Selfcalibrating 360-deg shape-measurement systems

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Introduction – problem description

It is quite difficult when using normally fringe projection, triangulation or light sectioning 3-D-measurement techniques to obtain a full-body view, i.e. to measure 360-deg around. For this, the sensor or the object have to be moved into multiple, overlapping measuring positions so as to view the entire surface. The resulting point clouds taken from the different views then have to be merged into a common coordinate system to obtain the final complete 3-D view by time consuming matching procedures or the viewing positions have to be known a-priori with a high accuracy.

Our solution – measurement principle

At the IOF a concept of selfcalibrating 3-D-measurement using structured-light illumination with a digital-light projection unit (DMD) has been developed overcoming these problems /1, 2/. On the basis of this concept measurement set-ups have been developed, which have the ability to obtain a full-body view within a selfcalibrating measurement procedure, whereas the necessary merging of the single views takes place fully automatically and is done without any marker on the object surface, objects features, other merging procedure or high accurate object/sensor handling system.
To get an automatically, selfcalibrating full-body the following measurement condition has to fulfil. Two or more cameras have to image the object from the desired different views. Neighbouring cameras should have overlapping area of their viewing fields, see Fig. 1. During the measurement procedure it have to ensured that these neighbouring cameras measure phase values for ³ 2 projector positions, whereas from each projector position two sets of fringe systems rotated by 90° have to project. These phase values in the overlapping areas can be used like the markers in photogrammetry to calculate the orientation of the projectors to each other by using a bundle adjustment calculation. This can be done step by step around the complete object. As a result one get different single 3-D views within one world coordinate system. It should be pointed that because all of the calculations are performed within one world-coordinate system, no further fitting/merging of the single views have to be performed to get a whole-body view. Because of that an error between the overlapping views (patches) cannot occur i.e. a homogeneous all-over-all accuracy is achieved.

On the basis of this strategy different mobile and stationary arrangements have been proposed.

A) Mobile camera – projector network

The simplest arrangement consists of one mobile projection unit and two mobile cameras, as shown in Fig. 2 and Fig.3. Both of the cameras capture the image simultaneously having a small overlapping area, while projecting the two sets of fringes from at least two different positions. Then one of the cameras can change in its position to get an other view of the object. The projection of the fringes is now repeated from other positions. Subsequent the other camera can change its position and a further set of fringes have to project. These procedure can be repeated as much as necessary to get the whole body measurement, i.e. one can “go” step by step completely around the object. The calculation of all of the necessary orientation parameters and 3-D coordinates then takes place

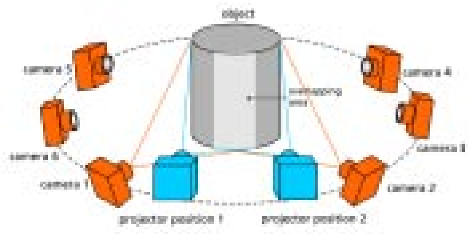

Fig. 1:
Basic camera – fringe projector arrangement for whole body measurement.

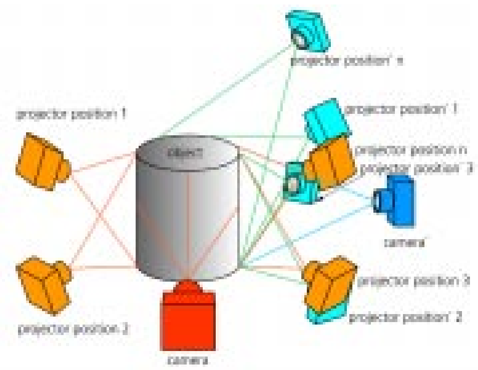

Fig. 2:
Mobile selfcalibrating camera – fringe projector network for whole body measurement.

Fig. 3:
Mobile camera-fringe projector network while measuring the owl above the entrance of the Fraunhofer IOF.

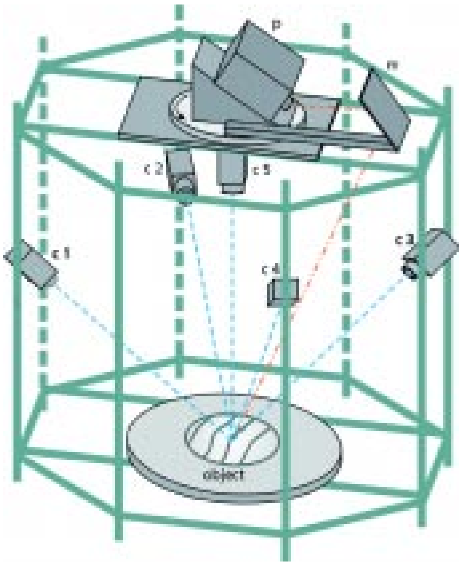

Fig. 4:
Schematic representation of a self-calibrating measurement system – kolibri.

