Project Number 032721

OP3MET

OP3MET - Optical 3D Metrology – Automated in-line metrology for quality assurance in the manufacturing industry

FP6 ~ CRAFT

COOP-CT-2006

Publishable Overall Activity Report

Period covered: from 10 Nov 2006 to 9 Nov 2008
Date of preparation: 29 Jan 2009

Start date of project: 10 Nov 2006 Duration: 2 years

Project coordinator name: Karl Hollenbeck
Project coordinator organisation name: 3Shape A/S Revision 1.

Background

In industrial metrology, there is growing demands for measurements with higher accuracy and speed. Although optical 3D metrology fulfils the speed requirement in most cases, this is often at the expense of accuracy and traceability of the measurements. OP3MET focuses on the development of innovative equipment for automated in-line 3D metrology.

A main objective in OP3MET is to develop an integrated 3D laser scanner and software solution for the verification of dimensional and geometrical tolerances, including free-form surfaces, on metallic and plastic parts with dimensions up to 200x200x200mm. The system, besides ensuring the automatic reconstruction of complete surface models, will be designed to guarantee user-friendliness (one-button operation), versatility, reliability and speed. The new system's price will be one-third of that of comparable existing equipment.

A second objective is to develop innovative laser and optics for the new system, optimised with respect to measurements on 'difficult' materials such as reflective metal and translucent plastics. Another objective is to develop a mega-pixel USB camera for use as main component in the system. A fourth objective is to develop procedures and artefacts for good industrial practice in connection with achieving traceability of optical systems. The goal is to reach with optical systems the accuracy levels of mechanical coordinate measuring machines (CMMs) at up to double their measuring speed.

OP3MET is a unique opportunity to create competitive high-tech products for global distribution in the field of optical 3D metrology, as a European response to the strong competition in this field by North American and Asian firms.

The consortium is composed of 3 SMEs, 3 end-users and 4 RTD performers, from 5 different EU countries (DK, I, UK, P, RO). One of the countries is an Associate Candidate Member (RO).

The coordinator is 3Shape A/S, a privately-held Danish SME established in 2000. 3Shape's core competencies lie in the development and marketing of integrated 3D scanners and CAD/CAM software for the creation, processing, analysis and management of high-quality 3D data. Contact details:

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Cambridge Optical Sciences (COS), a British SME, specialises in the design and construction of very high reliability optical modules for a variety of markets (such as Aerospace, power supply monitoring, test structures for gigabit telecoms etc).

The third SME is Devitech Aps, a Danish engineering company founded in 1994 as a spin-off from the Laboratory of Image Analysis at Aalborg University, Denmark. Devitech has a solid R&D track record from a number of highly innovative embedded vision projects

João de Deus (JDeus) of Portugal, and end user, is an international leader in the development and production of thermal systems for the automotive industry. With an industrial area of 33.000 m2, Jdeus manufactures water-cooling radiators, heaters, charge air has well air conditioning condensers, both in cooper and aluminium, selling also oil coolers.

Askoll Holding is a private Italian company leader in the supplier chain for the manufacturers of household appliances. The main business is the production of pumps with synchronous motor for dishwashers and washing machines. Within OP3MET, Askoll is an end user.

The third end user is SINTEROM of Romania. Having a tradition of more than 60 years SINTEROM develops and produces small to medium sized high precision sintered parts mainly for automotive industry.

An RTD performer, the National Physical Laboratory (NPL) is the UK standards laboratory responsible for the UK national measurement system and metrology, and the transfer of new metrology methods to UK industry.

DIMEG (Department for Innovations in Mechanical Engineering and Management) is a department of the University of Padova, Italy, Faculty of Engineering. Also an RTD performer, DIMEG is active in research, contract work and education on production management, manufacturing processes, industrial metrology and automation.

Another RTD performer, the Institute for Product Development (IPU) is a financially and administratively independent organization with a unique location at the Technical University of Denmark (DTU), operating since 1956 in the field of manufacturing including geometrical metrology.

The forth RTD performer is the Department of Mechanical Engineering (DME) at the Technical University of Cluj-Napoca, Romania. It hosts the Regional Center of Industrial Metrology, delivering solutions for quality control, reverse engineering and 3D digitizing to the design and manufacturing community.

