Integrated approach of different simulation strategies to achieve an efficient reconfiguration of assembly systems

S. Quinders
Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Germany

Abstract

An efficient reconfiguration of assembly systems is one of the mayor challenges of todays requirements of global megatrends. Therefore the framework requirements of production systems must satisfy an increasing product variety, alternating market condition, high wage structures and a high demand on quality.

Cooperating robots are a key technology for future production systems. By enhancing the path accuracy with indoor Global Positioning System (iGPS) fast, simplified and strong settings of cooperating robots can be achieved.

WZL masters this unique concept to improve the manufacturing quality of numerous dynamic industrial applications, including handling, assembly, burnishing, deburring, welding and pleating. The additional measuring system allows a fast reconfiguration of the system as well a high path accuracy and process security, because of the additional sensor information.

But the need of such a dedicated measuring system introduce additional complexity into the overall system. Therefore the system consist of the cooperating robots, the measuring system and the application.

Today's simulation- tools are not able to reflect the special characteristics of such a system. For this purpose the integrated approach of different simulation strategies is needed to perform an efficient reconfiguration of the assembly systems. This paper introduce 3 necessary simulation strategies to do so:

1. Simulation of cooperating robots
2. Simulation of sensor visibility (quantity of measurement signals)
3. Simulation of the measurement uncertainty (quality of the measurement signal)

The simulation of cooperating robots includes the offline programming and path planning. Also all process dependent components like grippers, measurement system, application etc. are represented.
The dedicated measurement system (iGPS) indispensable needs a guaranteed and strong visibility view (line of sight) between the iGPS transmitters and the corresponding receivers which are positioned at the robots TCP. That guarantees the quantity of measurement signals which are needed.
Additional the simulation of the system uncertainty is necessary to get information about the signal quality. This is of major importance for deciding on the assembly capability and the position accuracy of the cooperating robots in the assembly system.
The result is a prediction of the iGPS measurements signal quantity and quality during the movement of cooperating robots. The number of iPGS-signals and the uncertainty, means the measurement quality, can be controlled and monitored. The simulation includes all three strategies, as described above, and enables a fast reconfiguration of the modified robot-assembly-cell and processes.

1 Introduction

In today's manufacturing systems, cooperating robots are a key technology. The robots are either directly or through a component part in contact to each other. The advantage is the quick adaptability to changing market conditions in fixture-less assemblies.
The setup of cooperating robots, however, is complex, error-prone and takes too much time, due to the lack of path accuracy. Therefore, a fast, robust and simple setup of cooperating robots with simultaneous securing of the required path accuracy is needed.
This is already guaranteed in the planning phase by the realized programming and simulation of the robot cells in an indoor GPS measuring environment. Therefore, the needed direct visual contact is also simulated and the satellite-receiver-visibility is monitored by assistance of collision detection. The simulation software, EASY-Rob [4], is used and it supports the developed application software interface (API) for the evaluation of the iGPS signal-stability.
The main challenge of the API is to monitor the loss of direct visual contact between the satellites (iGPS beam transmitter) and the corresponding receivers which are positioned close to the robots TCP during the operating process of cooperating robots. [3] The direct visual contact means to monitor the signal stability.
The next step is to monitor the signal quality as well. This means to integrate a model of the systems uncertainty to evaluate the best configuration in terms of, robot path planning, a strong signal stability and an estimation of the measurement uncertainty.

2 Scope of analyzed assembly processes

As previously mentioned, the use of cooperating robots enables novel assembly processes. Exemplary processes are the handling of large components and the jig-less assembly. The handling of heavy, awkwardly shaped and refractory components, in particular, such as glass panels needs the performance of cooperating robots.

