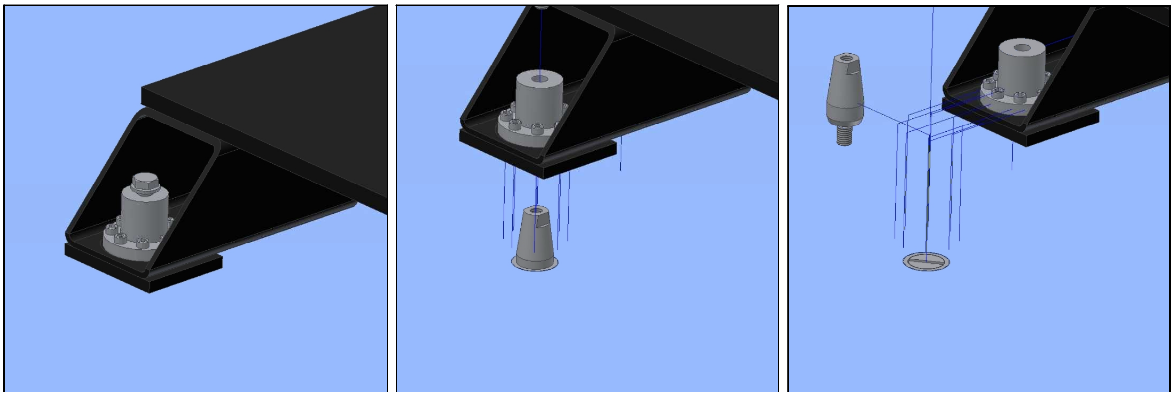
The central point of the concept allowing for flexible temporary deployment of a robot system is the ability to move the complete system as an integrated unit. Only through this capability does it become realistic to deploy the system at varying locations for varying tasks in an efficient manner.

As shown in Figure 2, the complete system consists of a steel base plate that carries the robot manipulator as well as its controller, an industrial PC and sensors for the personnel safety system.

Figure 2: Full view of Porthos pilot system as deployed at WMF AG for tests in production.

The dimensions of the steel base plate have been chosen for compatibility with the standard Euro-pallet format, making it possible to transport the complete system either with a hand truck or on a forklift. Given a total weight of about 1200 kg, one can realistically move the system manually on a hand truck on level surfaces. For transportation over larger distances or uneven surfaces, up or down ramps, a forklift is necessary.

Specially developed anchors cemented into the floor at all locations planned for deployment allow for quick mechanical fixing at each location. Two diagonally opposite corners of the platform feature special conical sleeves that match to the self-centering pins in the floor anchors. This provides for repeatability of the position of the platform to within a few 0.1 mm (see Figure 3). The remaining two corners are bolted to the floor using conventional anchors. When a given location is not in use, dust cover screws protect the floor anchors and provide for a level floor surface without obstacles or tripping hazards.

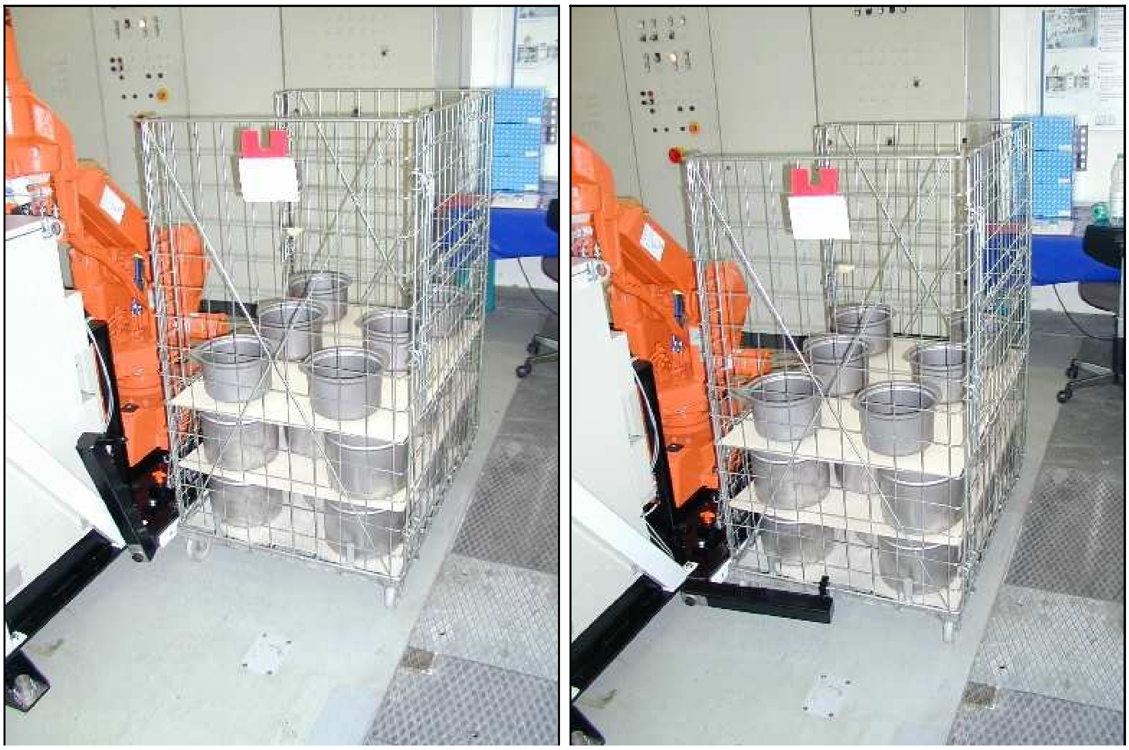


(a) (b) (c)

Figure 3: Anchoring concept for platform corners with provision for self-centering (a) in mounted state, (b) while being lifted and (c) with platform and centering pin removed and dust cover screw in place.

