http://dx.doi.org/10.21611/qirt.2006.086

Quantitative 3D – Thermography

W. Satzger*, G. Zenzinger*, V. Carl**

* MTU Aero Engines, Munich Germany
** T-ZfP Messtechnik, Dinslaken Germany

Abstract
In this paper results of the European Project VERDICT (2003 - 2006), work package 4 are presented.
In traditional thermography we get 2 dimensional pseudo colored images. There is no or only a very inexact information available about the 3 dimensional spatial coordinates of the points of the image.
The idea to get correct data is to fuse infrared data and 3d – measurement data taken on a surface contour. The 3d – measurement delivers a so called pointcloud, which represents in three dimensions the specimen's surface without distortion. Standard 3d -software for point clouds can derive geometric entities like positions, length, areas, angles etc. The crucial step for this fusion is to put the infrared camera into the 3d-scene and to measure the position and specimen together. In this way the metrical relation between the infrared camera and the specimen is derivable. The 3d – measurement is done with fringe projection technique which generates a point cloud of a surface contour with approximately 500 000 3d-points in 30 seconds. Since not all pixel rays of the infrared camera hit such a 3d-point interpolating steps are necessary.The technique of texturing point clouds is not restricted to one point of view of the specimen. Different thermographic images can also be mapped back onto the point cloud. To do this without contradiction in an overlapping region normalized thermal images are employed. With the quantitative 3d-thermography it is possible to calculate the area of curved surfaces. It also turns out to be very helpful, to have a 3d- visualisation of the thermographic indications.

1. Acquiring 3D-surface Data of a Specimen

With a technique called fringe projection, it is possible to acquire all the 3-dimensional points of the specimen's surface as (x, y, z) tupel (half a million points are usual)

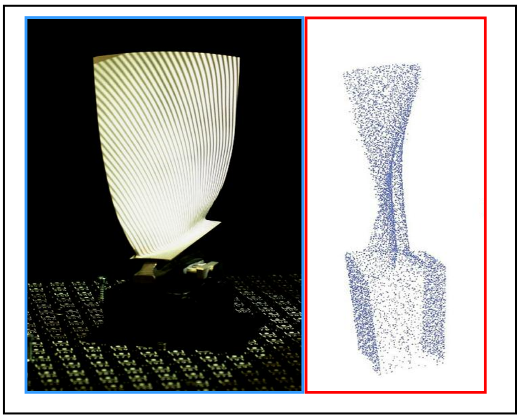

Fig. 1: *Blade with fringes and Pointcloud of the blade*

The underlying principle of fringe projection, shown in fig.2, is triangulation. Each surface point, which is covered with a fringe, is also in a light plane (the one, which produces the fringe). The plane is known mathematically by calibration, the same is true for the line of the object point to the corresponding matrix pixel of the camera (so called pixel ray). Hence to get the three dimensional coordinates of the point we have to intersect this light plane with the pixel ray. This is done for every object point which is seen by the camera and covered by a fringe. With a fringe projection system different sides of a specimen can be measured, but it is not possible to fit these smoothly together. For this purpose so called navigation cages are used.