Fig. 5:
View within the measurement system kolibri.

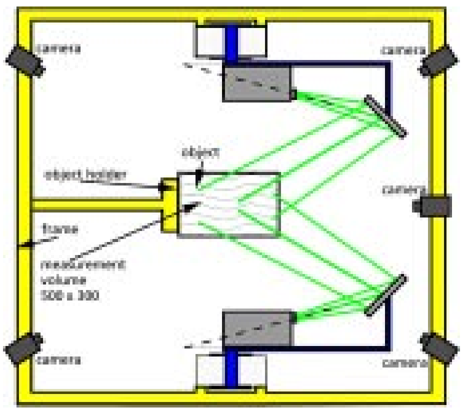

Fig. 6:
Schematic representation of a self-calibrating measurement system – kolibri-duo.

within one calculation after the consumption of the measurement values. It should be pointed out that no information of the position of the projector(s) as well as of the cameras during the whole measurement is necessary.

B) Stationary measurement system – kolibri™

A possible stationary self-calibrating measurement set-up for whole body measurement – named "kolibri"™ – according to the above concept is shown in Fig. 4 and 5 /3, 4/. Here the object under measure is put on a holder which is mounted on a frame. At this frame the cameras (c1–c5, for example) are mounted so that the position of the cameras with respect to the object are fixed during the whole measurement procedure.
To get the necessary different projection directions for the self-calibration (i.e. at least two) the projector P, illuminating the object via the mirror m, is rotated with respect to the fixed object and cameras.

The procedure of data consumption is the following one. At each rotation (projection) position the mentioned two grating sequences rotated by 90° are projected onto the object.
All cameras capture these fringe pictures simultaneously. On the basis of these fringe pictures at least 4 phase values for each pixel of the camera can be calculated. Using these phase values, the 3-D-coordinates as well as all of the orientation parameters are calculated.
As described before each camera measures its own single view (patch), whereby the different patches automatically fit together to the full-body view because they are measured in the same world-coordinate system.

The following features of the measurement system have been realized:

- measurement field:
  Æ 100–600 mm
- maximum number of simultaneous measured patches (cameras): 12
- maximum number of measurement points: 3 Mio.
- maximum number of measurement points per patch:
  250 000 (512 x 512 pixel)
- measurement accuracy:
  1/20 000 of the illuminated field
  < 20 µm standard deviation
- measurement time
  (with 12 cameras): 30 s–5 min

The only restriction of the measurement set-up kolibri is that it is not easily possible to measure an object from the top and from beneath within one measurement procedure, because only one projection unit can be used illuminating the object within one half sphere.

C) Stationary measurement system – kolibri-duo™

To solve the mentioned problem it is straightforward to illuminate and observe the object at the same time from the top and beneath. The schematic arrangement of such a measurement setup is shown in Fig. 6 – named kolibri-duo.

Measurement examples showing the power of this system-concepts are shown in Fig. 7, 8 and 9.

Conclusions

The developed system-concept(s) ensure a high number of object points, quick data acquisition, and a simultaneous determination of coordinates and system parameters (self calibration), making the system completely insensitive to environmental changes. Furthermore, there is no necessity of any marker on the object surface and a subsequent matching of the single views is not required to obtain a full-body measurement. These all giving the possibility to use the systems directly in a production line.

References

/1/ Kirschner V., Schreiber W., Kowarschik R., Notni G., “Self-calibrating shape-measuring system based on fringe projection”, Proc.SPIE (3102) p.5-13, 1997

/2/ Schreiber W., Notni G. “Theory and arrangements of self-calibrating whole-body three-dimensional measurement systems using fringe projection technique” Optical Engineering 39 (2000) S.159-169

/3/ Notni G., Schreiber W., Heinze M., Notni G.H. “Flexible autocalibrating full-body 3-D measurement system using digital light projection” Proc.SPIE 3824 (1999) S.79-87

/4/ Schreiber W., Notni G. “Vorrichtung zur Bestimmung der raeumlichen Koordinaten von Gegenstaenden” PCT/EP99/08272

Fig. 7:
The owl above the entrance of the IOF (STL-data set).

Fig. 8:
Seat measured with kolibri (STL-data set).

Fig. 9:
Point-cloud of an automotive part measured with kolibri.