In order to achieve the required position accuracy for the anchors, a precision jig is used to hold the anchors in place in the factory floor while the cement cures. Measurements of the extrication force have demonstrated the ability to hold an average of 80 kN per anchor. The torque withstand has been measured to be greater than 110 Nm.

For reproducible positioning of parts bins (blank parts, finished parts) on both sides of the robot platform, eccentrically mounted lever arms clamp the parts bins in place on either side, as shown in Figure 4.



(a) (b)

Figure 4: Clamping mechanism for work piece bins using eccentrically mounted lever arm in positions (a) open and (b) closed and clamped. The parts bins used in the pilot system at WMF are the container carts shown in the photographs.

Given that all locations planned for deployment of the system have been equipped with the required anchors, the complete system can be moved from one location to another and powered on in less than 30 minutes. If in addition all of the intended applications at each location have been set up, commissioned and stored in a previous phase, the relevant settings and programs for a given location and application then can be loaded as needed. After an optional semi-automatic calibration procedure, production running can begin immediately. The relocation of the Porthos system thus consists of the following steps in sequence, beginning with shutdown steps at the present location:

- Shutting down the present application and program
- An optional run of the calibration procedure for future reference, comprising position data for platform and for cell components
- Parking the robot in its transport position
- Shutdown of robot controller and PC
- Shutting off power and media (e.g. compressed air); disconnecting power, media, and communication lines
- Removal of fastening bolts on platform
- Lifting platform with hand truck or by fork lift
- Removing centering pins from floor anchors
- Insertion of dust cover screws to protect anchor threading and to give a level floor surface
- Transportation to new location by hand truck or fork lift

After arriving at the next planned location for the Porthos system, the procedure is as follows:

- Removal of dust cover screws from floor anchors
- Insertion of centering pins into two diagonally opposite anchors
- Lowering the platform into place, making sure to fit over the centering pins
- Bolting down the platform to the anchors
- Connecting lines for power, media and communication; opening valves for media and turning on power
- Startup of robot controller and PC
- An optional run of the calibration procedure to check the position of the platform and of the relevant cell components; if required due to significant deviations, the new calibration constants are loaded
- Loading the desired application program from disk followed by an optional verification cycle as a quality control measure
- Production running

For some applications the accuracy of the platform fixing system can be sufficient to ensure reproducibility of the programmed robot paths in the cell within the required tolerances. In this case one may need to check critical cell components for proper positioning.

Sensor-Based Personnel Safety

The conventional approach to protecting personnel from injury in the vicinity of industrial robot systems and application cells is to enclose the cells by safety fences with interlocked doors. Automatic mode operation of the system is interrupted and manipulator motion is stopped as soon as any interlock device detects a possible intrusion. This type of safeguarding strongly constrains the system's flexibility with respect to frequent relocation, since each intended location of deployment would require its own dedicated safety fence installation. Clearly, a more flexible approach to safeguarding a portable robot system is needed.

The past several years has seen significant advances in safety technology, especially in the area of safe sensors and safe signal processing. Thus, a wide selection of safety sensors and processing devices is available that can be used for safety relevant detection of personnel in hazardous areas. In case of imminent danger, these devices are configured to halt the source of danger, in our case the robot manipulator. The Porthos pilot system at WMF is safeguarded by laser scanners on two sides and in the rear of the platform (see Figure 5). The arm members holding the laser scanners to the left and right of the platform allow for mechanical adjustment of the position of the safety fields, thus being able to accommodate varying sizes of parts containers. The press or machine being tended blocks off the front of the working envelope of the robot. The scanners monitor their programmable safety fields actively and are equipped with self-check functions to ensure their proper operation at all times.

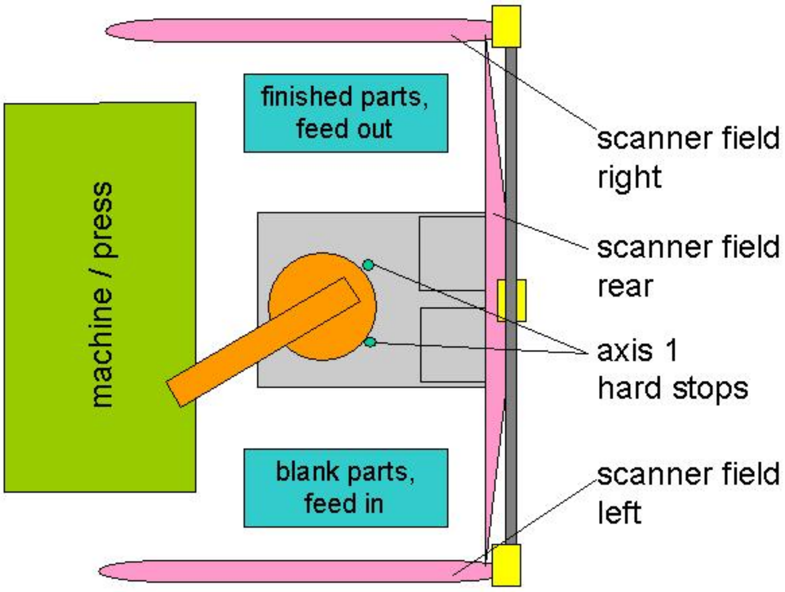


Figure 5: Personnel safety concept for pilot system at WMF using three laser scanners.

