IPROMES

- *Using Image Processing as a Metrological Solution* -

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-PUBLISHABLE FINAL ACTIVITY REPORT-

Project Coordinator : ALMA Consulting Group SAS **Project Technical Coordinator:** ActiCM SA

Partners:
Axist srl
Commissariat à l'Energie Atomique
EMT
COORD3 spa
ESIC-SN
Israeli Aircraft Industries
Seroma
Techspace-Aero
Metrostaff SRL

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Approvals

	Name	Company	Date	Visa
Technical Coordinator	Jean-François LARUE	ActiCM	16/07/07	OK
Quality Manager	Fabienne BRUTIN	ALMA	19/09/07	OK

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Project overview and objectives

The dimensional control plays an important role within the manufacturing industry. In the aeronautics sector, the metrology reaches a highly critical level, due to the high measurement precision required on large parts. The metrology operation is required not only during the final inspection, but above all in the scope of the assembly process.

Facing drastic requirements, and in order to take into account the size of the aircraft parts from the early beginning of aircrafts manufacturing, the industrial actors use complex frames which support both the parts to be controlled and the manual measurement tool. This solution is both time and cost consuming due to the characteristics of the frame which guarantees the accuracy of the measure.

The IPROMES project aimed at developing relevant photogrammetry and image processing techniques to perform the “in-process” positioning (during the assembly phase) and “afterwards”, to complete the final dimensional control in the aeronautics sector. The development of these innovating optical solutions will enable end-users to get direct measurements without specific instrumentation (particularly without targets). Consequently, the use of the sensors leads to a new concept of frame that will support only the parts to be controlled and the cameras.

IPROMES addressed the FP6 aeronautics area "Strengthening and competitiveness" and particularly the research topics 1.3.1.1 b) manufacturing by providing concrete solutions in following four areas: in-process inspection, flexible tooling, reducing recurrent and non-recurrent cost, enforce automated processes.

1. In-process inspection
This project uses optical sensors (cameras) instead of the traditional gauges. Consequently, isostatic positioning or referencing issues will be no longer required. So with this optical solution, the frames are simplified (up to 50% lighter) because they only support the parts without hard mechanical stability. The sensors are fixed besides the frame or on a robot arm. With the photogrammetry technique, the measurements are calculated in real time with instant feedback from the cameras so that system operators can advise the assembly personnel of adjustments to be made for the proper positioning of the strut relative to the aircraft. A demonstrator was implemented on this point.

2. Flexible tooling issues
As mentioned above, through the use of the photogrammetry solution, the manufacturing of the frame has been simplified. This allowed using a multi-purpose and versatile frame on which same structures from different aircrafts could be controlled. This led to design a new concept of frame: the “universal frame”. A numerical simulation is available to illustrate this point.

3. Recurrent and non-recurrent costs

The way to reduce the non recurrent-costs is to simplify the frame by using a measurement system which doesn't use it as metrological reference. The photogrammetry solution which uses optical camera responds entirely to this criteria and it allows the frame to become only a support for the elements to be controlled.

The solution for saving time and money (recurrent-cost) is to implement without contact measurement systems. It allows to drastically reduce the control duration, and to standardise the tools for the control.

4. Automated processes

IPROMES project aimed at exploiting optical sensors in order to automatically access to geometrical data of parts and structures to be controlled and then to proceed to three-dimensional measurements. A second demonstrator addressed this specific point.

IPROMES organization and consortium

The project was organized in 10 work packages (including Management and Dissemination):

Work-package No	Work package title
1	End user requirements & technical specification
2	Development of aeronautic specific large volume 3D measurement
3	Development of the aeronautic-specific image processing
4	Development of the image acquisition technique and sensor prototyping
5	Development of CAD interface
6	Specification and Design of the multipurpose frame
7	Prototyping and integration of the multipurpose frame, sensors and software
8	Industrial validation
9	Exploitation and dissemination
10	Management

The consortium is composed of 10 organisations from 5 countries (France, Italy, Austria, Belgium, and Israel) with the complementary competencies required to reach the project objectives:

- Technologies suppliers (ACTICM, COORD3, SEROMA, ESIC SN, AXIST) to lead the project and exploit its results,
- Research organisations (CEA, TECHNISCHE UNIVERSITAET GRAZ),
- Aeronautics end-users (IAI, TECHSPACE AERO) to fully validate the technology,
- A consultancy company (ALMA) that was the coordinator of the Project.