http://dx.doi.org/10.21611/qirt.2006.086

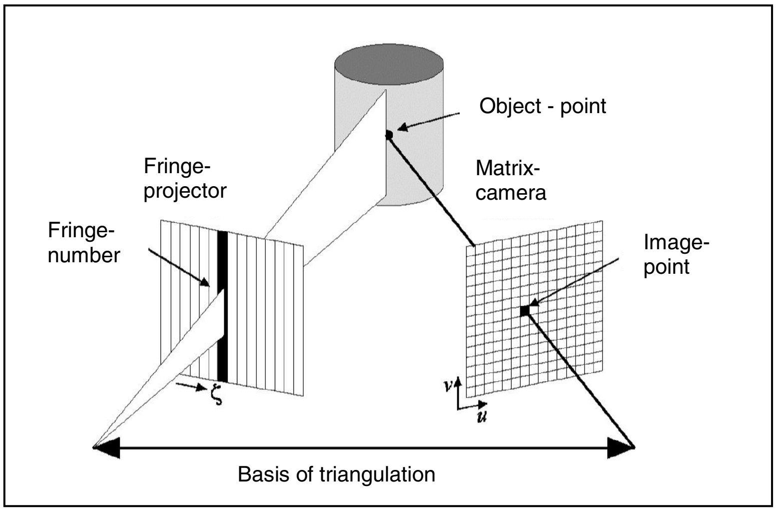

Fig 2: *Principle of fringe projection*

2. Navigation of Optical 3D Measurement Systems

To fit point clouds, taken from different point of views, smoothly together (i.e. in a way, that the specimens dimensions and angles a truly represented) a so called navigation cage is used, see Fig .3

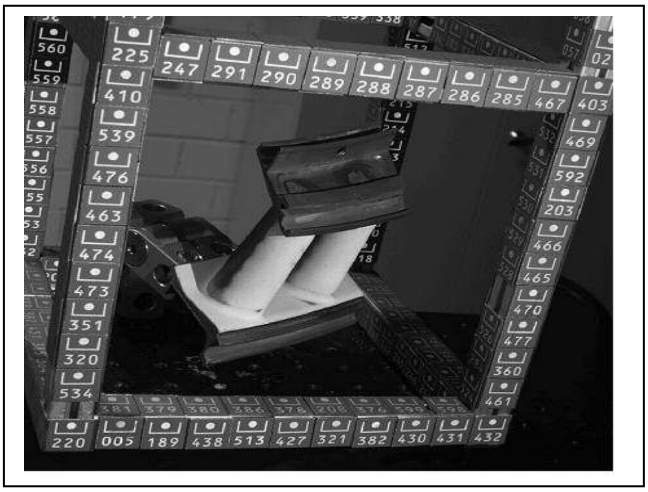

Fig 3: *Specimen in a navigation cage.*

The navigation cage and specimen have to be rigidly connected during the whole measurement process including thermographic data acquisition. The marks on the cage, together with the numbers there, the optical 3d-measurement system can identify. Since the midpoint of the mark's dot is exactly known (better than 0.01 mm) in a coordinate system, the optical system 'knows' where it is and can transform all the point clouds in this coordinate system. As a result, we get a 3 dimensional point cloud, where all the different sub clouds fit smoothly.

Remark: The dots in the marks on the cage are measured with a optical technique called photogrammetry. Nowadays it is almost an industrial standard.

For this kind of navigation to work properly it is necessary, that the camera is calibrated. This means that all distortions of the two dimensional image, this camera makes, have been compensated (see fig. 4).

http://dx.doi.org/10.21611/qirt.2006.086

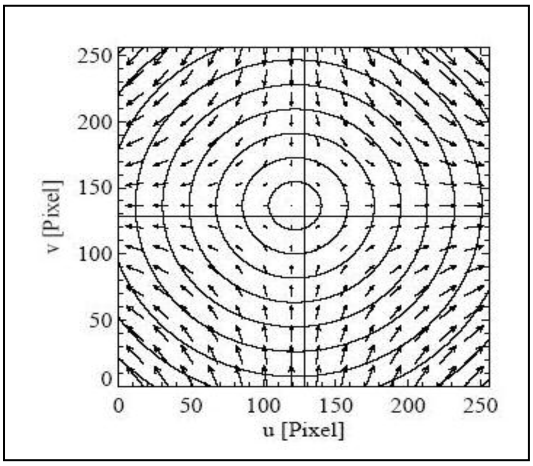

Fig 4: *Correction field for the distortion of an optical camera*

This kind of correction we have also to do for infrared cameras – in fact fig.4 shows such a calibration.