This safety system is an integral part of the Porthos system, moves with the platform wherever it goes, and is parked in a space-saving position during transportation. Setting up separate safety fences at each of the intended deployment locations of the robot system thus becomes obsolete, resulting in savings of time and costs as well as simplifying practical use.

The new version of the European Machine Directive features has somewhat increased the requirements on manufacturers of robot systems that are safeguarded by sensory means, such as our system is. Porthos is an “incomplete machine” or “component” in the sense of this regulatory directive and must fulfill the requirements of the old version of the directive as well as being accompanied by appropriate documentation, especially describing the interfaces between the Porthos system and other machines in the cell in which it shall be operated. The focus here is on the connections between emergency stop circuits and safety interlock circuits. A separate and independent CE-certification of the Porthos-system is not possible, since a complete “machine” in the sense of the directive is only created upon connection with other components.

The Porthos system fulfills the requirements of the new Machine Directive as well as the new robot safety standard ISO 10218, in which robot systems, cells and lines are now also explicitly described.

Easy-to-Use Graphical Programming and Operator Interface

Robot programming systems are either of the online or of the offline type. Online programming is performed directly on the robot system with actual motion by the manipulator and direct verification by the programmer. First, the program body with the desired logic must be written without specified or verified position data. This working step requires expertise in the given robot programming language, typically a vendor-proprietary language. The second step is the acquisition of position data for the application at hand by moving the robot to the appropriate positions manually and saving the position and orientation information into the program data structures. However, the generation and testing of robot programs generated in this way can turn out to be very tedious [5].

While the required degree of expertise in direct editing of a given robot programming language may be somewhat lesser, offline programming methods hold other disadvantages. Before the user can start generating a robot program, a full geometric model of all objects within the robot’s working range must be generated. Especially if the robot is to be integrated into an existing shop floor infrastructure, it cannot be assumed that usable CAD data is available for all machine tools and other relevant objects. In general, the application of offline programming systems can lead to a poorer quality of robot programs because of differences between the geometric model and the real environment of the robot [6]. Because of these disadvantages, offline programming systems are mainly used in more complex applications like e.g. bonding, arc welding, spot welding or gauging [7]. In these applications, however, the generation of a program in the offline mode is almost always followed by an online verification and fine-tuning of the program.

Based on the disadvantages of common robot programming systems, the following specifications of a programming system can be derived to meet the demands of SMEs with frequently varying material handling tasks:

- *Operability without any special qualifications*:
  The daily operation of the robot system, i.e. the reinstallation at previously prepared machine tools and the generation of robot programs, should be carried out by an operator with limited experience in the field of robotics. The working steps that require more technical knowledge, e.g. the initial ramp-up at new stations, will be separated from the daily operation routine.

- *Adaptability of the programming system to specific environmental conditions*:
  While the programming system is tailored to generate handling and machine tending applications, a fair degree of flexibility is necessary to accommodate site- and application-specific requirements. To guarantee a fast ramp-up for new applications and sites, the programming system must be scalable in terms of specific components that are used in a given environment. Examples for such components are grippers that demand certain signals for operation, or special pallets that are used in a given company. An easy integration of such user-defined components is essential for the acceptance of the programming system.

- *Time optimized acquisition of position data*:
  As the robot system must be easy to integrate into existing shop floors, it cannot be assumed that CAD data is available for all relevant machines and objects. Therefore, the position data for the application program must be acquired via teach-in. The accuracy and the completeness of the position data must be assured, as it is essential for an error-free automatic generation of the actual robot programs for the tending task at hand. Nevertheless, the duration of teach-in procedures should be minimized.

- *Integration of communication cycles*:
  Almost every material handling task contains the exchange of control and synchronization signals between the robot controller and peripheral components, e.g. for operating machine doors or starting a machining program. To be independent of the types of machine tools and robots, the communication cycles should be limited to digital inputs and outputs instead of using more complex or even proprietary protocols.

- *Sensor integration*:
  For the case that either the work piece bins or the work pieces are not reliably located at their ideal designated positions, there must be an option for an easy integration of appropriate sensor algorithms. In particular, the calibration of the robot cell may have to be performed at certain intervals, while the measurement of work piece location may have to be done for every cycle of the application.

- *Task-oriented generation of robot programs*:
  A grouping of motion and IO instructions into task-oriented operations, e.g. “Pick work piece from chuck,” can be a powerful possibility for simplifying the programming process. The whole handling task then can be composed of such operations in a generally understandable way. Presentation for visualization and editing can be realized by demonstrative flow charts.

- *User support*:
  User input should be checked for plausibility whenever possible. Examples for plausibility tests are checking the logical sequence and composition of handling tasks (each pick operation is followed by a place operation) or checking for completeness during the ramp-up (e.g. highlighting of missing position data).

Modeling of the robot cell

The programming system presented here is based on a two-stage programming concept (see Figure 6). In the first stage one creates a data model of the robot cell that contains all information necessary for generating robot programs for applications in this cell. It is composed of pre-defined library elements that can be adapted to the real cell by varying parameters. The XML-based library is easily extendable by user-defined elements, e.g. special grippers, work pieces, or work piece depots, bins or containers as well as holders, chucks, etc. During the modeling stage the operator is guided by the programming system in order to enforce the completeness of the cell model.