Partner name	Contact Name	Address	Phone	E-mail
ActiCM	Jean-François LARUE	122 rue de la Roche-de-Lorzier Centr'Alp 38340 MOIRANS FRANCE	+33 - 4 76 91 37 60	jflarue@acticm.com
AXIST	Luigi BERRI	Viccolo Morra, 4 10098 RIVOLI (TO) ITALY	+39 - 011 956 44 37	lberri@axist.it
CEA	Sylvie NAUDET	31-33 rue de la Fédération 75752 PARIS FRANCE	+33 - 1 69 08 82 91	sylvie.naudet@cea.fr
EMT-TUGraz	Markus BRANDNER	Graz University of Technology 24 Kopernikusgasse 8010 GRAZ AUSTRIA	+43 - 316 873 7773	brandner@ieee.org
Coord3	Stefano TORRE	SS del Moncenisio K.M 42.200 10050 BRUZOLO ITALY	+39 - 011 963 55 11	storre@coord3.com
ESIC-SN	David LEROUX	1 Allée des Châtaigners 78190 TRAPPES FRANCE	+33 -2 40 68 79 00	david.leroux@esic-sn.fr
IAI	Aharon MINKOV	Ben Gurion Intrenational Airport 70100 TEL AVIV / LOD (airport) ISRAEL	+972 - 39 35 36 54	aminkov@iai.co.il
SEROMA	Patrick FORTIN	Les Estresses 19120 BEAULIEU / DORDOGNE FRANCE	+33 - 5 55 91 09 67	Patrick.fortin@seroma.fr
TechSpace Aero	Jerome D'AGRUMA	Route de Liers, 121 4041 HERSTAL / MILMORT BELGIUM	+32-4 278 84 20	jdagruma@techspace-aero.be
ALMA	Stéphanie OUSACI	55 Avenue René Cassin 69009 Lyon cedex FRANCE	+33 - 4 72 35 80 30	sousaci@almacg.com
Metrostaff	Sandro MARTA	Corso Susa, 242 10098 RIVOLI (TO) ITALY	+39 - 011 95 3 61 62	smarta@metrostaff.it

Work performed

WP1 End user requirements & technical specification ESIC SN

WP1 showed that the problematic in the aeronautic sector is two fold. The first problem is the verification of the conformity of aeronautic parts with respect to the CAD models. The second problem is the assembly of aeronautic parts. The consortium decided to have two demonstrators, one for each problem.

WP2 Development of aeronautic specific large volume 3D measurement ACTICM

One of the IPROMES goals is to fully automate the measurement process of aeronautic parts using a camera sensor mounted on a robot arm. We have high volume parts and high precision requirements on the measurements. To meet these requirements all transformations (camera to target and global reference to camera) need to be known with high accuracy. Photogrammetry ensures the accurate estimation of the transformation between the camera and the target. The robot arm provides an approximate position of the sensor. The precision is not sufficient to ensure the final measurements precision. This workpackage addressed the problem on how to localise accurately the position of the sensor mounted on the robot arm in the case when reference points are available and in the case when natural landmarks must be used.

Sensor pose estimation from 3d coordinates of known points is well addressed in the literature. ActiCM implemented several state-of-the-art algorithms and compared their performance. A series of experiments were conducted that evaluated the accuracy of pose estimation using different types of reference points such as self-identifying landmarks. ActiCM has developed software that allows the accurate detection of drilled holes. This allowed the comparison of the sensor pose estimation algorithms using reference points or natural landmarks as input. We found that the most accurate sensor pose is estimated from a large number (more than 200) reference points using the state-of-the-art algorithm ”bundle adjustment”. Using a less complex algorithm, less reference points or drilled holes instead of the reference points degrade the accuracy of the estimated sensor pose.

The sensor pose estimation algorithm is integrated in the ActiCM software and was used by other partners of the consortium. The demonstration platform “quality control” and the demonstration platform “aeronautic part assembly” were both using the developed software module.

