VI Special Features:

VI.1 IERA Award 2010:

The IEEE Robotics and Automation Society (IEEE RAS) and the International Federation of Robotics (IFR) jointly sponsor the Invention & Entrepreneurship Award (IERA Award). The purpose of this award is to highlight and honour the achievements of the inventors with value creating ideas and entrepreneurs who propel those ideas into world-class products. The IERA Award 2010 was presented to Univ.-Prof. Dr.-Ing. Alexander Verl, Fraunhofer IPA for his project „Inline Measurement Robots - Robots Get the Precision for Car Body Inspection".

Inline Measurement Robots
Robots Get the Precision for Car Body Inspection

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Summary

Inspection has emerged as a new application for industrial robots. Until this innovation, car bodies were inspected on-line with arrays of laser sensors fixed in position over the production line. Using a robot to manipulate the same type of sensor gives more flexibility in the areas of the car to be measured and also reduces the number of sensors needed. Since standard industrial robots are only accurate to approximately 0.5mm they have long been considered as unusable for these measuring tasks. The flexible in-line measurement system (FIMS) therefore works with model-based error correction that determines kinematic errors such as arm length, joint offsets, backlash, compliance, twist angles and the like within the manufacturing process. This remarkable feature of FIMS is primarily realized by a thermally stable reference device: a carbon fiber sphere. Most major car companies have introduced applications of FIMS to date.

1. Motivation and Description of the Innovation

A rapidly increasing demand for quality assurance has forced most manufacturers to look to in-line inspection to solve problems of quality assurance. As in many cases, it is the automotive industry that is taking the lead with systems able to check on every part built.

Hard gauging has turned out as too slow and inflexible, and even the programmable coordinate-measuring machine which has the flexibility cannot fulfill specific requirements, as well as being less robust for production line applications. The answer until now has been to install banks of laser triangulation sensors mounted in tunnels spanning the production line.

Figure 1: Traditional in-line measurement system

Figure 2: Flexible in-line measurement system

But now there is an alternative, using robots to manipulate the same type of sensor, still allowing inspection within the line cycle time but with the flexibility to handle different variants, design changes and even the introduction of new models. Amatec Robotics, a former subsidiary and now part of KUKA Roboter GmbH has developed the flexible in-line measurement system (FIMS). It employs the same type of 3D vision sensor that is used in fixed sensor tunnel systems, but attached to the end of the robot arm so that it may be manipulated within a large working envelope. One robot-mounted sensor is capable of doing the work of a multitude of fixed sensors.

The reason Amatec is able to use a standard unmodified robot for accurate measurement is due to the error detection and calibration software called X-Rob uniquely developed by Amatec. It is based on model-based error correction that determines kinematic errors such as arm length, joint offsets, backlash, compliance, twist angles and the like. A total of 42 different parameters can be entered into the error detection calculation.

The physical errors are determined using a carbon fiber calibrating sphere that is thermally stable and to which a series of retro-markers are attached. During a calibration cycle the robot directs the sensor at these markers in set poses, each of which has a different combination of errors, and records their position. By taking measurements on the sphere in different poses and positions, a complete kinematic model of the robot is built up so that error compensation is accurate over the whole of the robot's working envelope, and incorporates inaccuracies due to both the robot and the measurement system. This is unlike other systems, that only calculate offset errors at certain points and positions, and does not require the use of a more accurate and expensive robot.

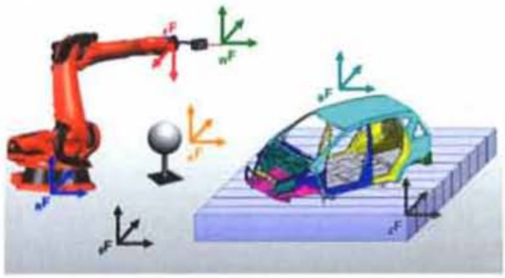

Figure 3: Coordinate frames in FIMS

2. Stages of the Product Genesis

Alexander Verl founded Amatec 1997 together with his former diploma student Stefan Pieters as an integrator specialized in combining off-the-shelf sensors with KUKA-robots to meet the needs of different customers. Even until its integration into the KUKA Roboter GmbH Amatec became market leader for measuring robots.

