Minimizing technical and financial risk when integrating and applying optical sensors for in-process measurement

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Abstract
Many advantages of in-process measurement with non-contact sensors are well known in industrial manufacturing process. Nevertheless a very small percentage of potential applications with non-contact measurement are already established. This is also true for co-ordinate measuring machines (CMM’s). An initiative of leading manufacturers of optical sensors and CMM’s has the goal of releasing a common interface standard. This standard is called OSIS (Optical Sensor Interface Standard). In the future this can help CMM, robot and machine tool manufacturers to reduce technical and commercial risks of the integration of optical sensors tremendously.

Worldwide co-operation of companies has also effects to standardization. Not only national standards and guidelines must be established but also international standards (e.g. ISO-Standards) are necessary to ensure the successful co-operation of suppliers from different parts of the world. To shorten development time of the standard, OSIS will be first established as an industrial standard.

Keywords
OSIS, optical sensor, CMM, in-process measurement, minimizing risk, integration

1 Introduction
Short cycle time for feedback-control of a manufacturing process is one of the most important advantages of in-process measurement. Less effort due to the same measurement reference and the same work piece setup for the manufacturing and the measurement process is another. One major requirement of in-process measurement is that it must meet the cycle time of the manufacturing process. Therefore many in-process measurement tasks can only be performed with non-contact measuring systems. In general these systems have much higher measurement frequencies compared to touch probing systems. Another major advantage of non-contact measurement is the higher flexibility of the measurement equipment. A wide range of similar parts can be checked without changing, readjusting and recalibrating the equipment.

Nevertheless a very small percentage of potential applications for in-process control with non-contact measurement are established so far. Especially in robot and machine tool industry this is true. Very little tooling machines are available with integrated non-contact measurement capabilities. One major reason is that many varied sensor principles available on the market and missing guidelines and standards have to date hindered the wide integration of optical sensors for in-process measurement.

This is also true for co-ordinate measuring machines (CMM’s). An initiative of leading manufacturers of optical sensors and co-ordinate measuring machines has the goal of releasing the first official version of a common interface standard. This standard is called OSIS (Optical Sensor Interface Standard). This can help CMM manufacturers to reduce
technical and commercial risks for the integration of optical sensors tremendously. It is estimated that saved costs in an order of magnitude of several hundreds of thousands Euros are realistic for every integration of a new sensor in a CMM with this standard. Also manufacturers of robots and machine tools can apply this standard to integrate optical sensors much more efficient than in the past.

Figure 1: Fields for the integration of optical sensors

2 Standardization in the era of global economy

Standards have been one of the most important fundamentals of modern industrialisation and will gain importance in the future. This is especially true because worldwide co-operation of companies continues to grow in every field of economy. In the past national standards and guidelines have been a sufficient possibility to document state-of-the-art and to insure efficient co-operation of companies. In the era of growing global economy only international standards can take this role. Evidence for this enormous alteration is the fact that 85% of the activities of DIN are concentrated on European and worldwide standardisation. A survey [DIN, 2000] estimates the yearly economic value of standardisation of Germany is about 15 billions of Euros. They say that standardisation is not only essential to document state-of-the-art technology but plays an important role for a fast market penetration of new technologies. The period from the first ideas of a national/company standard until its publication as an ISO standard lasts about 5 – 10 years.

2.1 New grounds for standardization

The goal of the industrial initiative OSIS is to shorten this period and to help new technologies to find their breakthrough [Boucky, Ercole, Keferstein, Wallace, Züst, 2003]. OSIS was founded with the objective to actively support the integration of optical sensors into CMM’s. The task of standardising the integration is very complex. Therefore the job is split into three different tasks.

- Mechanical / electrical interface
- Data integration (Software interface)
- Classifications, specifications and performance verifications

Its activities are supported by the International Association of Coordinate Measurement Machine Manufacturers (ia.cmm). After around three years of intensive collaboration of
about 25 companies from Asia, America and Europe involved in this field the first version of the standard will be available in the first half of 2004.