After this step, the data model is stored as an XML document. It encompasses task-independent information about the cell layout, target positions, robot motion and path parameters, and specifications concerning interaction with the environment, such as digital IO signals. The modeling procedure the robot cell can be summarized as follows:

- Selection of cell components from library file
- Adjustment of the cell components' parameters
- Definition of input and output signals
- Modeling of communication cycles
- Acquisition of position data (teaching)
- Optimization of motion and path parameters (e.g. speed, acceleration).

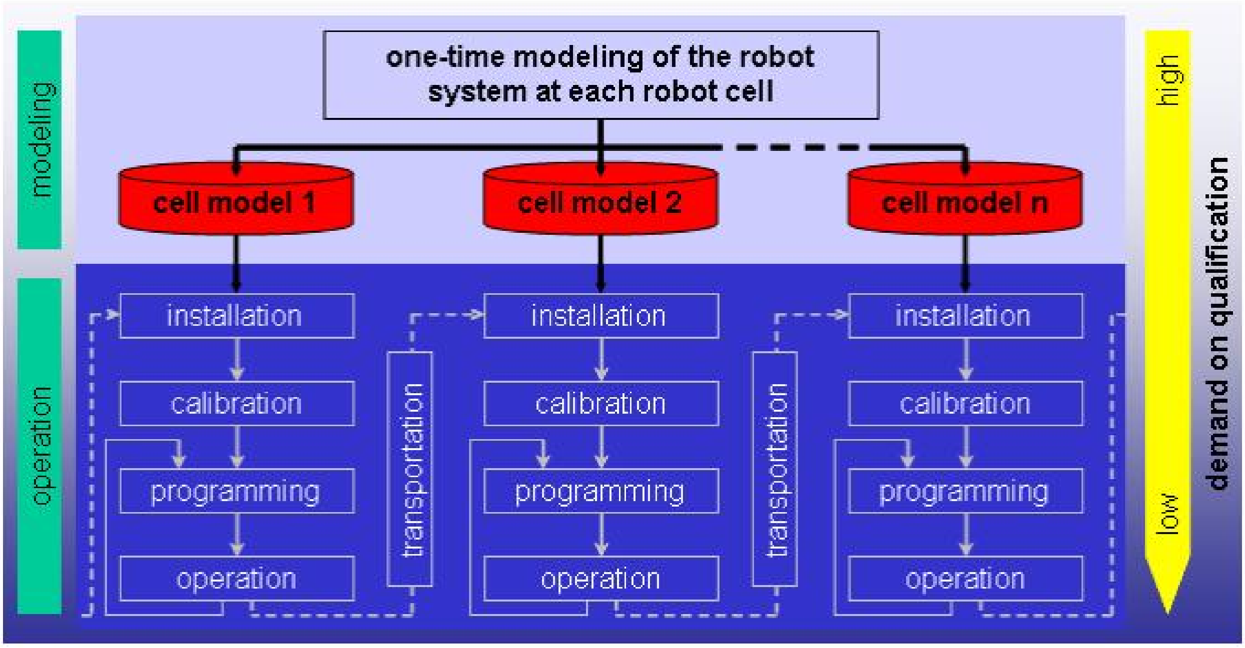


Figure 6: Two-stage programming concept: modeling and operation.

In contrast to conventional offline programming systems that require extensive geometric data, the components of the presented programming system demand only the minimum required data. The scope of this data depends on the type of component. Altogether, the prototypical robot cell for machine tending consists of four different types of components: a robot, a gripper, one or more work pieces and one or more work piece depot. In this context, the type "work piece depot" also comprises machine tools. That is, a turning machine is reduced to its chuck, the relevant part of the machine when performing the task of tending it with work pieces.

The most time consuming part of the modeling stage is the acquisition of the position data for the robot path segments of the application. As the programming system is specialized to the programming of material handling tasks, the operations the robot can perform are limited to pick and place operations. Thus, all positions for every pick and place operation for each work piece depot are stored in the data model of the cell. In many cases, the number of points to be taught can be reduced by symmetry considerations, such as re-using the points of the pick operation for the place operation or by applying the same points for the movements to and from the grasping position. Such short cuts in teaching the points for the robot paths can significantly reduce the overall teaching effort for an application. When the user begins teaching the cell, he is offered a choice among these short cut options.

After this, the programming system automatically generates a teaching assistant robot program. This robot program guides the operator step by step through the teach-in process, making sure that no critical points are left out. During the process of teaching, the operator can define the number of points needed for the specific operations or robot path segments. Thus, both complex path segments that demand many intermediate points and simple trajectories, such as approaching a flat pallet without any risk of collision, can be handled with this teaching procedure. Finally, the position data is automatically transferred from the robot controller into the data model.

Task-oriented Programming

As all relevant data for generating robot programs has been stored in the cell model during the modeling stage, the programming stage can be reduced to an easily understandable description of the material handling task. Each work piece depot has a number of operations that can be concatenated to yield the handling application in a graphically interactive way (see Figure 7). The program flow is structured by using control elements such as loops, wait functions, or if-then-else blocks. The conditions tested in these elements can consist of digital IOs of the robot controller as well as of the number of work pieces in any of the depots. Manual intervention for filling, emptying or exchanging of work piece depots also can be integrated into the program flow.