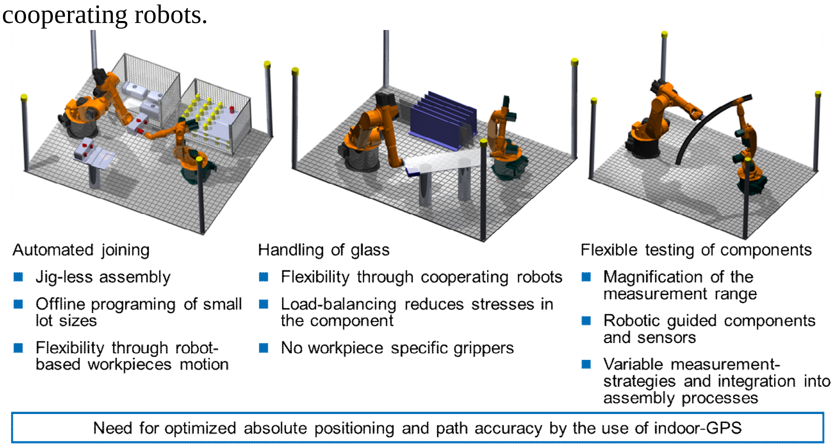

Fig. 1: Exemplary assembly processes for cooperating robots

Figure 1 shows exemplary configurations of cooperating robots. This robot cell is equipped with an iGPS system which is implied by the four columns carrying iGPS satellites which transmit the sensor signal into the measuring area of interest.

In common application, robot's end positions or the path of one robot (during a welding or painting process) is relevant. But in this cooperating operation, special product and process requirements determine additional performance requirements of the system. To handle an awkwardly shaped and refractory glass panel, position and orientation of the robots' grippers must be positioned oppositely during the complete movement. Especially during load changes between the robots the external measurement is needed, because the robots' components distortion by the payload cannot be recognized by the internal measurement system.

The advantage is that the iGPS receivers are directly positioned at the robots TCP. Thus, the measurement of the robot pose is not distorted by the deformation of individual components of the robot.

However, using the performance of an external measuring system must be guaranteed by strong signal stability. This yields especially for the iGPS measuring system because every receiver must have direct visual contact to several satellites which transmit the measuring signal.

Therefore, it is not easy to guarantee a stable signal for all robot poses. Additionally, the process dependent components like the glass panel and parts of the robot cell influence the direct visual contact enormously. Furthermore, the demand for a reconfigurable system with constantly changing setups drives the need for a prediction of the signal stability during the planning phase. Otherwise, the iGPS-signal-stability cannot be checked in advance and this will lead to expensive and time consuming tests during the commissioning of the robot cell.

2.1 Using iGPS for this challenge

The indoor-Global Positioning System (iGPS) is a relatively new measurement technology for use in large-scale metrology and tracking applications [6]. The system is able to measure both static and dynamic performances of the target objects with six degrees of freedom (DoF).
The iGPS system operates on the same general principle as traditional GPS and determines the position of sensors within a measurement volume encompassed by a network of transmitters (figure 2).
The transmitters send one-way signals to the sensors. Similar to a spherical coordinate system, the ray between a sensor and a transmitter can be defined uniquely by the combination of azimuth and elevation angles (figure 2). Under the assumption of known relative position and orientation of the transmitters, the intersecting rays from multiple transmitters at a sensor enable the triangulation for position calculation (figure 2).
Two or more sensors are internally connected in a fixed configuration, which forms a receiver and allows the determination of orientation.

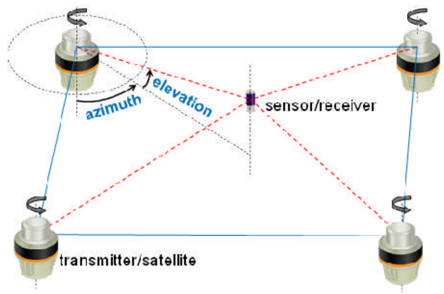

Fig. 2: The iGPS network and sensor triangulation

For the determination of line-of-sight between transmitter and sensor, azimuth and elevation angles are measured.

Please find a detailed description of the iGPS in literature. [7], [5], [6], [1], [2], [3]

The iGPS is suitable for the control of cooperating robots, because it allows the usability of many measuring points, a large measurement volume and the system is scalable.

However, the advantages of the measuring system can only be used, if a good signal quality is already predicted during the CAD-planning-phase for the setup of cooperating robots.

