

THE NEED FOR AN INTUITIVE TEACHING METHOD FOR SMALL AND MEDIUM ENTERPRISES

R. D. Schraft
Fraunhofer IPA
Germany

Christian Meyer
Fraunhofer IPA
Germany

Speaker: Christian Meyer, Fraunhofer Institute for Manufacturing Engineering and Automation, Nobelstrasse 12, 70569 Stuttgart, Germany, +49(0)711/970-1092, christian.meyer@ipa.fraunhofer.de

Topic: Research and Development

Keywords: Walk-Through-Programming; Teaching; Programming; Human-Machine-Interface

Abstract

Small and medium enterprises currently do not often use robots in their production; one reason is the complex handling, especially the time-consuming programming. Using the well known walk-through approach this drawback could be overcome. We discuss the defiances of this approach and present means of adapting trajectories by transforming them into sequences of geometric primitives. By means to interact these sequences they can get changed according to the specific task. A metric is developed based on triangulation of the trajectories. A gluing robot cell is presented using this technology.

Introduction

Industrial robots are widely used in companies producing mass market products in high lot sizes. Body shell work in the automotive industry for example mainly consists of robots handling, machining and joining the sheet metal parts. Besides the further development of these applications, industrial robots are currently intruding other markets: in a few years small and medium enterprises will benefit from industrial robots as much as the automotive industry does today.

Deficit: Small Lot Size Production In small and medium enterprises robots are not commonly found. One of the reasons, the high investment, is rapidly vanishing: the cost of a robot system has fallen to 25 percent of the costs of 1990 (quality adjusted, [IFR04]). Another reason is the necessary environment, especially the programming capabilities. To work with today's systems, the SMEs need to set up a robots department with programming engineers and trained service personal. These financial efforts do not pay up till now. In the upcoming part of this contribution, we will focus on the area of programming.



Figure 1 : Examples of small lot size processes: welding (left), cutting (right)

Definition of Niche Common industrial robots are programmed by a teach panel in lead-through programming, or with an offline programming system. These and other programming possibilities have been described e.g. by Biggs and McDonald [Biggs03]. Both methods only pay for high lot sizes; they need a long time and much experience.

Figure 2 shows some connections between lot size, degree of automation and programming method. Offline programming systems will also be used for production lines in the mid or low lot size, single robots will be programmed with the teach

panel. In this lot size area human workers can be more efficient than an automated cell or line. Single work pieces will normally be processed by human workers.

We propose to get a transit of manual production to automated robot cells for small lot sizes. The main problem, the complex and time consuming teach-in shall be done with the Intuitive Teaching method.

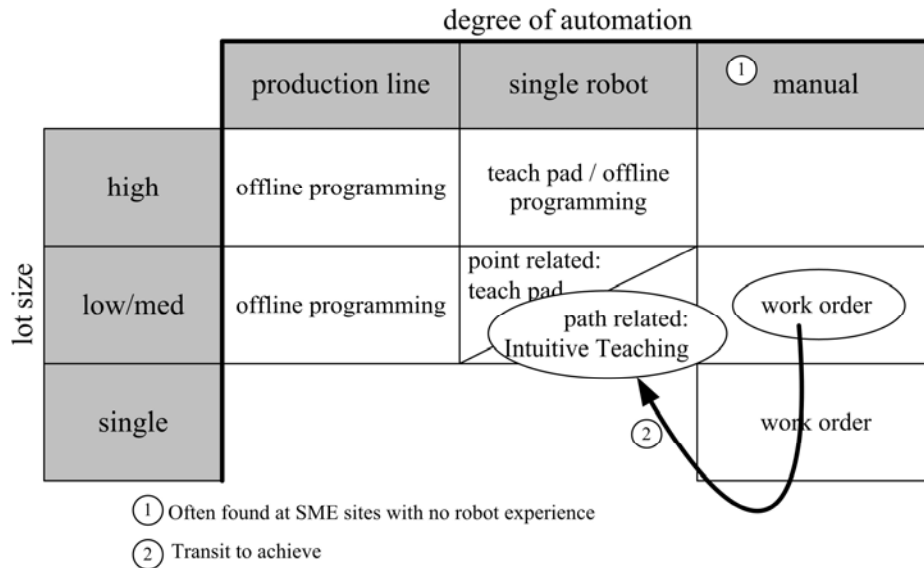


Figure 2: Definition of niche

Requirements and Applications To succeed with the transit, several prerequisites have to be fulfilled:

- New users can get trained to program the robot system in less than one day
In small and medium companies the work force is often not big enough to have one person assigned to the robot with a big part of his working time. So long trainings have to be avoided.
- Programs can be changed easily
When working in small lot size production the number of variants is often high. For work pieces that are nearly the same the same robot program should be used, slightly adapted.
- Programming time reduced to a fraction of today's methods
The ratio of programming to production has to be increased for small lot sizes.