WP3 Development of the aeronautic-specific image processing CEA/EMT

In the WP3, CEA and EMT have proposed different optical solutions to measure specific features in aeronautic parts such as circular holes, curved edges, planar surface patches, and wall thickness.
Algorithms developed by CEA cover the robust detection of circular holes including the special case of holes with chamfer. For difficult situations where the chamfer is small (less than 3 pixels in the image domain), a solution based on the projection of structured light was proposed. Further, CEA has developed new images processing tools for the measurement of curved edges. The main issue of this task concerned the ability to propose a fully automated measurement. For that, CEA proposed, an innovative solution based on the projection of the CAD model in images. The complete algorithm chain has been implemented from the acquisition system to the 3D registration of the reconstructed curve with the CAD model
The main focus of the contribution of EMT was on the development of robust methods to measure planar surface patches and derived measurands such as parameters of straight edges, angles between adjacent planes, and wall thickness. Robustness is achieved by rigorous application of structured laser light. EMT has designed and built a close-range photogrammetric sensor with a working distance of 170mm based on a stereo-camera and a stereo laser-projector pair. The novelty of this sensor is the full calibration of both camera and laser projectors leading to a system of 1 passive and 2 active stereo setups.

The contributions of the research partners in WP3 have successfully been integrated into both the quality control demonstrator and the final assembly demonstrator of the project.
The image-based measurement processes proposed in WP3, extend the state of the art in the field of optical 3D measurement by innovative algorithms that target at measurements of highly reflecting surfaces, of curved edges, of chamfered edges, taking into account the required level of automation, accuracy and robustness. Concerning the accuracy and the robustness, the experimental results show that the proposed approaches have a promising potential in automatic 3D control of aeronautic parts. The main results of WP3 have been published in reviewed international conferences or are protected by a patent.

WP4 Development of the image acquisition technique and sensor prototyping ACTICM

This workpackage aimed at specifying the sensors and test their compliance with the application requirements in aeronautics. The goal was to provide a set of prototype sensors.

Aeronautic industry compared to automotive industry uses different types of materials for manufacturing aircraft parts. In the beginning of this work package, different materials and related reflectance properties were studied. Optical sensors are sensitive to the ambient illumination and the reflectance from the material surface. An interesting result of the various studies conducted in this workpackage allowed ActiCM to develop software algorithms to automatically adapt to ambient lighting, improve the hardware to become more robust to illumination changes and at the same time enhance the contrast of the images. For the measurement of surfaces without visible structure, a structured light projector and associated software was developed. The system can now measure points on arbitrary surfaces with high accuracy.

In aeronautics, high volume parts need to be inspected. The coverage of an aeronautic compliant volume was a particular challenge of IPROMES. To tackle this challenge, ActiCM performed evaluations on two types of calibrated benchmark objects: one object to demonstrate the measurement accuracy of different features and one object to demonstrate the system's capabilities in a large volume. During the project, ActiCM succeeded to increase the measurement volume and the measurement accuracy.

WP5 Development of CAD interface ACTICM

The aim of this workpackage was to provide a full integration of the photogrammetry system Advent and the measurement software Arco. It is important that the software can treat CAD formats used by the end users.

Coord3 and Metrostaff implemented a module such that Arco can read the most common CAD formats. ActiCM developed a generic interface between Advent and a generic measurement software with associated interface specifications. Metrostaff developed the interface that allowed to connect Arco and Advent. The interface is fully operational and was used for the quality control demonstrator and the assembly demonstrator. This is an important result, since it proofs that Advent can be driven by different measurement software.

WP6 Specification and Design of the multipurpose frame SEROMA

The goal of this workpackage was to specify and design a multipurpose frame that is appropriate for non-contact measurements. The frame should be more versatile and lighter.

Several meetings with end users and consortium partners allowed the definition of a representative mock up part and associated multipurpose frame. After this initial phase, Seroma generated the CAD models that were modified and updated several times until validation by the consortium.

WP7 Prototyping and integration of the multipurpose frame, sensors and software SEROMA

The consortium decided to have two demonstrators, one for quality control and one for photogrammetry assisted assembly on a multipurpose frame.

The quality control demonstrator was set up in January 2007 at ActiCM offices in Moirans, France. The platform consists of a robot that serves to hold the different sensor prototypes (ActiCM's Advent and EMT's planar structure sensor). The platform can accomodate small objects and demonstrate a full quality control cycle.

Seroma was in charge of building up the assembly demonstrator platform at Seroma offices in Beaulieu sur Dordogne, France. The platform consists of the multipurpose frame, the mock up part, a robot and the sensors linked to the associated servers respectively. The mock up is composed of two large cylinders (simulating the body of an aircraft) that can be assembled using the multipurpose frame. The multipurpose frame is composed of a static part and a mobile part. The mobile part can be moved with 6 degrees of freedom in order to perform the assembly.