2.2 Necessity of three simulation strategies

The wide scopa of the analysed assembly processes guides to the necessity of three simulations strategies which musst be operated in parallel. Otherwise the overall simulation do not provide enough information of such complex system with an integrated external measurement device.

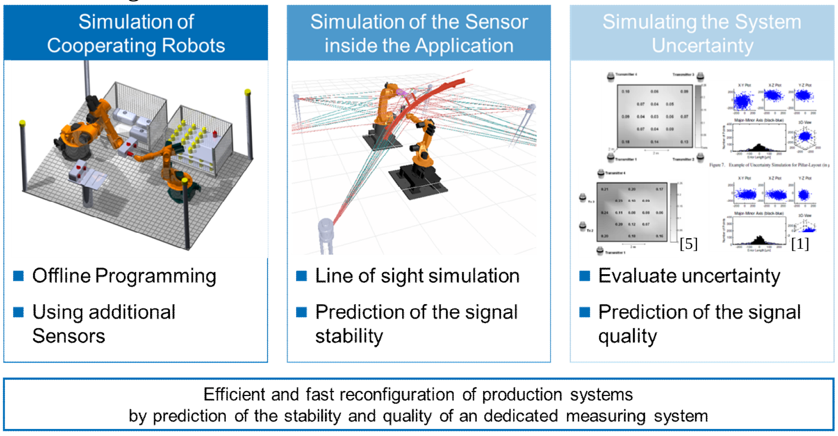

Figure 3: Introduction of three necessary simulation strategies

The needed strategies presented in figure 3. All strategies are integrated into a single simulation environment to evaluate the best configuration in terms of, robot path planning, strong signal stability and estimation of the measurement uncertainty.The three simulation strategies which have to be used in parallel are explained and presented in the following chapters.

3 Simulation cooperating robots

The simulation of cooperating robots is a state of the art instrument and implemented in nearly all offline programming and simulating tools. Therefore it is not a special topic in this paper.

4 Simulation of signal stability

EASY-Rob is a simulation tool which is used to model the robot cell and the iGPS measuring system. The advantage of EASY-Rob is the applicability of collision detection and an API (application programming interface) to program the evaluation for the collision detection.

At first, the entire cell and the robots themselves must be modeled. This is a routine process for this kind of simulation. In addition, the process dependent components, like grippers, objects and obstacles are added.
The modeling of the iGPS sensor system and the prediction of the signal stability is shown in this chapter.

4.1 Modeling of the iGPS measuring system

The iGPS system is split up into three main devices. The satellites sending the signals are positioned around the application. They should cover a wide measuring area with a high probability of direct visual contact.
To get optimal information about the pose of the robots TCP, four receivers are directly positioned to the robot flange as shown in figure 4. Figure 4 shows the model of the real robot cell and the iGPS measuring system.

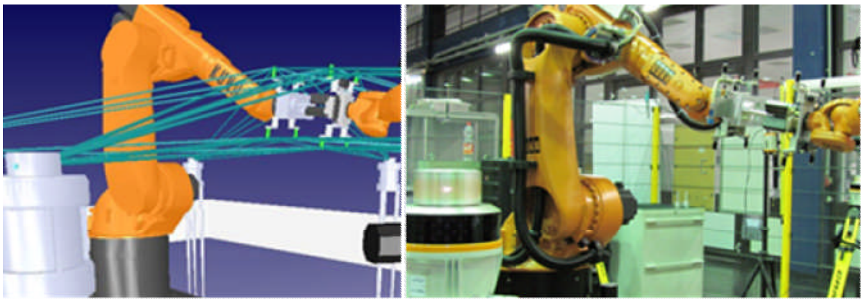

Fig. 4: Modeling of the iGPS measuring system

The four receivers are fixed on a frame, which is carrying the robotic gripper. The receivers are directly positioned to the TCP which will be controlled and monitored by the system. The iGPS beams are described as robots with 6 degrees of freedom. They describe the invisible beams as “real” objects which can interact and collide with other objects. They connect each satellite with each receiver and simulate direct visible contact.
To do so, the beams are introduced as a robot into the simulation tool. The iGPS beams will follow the movements and is able to generate collisions. These collisions are registered and can be evaluated to determine the signal stability of the iGPS measuring system. [3]
The flexibility of the 3D simulation allows the performance of:

1. A fast reconfiguration of the robot cell for different applications.
2. The complete cell can be rearranged to find sufficient signal stability for the iGPS measuring system.