In the next chapter we propose a programming method that fulfils these conditions. It is especially designed for trajectory oriented tasks because these are the most time consuming. Possible applications are, among others:

- Arc Welding
- Gluing
- Material Handling

Proposed Solution: Intuitive Teaching We propose to use a walk-through attempt to provide a tool for fast and effective teaching of industrial robots in this niche. The user guides the robot with a handle that is equipped with a force torque sensor. The robot moves actuated by an admittance control strategy. The trajectory guided by the human is recorded and can be replayed. Before replay, parameters like velocity, position and orientation can be adopted.

This programming approach is not new, it has been used e.g. with early painting robots. But today, it is not in use anymore. Our goal is to solve the problems that prevent the usage of this intuitive teaching approach.

State of the Art

The American Occupational Safety and Health Administration defines three means of programming a robot: lead-through programming, walk-through programming and offline programming [OSHA06]. Today's robots used in industry rely on lead-through programming with a teach panel, or the offline programming with complex tools.

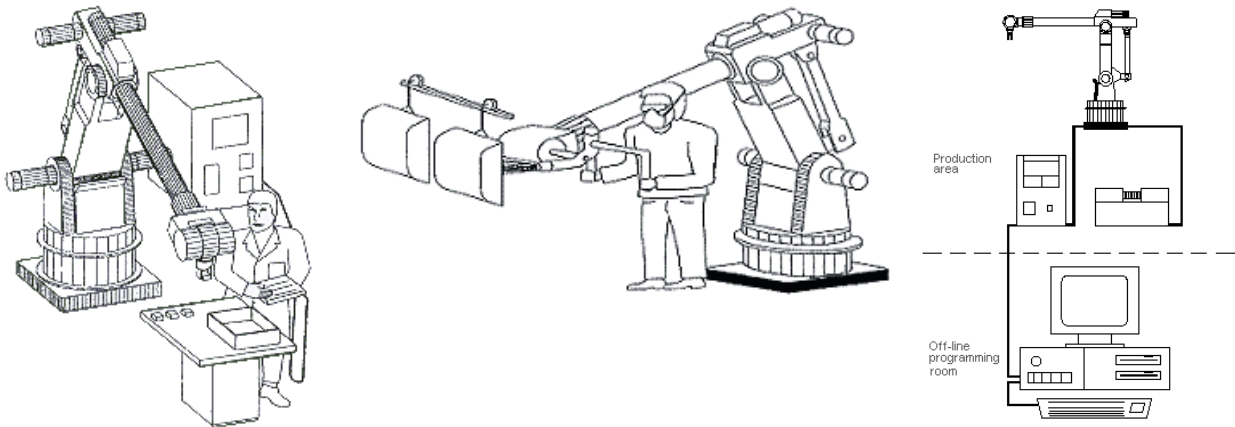


Figure 3: Different means of programming, lead-through (left), walk-through (middle) and offline programming (right). Source: [OSHA06].

The walk-through programming is commonly not used in the industry, but there exist several companies with products in this area. The Barrett arm (Figure 4, left) can be guided by the user, trajectories can be recorded [Leeser94]. Additional functionalities like virtual walls add value. The robot is actuated on the base of motor current measurements.

Manutec robots can get equipped with mz robotlab controls, these are able to conduct force sensitive processes like grinding or deburring, also they can be programmed by guidance (Figure 4, right, [Zahn06]). The motion control is done using the measurements of a force torque sensor.

KUKA robots can be ordered equipped for safe handling, then the robots can be guided using a 6-DOF-joystick.



Figure 4: Barrett WAM [Leeser94], KUKA Safe Handling [Heiligensetzer05], mz robotlab [Zahn06]

Defiances The presented robots can be guided by the user, but there is no possibility to overcome the problems that prevent and industrial application up till now.

