POTENTIAL OF HIGH-PRECISION MEASURING TECHNIQUES FOR THE MONITORING OF SURFACES FROM HERITAGE OBJECTS

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Abstract

A comparison of different high-resolution and high-precision three-dimensional measuring techniques to be used for the documentation of the spatial structure of natural surfaces will be presented. The potential of different strategies will be shown at the example of a sandstone surface which underlies degradations due to atmospheric factors. Different aspects like spatial resolution, accuracy and ways of application will be compared for techniques like fringe pattern projection, digital stereo photogrammetry and a hand-guided close-up range triangulation laser scanner. A conclusion with regard to the task of stone conservation is presented too.

1. Type of technology/methodology

Our investigation focuses on the use of modern technologies originally developed for the use in other fields of applications, like industrial quality control for example, and to see how suitable these tools are for surface monitoring purposes at monumental surfaces. The equipment used comprises three different types of instruments:

- Fringe projection
- Hand-guided high precision close-range triangulation laser scanner
- High resolution digital stereo photogrammetry

The project continues an investigation which has been started in the early 90ies and was dedicated to show the possibilities of analytical photogrammetry for a verification of small surface degradations.

Test field

For that purpose a permanent test field had been established in the ruins of the former Romanesque convent Limburg, being located close to Bad Dürkheim (cf. Fig. 1). The test field shows a sandstone area at the outer surface of the object. As the test area consists of a soft stone (cf. Fig. 2), it is a prominent candidate for degradations due to the impact of whether and/or environment and very suitable to show the potential of techniques trying to monitor any kind of morphological changes. The object contains many original faces of many sandstone ashlars being preserved for nearly 1000 years and are therefore also of high interest for conservators.

In order to respect the needs of a high precision analysis a fix and stable reference frame had been introduced. The frame consists of several cylindrical control points which had been deeply embedded into the stone (cf. Fig.3) and are able to represent a long time stable co-ordinate system allowing to transform all measurements into a common framework. That guarantees best conditions for a comparison of different date sets and the derivation of significant results.

Figure 1. Convent Limburg, built in the 11. century, ruin since 16. century.

Figure 2. Test field with decorations of the medieval masons

Figure 3. reference point

Equipment

As already mentioned, three different technologies have been applied, in order to comparatively evaluate their suitability for the purpose of monitoring. For each technology we could use state of the art equipment allowing to produce typical and representative results.

Fringe projection (cf. Fig. 4): This technology can be seen as a photogrammtric solution equipped with an active light projection and designed for highest accuracy demands. The whole system is characterized by a stable and invariant mounting of two cameras, a pattern projector with high luminosity, a control device and an attached notebook, which runs all programs necessary to derive precise results. The cameras are arranged with converging optical axes, so they see the same object part. For the spatial measuring process the projector illuminates the object with different patterns, why each object pixel along the camera base gets a unique characteristic. This allows to solve correspondence problems and to calculate the spatial position of each object pixel. The system allows point spacings of 0.12 mm up 1.4 mm depending of the configuration and distance to the object with an accuracy for an object point of 1/20 of its size.

Figure 4. fringe projector type GOM Atos II

Figure 5. hand guided arm, type Faro

Figure 6. stereo configuration, with AVT cameras, type Pike

Hand-guided scanning arms (cf. Fig. 5): Such mobile scanning systems are typical tools dedicated to monitor the quality criteria in industrial production processes and have found a world-wide acceptance meanwhile. These instruments are characterized by an arm separated into several pieces, which are linked by precise 360° joins. When the head of the arm is moved in space, his position will be calculated using the rotation angles between the elements and with their length. This conception allows to get an accurate individual head position. In order to measure surfaces the head has to be equipped with a scanning device. Then, the object is captured in conformance to the number and size of elements in the scanning head. Our system was configurated with a line scanner with a swath width of 35 mm and a resolution of 0.3 mm.

Digital stereo photogrammetry (cf. Fig. 6): Stereo photogrammetry is a well known and experienced technique and at the beginning of the monitoring project, this was the only technology allowing to generate precise numerical object models. As in all other technological fields, the process of innovation by an increasing use of semiconductor elements gives also new possibilites to photogrammetric solutions. We therefore checked also the usefulness of a stereo arrangement with high resolution digital cameras. With the configuration selected (chip size ~ 2K by 2K Pixel; scale ~1:50; b/h ratio ~1:6) we got a resolution of about 0.4 mm and a good stereo impression for the operator.

Selection and configuration of the three instruments supports different investigations and evaluations. Both scanning devices generate directly complete spatial models of the surface, without any interactive compilation process from the users side, whereas stereo models primarily provide the potential to make spatial measurements, being guided by a visual impression. So we have different kind of information and processing.