3 Current difficulties of optical sensor integration

A wide range of optical sensors is available on the market for quite a while now. Many companies see the advantages of available technologies and are strongly demanding their application in manufacturing processes. Experience in the past showed that this can lead to integration projects with high risks and unpredictable costs. Currently the different steps of optical sensor integration are:

- Sensor evaluation
- Realization of the integration
- Tests and acceptance

3.1 Sensor evaluation

In general sensor manufacturers are small start-up or spin-off companies with bright ideas and powerful sensors. Small market shares lead to small quantities of sensors and open system architecture. This is necessary that sensors can be adopted in a very wide range of applications to ensure a minimum quantity. Most of the time sensor evaluation is done based on the sensor specification and testing measurement at the sensor manufacturer site. The range of evaluated sensors is mainly random based on individual market research on exhibitions and on the World Wide Web. Systematic market enquiries help to improve this situation [Keferstein, Ritter, Züst, 2003]. Common criteria for the evaluation are:

- Measurement range
- Measurement uncertainty
- Measurement speed
- Behaviour on different surface finishes (roughness, colour, material)
- Sensitivity to ambient light
- Range of application
- Interfaces

Misunderstanding of individual sensor specification and unclear interpretations of results of testing measurement are dangerous risks during this stage of an integration project. Independent inquiries can reduce the risk of the sensor evaluation task [Keferstein, Marxer, 1997], [Keferstein, Marxer, 1998].

3.2 Realisation of the integration

Realisations of integrations have a lot of different partners from different companies. It is important to understand that most partners have a complete different background and different expectations for these projects. Figure 2 shows the most common constellation.

Usually a sensor manufacturer contacts a user or the other way around. Together they do all inquiries to evaluate a certain sensor for an application or a range of applications (step 1). After this evaluation the user contacts the machine manufacturer (e.g. CMM manufacturer) and demands integration in already existing or new equipment (step 2). Detailed communication on interfacing between machine, sensor and third party software manufacturer starts (step 3). Usually all these three partners have limited knowledge for the integration task. Therefore an additional partner – the integrator – gets involved in the project.
(step 4). He has to merge all different interfaces to meet the requirements of the user. Usually this is a time consuming process with a lot of compromises and unpredicted costs (step 5).

![Diagram showing partners and relations for optical sensor integration]

**Figure 2: Partners and relations for optical sensor integration**

3.3 Tests and acceptance

Defining requirement specifications for a machine equipped with an optical sensor is very difficult. A common way is to adopt existing standards to the new situations of optical measurement principles [ISO 10360]. Pilot or testing installations at the customer site (user) intend to show if the requirement specifications are met. Usually at this stage of the project extensive testing of the user brings up some lacks or obscurities in the requirement specifications. Unclearness or differences in interpretations delay acceptance of the installation add additional costs to the project and can trouble the relation between the customer and the suppliers.

4 OSIS – a standard for the integration of optical sensors

Optical measurement technology can develop new areas of application for coordinate measurement, robots, machine tools and specialized measurement equipment in general and for 3D applications in particular. At the same time they can substantially reduce manufacturing time of existing processes. Many companies are already aware of these two main advantages. In the past, however, the complexity and high integration cost of optical sensors have prevented widespread use. This is true for both standardized, universally applicable machines and for the wide field of specialized machines (e.g. crank shaft measurement). The wide variety of available sensor principles and the missing guidelines and standards for integration of these systems posed a high technical and financial risk. Assessment of the performance of said principles, or actually existing sensors, is very difficult, needs a lot of dedicated knowledge about the sensor or is only possible at high costs. Results are often not directly comparable to those from conventional measurement techniques. To make things more difficult, terms used in coordinate measuring technology and the optical sensor area are not harmonized. This was true for all involved: machine and sensor manufacturers as well as integrators and end users.
4.1 Classification of optical sensors

Initially the modes of operation and differences between the varying optical sensor principles were defined and consolidated in an optical sensor classification scheme. The classification is based on the nature of their measurement result and on their basic functionality. The understanding of this classification is important, as there can be large differences in the complexity, integration, application and functionality of various sensor classes.