- *Precision of path regarding position and orientation:* The user cannot guide the robot within a tenth mm or degree, the precision has to be achieved in post processing.
- *Adaptability of the trajectory:* Errors in the teaching process have to be easily overcome, changes should be possible.
- *Human Machine Interface:* The user needs multimodal and intuitive interaction.

A few years ago safety was another aspect to prevent applications with direct human robot interaction from being used. But with new technologies like the Reis safety controller or the KUKA safe robot technology, and on the other hand standards like the new ISO10218:2006 allowing the collaboration under defined circumstances, the safety is no problem any more.

Human-Machine-Interface

The first problem to get robots into SME applications is an intuitive human machine interface. Today's teach pendants are very efficient, but complex devices. Training takes a too long time for some applications and situations. We propose the combination of several input channels:

- Guiding the robot through the trajectory using a force torque sensor
- Commanding the robot while guiding using a speech dialog system
- Adapting the trajectory by using a PDA and 3-D graphical user interfaces

In Figure 5 the different devices are depicted. A common device interfaces allows swapping different devices between different applications.

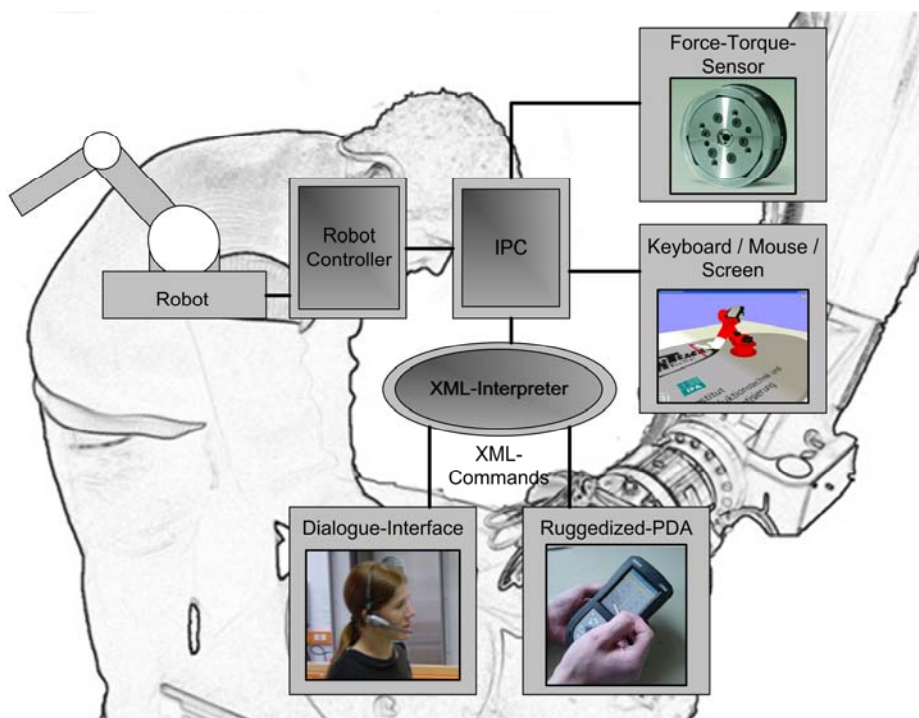


Figure 5: Integration of different devices into the instruction environment, dialogue interface, PDA, 3-D graphical interfaces and force torque sensor.

Guidance Up till now the guidance is realized using admittance algorithms; see [Albu-Schaeffer02]. Several means of supporting the user can be added, e.g. the implementation of virtual walls as in [Leeser94].

To avoid unintended motions following a change in orientation the gravitational forces applied by the tool have to be compensated. To do this, the mass and the centre of gravity (COG) have to be known.

In the following lines a procedure is depicted how to compute these values with the mounted tool using the robot. The four positions described in Figure 6 have to be reached with the robot. After each position the sensor has to be reset to zero values. After reaching position two, three and four relative values of forces and torques are measured.