Major achievements

The OP3MET project set out with a set of objectives, which combined would result in the new metrology scanner. In the following, the individual objectives are listed, and commented with the major achievements and findings made.

1. Innovative optical measurement system with:

a) *Substantially improved optical 3D scanner providing measurement uncertainty and metrological traceability, comparable to state-of-the-art touch probe coordinate measuring machines (CMMs). Target measuring uncertainties for free-form surfaces are 5-20μm*

3Shape, DME, IPU, and DIMEG have completed ISO tests on the current 3Shape scanner. Here, it was a particular challenge to adapt the ISO procedures – originally developed for tactile CMMs – to optical systems. Several inaccuracies were identified in the 2007 3Shape scanner, so it is has been possible to pinpoint the sources of inaccuracies in the mechanical design, and these have been improved.

By the end of the project, according to VDI norm 2617, the maximum permissible error of form at 60 mm is **16 µm**. So the success criterion has been met. End users, however, are really looking for something not covered by any norm, best termed "detail level" – the sharpness of edges, the smallest gaps still discernible. OP3MET has shown that standards for these criteria are still missing. This need will be brought to the attention of the relevant bodies by IPU and DIMEG.

Scan indicating the accuracy of the scanner

b) *Versatility with respect to part geometry and material within dimensions of 200 x 200 x 200 mm. In particular, the system will handle traditionally difficult materials for optical systems, such as plastic and metal. The performance will be evaluated on a set of representative end-user test samples.*

Two types of scanners have been developed during this project. The first is an improvement of 3Shape's 2007 scanner with a measuring volume of 80 x 80 x 80 mm. This scanner is now being marketed. For larger object, a second, entirely new scanner has reached prototype stage. It uses a robot arm and has a measuring volume of 300 x 300 x 300 mm. The first prototype design has turned out too unstable, so a re-design has been started towards the end of OP3MET, and will be continued past

the project by 3Shape. A patent application for some principles in the scanner is being prepared at the time of this writing.

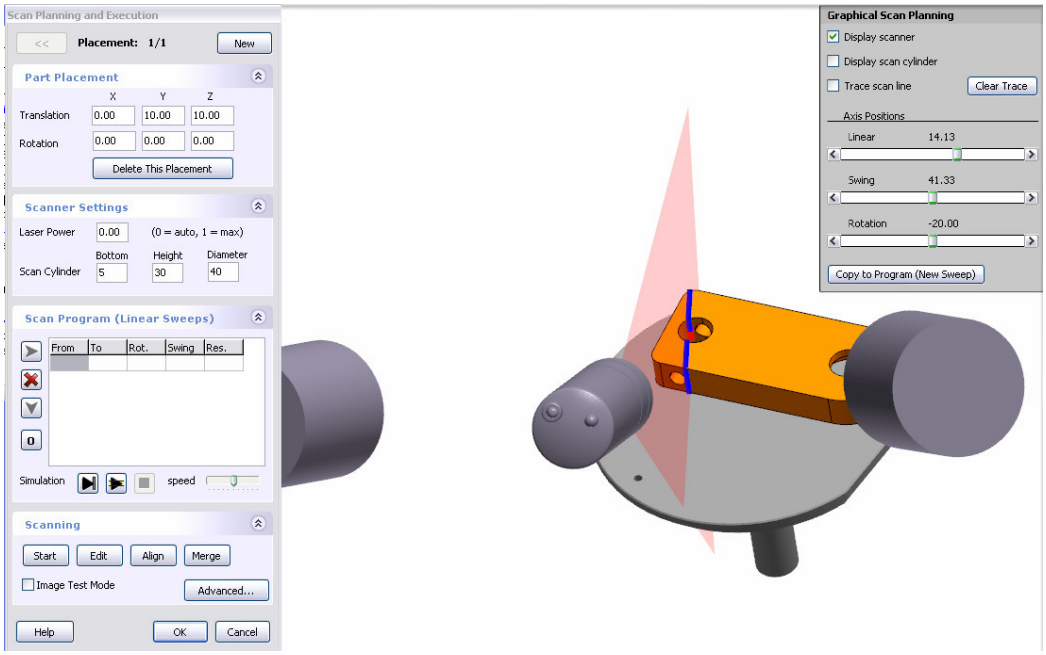
The new line generator developed by NPL, COS, and 3Shape is revolutionary. It has been demonstrated to be able to scan non-homogeneous and even metallic surfaces, a completely novel achievement that will give 3Shape a significant competitive advantage. A patent application has been submitted.