<table>
<thead>
<tr>
<th>Heading Description</th>
<th>Classification Criteria</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trigger</td>
<td>Sensor must move to acquire data</td>
<td></td>
</tr>
<tr>
<td>Stand still</td>
<td>Sensor must not move to acquire data</td>
<td></td>
</tr>
<tr>
<td>Scanning</td>
<td>Sensor can acquire data whether moving or not</td>
<td></td>
</tr>
<tr>
<td>Point Data Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point with 1 degree of freedom</td>
<td>One coordinate measured (r, s or t)</td>
<td></td>
</tr>
<tr>
<td>Point with 2 degrees of freedom</td>
<td>Two coordinates measured (rs, st, rt)</td>
<td></td>
</tr>
<tr>
<td>Point with 3 degrees of freedom</td>
<td>Three coordinates measured (rst)</td>
<td></td>
</tr>
<tr>
<td>Multiple points with 1 degree of freedom</td>
<td>Multiple r, or s, or t</td>
<td></td>
</tr>
<tr>
<td>Multiple points with 2 degrees of freedom</td>
<td>Multiple rs, or st, or rt</td>
<td></td>
</tr>
<tr>
<td>Multiple points with 3 degrees of freedom</td>
<td>Multiple rst (Point cloud data)</td>
<td></td>
</tr>
<tr>
<td>Sensor Data Acquisition Style</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simultaneous acquisition of points</td>
<td>Points acquired at the same time</td>
<td></td>
</tr>
<tr>
<td>Sequential acquisition of points</td>
<td>Points acquired one at a time, fast or slow</td>
<td></td>
</tr>
<tr>
<td>Single Point measurement only</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Feature Output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can provide complex feature extraction</td>
<td>Provides geometric feature information (e.g. Gap &amp; Flush)</td>
<td></td>
</tr>
<tr>
<td>Cannot provide complex feature extraction</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Light source</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal light source</td>
<td>Active light source</td>
<td></td>
</tr>
<tr>
<td>External light source</td>
<td>Ambient light source</td>
<td></td>
</tr>
<tr>
<td>Technology features</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active mechanics</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Does not have active mechanics</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Optical sensor classification scheme (© OSIS)

It is essential to understand the different sensor movement requirements. Non-contact and touch probe trigger type systems are very similar in terms of required movements to acquire data. Both need a movement towards or away from a surface to take a single measurement. Due to the integration time of the detectors stand still type non-contact probing system must not move during data acquisition for a measurement. Any movement during data acquisition would lead to an averaging effect and result in a higher measurement uncertainty. Since scanning type non-contact sensors can move during data acquisition they are the most flexible of the three kinds of sensors.

The number of degrees of freedom of a measurement result is another criteria for classification and is called point data output. Where for example one degree of freedom means that one coordinate of the point data output is measured and the others are either not reported or set to a nominal value.

Sensors also vary in their data acquisition style. There is either one single point or multiple points acquired at a time.

Some sensors include dedicated feature extraction software modules and can therefore output complex feature data.
4.2 Integration Model

As the first step towards an interface standard it was important to define which interfaces should exist between a CMM and an optical sensor. It is also important which of these should be standardized in detail by the initiative. This led to the OSIS integration model (refer to Figure 3). Depending on the varying tasks, not all interfaces are always involved. It was also necessary to differentiate between logical and physical boundaries in the area of data integration.

Interface 3, 4, 6, 7 are within the scope of the standardisation of OSIS. Interface 3 is mainly targeted by data integration task and interface 4, 6 and 7 are by the electrical / mechanical interface. For interface 1 a standard already exits and OSIS recommends using DMIS (Dimensional Measuring Interface Standard) to interface any off-line programming to a CMM. In most existing CMM’s interface 2 is proprietary to the CMM manufacturer. Nevertheless standardization is also in progress at this interface within I++/DME committee (www.iacmm.org, workgroup I++/DME). Future CMM’s shall be able to use application software from other manufacturers than the rest of the CMM. Communication to the firmware of the CMM controller is proprietary and out of scope of any standardization at the moment.

4.3 Electro-mechanical Interface

The electro-mechanical interface between the sensor head and its holder is defined as well as the electrical synchronisation (trigger, interface 4) for data acquisition and relevant cables with connectors and pin-out. Normally the CMM manufacturer supplies the cables and connectors for interface 7 on its machines. It is important to understand that they strongly influence the measurement data transfer from the sensor (probe head) and its controller. This is especially true for long cables (e.g. 50m) where signal transition behaviour is highly influenced by the electrical properties of the cable. The sensor manufacturer is responsible for this data transfer. Therefore both manufacturers strongly relay on each other at this point of integration and standardization is essential for this interface.