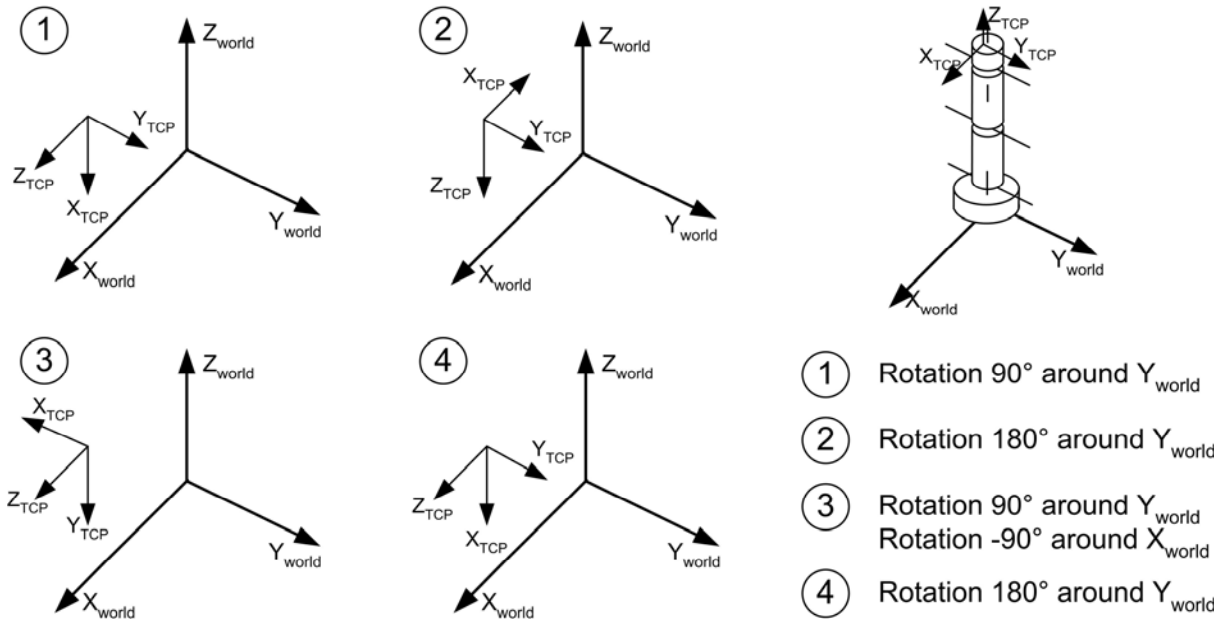


Figure 6: Positions to compute mass and COG

From these measurements mass and centre of gravity can be computed:

$$m = \frac{1}{3} (|dF_x^1| + |dF_z^2| + |dF_y^3|); \quad \overline{cog} = \frac{1}{m} \begin{Bmatrix} M_y^3 \\ M_x^1 \\ M_z^2 \end{Bmatrix}$$

The expected forces and torques generated by the tool can be achieved by multiplications with the current position matrix mat^{pos} . The forces result from

$$\vec{f}_{comp} = m \cdot \overline{\cos FG}$$

with $\cos FG$ as the angle between gravitational force and the vectors of the TCP coordinate system:

$$\overline{\cos FG} = \frac{(0,0,1)^T \times mat_1^{pos}}{\|mat_1^{pos}\|}$$

The torques are computed accordingly:

$$\vec{M}_{comp} = \overline{COG} \times \vec{f}_{comp}$$

When next time initialising the current forces and torques of the tool are stored as $\vec{f}_{removed}$. The from gravity separated forces and torques $\vec{f}_{compensated}$ are computed as:

$$\vec{f}_{compensated} = \vec{f}_{act} - \vec{f}_{comp} + \vec{f}_{removed}$$

Speech Dialogue System Guiding the robot with both hands, a speech dialogue system is needed to forward necessary commands to the robot system, e.g. 'start recording' or 'faster'. In this application the Sympalog speech dialogue system is used to interact with the user. A DECT headset provides the necessary convenience.

Path Adoption

To meet the goals of robot programming the recorded trajectories has to be adopted. Several reasons are responsible for this need of manual interaction:

- The path guided by the human worker cannot get into tolerances needed by some processes, e.g. tenth of a millimetre in welding applications.
- There should be the possibility to change the path e.g. for a new, almost identical work piece.

In this section we will present possibilities to compress the path data and generate an abstraction of the path in an automatic way. Afterwards several means of interaction with this path segments will be defined. Figure 7 shows a visualisation of the recorded path, the segments generated by this path and an example for a deviations metric. At this time the presented processes only deal with three of the six degrees of freedom the robot can move in. The orientation has to be included in the further work.