WP8 Industrial validationAXIST

This work package aimed at validating and testing the prototype dedicated to aeronautics applications. Following the type of control and the type of parts, the evaluation criteria that were used:

- Accuracy of control (objective of 0,1 mm for most critical entities, 0,5 mm for others)
- Control time (objective : 10 times faster as traditional measurement)
- Automatic control : no operator intervention on the frame or on the parts

With respect to the assembly procedure adopted by the end user today, the IPROMES system is fully automatic. It does not involve the presence of an operator on the frame during assembly. The assembly phase itself requires the simultaneous collaboration of 3 operators. With the IPROMES system, the assembly can be performed by a single operator in much shorter time. The robotize version of the step and gap measurement allows accurate positioning of the sensor at points that are difficult to access by an operator. In this case as well, the IPROMES system demonstrates its benefit with respect to the state-of-the-art.
The demonstration addresses the 3 major phases of an assembly procedure. First the parts are inspected using ActiCM's system Advent in order to validate the conformity with respect to the CAD model. Then the parts are assembled using the motion capabilities of the frame. The assembly process and the alignment (distance and rotation) of the two parts are monitored in real time using ActiCM's product Actiris350 with a specially developed module for part

alignment monitoring. After assembly, a robotized version of Coord3's Magam is used to verify the step and gap of several critical points.

Publishable results

Result no 1: New Image Processing Algorithms

The image-based measurement processes of R1, extend the state of the art in the field of optical 3D measurement with innovative algorithms that target at measurements of highly reflecting surfaces, of curved edges, of chamfered edges, taking into account the required level of automation, accuracy and robustness.
The different experiments showed that due to the properties of the aeronautic parts (specular material, shape of edges), each type of feature requires specific investigation in terms of image processing and photogrammetric techniques. For the automation, the partners have proposed original solutions in order to make the process fully automated. Concerning the accuracy and the robustness, the experimental results show that the proposed approaches have a promising potential in automatic 3D control of industrial parts.
Some innovations are protected by a patent, and the results of WP3 have been published in several reviewed international conference proceedings:

- **"***Optical Measurement system for the quality control of aeronautic parts."* , S Naudet-Collette, F Gaspard, F Dekeyser, - 8th International Conference on Quality Control by Artificial Vision QCAV 2007 – May 2007 - Le creusot France.
- "*3D Optical Measurement of curved edges*." –, S Naudet-Collette, F Gaspard, F Dekeyser, H.. Martinshon, SPIE Europe Optical Metrology Conference, – June 2007 – Munich .
- *"State of the Art on Vision-Based Structured Light Systems for 3D measurements"* – M. Ribo, M. Brandner, IEEE ROSE 2005
- *"Fully Mobile Surface Inspection"*, M. Brandner, D. Hrach, P. Fossati, S. Marta, Sensor+Test 2007
- *"Vision-Based Surface Inspection of Aeronautic Parts using Active Stereo"* M. Brandner, IWK Ilmenau 2007

Contact: S. Naudet, CEA Saclay, France

Result no 2: New optical sensors answering the requirements of the aeronautical sector

In R2 ActiCM developed a sensor that extends the state of the art in the field of optical 3D measurements using innovative algorithms specially tailored for the requirements of the aeronautic end user in terms of accuracy and illumination robustness. ActiCM's AdventCR system with this new sensor measures geometrical feature coordinates using images taken from parts and estimates point coordinates on parametric surfaces using structured light patterns projected onto aeronautic part. This sensor is particularly tailored to perform following medium-range measurement of geometrical features (circular holes, square holes, slot holes) and medium-range measurement of surface points and edges.

The sensor development is closely linked to the development of image processing algorithms (see Result R1). For the highly accurate measurement of surface points, a new structured light

pattern was developed and filed as a patent by ActiCM. The new design of the sensor allows handling of difficult surface properties as encountered on aeronautic parts, such as high reflectivity of the surface patches. Furthermore, the scientific progress in sensor design improved the accuracy requirements and the robustness to ambient illumination.

The proposed sensor provides a basis for a wide range of different optical 3D measurement systems and methods. ActiCM intends to exploit the sensor design for automotive industry QC and for QC and assembly process in aeronautic industry.