All these instruments have been used in summer 2007 to monitor the surface of the test field. The data collected then served as base for a comparison allowing to show the suitability of each technology.

2. Type of parameter that is preferentially measured and of material monitored

In the context of in-situ monitoring purposes our investigation corresponds to questions concerning degradation processes. Mainly those degradations which have an impact on the morphological structure of the monuments surface. Such variations may be expressed in different scales, wherein the ability to proof already very small changes would be most helpful. Only then it could be possible to identify at a very early stage an existing degradation and to express its strength.

For conservators the precise checking of the morphology of a decayed surface (stone, mural painting or plaster) is mainly interesting for recording future changes in order to estimate the risk of serious damages. Therefore the examination has to be repeated after a certain period (several month, years or decades). In the past such evaluations have been founded simply on photos. But a reliable analysis is then difficult because of missing spatial information and the variability of visual appearances due to resolution, different light conditions or view point.

Certainly such activities are primarily applied to really high-quality surfaces, where already very small losses (<1 mm^3) are critical. But also then it should be possible to have a powerful technique, which gives the messages required and can be applied under controlled conditions with justifiable costs.

Therefore it’s the main objective of the project to analyze and compare above mentioned technologies for the purpose of precisely checking the geometrical shape of the test field surface. In this context it is of interest to distinguish different characteristics, which may be important for a surveillance. This are at first pure geometrical aspects, but also things concerning the potential to guide further reasoning, questions of practical use or demands to the user and his experience may be of interest.

From the geometrical side there are characteristics of interest like

- Resolution
- Precision
- Morphological quality

which allow to evaluate the potential of these techniques. However, in the context of cause studies other parameter like

- Ability to monitor the objects appearance

- Interpretability of data sets

are of value and have to be seen also. Finally practical things like

- Effort
- Practical constraints
- User requirements

are further elements of an evaluation showing the usefulness of an instrumentation.

3. In situ application

The test field has a dimension of about 0,2 by 0,3 m^2 and shows several linear depressions in a general flat stone. The appearance is the well known diffuse red sandstone characteristic and can be seen as a representative stone surface. Although it's size reaches not even a square meter, it is large enough to show the general characteristics of the technologies used and to compare their features.

From the practical side we have to distinguish steps like calibration, orientation/transformation, data collection and evaluation, what differs considerably for the techniques used, why we have to look at each instrument separately.

Fringe projection (cf. Fig. 7): Each individual measurement frame consists of one spatial object model in the field of view. In function of quality and spatial coverage several individual frames have to be collected in order to avoid small missing areas, which may be produced by occlusions due to the perspective view or problems due to insufficient reflectivity. Fig. 7 shows the overlap of 4 different frames which have been collected to get reliable results.

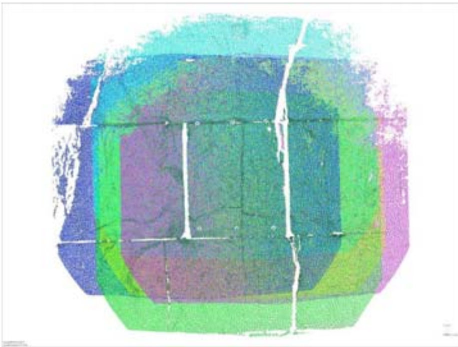

Figure 7. patches generated from fringe projection

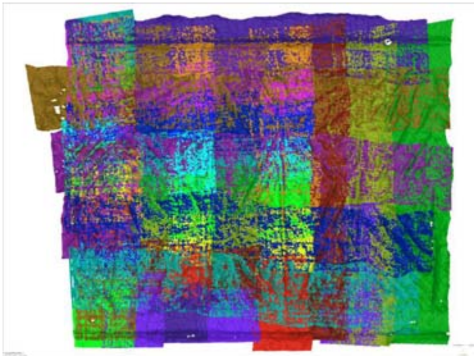

Figure 8. patches generated from hand guided scanning

In the context of preparatory steps we have to calibrate the device prior to a measuring campaign, because the interior orientation has to be well known. Furthermore a geometrical frame has to be established, allowing to combine multiple, partial overlapping frames. This is the general case, because mostly the object is larger as an individual frame. Simply in our case the object fits already into one frame.

Finally, all data set have to be registered into the same geometrical base and the surface has to be triangulated. Then, the final data set expressing the whole object surface is available.

Hand-guided scanning (cf. Fig. 8): Each individual measurement consists of a small line scan at an individual position of the arm. A continuous surface coverage is achieved by slowly moving the head over the surface. In function of quality and spatial coverage here also several individual strips are necessary in order to avoid small missing areas, which may be similarly forced by occlusions or insufficient reflectivity. Fig. 8 shows the overlap of the patches which have been collected.