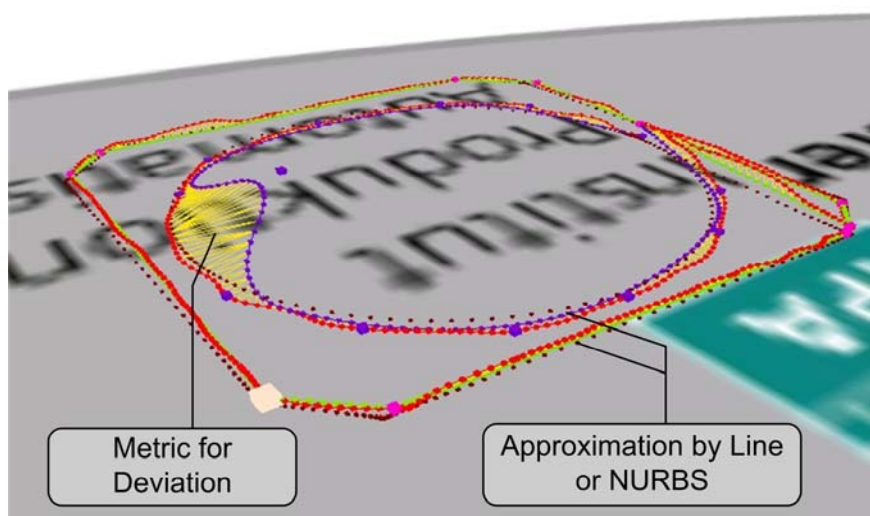


Figure 7: Visualisation of the path adoption

Data Compression As a first step the data complexity has to be minimized. In this application the Douglas-Peucker algorithms [Douglas73] is used. Known from the area of cartography this recursive weeding algorithm detects so called dominant points. These dominant points are chosen in a way, that a zigzag line approximates the original path within a defined tolerance. The algorithm is defined by three steps:

1. construct a connecting line between start and end point
2. search point with maximum perpendicular distance to this connecting line
3. if distance $> \epsilon$ then add point and return to 1. With the two resulting connection lines. If distance $< \epsilon$ then end.

Segmentation After the compression geometric elements are fitted in between the dominant points. Currently lines and NURBS are used to approximate the recorded path. The algorithm for deciding what geometric primitive maps best to the according points is under further research.

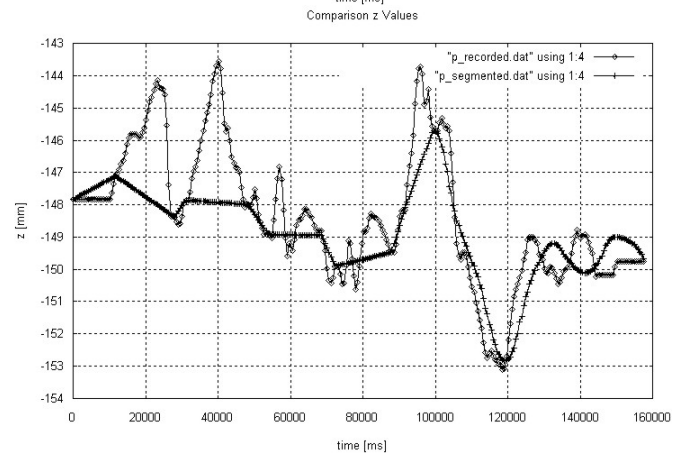
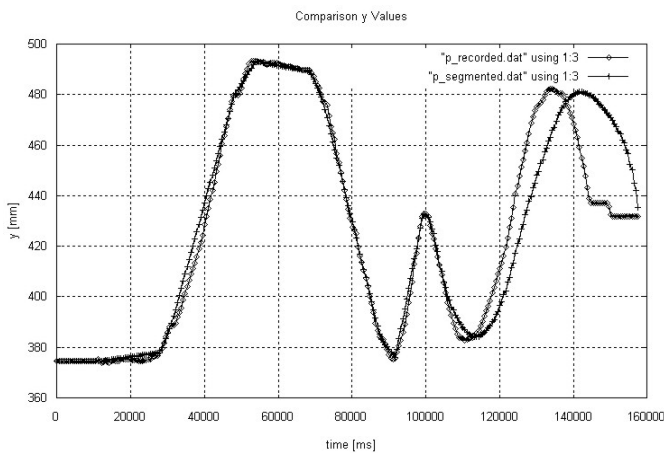
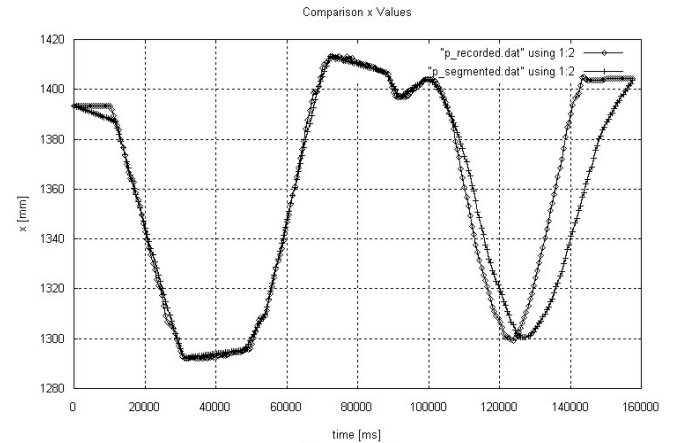
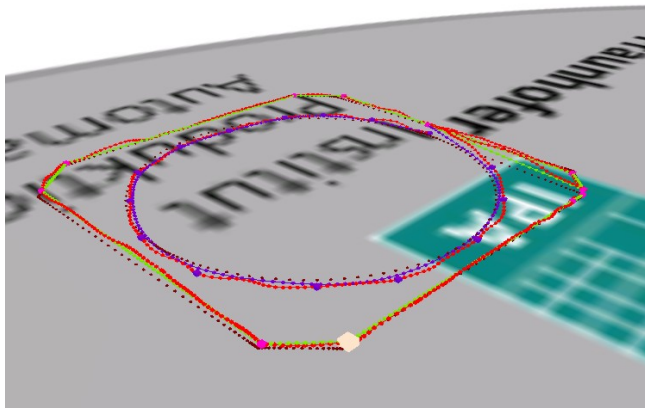