3. Calibration of an Infrared Camera

In order to avoid complicated and expensive mechanical guide rails, which transport an infrared camera to well defined positions in measuring set up, we prefer the concept of self navigation described above. For this it is necessary to calibrate the infrared camera in the same way as optical cameras. To do this a so called calibration plate is needed (see fig.5)

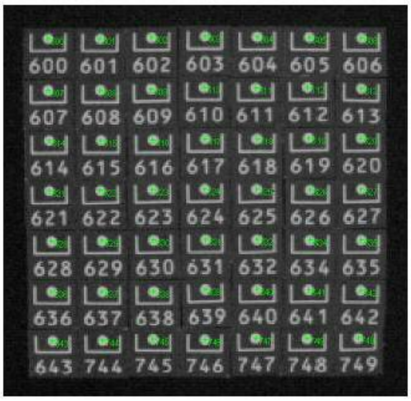

Fig. 5: *A calibration plate, which can be used in the optical and infrared regime*

This plate carries marks, which are accessible to optical and infrared cameras. With optical cameras the marks are measures (the position of the dots). There is no need for the marks to fit exactly in a rectangular schema etc., even their height is not important. Only one point is mandatory: Each dot has to be a plane disk (but each dot can have another plane!).
Since the marks can also be seen by the infrared camera, it is possible to calibrate. Hence, if a infrared camera sits before a cage as in chap. 2, it 'knows' where it is relative to the cage without a complicated mechanical guide rail system.

4. Fusion of Geometrical and Thermographic Measurement Data

There is a second advantage of calibration: Since via calibration all internal parameters (principal point of objective, distance of principal point to chip, etc.) of the camera are known, it is easy to calculate the spatial position and orientation of the pixel rays (see chap. 1). Along these pixel rays we can transport thermographic information back to the point cloud and give 3d-point the pseudo color of the temperature measured there.

http://dx.doi.org/10.21611/qirt.2006.086

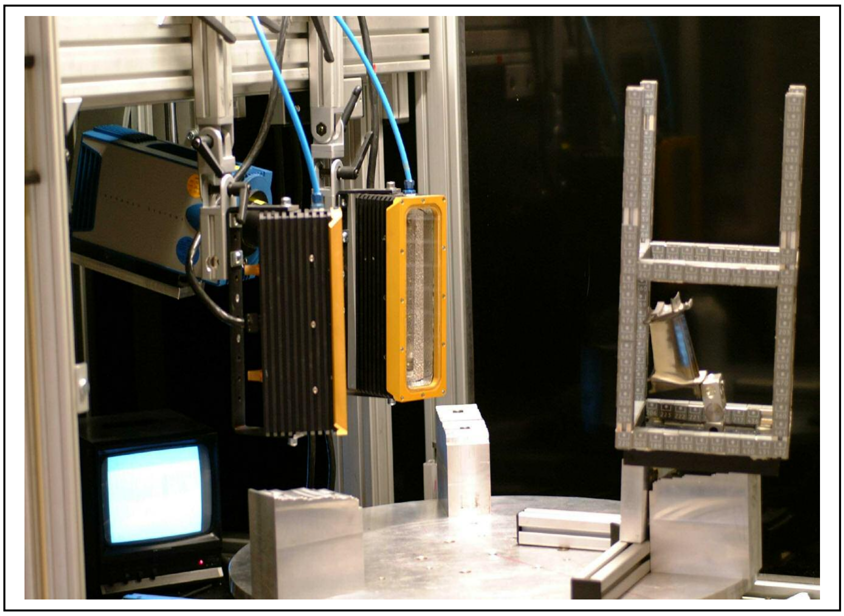

Fig 6: *The thermographic equipment, the specimen and the cage. The infrared camera also records the optical marks. Since this camera is photogrammetric calibrated it is possible to calculate the position of the camera relative to the cage.*