4.2 Approach for the prediction of the iGPS-signal-stability

The main idea of this approach is to integrate the iGPS beams in the simulation. Therefore, the beams are modeled as a robot, which connects the satellites and receivers of the iGPS system.

As soon as the robot cell, iGPS system (beams, satellites and receivers) and the process dependent components are modeled, the positioning of the application setup and especially the positioning of the iGPS system can be performed. The signal stability depends of the arrangement of the overall system. The positioning of each component determines the line of sight between satellites and receivers during the robot's movements, depending on the application.

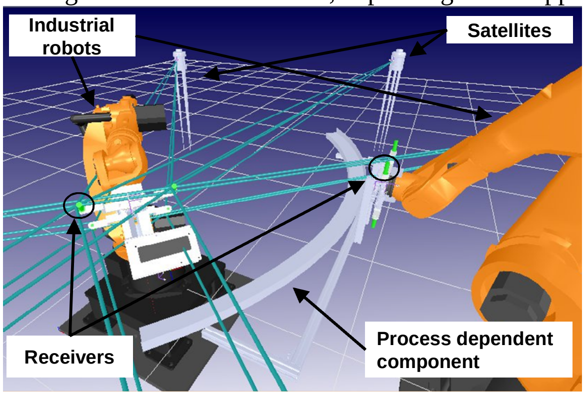

Fig. 5: Robot cell equipped with iGPS system

Figure 5 shows a fully equipped robot cell with iGPS measuring system and a process dependent tooling. For this setup, the offline programming and path planning for the process flow can be performed.
Now it is possible to use the function "collision detection" to check all collisions in this system. Nevertheless, for the evaluation of the signal stability, all collisions must be rated and evaluated due to the signal stability for the complete robot movement during the application.
An algorithm distinguishes between collisions which influence the signal stability and rates the actual measuring accuracy of the iGPS system in every robot pose of this system.

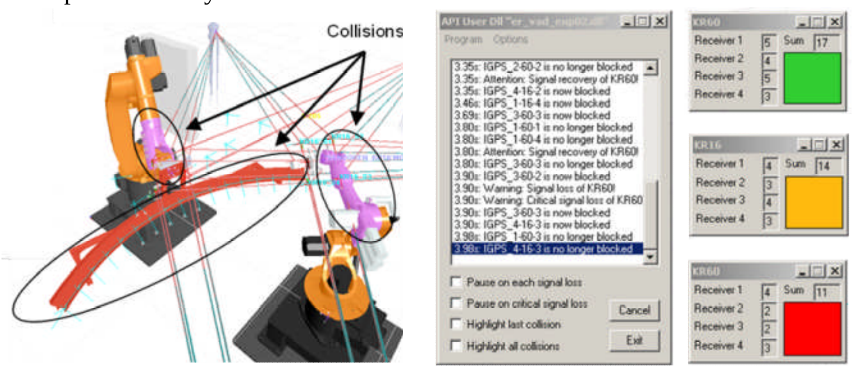

Fig. 6: Disturbed line of sight and assignment of the signal stability

Figure 6 shows how collisions are indicated in the simulation and the disturbance of the line of sight. The assignment of the signal stability is indicated by traffic light symbols.
If the signal stability is insufficient, the arrangement of robot cell, iGPS system or process components must be changed or the path of the robot movements must be adapted.

4.3 Evaluation of the signal stability

To evaluate the improvements of the signal stability figure 7 shows two different configurations of the iGPS sender setup. In both configurations the same process is performed by the robots. The graph shows the number of valid measuring signals (means visible sensor signals) of the robot (KR 16) during the simulation time. The green columns in the chart shows, that there are in average a higher number of valid signals for configuration 1 compared to configuration 2.