Figure 8: Adoption of a recorded path.

Means of Interaction The user has several possibilities to interact with the segmented path through the 3-D environment, but it is not intended to generate an interface as complex as an offline programming system. The interaction should be simple and easy to understand. Several possibilities are available up till now:

- Move a dominant point with the mouse
- Change a dominant points character, from edge to smooth and vice versa
- Add a dominant point at a specific position on the recorded path
- Delete a specified dominant point

With these means of interaction a recorded path can be adopted as shown in Figure 8. The upper left image shows the user interface with several trajectories: the originally recorded and the segmented path. In the image it is obvious, that the guidance by the user is not exact enough to generate for example straight lines.

After the automatic compression and segmentation of the path a sequence of lines and NURBS is generated. This sequence has been optimized by the user; the direct comparison of recorded and segmented path is shown in the remaining three graphs of Figure 8:

- Comparison of x values (upper right graph)
The adopted trajectory is smoother than the original recorded one, this is obvious for example in the area of the second local minimum. The trajectories are not identical any more, the reason is breaks in the movement. The velocity has to be adopted after segmentation.
- Comparison of y values (lower left graph)
This graph shows pretty much the same characteristics as the former. The segmented trajectory is smoother, but in the end they are no more identical.
- Comparison of the z values (lower right graph)
This graph looks much more upset, the reason is the much smaller scale on the y axis. The trajectory is intended

to be in one level, so there should be nearly not movement on the z axis. The zigzag movements of the recorded path are much more obvious here.

Further means of interaction are related to the definition of a velocity profile via a graphical user interface.

Deviations Metric Between the recorded and the segmented path there will be always deviations. Also, and even more interesting, there will be deviations to a commonly programmed robot program. To get an indicator for these deviations a metric has been implemented.

The simplest form of a metric is the sum over all deviations between a new and an old frame:

$$g = 1/e = 1/\sum \|frame_{new} - frame_{old}\|$$

This metric can be applied when dealing with an equal number of points and two points with the same number describing the same position. In our problem both conditions do not meet.

In [Teh89] two different Metrics are defined, the integral square error (a) and the maximum error (b):

$$(a) E_2 = \sum_{i=1}^n e_i^2, \quad (b) E_\infty = \max_{1 \leq i \leq n} e_i$$

The error e_i is the perpendicular distance from point i to the according line. But also these metrics only make sense in chain-code applications. We propose the computation of the area between the two trajectories. This error value can get obtained by a triangulation of the area in between the two curves. Of course the result will not be an indicator for the quality of the trajectory; several problems arise:

- To provide a quality measure a reference path has to be known. This is only the case for few training applications.
- In this graphical representation only six degrees of freedom are represented, orientation is not included.
- The user does not necessarily know which trajectory is the best.