Contact: J.-F. Larue, ActiCM, France

Result no 3: Step and Gaps measurement system for aeronautics

Aeronautics has high accuracy requirements on the step and gap measurements. Coord3 and Metrostaff optimized the MAGAM sensor by a software solution that increases the accuracy of the sensor. The patent of the MAGAM sensor is owned by COORD3/ESIC-SN/LOGITEST WESTINGHOUSE.

Current MAGAM system allows to measure flush and gaps with an automated procedure, developed for car bodies and tuned on these particular shapes made of sheet metal. The new sensor provides to the user the possibility to align the measured shape and to define his/her own frame of reference based on measured data. This enables the operator to measure any arbitrary shape without any restriction. Moreover the operator will be able to perform as many measurements as needed on each single profile. In particular this extends the range of application to many common shapes such as aircraft parts or panels, which are presently unfeasible.

Aeronautics needs high accuracy as well as flexibility in the measurement of flush and gaps. The development of this new interface extends the possibilities of MAGAM system towards precise measurement of any shape. This option in the software will be released under a new licence. Future activities include the enhancement of the resolution of the sensor, in order to achieve a better sampling of high curvature corners, and a wireless connection to the host PC, to overcome restrictions related to the presence of a cable.

Contact: G. Chiolero, Coord3, Italy

Result no 4: Flexible frame prototype equipped with optical sensors

The flexible frame is an innovative concept in the field of the inspection and assembly tools. It makes possible to use the main structure of the tool for a quantity of application and to add the tool with “inspection capacity”. While the standard tools can measure only a limited number of features (mainly points), the flexible frame can be re-configured upon the need and the optical sensor can be programmed for different measuring tasks.

The innovation consists in at least two aspects:
- a single tool is used for inspection of different parts and
- reconfiguration of the sensors is easily possible when the measuring strategy must be changed. Applications are a large range of inspection tools for aeronautical industries. The

new flexible frame could be purchased or rent by the user companies. Besides, Axist can promote his activity in term of inspection activity for re-calibration of the tool when the new part interfaces must be replaced and the sensor position needs to be moved.

Contact: P. Fortin, Seroma, France

Result no 5: New assembly concepts

IPROMES studies the concept of multi-purpose frame in combination with photogrammetry sensors to perform the "in-process" positioning (during the assembly phase) and "afterwards", to complete the final dimensional control in the aeronautics sector. Today, dedicated frame and measurement tooling are developed and manufactured for each aircraft type. Indeed, due to its complexity it is not possible to modify and to adapt the frames system for other types of aircraft.

This project uses optical sensors (cameras) instead of the traditional gauges. Consequently, isostatic positioning or referencing issues is no longer required. The development of these innovating optical solutions enables end-users to get direct measurements without specific instrumentation (particularly without targets).Another important goal of IPROMES is to reduce the presence of operators on the frame during assembly. The photogrammetry coordinate measurement technology provides a solution for this point.

Following points have been demonstrated during the project. The assembly demonstrator responds to the problem of assembly of aircraft parts. First the single parts are inspected by the photogrammetry part inspection system (Advent). Then the parts are assembled with the help of a real time photogrammetry monitoring system (Actiris350). The flush and gap of the assembled parts are then inspected using the specialised step and gap sensor (Magam).

The frames that support the parts are versatile. Different parts could be inspected using the same frame. Cost and time are reduced drastically for the part inspection and for the assembly of parts. With the Actiris350 monitoring system, aircraft parts can be assembled by a single operator in much shorter time (the traditional approach requires at least 3 operators that work simultaneously). The flush and gap sensor is positioned automatically using the robot. This allows the acquisition of measurements without the presence of an operator on the frame.

Contact: P. Fortin, Seroma, France and J.-F. Larue, ActiCM, France

Result no 6: Integrated targets

Esic SN responsible for the study of integrated targets did not proceed as desired during the project period. For this reason, the other involved partners could not evaluate the benefit of integrated targets for the assembly demonstrator. Today, no conclusion can be drawn on this result.