Scanning of object with non-homogeneous reflectivity (left). Top right: traditional scanner; bottom right: With OP3MET line generator.

NPL measured adsorption spectra for the ASKOLL plastic end user samples. Unfortunately, there was little sensitivity to wavelength, so the idea of using multiple wavelengths laser light has been dropped. For moderately transparent plastic materials, good scans have been obtained.

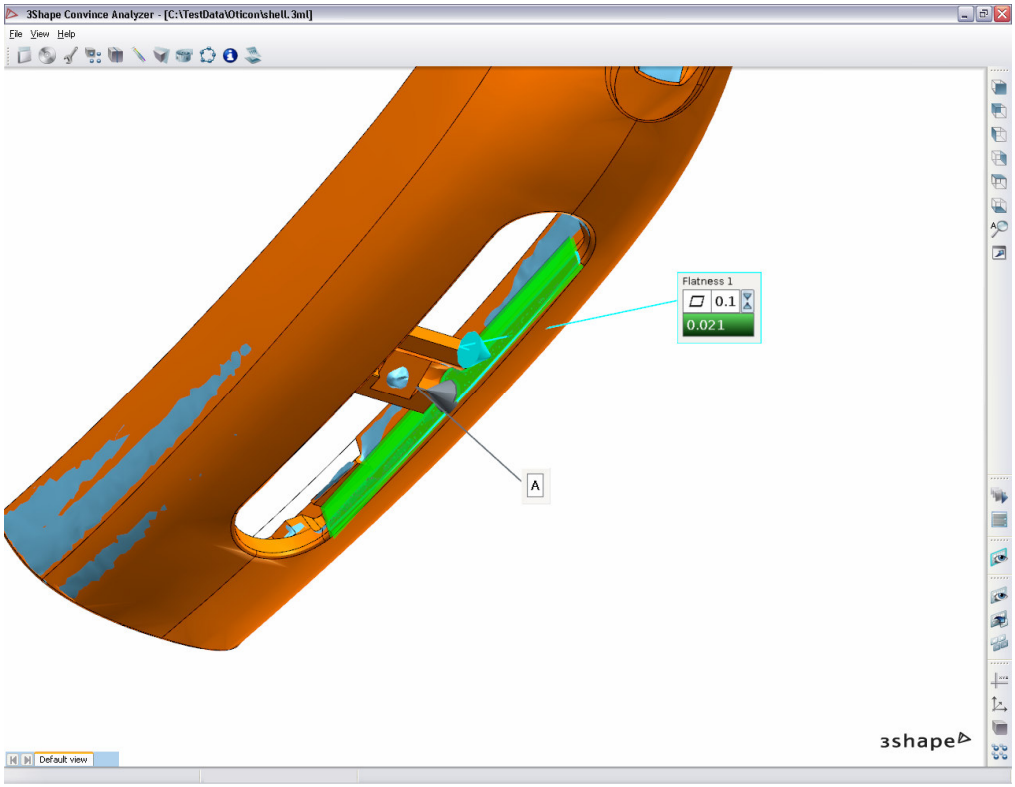
c) *Completely automated in-line measurements guaranteeing full coverage scans, integrated with automated feature extraction for verification of defined tolerances.*

3Shape has developed software to simulate a scan given just the CAD model of the part. This has drastically reduced the time needed for defining a scan sequence with full coverage. 3Shape has completed the automated feature extraction software. The industry survey (IPU, JDeus, Askoll, Sinterom) and workshops with other potential end users at 3Shape have indicated that the scan sequence must be fully defined and reproducible. This requirement prevents the adaptive scanning algorithm proposed in the original solution, because it results in a unique scan sequence for every realization of the part. Accordingly, the scan simulation software is now the centerstone in fulfilling the full coverage requirement.