Figure 9 shows two case studies with trajectories and the proposed metric. On the left picture artificial deviations have been introduced to the segmented path to show the triangulation. On the right side the triangulation takes place between the hand guided path and the segmented path. Deviations of the hand guided path are overridden by the abstraction by lines or NURBS, but there is an error: in this example the deviation between both trajectories amounts to 678.9 mm².

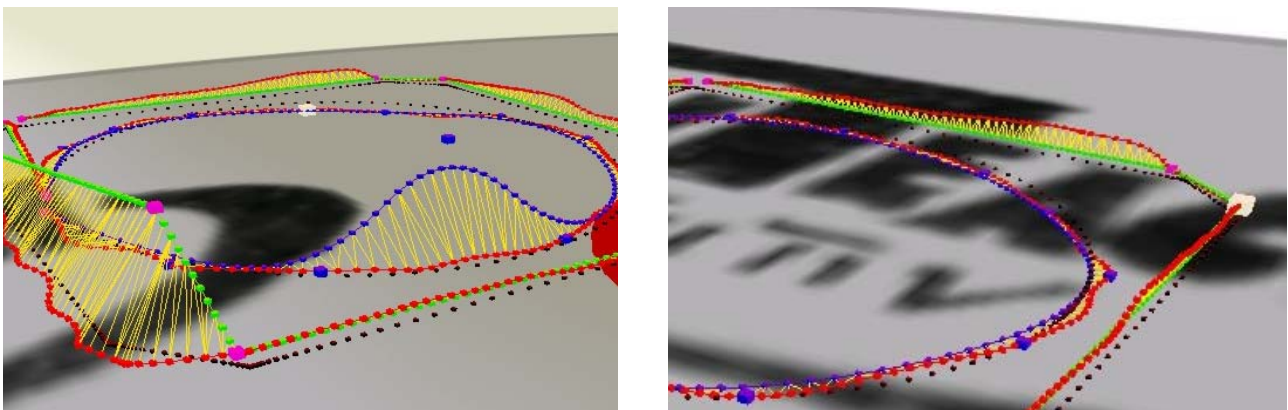


Figure 9: Active Metric in artificial (left) and original (right) deviation

Applications

In our labs at Fraunhofer IPA a simple gluing scenario has been set up to get first impressions of how to interact with the robot system. A Reis RV40 robot forms the base of the robot cell; the robot gets motion commands via an XML Ethernet connection from an industry PC. This PC provides interfaces to the force torque sensor, the PDA and dialog system and a graphical user interface.

The robot implements a complex safety concept to allow the user in the robot cell while the robot is working in automatic mode. Using the standard Reis safety controller in the robot controller velocities and motion areas can be supervised according to Category 3 of EN954. It is also possible to adapt the robot cell to the new ISO10218:2006 that will be published soon.

The PDA used is ruggedized to conform to industrial environments. With its touch screen the user can command the robot, have a 3-D visualization and define a velocity profile (see Figure 10, right).