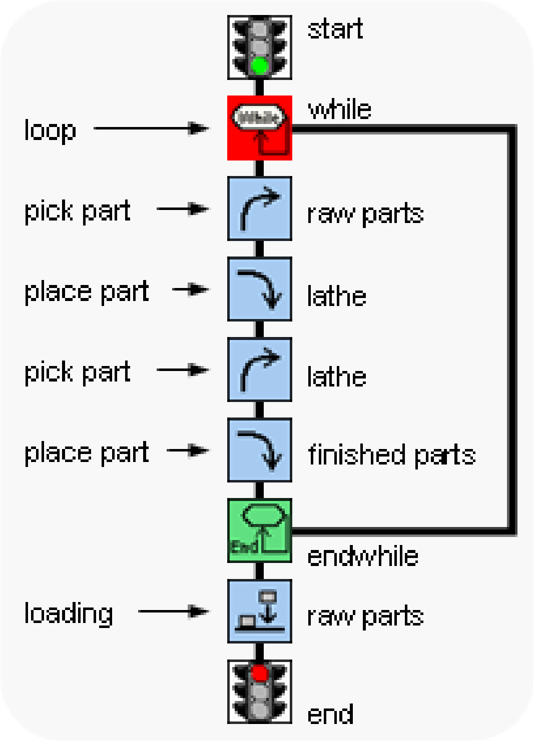


Figure 7: Example of program flow as visualized in graphical programming editor.

In this case, for example, the operator is informed about the parts container that needs to be exchanged as soon as the robot moves to a halt position and waits. After exchanging the container, he must approve or correct the number of work pieces in the new container before restarting the application.

Flexible, Sensor-Assisted Grasping of Work Pieces

Extending the range of different work pieces to be handled in a conventional robot cell normally leads to the design and manufacturing of additional grippers. To reduce such efforts, grippers should offer a certain degree of adaptability for grasping work pieces of different sizes and geometries. In practice, the level of flexibility that can be built into a single gripper is limited for reasons of cost as well as speed and robustness. A reasonable level of flexibility is obtained when a single gripper is able to handle all work pieces to be processed at a given robot station, i.e. no change of grippers is required for carrying out a single machine tending application.

For many applications it will be necessary to integrate appropriate sensors into the gripper, e.g. for locating work pieces or for calibrating the positions of components of the robot cell. The functionality required of sensors in standard machine tending applications can be divided into

- Time-critical measurements, e.g. occurring every cycle
    - Compensation of work piece displacements
- Non-time-critical measurements, carried out aperiodically on demand only
    - Initial calibration of sensors, grippers and cell components during commissioning
    - Re-calibration of cell components after re-installing the robot system at prepared location

Generally the choice of an appropriate sensor solution depends on a number of different factors. Among these are functionality, processing speed, complexity, robustness, reliability, and costs.

Within the project Porthos, two different gripper-sensor-combinations have been developed and tested. The first is a flexible multi-functional gripper that was built as a lab demonstrator for scientific purposes. The kinematics consists of two servo-electrical actuators and three grasping elements, which enables the gripper to handle an appreciable number of different work piece geometries (see Figure 8). Furthermore, this gripper has an integrated grayscale CCD-camera for measuring work piece displacements, thus guiding the grasping procedure.

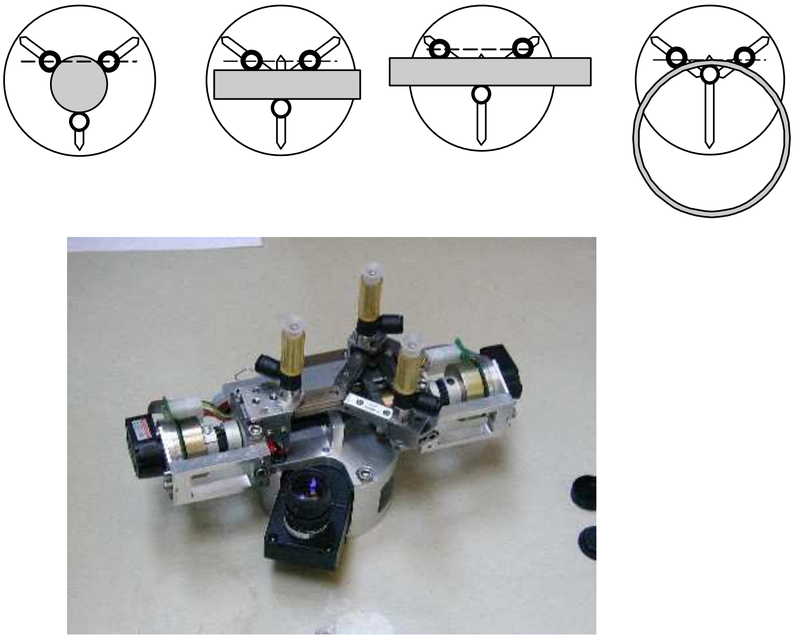


Figure 8: Servo-controlled multi-functional gripper with two degrees of freedom and three grasping elements ("fingers"). Also shown are selected examples of grasping configurations for different objects.

For the Porthos pilot system, the focus of the gripper capabilities is on the specific work pieces to be handled at the stations at WMF (see Figure 9). The required flexibility in this case lies in the capability of grasping the main work pieces (pots for food-processors) in two different configurations via force closure, to grasp the rim cuttings via form closure, and to suction-lift the large sheets of cardboard, which separate the layers of work pieces in the container carts at WMF (see Figure 10).