User interface for scan planning software

IPU and 3Shape have developed a metrology software package that has been released and is being marketed under the trade mark “Convince”. The package is much more user-friendly than existing competitor products, and more thorough in its implementation of Geometric Product specification (GPS) standards as defined by numerous ISO standards and similarly in ASME Y14.5.



Convince metrology software for GPS

An easy-to-use workflow for 100% surface models put together from several partial scans has been developed and tested successfully. Automatic feature extraction works without problems, whereas inline measurements are still not possible. The major issue is noise from ambient light. NPL and 3Shape have tested optical filters, but the signal-to-noise ratio was too small.

d) *Efficiency with respect to setup time for new parts, low training requirements and measurement speed. The aimed measurement speed is at least twice as fast than for comparable CMM measurements.*

The scan simulation software has brought down setup times at 3Shape from several to maximum one hour. The parallel calibration algorithm also developed at 3Shape has brought down calibration times from approximately 5 to 1 minutes. These figures indicate that we have achieved the objective already now.

DME, Askoll, Sinterom, and JDeus all have tried the small prototype scanner. They could use it without any training. Measurement speed is at least 10 times faster, for free-form parts up to 50 times faster than for CMM's.

e) *Target customer price of 40.000 Euro. This corresponds to one third of end user price for a comparable measurement system including CMM with traceability and metrology software.*

For the simpler scanner without robot arm, but 3Shape's traditional three-axis motion, the goal has been achieved. The scanner is being marketed at 39000 EUR. The final prototype of the robot arm, however, is more expensive than expected, and final manufacturing cost in series production is not yet known.

Prototype of robot arm scanner

2. A novel laser and optics system with:

a) Laser speckle control and tight focusing

NPL and COS have identified means to eliminate laser speckle. The first is to operate the laser below threshold. This has the advantage of simplicity, but limits the amount of power available for illuminating an object. This could become a problem if fibre coupling is used to direct light from the source to the object. It could also be a problem when scanning dark objects. The second way is to use a rapidly scanning mirror. When this is done on timescales must faster than the camera shutter time, the effect is to reduce or eliminate speckle by time-averaging a changing speckle pattern. The scanning mirror is unfortunately rather costly (£800 for a quantity of one).

The scanning mirror developed by NPL and 3Shape has been proven excellent; it is part of the patent application. The hardware is significantly more expensive than a fixed laser, but the advantages are significant as well, so the market is expected to be willing to pay the price.

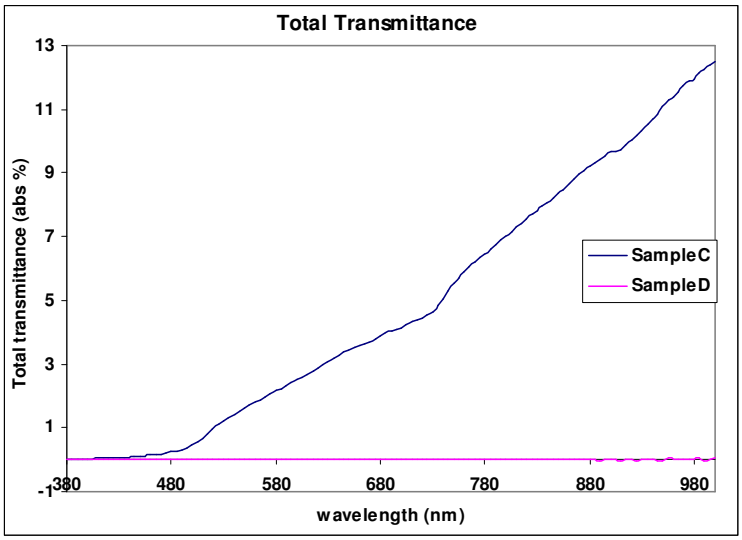
The blue laser developed by COS creates sharper lines than the 660 nm laser used by 3Shape so far. Unfortunately is can not yet supply the same power level, and will thus not be considered for serial production in the first round. COS and 3Shape hope to be able to improve this issue in the future, though.

Line of COS 405 nm laser on Askoll plastic wheel (room lights on)

b) Reduced penetration and specular reflection for semi-transparent and reflective materials, respectively.