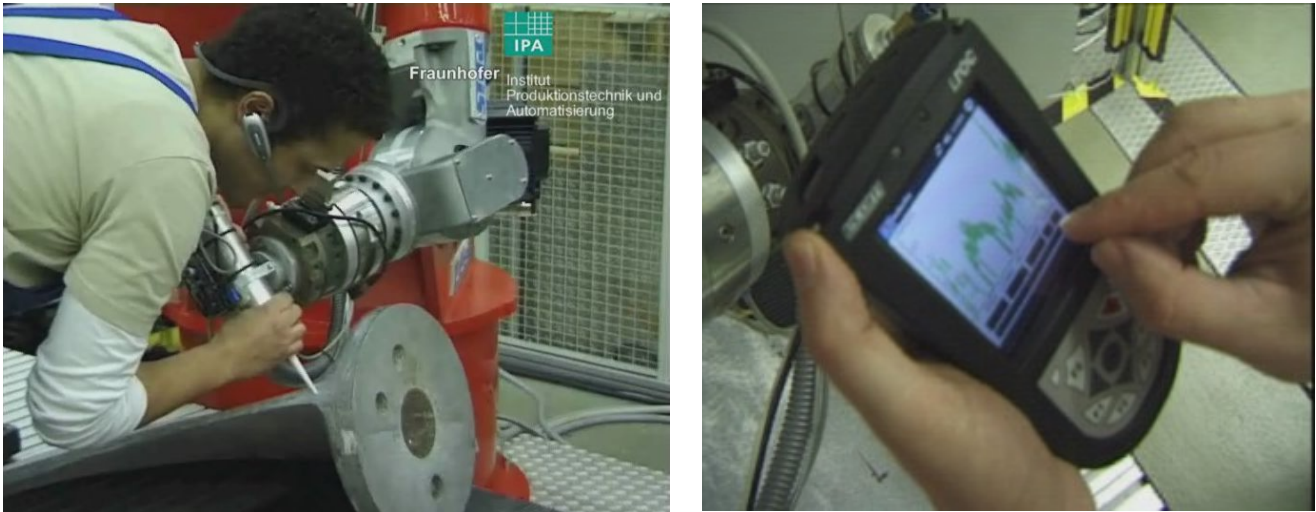


Figure 10: Gluing scenario with a Reis RV40 robot, programming (left) and defining a velocity profile (right)

Experiences The investigations with the robot systems are still running. First impressions support the anticipated objective that a very fast programming should be possible. By means of guiding the robot and simple graphical interaction interfaces working robot programs can be defined very fast.

The guiding of the robot is more simple with less degrees of freedom, so with only translation or only orientation. On our interfaces simple means are included to provide a transition from orientation to translation and vice versa.

Conclusion and Future Work

We presented the old idea of teaching a robot while guiding him through the cell and discussed the defiances that prevented the application of this method so far. Problems like the human machine interface, the safety of the human, and the adaptability of the trajectory can be overcome with state of the art technology. More challenging is the question how to reach the necessary precision.

We will further conduct experiments to verify the intuitive teaching method; we will put much effort in the development of HR-interfaces and safety systems. To reach the needed precision in the trajectory either the integration of sensor into the programming environment, or the use of the physical data of the work piece have to be used.

Acknowledgment

This work has been funded by the European Commission's Sixth Framework Programme under grant no. 011838 as part of the Integrated Project SMERobot.

References

- [Albu-Schaefer02] Albu-Schaefer, A.; Hirzinger, G.: Cartesian Impedance Control Techniques for Torque Controlled Light-Weight Robots. In: Proceedings of the 2002 IEEE International Conference on Robotics and Automation (ICRA). Washington, 2002.
- [Biggs03] Biggs, G.; MacDonald, B.: A Survey of Robot Programming Systems. In: Proceedings of the 2003 Australasian Conference on Robotics and Automation (ACRA). Auckland, 2003.
- [Douglas73] Douglas, D.; Peucker, T.: Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. The Canadian Cartographer 10(2). 1973.

- [Heiligensetzer05] Heiligensetzer, P.: Safe Operation – Safe Handling. 4. OTS-Workshop. FpF - Verein zur Förderung produktionstechnischer Forschung, Stuttgart, 2005.
- [IFR04] World Robotics 2004. UNCE, IFR. United Nations, Geneva, 2004.
- [Leeser94] Leeser, K., Donoghue, J., Townsend, W.: Computer Assisted Teach and Play. In: Proceedings of the Robotics International/SME/Fifth World Conference on Robotics Research. Cambridge, MA, 1994.
- [OSHA06] http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_4.html. Homepage of the Occupational Health and Safety Administration, U.S. Department of Labor. April 2006.
- [Teh89] Teh, C. H.; Chin, R. T.; On the detection of dominant points on digital curves. In: IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 11. ,1989.
- [Zahn06] <http://www.robolab.de>. Homepage of mz robolab GmbH, March 2006.

Curriculum Vitae of the Authors

Rolf Dieter Schraft (Prof. Dr.-Ing. Dr. h.c. mult.) is head of the Fraunhofer-Institute for Manufacturing Engineering and Automation (IPA), Stuttgart, Germany. Prof. Schraft studied Mechanical Engineering at the University of Stuttgart and graduated in 1969. In 1976 he got his Dr. degree. He started the research group for Material Handling and Assembly at the IPA which did numerous projects and developments for national and international research agencies and mainly for industry. Right now he is very much involved in promoting and developing service robots.

Christian Meyer is researcher in the department robot systems, Fraunhofer-Institute for Manufacturing Engineering and Automation (IPA), Stuttgart, Germany. Christian Meyer studied Applied System Science at the University of Osnabrück and graduated in 2002.