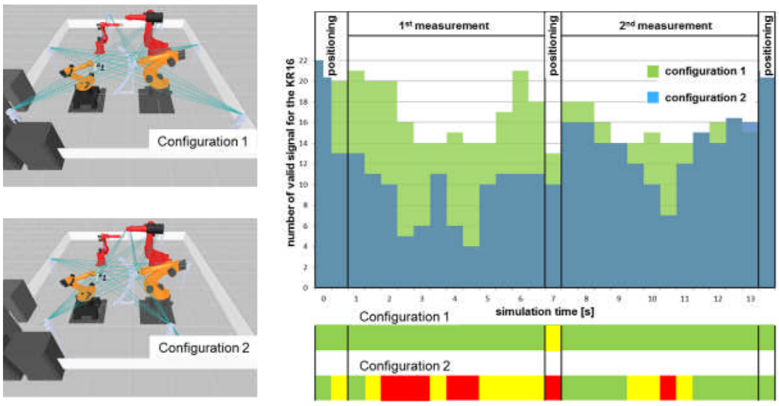

Fig. 7: Modeling of the iGPS measuring system

The assessment of the number of valid signals shows, that for configuration 1 there is a sufficient (green) signal quality during the complete simulation. For configuration 2, there are several spots with minimum (yellow) and insufficient (red) signal quality. It is approved that already slight movements in the sender-setup produce a big impact into the signal stability of the overall iGPS.

5 Integration of an approach for simulating the iGPS uncertainty into the offline programming

To integrate an approach for estimating the iGPS uncertainty into the simulation an elementary approach is used. The iGPS based on a multi angulation measurement. Therefore the determined area between the cones somehow indicates the measurement uncertainty geometrically (figure 8, right). Due to the simple geometric description this model is used to determine the iGPS uncertainty in this paper.

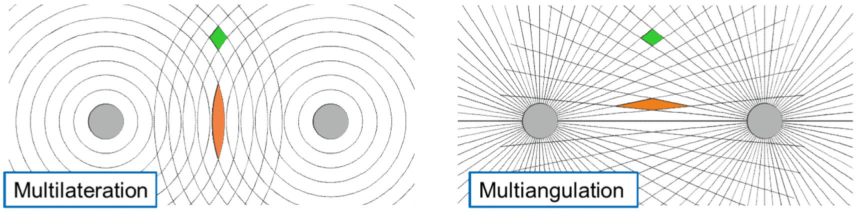

Fig. 8: Multi lateration vs. multi angulation

Nevertheless the estimation of the uncertainty of such a dedicated measurement for three dimensional measurements is a much more complex issue. In fact the iGPS uncertainty depends on the angle measurement, number location and orientation of the transmitters and the relative position between the transmitters and sensors.

But stick to the simple geometric considerations, which is used in this paper, additional assumptions are needed. The first assumption, due to different uncertainty for the azimuth and elevation- angle, is to reduce the 3D problem in the X-Y plane. The second assumption is that all cones of the senders are equal and linear.

At first the vector between the transmitter and sensor is calculated in Cartesian coordinates. (figure 9, left side)

$$\vec{f} = \begin{pmatrix} x_{Transmitter} \\ y_{Transmitter} \end{pmatrix} + \gamma \begin{pmatrix} x_{Sensor} - x_{Transmitter} \\ y_{Sensor} - y_{Transmitter} \end{pmatrix} = \vec{P} + \gamma * \vec{O}$$

In the next step the boundary vectors of the cone are determined by a positive and negative angle.

$$\vec{f_+} = \vec{P} + \gamma \begin{pmatrix} \dfrac{O_y}{\tan\left(\tan^{-1}\left(\dfrac{O_y}{O_x}\right) + \alpha\right)} \\ O_y \end{pmatrix}$$

$$\vec{f_-} = \vec{P} + \gamma \begin{pmatrix} \dfrac{O_y}{\tan\left(\tan^{-1}\left(\dfrac{O_y}{O_x}\right) - \alpha\right)} \\ O_y \end{pmatrix}$$

These cones of two vectors belonging to two transmitters are used to calculate the four interception points $\vec{P_i}$.