In the context of preparatory steps a calibration can be avoided, simply an initialization is required to get the arm ready for measurement. However, a geometrical correspondence between scanning device and arm has to be introduced. For that purpose a calibration object, like a cube for example, has to be measured in both systems. A geometrical transformation then establishes the relation needed. Further geometrical actions arise from the need to measure reference points in the objects and in case of the necessity to displace the whole arm some further objects points are required to combine the data from different positions. At the end, all measurements have to be triangulated.

Digital stereo photogrammetry (cf. Fig. 9): As photogrammetry is split into a capture step and an evaluation step acting looks a bit different to the two former ones.

Figure 9. high resolution image from stereo pair

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The task to be performed at the object is simply to assure, that images will be collected with the required resolution, overlap and at the right position. This will be simplified, when – as has been realized in the test- two cameras will be used at the same time, firmly mounted on a stable base in the correct geometrical relationship.

Number and geometrical coverage of the stereo models has to be chosen in accordance to size, curvature and morphological structure of the object. The latter aspect is again important with respect of occlusions to be expected.

In the context of preparatory steps, we have the typical chain of calibration and orientation, similar to a fringe projection. Calibration has to assure the interior structure of the cameras, whereas the orientation establishes the correct relation to the object coordinate system. A calibration is necessary after changes in the optical set up of the cameras and can also be done beforehand in the laboratory.

In contrast to the other two principles, the image capture doesn't provide a spatial model of the object. It only generates a "virtual model", allowing to derive spatial measurements in a subsequent compilation process. This might be done interactively be means of a human operator or with help of computer algorithms.

From the practical view there are some common aspects and other ones, which may vary considerably. All techniques have in common, that object and circumstances have to be in a acceptable state (dust, humidity, temperature,....)

4. Evaluation of methodology/technology used

Looking at the results in a more general way, it turns out that all techniques were able to provide a detailed real or virtual surface model. There were no practical limitations, which might have avoided to generate reliable measurements.

	Fringe projection	**Hand guided scanning**	**photogrammetry**
Result	**digital 3D surface model**		**virtual 3D surface model**
general			
Calibration / orientation	+	o	-
Complexity of acting	o	-	+
Measuring time at object	o	-	+
characterstic of data			
resolution	o	-	+
accuracy	+	-	+
constraints from object size	o	-	+
quality for interpretation	o	-	+
evaluation			
Handling of data	+	o	-
effort	+	o	-
costs	-	-	+

Table 1. comparison of techniques used

All equipment is sufficiently robust to be applied outside under normal meteorological conditions. Some smaller restrictions have to be respected by fringe projection systems, as they are sensible to ambient light, why it is helpful to use the system in the early morning or late evening hours. A typical result is visualized in fig. 10 and 11, a comparison of general characteristics shows table 1.

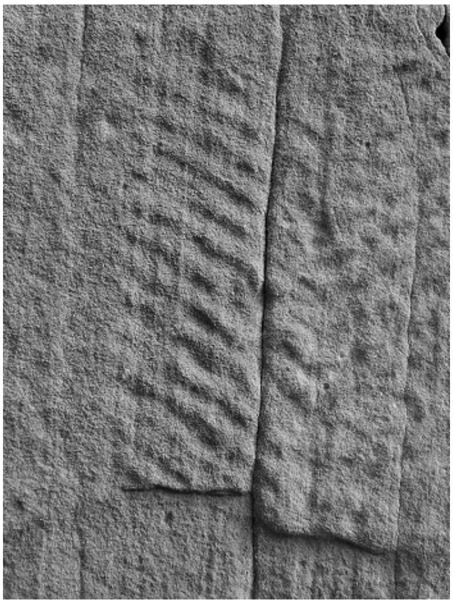

Figure 10. surface patch in one image from stereo pair

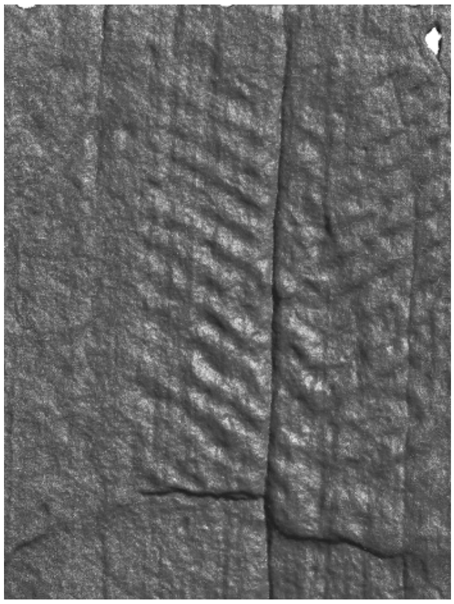

Figure 11. visualized shape of surface patch as derived from fringe projection

Confronting the techniques, we first have to see one vital difference: photogrammtry provides virtual 3D models, whereas the other system give directly real spatial data. As consequence, a photogrammetric processing chain needs a further compilation process, which might be achieved by a human operator or by an algorithmic processing of the digital image data. This might be advantageous, as an interpreting human operator allows to extract exactly those surface elements needed for his investigation and thus avoiding a huge amount of redundant data. But the effort produced is surely disadvantageous, when a complete and detailed spatial discretization of the surface has to be achieved. Alternatively such a discretization might be produced applying matching algorithms. But then the quality strongly depends on surface complexity and object texture and is in general poorer than acquired from the two other systems.