A major aspect of the product innovation was the handling of the temperature drift of the robots. The benefit of temperature compensation is shown in typical test trials, during which the temperature of the robot rose from 20°C to 33°C (figure 4). Without compensation the robot TCP moved by 0.4mm, but with compensation it remained stable within 50microns. The measurement uncertainty is rated at 60±30micron even after a 20°C temperature change, compared to 180±140micron without any compensation.

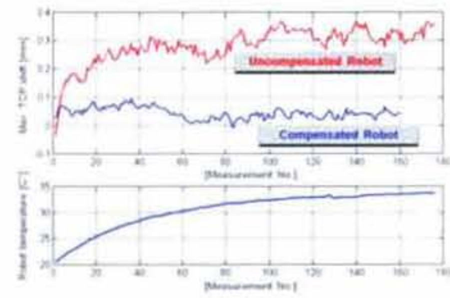

Figure 4: Temperature drift compensation

In further steps of development all elements have been integrated into one system: the robot, the sensor, the sensor HMI and database, and the reporting software. Finally clear and well-documented interfaces were implemented, and the software was modularized. The customer is now able to use the robot teach pendant to program both the robot and the sensor.

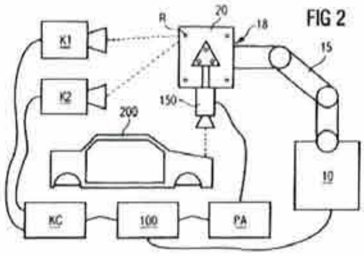

Figure 5: Patent from 1999

Figure 6: Multi-robot cell

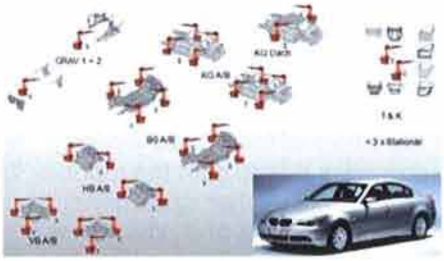

Figure 7: Project example

3. Novelty of the Product

The main advantage of the fixed sensor solution is speed, as the sensors work in parallel so that, for instance, 100 measurements can be taken in 5-6 seconds. Its problem is lack of flexibility, as each inspection point must have its own sensor. Therefore, different body variants need additional sensors, which are redundant for some of the time, adding to cost. Second, model modifications or introduction of new models require adjustment to the layout and/or the addition of more sensors, adding to the changeover time and also increasing costs. Coordinate-measuring machines have the flexibility but are slow and expensive (costing anything from $250,000 to $1million) and in the main do not have the robustness for on-line applications, although one or two have been developed for this purpose.

Figure 8: Measuring gauge with fixed sensors

Figure 9: Calibration cycle

The evidence coming from Amatec contradicts the notion that the robot solution is only economic for variants or medium volume application. At a cycle time of 40 seconds one robot measures up to 15 points. A further advantage of the Amatec system is that the robot can be switched to the area of interest for inspection according to any problems being encountered or the particular customization on the model. That would not be possible with a fixed sensor system.

4. Market Analysis, Economic Viability and Pathway of Commercialization

The automotive industry is a major market with some companies deciding to use robots in the bodyshop to check 100 per cent production for each major body sub-assembly. Many companies are first trialing in-line robot inspection before making a decision.

The first Amatec system went into a BMW plant at Dingolfing in Germany where the 5-series is built. Installed in the summer of 1999, it was used to measure 30-40 points on the rear body of the limousine and station wagon versions within the two minute line cycle time. As BMW was convinced of the new technology they introduced it also for inspecting the complete body of the 7-series. Later applications for the 1-series and the 3-series followed.