$$\vec{P}_i = \begin{pmatrix} P_{ix} + \dfrac{P_{(i+1)x} - P_{ix} + \dfrac{O_{(i+1)x}}{O_{(i+1)y}} * \left(P_{iy} - P_{(i+1)y}\right)}{O_{ix} - \dfrac{O_{(i+1)x}}{O_{(i+1)y}} * O_{iy}} * O_{ix} \\ P_{iy} + \dfrac{P_{(i+1)x} - P_{ix} + \dfrac{O_{(i+1)x}}{O_{(i+1)y}} * \left(P_{iy} - P_{(i+1)y}\right)}{O_{ix} - \dfrac{O_{(i+1)x}}{O_{(i+1)y}} * O_{iy}} * O_{iy} \end{pmatrix}, 1 \leq i \leq 4$$

$$P := (P_1, P_2, P_3, P_4), P_i \in \mathbb{R}^2, 1 \leq i \leq 4$$

Subsequent the polygon vertices for the following transmitters are added and reduce the area of the polygon. The maximum number of corner points is twice number of transmitters.
The determination of the size of the inner area of the polygon estimate the uncertainty of the transmitter setup in a very heuristic approach.

$$A = \frac{1}{2}\left|\sum_{i=1}^{n}\left(P_{iy} + P_{(i+1)y}\right) * \left(P_{ix} - P_{(i+1)x}\right)\right| = \frac{1}{2}\left|\sum_{i=1}^{n} P_{ix} * P_{(i+1)y} - P_{(i+1)x} * P_{iy}\right|$$

The maximum diameter of the polygon is in X and Y direction defined by

$$\vec{P}_{x,max} = \vec{P}_i(\max(P_{ix})), \vec{P}_{x,min} = \vec{P}_i(\min(P_{ix}))$$
$$\vec{P}_{y,max} = \vec{P}_i(\max(P_{iy})), \vec{P}_{y,min} = \vec{P}_i(\min(P_{iy}))$$

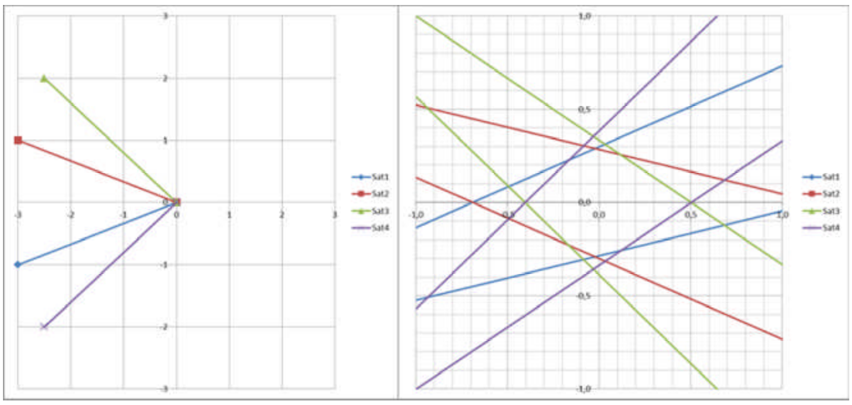

Fig. 9: Modeling of the iGPS measuring system

Figure 9 shows the 2 dimensional sketch of the polygon inner area. In the left, four transmitters (colored vectors) are shown, which are pointing to the receiver in the center of the graph. In the right, a close shot of the center indicates the area of the polygon. The area and size of this polygon depends on the arrangement of the transmitters.