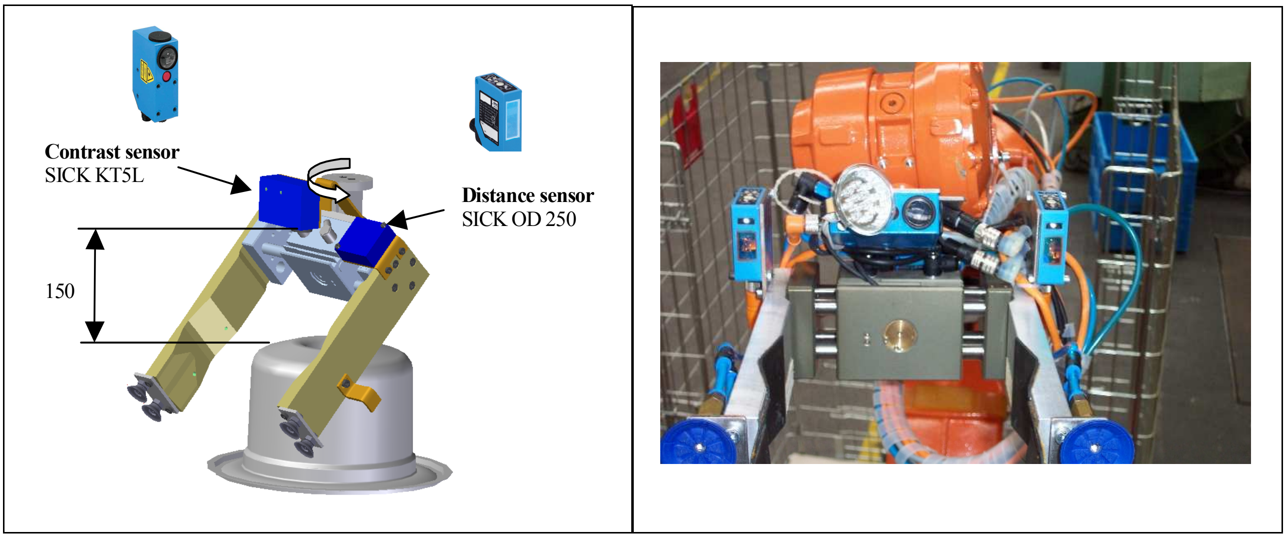
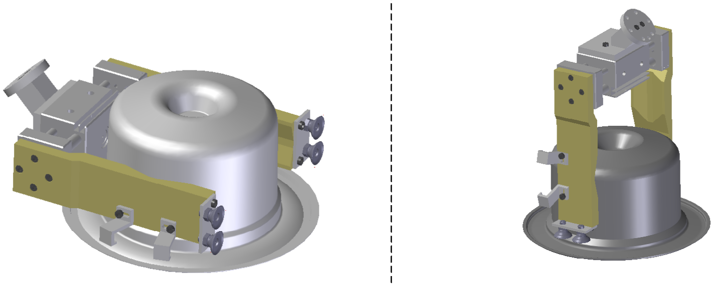
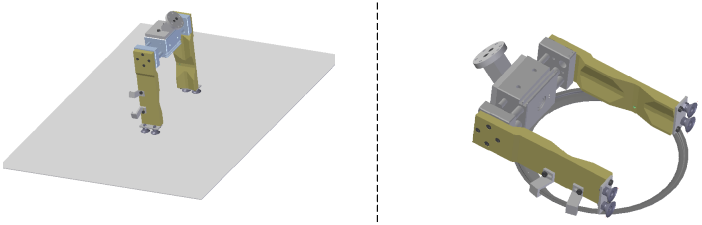


Figure 9: Multi-functional gripper with sensors for pilot application at WMF – model and photograph.



pots from side

pots from top



layer separators
suction grip

cuttings

Figure 10: Different grasping configurations with several objects, as required for WMF pilot applications.

In addition to the ability of handling different work pieces, sensors for realizing the required adaptability have been integrated into the gripper. Two laser distance-sensors, mounted on the grasping elements, are used for both the calibration of cell components and the measurement of work piece displacements. For the WMF pilot system, we chose this type of sensor for cost and robustness reasons. Straightforward use of their ability to switch a digital signal at a certain well-defined distance from an object does, however, gives rise to powerful functions for object detection and calibration.

When moving in direction towards an object or when moving parallel to its surface with a laser distance sensor on-board a robot end-effector, the digital output of the sensor signals when a certain distance to the object is reached or when we "go off the side," as illustrated in Figure 11.

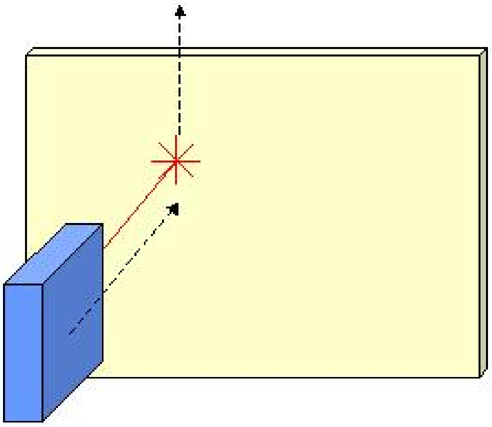


Figure 11: Illustration of ability of simple one-dimensional laser distance sensor to detect planes and edges of geometry.

We used this feature to detect the location of pots on a layer in the parts bins at WMF by scanning across the pots and noting the position of the edges. With this information and knowledge of the pot dimensions, the location of the pot center is computed and the gripper guided to the correct grasping point.

In addition, the task of verifying the position of the press, its tooling and recalibrating these when necessary is elegantly automated using the laser distance sensors (see Figure 12). The procedure assumes one has a rectangular geometry feature on the cell object to be calibrated. This feature may either be intrinsic or may be a calibration plate mounted to the cell component in a well-defined manner. Then, one teaches three points from which linear searches towards the plate give three new points, all the same distance *d* away from the plate, as they are triggered by the distance sensor (motion from position (1) to (2) in Figure 12 (a)). These three new points are used to position the sensor beam perpendicularly to the object surface, if this was not coincidentally the case to start with. In the next step, the sensor is used to detect the edges of the rectangular plate (motion from (1) to (2) and then to (3) in Figure 12 (b)). The coordinates of the edges are then used to compute the coordinate system spanned by the rectangular object.