Looking at the optical impression from fig. 10 and fig. 11 it shows, that the spatial quality of the real 3D model is very high. The spatial resolution is not exactly the same as the visual, but is close to it. This depends at a certain degree on the set up of this test and the chosen parameter. But in general, image richness will still be superior to the spatial one. Nevertheless density and quality of the spatial model are very high and can also be further adopted to the needs of an investigation. To the cost of a higher effort spatial models of a resolution far beyond 0.1 mm are possible. However, such a parameterization is not very applicable to larger surface patches of several square meter.

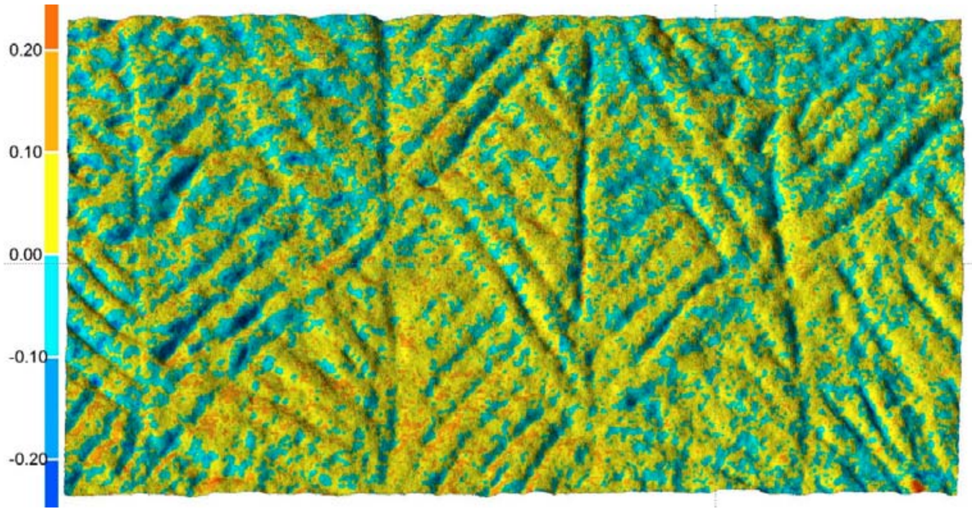

Figure 12. difference map of surface patches from fringe projection and scanning

Comparing scanning and projection technique, there are significant differences visible, as shown in fig. 12. There, a difference map (Z_{fringe} - Z_{scan}) is displayed giving an impression of the morphological variations between both spatial models. Red areas show areas of higher values for fringe projection, whereas towards green color fringe data is lower. As the distribution of the colors proofs, the spatial model of the scanning head shows less details. In regions of spatial depressions or of ridges the data cuts the morphology in a stronger way, than it is the case for the projection. The quality of the scanning data therefore has to be classified worse in relation to fringe projection.

In addition, the manual effort for data collection is considerably higher for a scanning process, why it seems not as good suited for monitoring. This rating may change, when the object surface shows strong spatial complexity. Then it is simpler to follow the surface by hand, whereas a projector needs several different views onto the object in order to avoid unmeasured surface parts which may be forced by occlusions.

Looking at practical aspects in a more general way, we have an increasing complexity of handling from photogrammetry to hand-guided scanning. A stereo-photogrammetric equipment is demanding in the context of determining the interior camera geometry, but when some general aspects like overlap of adjacent models or sufficient reference points are respected, the whole process can even be effected by a non specialist. This is not that simple for the two other systems, with some additional handling features for and hand guided system, why it is classified as least suitable for non techniciens.

Conclusion

A final evaluation of the test has to conclude with the fact, that modern equipment for quality control in the industry and modern digital photogrammetric systems provide new possibilities for the control of monument surfaces. It is possible to derive quantitative descriptions of the object surface with a resolution of better than 0.1 mm, what gives good preconditions for an objective estimation of surface degradations. This considerably simplifies the monitoring process and allows to state at a very early stage potential degradation processes.

Photogrammetry is not able to produce comparable discrete spatial models at low costs, but has the advantage to provide visual information of highest resolution, what may optimally support an analysis of the object and gives additionally a virtual spatial model allowing to support spatial investigations at those locations in the object which are very prominent and significant for the analysis.

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