The Peugeot 206 being built at PSA's Poissy plant is using the Amatec system (with Perceptron sensors) for complete body inspection. Such has been the enthusiasm by PSA for the Amatec system that it is installed in several of its factories in France, including Poissy, Sochaux, Mulhouse and Sevel Nord.

Sales of the Amatec system have been growing since its introduction 1997. Its customers include Audi, Daimler, BMW and VW, as well as Jinbei China, Renault, Land Rover or Opel/Vauxhall (table 1). Amatec also has made a penetration into the USA market. And it still expects the market to grow significantly in the future.

Major competitors are Stäubli with its FRAMS and Dynalog with its FMS. Stäubli believes that the average welding or palletising robot is not suitable for precise measuring. It claims its RX series precision robots are designed for such applications, but they are also more expensive. Also, many plants prefer to have one robot type throughout the plant for ease of training, spares and maintenance. Dynalog achieves accuracy by measuring reference points placed inside the FMS cell combined with temperature compensation.

106 x BMW D	
121 x Daimler D + USA + ZA	Mercedes-Benz
39 x PSA France + Spain	PEUGEOT CITROËN MOTEURS
38 x GM USA + D + UK	GMC
18 x FORD D + Spain	Ford
16 x VW D + Spain	
10 x Audi D	Audi
9 x LANDROVER UK	LAND-ROVER
8 x Nissan USA	NISSAN
4 x Porsche D	PORSCHE
3 x Renault F	RENAULT
33 x Others in D + USA + India	HONDA

5. Sustained Competitive Advantage

Flexibility

In effect, the Amatec system is virtually immune from the influence of thermal drift on measurement accuracy. Even fitting an extension piece to the arm, which is an option available with most KUKA robots, will not affect the accuracy of the Amatec system. Amatec applies any KUKA robot to its measurement system, from the 1.57m reach KR15 to the 3.5m KR30L15 as well as the 3m KR150L90 welding robot, even though their repeatability according to the specification is no better than ±0.1 and ±0.2mm respectively.

Figure 10: Measurement of subassembly parts

Temperature Compensation

The Amatec calibration cycle can take place during the idle time of the process cycle, for example while a car body is being indexed between stations, and the calibration routine does not increase cycle time. If time is a problem, the calibration cycle can be split into several steps without affecting the accuracy. Due to the redundant calibration technology embedded in the system, should some of the markers become obscured due to dust and dirt, for example, the system continues to operate, only a warning message is generated.

Compatibility

Unlike any of its competitors Amatec has references with Perceptron, LMI and HGV sensors. The KUKA robot controller is an open architecture system, and this has allowed Amatec to integrate some sensor controllers into the robot controller. With the integrated solution the sensor cards simply drop into the motherboard slots in the KUKA controller. This provides benefits in speed of operation and ease of programming. With Amatec's FIMS the average measuring time per point, including positioning, can be less than three seconds.

Teaching

The integrated solution developed by Amatec also allows the teaching of the sensor to be performed on the robot teach pendant. The sensor image is displayed on the pendant's display so that the sensor can be easily and quickly adjusted in concert with the robot, giving optimum set-ups quicker and easier than with systems of competitors.

Figure 11: Sensor software integrated in a KUKA controller

6. Current and Future Impact

In 2009 KUKA has been issued a new patent for the second generation: Scanning measurement robots, which will not only be able to inspect holes and edges but also complete shapes. Until now almost all applications of Amatec's FIMS are for automotive body inspection, but it has the potential for other measurement tasks outside this industry. Initially it is like in other robot applications a problem of satisfying the demands of the automotive industry, after which other sectors will follow. Besides that there are many other scenarios, in which the underlying methodology can be used. Areas of research that are investigated at the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) and the Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW) in Stuttgart are for instance the handling of an increasing number of parameters in more complex kinematic structures and the precision of tendon based kinematics. The latter will help to improve the assembly of innovative renewable energy technologies out in the field.

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