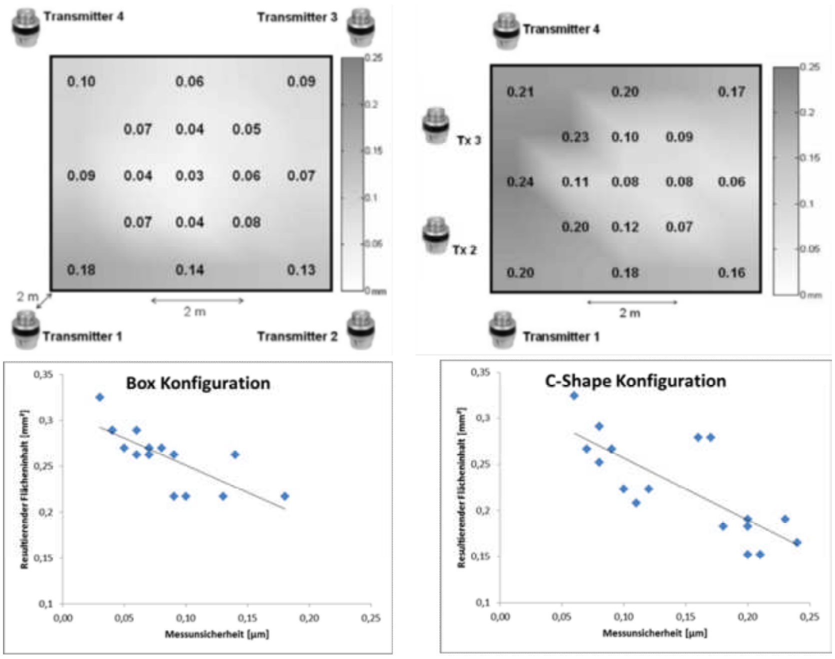

Fig. 10: Modeling of the iGPS measuring system

Figure 10 shows the relationship between the size of the polygon and the experimentally determined uncertainty for the Box and C-Shape transmitter configuration. [5]

Admittedly the estimation of the uncertainty of the iGPS by the determination of the polygon size is not very promising. But if we neglect some outlier regards to measuring points, which are close to the transmitters, we could estimate an (linear) correlation.

This heuristic model is integrated into the overall simulation of the cooperating robots and enable further decision guidance in the design of the assembly cell.

6 Summary and Outlook

All three simulations of cooperating robots, sensor visibility (quantity of measurement signals) and measurement uncertainty (quality of the measurement signal) are integrated in one system. Therefore it is possible to monitor the overall system performance of the cooperating robots, the transmitter setup and the quality of the iGPS measurement.

In future the uncertainty model of the iGPS will be exchanged by an much more complex an accurate model of the NPL (National Physical Laboratory). “Uncertainty calculations for multistation coordinate measuring systems” and “A reference model for multi-station co-ordinate measuring systems” by Alistair Forbes, Ben Hughes and Wenjuan Sun (February 2011) describes the new model.
The API will provide all necessary data for the NPL´s calculation and just receive the needed information. This will improve the overall simulation again significantly.

References

[1] Schmitt R., Nisch S., Schönberg A, Demeester F. and Renders S.: Performance Evaluation of iGPS for Industrial Applications; International Conference on Indoor Positioning and Indoor Navigation (IPIN), 15-17 September 2010, Zürich, Switzerland

[2] Schmitt R, Schönberg A, Damm B (2010) Indoor-GPS based robots as a key technology for versatile production. In: Proceedings of the joint conference of the 41st international symposium on robotics (ISR 2010) and the 6th German conference on robotics (ROBOTIK 2010). Munich, Germany, pp 199–205, 7–9 June 2010

[3] Schmitt R., Müller R., Jatzkowski P., Duffe A., Quinders S.: IMPROVING ACCURACY OF COOPERATING ROBOTS BY PREDICTION OF THE IGPS-SIGNAL-STABILITY, MM Science Journal, Special Issue | MATAR 2012, 9th International Conference on Machine Tools, Automation, Technology and Robotics, September 12-14, 2012, Prague, Czech Republic

[4] Anton, Stefan, EASY-Rob web page, www.easy-rob.com 30.05.2012

[5] Depenthal, C., Schwendemann, J.; Geodetic Institute, University of Karlsruhe: IGPS – A NEW SYSTEM FOR STATIC AND KINEMATIC MEASUREMENTS, 2009

[6] Norman, A., Schoenberg, A., Gorlach, I., Schmitt, R., 2010, Cooperation of Industrial Robots with Indoor-GPS, Proceedings of the International Conference on Competitive Manufacturing, 215-224.

[7] Mueller, T., Schwendemann, J., 2009, iGPS – ein vielseitiges Messsystem hoher Genauigkeit, Allgemeine Vermessungs-Nachrichten, 2009(04): 146-157.