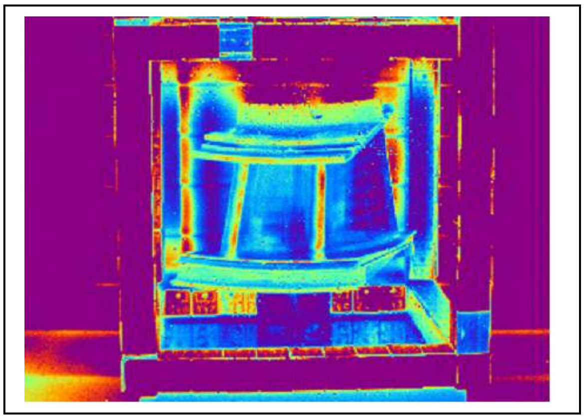

Fig 7: *Thermal image of the specimen and the cage (only slightly to see). This is only a two dimensional image.*

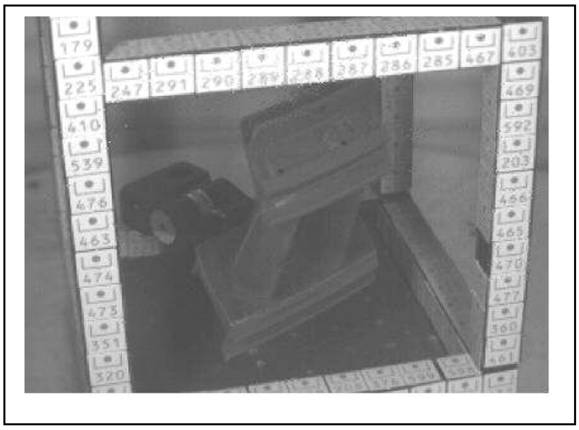

Fig 8: *Thermal image of the cage. This image is derived via different filters out of image 7. There is no extra image necessary!. It suffices for self navigation of the thermal camera.*

http://dx.doi.org/10.21611/qirt.2006.086

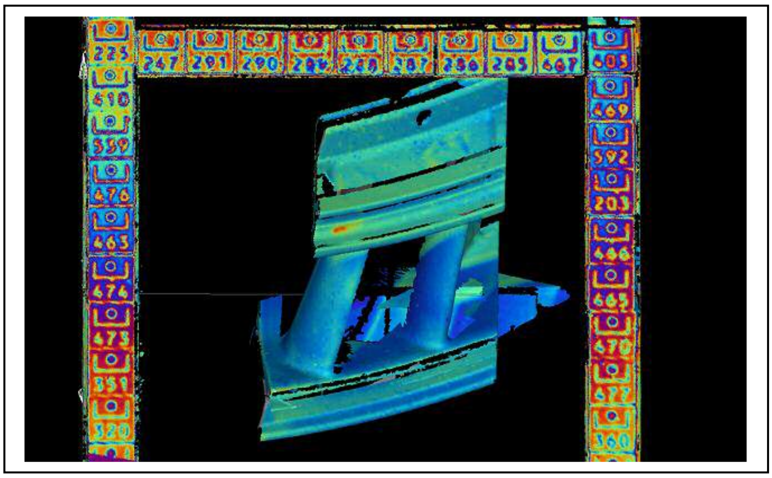

Fig 9: *Image of the 3d point cloud textured with the thermographic data image 7, using pixel rays. This technique is similar to the ray tracing methods*

5. Applications and Further Developments

With standard tools of optical 3d software now it is possible to measure the true size of thermographic indications, since on point clouds all optical distortions (mainly due to perspective) are disappeared. Fig. 9 shows the data fusion of the output of optical and thermographic metrology.
It is almost trivial but also the three dimensional position of a thermal indication can be deduced.

For large specimens the idea of self navigation solves the problem: How to fit two adjoining thermal images in an exact way. Only an adapted cage is needed.

Within the VERDICT project the fitting of two or more thermal images which have a significant geometric overlap is also successfully tested.

Another important aspect of the VERDICT program, not even mentioned till now, is VERDICT emphasizes the simulation of defects. This is also extensively done with data acquired in the way described in the preceding chapters.