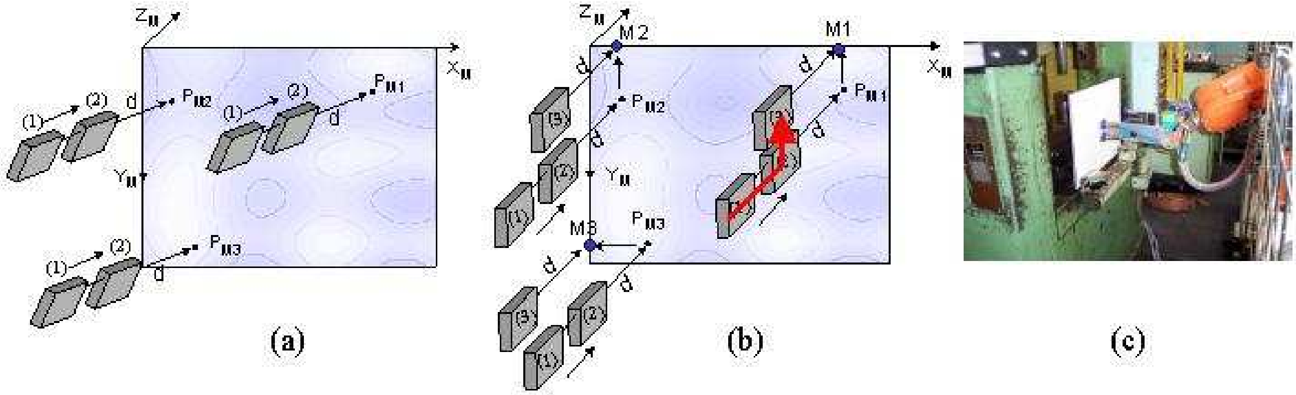


Figure 12: Principle procedure for calibration of coordinate system on a rectangular object. First step (a) is teaching three points from which the sensor is moved towards the plane of object. Based on three points thus obtained, each a fixed distance d from the object, the second step (b) is to set the sensor beam vertical to the surface (if it was not before) and to search for the edges of the object. These edges then are the axes of the desired coordinate system. In (c) we show an example view with calibration plane attached to the yoke of the press.

Calibration of the press tool and yoke with respect to the robot system is recommended as a last measure before moving the Porthos system and as a first measure after setting it up at a new location. The calibration results are stored together with the data and programs for each location and task the system is commissioned for. In the case of the pilot applications at WMF, our experience was that the excellent repeatability of the platform position due to the tight tolerance of the anchoring provisions gave enough position accuracy to run our applications without updating the calibration of the coordinate systems used in the robot programs.

Thus, our pilot system is equipped for tending two consecutive manufacturing steps in the production of pots for food processors. For additional applications, in which work piece geometries or masses could be quite different, the adaptability of the present gripper system might well be at its limit, and new grasping solutions must then be built.

Finally, to demonstrate the possibility of integrating more complex sensors into our system, we have tested in the laboratory a laser stripe sensor for the purpose of determining work piece positions. This sensor has the distinct advantage of relative insensitivity towards fluctuations in the lighting of the scene. Complex sensors in general, such as a stripe sensor or CCD cameras, have the advantage of providing richer information for the purpose of calibrating cell components or for measuring work piece positions.

Experience Gained from Deployment of Pilot System in Production Environment

Production testing of the Porthos system on the factory floor at WMF concentrated on two stations in the pressing plant. Here, we tended two consecutive manufacturing steps in the production of food-processor pots. The production sequence and a photograph of the product are shown in Figure 13.

Manufacturing of these pots begins with deep drawing of circular sheet steel blanks in a large drawing press. This step is not discussed further here, and we focus just on the subsequent two tasks, for which the Porthos system tends the presses.

