# ARCHITECTURAL SURFACE MONITORING BY MEANS OF THE ACTIVE VISION SYSTEM "AVS"

A.Balsamo[a], A.Chimienti[b], P. Grattoni[b], A. Meda[a], R. Nerino[c], G. Pettiti[b], M.L. Rastello[c], M. Spertino[b]
[a] IMGC, Strada delle Cacce, 75, 10135 Torino – Italy, a.balsamo@imgc.cnr.it
[b] IEIIT - CNR, C. Duca degli Abruzzi, 24, 10129 Torino – Italy, paolo.grattoni@ieiit.cnr.it
[c] IEN, Strada delle Cacce, 91, 10135 Torino – Italy, {nerino,rastello}@ien.it

**KEY WORDS: 3D Measurements, Colour Measurements, Active Vision, Cultural Heritage, Monitoring**

## ABSTRACT

Monitoring of works of art is essential in Cultural Heritage management. To this end, an active vision system (AVS) has been designed and developed to deal with architectural surfaces and frescoes. Typically it works in a range from 3 to 8 meters and allows to perform integrated geometric and colorimetric measurements. This paper presents the results of tests carried out on AVS in laboratory in order to assess the performances of this system in monitoring operations. Comparisons carried out with a commercial colorimeter and a laser scanner are presented too. Critical aspects and possible improvement of AVS are discussed in the conclusion.

## 1. INTRODUCTION

Monitoring of the conservation degree of art pieces is essential in Cultural Heritage management. It allows to detect possible degradation phenomena and to their diffusion, thus saving art pieces and money. Monitoring requires repeated measurements of relevant parameters of an art piece, to check their changes over time. In the field of interest of architectural surfaces (monuments, statues, …), frescoes and paintings, two of the most important parameters concern geometric and colorimetric information. To enable the detection of surface changes at a given resolution (e.g. erosion, mould growth, chemical alterations, …), geometric and colorimetric measurements must be sufficiently accurate and strictly correlated each other. A preliminary condition for this to occur, especially for colorimetric measurements, is to reproduce the same measurement conditions (surveying geometry, colour temperature of the light sources, test point localization, …) in subsequent measuring sessions. Indeed, results of colour measurement of a test point on a painted surface may change significantly with small shifts of the measuring device position. On the other hand, the use of landmarks to mark these points is not always possible for obvious reasons, so monitoring may become a tricky task. The Active Vision System (AVS), specifically designed for acquiring and monitoring frescoes and architectural surfaces (Grattoni 2002), overcomes these problems. AVS performs accurate integrated colorimetric and geometric measurements in a range ~ (3 – 8) m and with a field of view of about 6×4 m² at 8 m. Thanks to its computerized control of the operations, it can record both the results and the setup parameters of measurement, i.e.: relative spatial position between instrument and scene, integration time, fixation angles, spatial resolution of the cameras, artificial light positioning and colour temperature, and anything else that pertains to the acquisition stage. This way, AVS can accurately recover the measuring setup in subsequent measuring sessions, and repeat the measures automatically. In addition, it can process the acquired data on-field and compare the results with previous ones (monitoring), so avoiding possible waste of time and money due to postponing analyses to laboratory, as with traditional procedures. Aim of this paper is the description of laboratory tests carried out to estimate the system performances in monitoring tasks and the presentation of results. After a short description of the AVS system and of its working principle (Section 2), this paper first describes the procedures to measure and monitor surface geometry and colour (Section 3). Then, in Section 4, it presents the new results obtained in the laboratory tests, and compares them with a commercial laser scanner and a tristimulus colorimeter.[1]

## 2. SHORT DESCRIPTION OF AVS SYSTEM

In this Section a short description of the AVS system is given, just to make the comprehension of the remaining part of the paper easier, since AVS has been already described more extensively in (Grattoni 2002; Chimienti 2004). With reference to Fig. 1, AVS is composed of three B/W TV cameras aligned along a common axis $\gamma$. Two of these cameras (TL1 and TL2) are equipped with tele-objectives to frame only small portions of a scene at high resolution. They form a stereo couple and can be rotated by known angles, both around the parallel pan axes $\alpha 1$ and $\alpha 2$ and the tilt axis $\gamma$, to perform the fixation of any point of a scene. One of the TLs is equipped with tristimulus filters which allow the acquisition (measure) of high accuracy colour images of the examined surface. The third camera is equipped with a wide-angle lens (WA) which allows one to frame the whole region of interest at a lower resolution. The WA is mainly involved in system management tasks while TLs deal with surveying and measurement. When this system is used, the acquisition of pictorial and dimensional information is obtained as follows: AVS is placed in front of the subject to acquire (see Fig 2) and set to frame the whole region of interest using the WA camera. The WA image is processed to detect the structures of interest for the current task and then the TL cameras are made to converge on them (fixation), to perform the required measures (e.g. geometric, colorimetric). Once TLs are fixating a structure, AVS can compute the relative position of this structure by forward triangulating their optical axis, can compute the spatial evolution of the surface around the fixation point from the couple of TL stereo images, and can perform a pixel wise colour measurement (X, Y, Z and L, a , b coordinates) according to CIE standard.