NPL and COS have conducted experiments to examine reflection and translucency problems in detail. First results show that a 399 nm blue laser may give better lines on metal objects, and that translucency can be compensated by better image analysis software.

NPL have conducted absorption spectra measurements on various Askoll samples (Askoll being the end user working with plastic materials). Unfortunately, absorption over the visible part of the spectrum varied only by max 15%, too little to justify multiple light sources in a scanner.



Transmission spectra of samples C and D (noryl and a polyphenyl).

For metal parts, the new line generator module has solved the reflectivity problem by another approach, with great success (patent applied for).

3. An innovative low cost mega-pixel camera with:

a) Compression realising 6 times higher frame rate for optical scanning system.

Devitech have provided initial specifications for a 1.3 mega-pixels. 3Shape have built a camera with such resolution. Specifically, 3Shape's ScanServer software allows user control of the region of interest, i.e. laser beam area. The smaller the region of interest, the smaller the amount of information to be pushed through the USB cable, the higher the effective frame rate. Another means of reducing the USB transfer rate is data reduction by use of onboard data compression (in the FPGA). The intended gain in effective frame rate has been achieved by implementing this feature. 3Shape have completed this goal for the 1.3 Mpixel camera. A prototype 5Mpixel camera has also been created, and first scans have been made with it.

The boxed camera from front with lens mount and lens. The box shields electromagnetic emission.

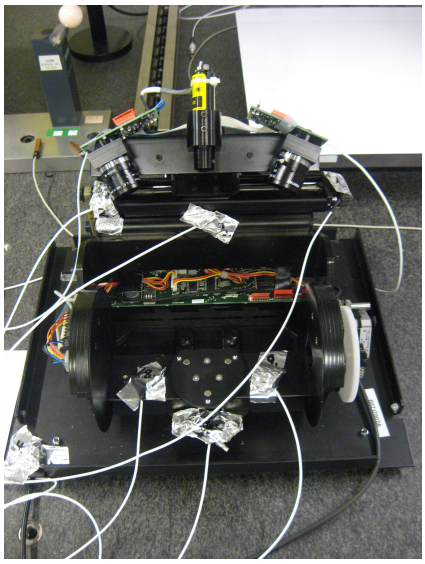
b) *Standard USB connection still facilitating multi image capture synchronisation.*

Devitech have provided initial specifications. 3Shape then built the camera and controller, which is ready for multiple cameras. Furthermore, detailed timing information makes motion compensation possible (3shape custom camera interface for synchronized systems).

4. General procedures and artefacts for:

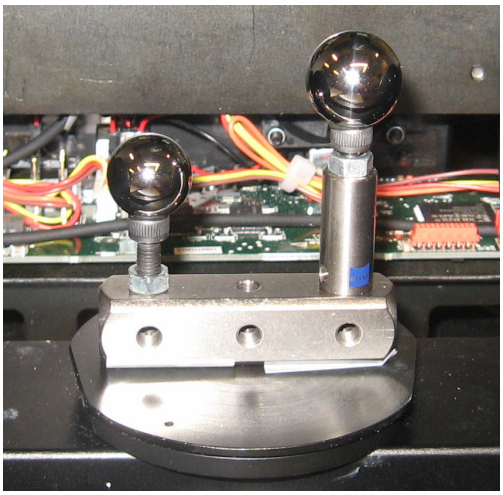
- *Performance verification and traceability establishment of optical measurement systems*

DIMEG, DME, and IPU performed ISO 230-2, ISO 10360-2, and ISO 10360-3 tests on the current scanner (with ISO 230-2 performed independently at both IPU and DIMEG). DIMEG have shown that to verify metrological performances of the laser scanner, it is possible to follow ISO 10360-2 with the necessary additional specifications for the use of optical sensors given by VDI/VDE 2617 6.2, and the necessary adjustments developed by DIMEG. DIMEG applied the substitution method for determining the uncertainty of the current 3Shape scanner on the measurement of a metallic cylindrical component. Using the row data, DIMEG noticed that the diameter values are similar to the calibrated values, whereas the form error values are much higher than the calibrated ones. This happens because the diameter is an average value, determined using all the points; whereas the form error is determined using just two points: the maximum and the minimum deviation from the regression cylinder. So in a sense an optical scanner – yielding thousands of measurements – is disfavoured relative to a tactile CMM, yielding only tens of measurements.