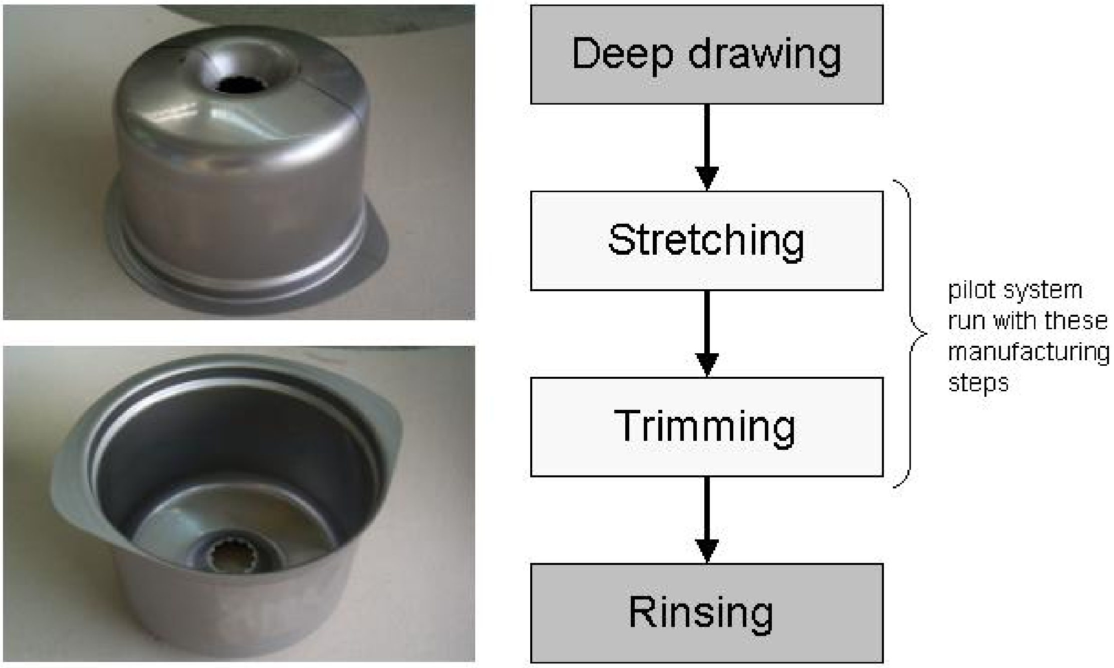


Figure 13: Photographs of food processor pot after trimming of rim. For production testing of the Porthos System, we automated the manufacturing steps "stretching" and "trimming".

After deep drawing the blanks, the rims of the pots are drawn once more to even out irregularities. The drawing press carrying out this step was our first pilot application for Porthos.

The next step in production is trimming the rim of the pots down to the final shape as well as punching a hole in their bottoms. Tending the eccentric press that runs this process was the second pilot application station at WMF. For several reasons, this step was significantly more complex. Among these are:

- Very limited space between the upper and lower tools in the press. Insertion and removal of the pots with the robot is just barely possible and, since the required trajectory is not simple, cannot be run at very high speeds.
- After the press cycle, the cuttings often end up wedged onto the periphery of the upper or lower press tool. The behavior is not reproducible and thus precludes reliable automation.
- Automation of this step would require the automatic removal of the cuttings, so it becomes clear that the station in its present state cannot simply be automated. More extensive preparations on the side of the press tooling are necessary.

One of the most important lessons learned from tests in production is, therefore, that the manufacturing tasks for which a Porthos system shall handle the tending of work pieces must be prepared for being automated by a robot system. Whenever humans handle manufacturing tasks, they regularly employ one of their most important strengths: the ability to handle irregularities as they arise and to improvise where necessary. The extreme degree of flexibility required for this is not a feature of any present-day robot system and one should not expect it to be anytime soon.

The prerequisites for a gainful deployment of a Porthos system can then be summed up into a few important points:

- A selection of manufacturing tasks that can be prepared for robot-automated operation with reasonable effort
- Varying lot sizes in connection with these candidate tasks
- Varying machine utilization imminent in varying order loads
- An appropriate degree of adaptation of processes like parts logistics or material flow leading into and following the manufacturing steps temporarily handled by a Porthos system
- Acceptance by the work force that the deployment of a Porthos system is a complement and not a challenge to their responsibilities

- A satisfactory overall trade-off between investment and payback at the particular site being considered.

Conclusions and Outlook

The application of industrial robots in small and medium-sized enterprises requires the development of flexible and easy-to-use robot systems. These systems must be portable and must be able to adapt to different application sites, various material handling tasks or work pieces. The time and effort required for reinstalling the robot system must be low and the re-installation and operation of the system must be feasible for unskilled machine operators. By fulfilling these demands, a cost effective application of the robot in SMEs with varying lot sizes and irregular utilization ratios of their machine tools can be achieved.

The project “Porthos” presented here aims to meet the demands of SMEs by integrating appropriate flexible, mechatronic components into one single robot system. In this system, the robot manipulator, its controller, an industrial PC as well as the support structure for the sensor-based personnel safety system are all mounted onto a single standard sized steel pallet. Our pilot system has a total weight of about 1200 kg and therefore can be moved conveniently either by hand truck or by a forklift. The floor-anchoring arrangement consists of four anchors at each intended location of the system, which match the four corners of the platform. Two of the fastening points are fitted with self-centering pins to provide position repeatability of approximately 0.1 mm. The required connections to the cell environment are for power, media, emergency stop and safety interlock signals, process control signals, and optional data network connection. Personnel safety is ensured through a system of three adjustable laser scanners that span a tailored protection field on three sides of the platform, the fourth being blocked by the machine or press being tended. The safety concept adheres to the robot safety norm ISO 10218 and, together with full documentation of the system, its interfaces to the rest of the application cell, and checklists for proper procedure when making this connection, our system satisfies the European Machine Directive when it is installed.

The mechanical setup is complemented by a graphical programming system that guides the user through the whole ramp-up procedure and reduces the efforts for generating robot programs significantly. The programming system is based on a two-stage approach. In the first stage, a data model of the robot cell is created, that contains all information necessary for generating robot programs. After this, the data model encompasses task-independent information about the cell layout, target positions, motion parameters and communication cycles with peripheral machines. In the second stage, the so-called operation stage, its main task is the generation of the robot program. This can be done in a task-oriented way by the graphical composition of operations like e.g. “Pick work piece from chuck”. Thus, the programming itself is reduced to an abstract and therefore intuitive description of the robot task.

Production tests of our system have shown that it can boost efficiency in a manufacturing environment that meets certain characteristics, such as small lot sizes, strong fluctuations in order load on various machines, preparation of production tasks at target machines for automatic operation, as well as a favorable balance of investment with pay-back.

While we have specialized the Porthos system to material handling tasks, one can envision portable robot systems for various other tasks in manufacturing environments requiring a high degree of flexibility. As manufacturing moves increasingly towards mass customization, we see a promising trend in providing highly flexible automation to meet the new challenges that arise.

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