One strong advantage of CMM’s is their flexibility for different measurement tasks. This high flexibility is only possible with a variety of different probing system (contact and non-contact) on one machine. To run automatic measurement tasks tool changing is needed. OSIS standardizes the process of digital sensor identification and assignment to its sensor controller. This opens a wide field of possibilities for the future of multi-sensor machines.

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Figure 3: Integration Model for CMM’s (© OSIS)
4.4 Development of a Software Architecture

The main attention of data integration is the software interface. In a first step, for this task a list of content information was defined. Associated definitions for which will be transmitted between the two systems. 109 relevant items were listed. Priorities for standardising were defined following the grouping and structuring of these items. Based on the 43 items of highest priority, a software architecture was developed. The architecture is object oriented and is documented in UML (Unified Modelling Language). These gives the biggest flexibility because it is independent of programming language (C++, C#, Visual Basic, etc.), operating systems (Windows, UNIX, Linux, etc.) or frameworks (CORBA, DOTNET) [Bach, Boucky, Keferstein, Züst, 2004].

4.5 Specification and performance verification

Other areas of coordinate and optical measuring technology are currently putting effort into standardization. To avoid overlap, the initiative contacted the relevant committees, and was thus able to take the available results into consideration. Particularly in the area of calibration, many guidelines and national and international standards already exist. Following documents have influenced the work of the initiative - ISO 10360, DIN 32877, VDI/VDE 2617 6-6.2 (6.3) as well as GUM, Guide to the Expression of Uncertainty in Measurement (ENV 13005).

![Four-shell model for performance verification (© OSIS)](image)

It is necessary to downscale complexity of the performance evaluation of optical probing system (OPS) during different stages of integration. Therefore OSIS introduced a four-shell model approach (refer to Figure 4). The idea is to provide a systematic approach and set or tests common for all shells to ensure comparability.

The focus of shell 1 is on OPS performance. This only includes influences from the sensor itself and tries to eliminate influences from the integration. The performance evaluation for shell 1 is done before the definition of the target system and on a “mover” of the sensor manufacturer’s choice. The results are specification data for the OPS performance.

Shell 2 evaluate integrated OPS performance. This includes all additional influences on the sensor itself after the integration in the intended system. It can include additional data processing not coming from the CMM that combines one or more raw points and position information from the CMM. It also includes any synchronisation problems, electrical disturbances due to cable length, position jitter etc. The “mover” for the test is the CMM on which the OPS is mounted.

Shell 3 spots on system performance and particularly on acceptance test criteria. The reason for this shell is to fill the gap due to the lack of clear interpretations for OPS in the existing
standards for the acceptance of CMM equipped with OPS based on system performance. The tests show conformance with the specifications.

If performance for certain applications has to be evaluated Shell 4, application performance, is applicable. This shows system performance on the real work piece with its imperfections (roughness, colour, etc.).

5 Outlook

The whole OSIS standard will be published in the first half of 2004 to general public as a first release. The workgroups of OSIS clearly understand that most of the definitions in the standard are based on past experience and theoretical consideration. It is seen very important that practical implementations from manufacturers will improve the standard in the future. Therefore several participants plan to release their first OSIS compatible products in the first half of 2004. Companies interested in actively supporting OSIS are welcome to become OSIS members. For further information about conditions of membership and benefits please refer to OSIS in the internet (www.iacmm.org, workgroup OSIS).

5.1 Benefits of OSIS

After publication of the OSIS standard it is important that industry understands to benefits of a common interface standard. Typical integration projects (refer to chapter 3) have budgets of several hundreds of thousands Euros. They last from half a year to several years from the first enquiries to an accepted installation at the customer’s site. It is estimated that OSIS will cut down project budgets to several thousand Euros and solutions will be provided practically off the shelf. It is expected that this fact will accelerate the development of a wide range of OSIS compatible solutions for CMM’s. But this standard is not limited to CMM’s. Future integrations of an optical sensor in any kind of moving and testing system can use OSIS. This will help sensor manufacturers to enter other industrial fields. For these new industrial fields this would mean that a ready to be used solution for the integration is available. Therefore development costs for such integrations will be noticeable lower compared to the situation without the OSIS standard. No application specific modifications on the sensor side will be necessary. Additionally this will give higher quantities to the sensor manufacturers they need to lower their selling price and attract a bigger range of possible applications.

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