Setup of ISO 230-2 temperature sensitivity tests on D600 scanner

In Year 2, DIMEG has developed more reference artifacts for important characteristics, particularly flat surfaces and sharp edges. DIMEG and IPU have also conducted several comparative measurements with a CMM.



The artefact manufactured according to ISO 10360-3

- *Good industrial practice in connection with achieving traceability using optical systems*

  DIMEG found that the most suited artefact for performance verification of the laser scanner is a ball bar with spheres having white surface or surfaces made of acid-etched stainless steel. IPU have also developed an artefact. DIMEG have provided a white paper on traceability and uncertainty analysis. The substitution method in

measurements of size and form, adapting ISO/TS 15530-3 with the necessary modifications for optical systems, seems to be the most practical method.

DIMEG have published a handbook. Askoll have set up a demonstration facility. DME have produced a manual for the OP3MET system, including the metrology software.

Dissemination and Exploitation of Knowledge

Overview table

Exploitable Knowledge (description)	**Exploitable product(s) or measure(s)**	**Sector(s)** of application	Timetable for commercial use	Patents or other IPR protection	**Owner** & Other Partner(s) involved
New scanning principle	Scanner	Quality control	2008 (2009)	1 submitted, 1 in prep.	**3Shape (owner)** COS (supplier)
Pigtailing of fibre	Lensed fibre	Telecom	2009		**COS**

For 3Shape, The new scanner is the most important outcome of OP3MET. It is being commercialized by 3Shape, with COS potentially becoming a supplier of laser light source units. The scanner is described in detail in the DoW. Given the one remaining problem with stabilizing the robot arm, only the smaller version with traditional axes is available so far, along with the OP3MET metrology software. This smaller package has been marketed since early December, 2008, with two sales appearing likely at the time of this writing. The robot arm version is expected to be completed in 2009.

3Shape markets the scanner as part of its line of commercial scanners. 3Shape has distributors in over 40 countries world-wide. However 3Shape will need to expand its marketing organization beyond its traditional fields, dental and hearing aid applications. For quality control, the market is much more diverse, and the number of units sold per customer will be smaller. Therefore, 3Shape has employed a Product Manager for the OP3MET scanner, starting Jan 15, 2009.

The market for 3D scanners for quality control is not virgin; there are already about ten players, many of them much larger companies. However, the novelty of the scanner developed in OP3MET is so significant that 3Shape can hope to enter the market. Sales targets are 50 units in 2009 and 150 units in 2009. The first sale was closed at the end of 2008.

For COS, OP3MET provided two “firsts” – these were:

- The first known successful repackaging of blue / near UV laser diodes from 5.6mm “cans” into sub-modules height – matched to apertures to enable fibre coupling.

- The first known hermetic and mechanically rigid sealing of 4 micron core fibre into stainless steel fixing tubes using quartz support tubes and LMP glass to metal sealing techniques. This followed the first known successful development of a fibre lens of high capture cross section into this small core fibre.

Potentially this gives rise to two new products. A lensed 4 micron cored fibre sealed into a housing that massively increases the mechanical strength of the fibre end, allowing it to be manipulated with much lower likelihood of breakage. Secondly, use of this fibre along with the techniques developed for chip removal and repackaging will allow a fibre – coupled blue laser diode to be developed, to a telecom – reliability level of performance. This will include the pigtail, which from one other manufacturer is merely glued together leading to a high reliability / low cost of ownership device.

It is expected that steps will be taken during 2009 to carry out these activities. In particular, the small – core fibre with lens and stainless steel jacket is expected to be marketed during this calendar year, a product "first".

For the academic institutions, OP3MET has been the platform for several M.S. projects and two Ph.Ds (DME, DIMEG). The results have been presented at conferences, industry workshops, on the web, and in scientific articles.

A particular challenge is the development of ISO norms for accuracy measurement of optical scanners. OP3MET has identified several gaps in the suite of existing standards, and IPU and DIMEG will try to make the relevant bodies aware of them.

Seminar InteRSeC 18, organized by DIMEG