Contact: D. Leroux, Esic-SN, France

Result no 7: New optical sensor using structured laser light patterns to estimate planar structures

Quality control of aeronautic parts demands a high degree of accuracy while being faced with surface properties that are difficult to measure using photogrammetric principles. EMT has developed an optical sensor that is able to perform close-range photogrammetric measurements on typical aeronautic parts in order to estimate quality control measures such as the position of straight edges (even with chamfer), the angle enclosed by adjacent planes, and the distance between planes (e.g. the wall thickness).
The presented sensor principle is based on fully calibrated active stereo setups using cheap and robust laser projectors without any moving parts that are compatible with the degree of robustness required for measurement tools on the shop floor. The contribution of EMT is published in:

- *"Vision-Based Surface Inspection of Aeronautic Parts using Active Stereo"*
  M. Brandner, IWK Ilmenau 2007

Contact: M. Brandner, EMT, Austria

Dissemination and use

Dissemination of knowledge

Result no (if applicable)	Partner responsible /involved	Type of dissemination means	Relevant details: Title/Subject/Reference/Place	Actual/planned date or status	Type and size of audience	Countries addressed
R1	EMT	Conference Paper	"State of the Art on Vision-Based Structured Light Systems for 3D Measurements", IEEE ROSE2005, Niagra Falls, Canada	October 2005	Scientific	International
R1	CEA	Scientific article	"Optical Measurement system for the quality control of aeronautic parts." , S Naudet-Collette, F Gaspard, F Dekeyser, - 8th International Conference on Quality Control by Artificial Vision QCAV 2007, France	May 2007	Scientific	International
R1	CEA	Scientific article	"3D Optical Measurement of curved edges." –, S Naudet-Collette, F Gaspard, F Dekeyser, H.. Martinshon, SPIE Europe Optical Metrology Conference, – June 2007 – Munich	June 2007	Scientific	International
R1	EMT, Metrostaff	Conference article	"Fully Mobile Surface Inspection", M. Brandner, D. Hrach, P. Fossati, S. Marta, Sensor+Test 2007	June 2007	Scientific	International
R2	ACTICM	Press report	"Contrôles-essais-mesures »	January 05		France

R2	ACTICM	Press report	Le Moci	February 05		France
R2	ActiCM	Conference poster	"High-Speed non-contact measurement solutions: Introducing the Advent technology for new applications in the automotive and aeronautics industry", Coordinate Metrology Systems Conference (CMSC), July 2006, Orlando, USA	July 2006	Scientific, commercial	Worldwide
R5	ActiCM	Poster	« Ipromes : using image processing as a metrological solution », Control exhibition, Sinsheim, Germany	May 2007	Scientific, commercial	Worldwide
R5	ActiCM, Seroma	Presentation, Demonstration	« Photogrammetry assisted assembly in aeronautics », Seroma, France	June 2007	Commercial, 4 groups of 2 -4 representatives of aeronautic companies	France
R5	Seroma	Press report	« Nouveau decollage pour Seroma », Local newspaper	June 2007	general	France
R7	EMT	Conference article	"Vision-Based Surface Inspection of Aeronautic Parts using Active Stereo" M. Brandner, IWK Ilmenau 2007	September2007	Scientific	International

iPROMES Using Image Processing as Metrological Solution

- The IPROMES project aims at developing photogrammetry and image processing techniques to perform the assembly phase and to complete the final dimensional control in the aeronautics sector. These innovating optical solutions enable aeronautic end-users to get direct measurements without specific instrumentation (particularly without targets).
- The consortium end users are Israel Aircraft industries and Techspace Aero.
- The quality control demonstrator allows the fully automatic control of aircraft parts with high accuracy.
- The assembly demonstrator gives insight to the feasibility of a photogrammetry assisted assembly of aircraft parts.
- IPROMES reduces metrology cost and operation time compared to the current solution.

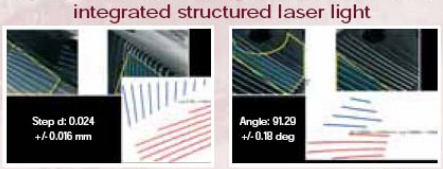
Photogrammetry assisted assembly demonstrator Seroma

Quality control demonstrator ActiCM

Innovative image processing algorithms for accurate measurement of 3D edges and circles

Work of CEA Saclay

Close range measurement of planar structures using a stereo sensor with integrated structured laser light



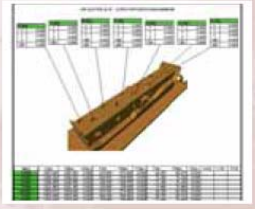
Work of EMT Graz

Specialised step and gap sensor for aeronautics

Work of Coord3 & Metrostaff Torino

Full quality control cycle using Arco measurement software Coord3 and Advent photogrammetry software ActiCM.

Control of large variety of features: holes of different shapes, surfaces, edges, round edges, studs



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iPROMES