All the measurement parameters and results are automatically recorded so that they can be recovered in successive measuring campaign for monitoring purposes allowing both the accurate repetition of the measures and results comparison. It must be outlined that AVS is able to acquire colorimetric and geometric information over large regions of the scene at high spatial resolution too (Grattoni 2003) but this facility is exploited, instead of the acquisition of a limited number of test points,

---

[1] This work has been carried out under grant of P.F. Beni Culturali and P.N. Parnaso – SIINDA.

only when explicitly required because of the large amount of data it supplies. The main features of the system are: a baseline length of 800 mm, rotation stages with 0.001° of angular resolution, TL1 and TL2 14 bit/pixel digital cooled cameras with a sensitivity of 4·10-7 lux, equipped with f = 105 mm objectives. For our tests, AVS was geometrically calibrated to work over a range from 3 to 8 m (Balsamo). Laboratory tests based on the measure of an 800 mm bar length showed a mean error of 0.31 mm, with a standard deviation of 0.28 mm, all over the working volume and in every orientation. AVS was also calibrated for colour measurements, in indoor environments, and laboratory tests on 11 reference tiles showed a mean error Δ = 1.36 CIE Lab unit with 0.9 standard deviation.

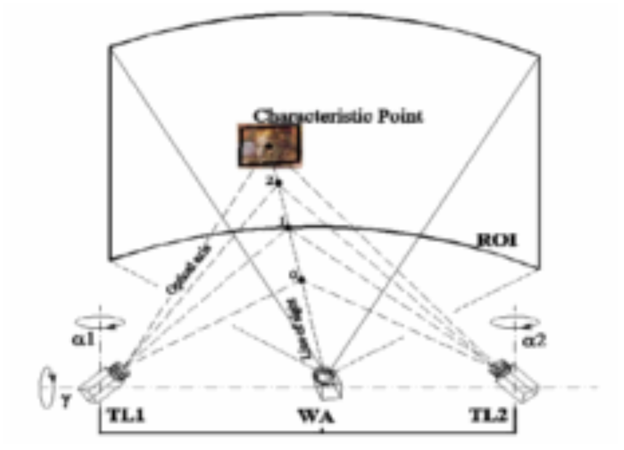

Figure 1 - AVS schematic description

.

Figure 2 – The measurement setup for colour monitoring

## 3. MONITORING PROCEDURES

Monitoring geometric and colorimetric changes of object surfaces require both a suitable accuracy of the measuring devices, to be able detecting changes at a proper degree, and the capability to recover the same measuring conditions in different sessions, in order to get comparable results. These requirements are especially true for (non-in-contact) colorimetric measurements which greatly depend on the measuring geometry, that is, on the capability of identifying the same testing areas in absence of landmarks and, at the same time, of recovering the same relative position among illuminant sources, surface under test and measuring device. For example a small change in location recovery of the reference testing area can produce significant variation in measure results because of the non uniform colour distribution of a painted surface. Thanks to its features AVS allows to overcome some of these drawbacks. In short, the monitoring procedure is as follows. The first time the AVS is set in front of a subject (monument, fresco, …) to be surveyed, it identifies some characteristic points (natural and/or artificial) on the subject, which are taken as spatial references, and measures their position with respect to its own reference system. In addition AVS measures the relative position and orientation of the illuminating lamps used for the measure. At this point the operator interactively drives the system to fixate and measure specific points of interest on the subject. For each of these points AVS records and saves all the measuring results:

- 3D position of the test point;
- colour components and 3D surface evolution around the fixation point;
- geometric parameters of some features (size, shape,…);
- measuring system parameters (sensor binning, integration time of the cameras, etc.).

In subsequent measuring campaigns, AVS is set again in front of the subject and once the original measuring position is recovered by fixating the same reference characteristic points, measurements can be automatically repeated by using the report file of the reference measuring campaign. Obviously, the system usability in practical application depends on its measurement accuracy. In order to assess system performances in monitoring tasks we have devised two kinds of laboratory tests: one concerning the measurements repeatability and accuracy in different sessions, the other concerning the performance comparison with some commercial devices (Laser Scanner Minolta VI910, tristimulus colorimeter PhotoResearch PR650) In the following section we will describe these tests in detail.

## 4. LABORATORY TESTS AND RESULTS

Tests were aimed to assess accuracy and repeatability of AVS geometric and colorimetric measurement and were carried out on two different scenes. The first one (Fig. 3) consists of an almost convex object inserted in a corner-cube background which is used to test the accuracy and repeatability in 3D reconstruction. The second one (Fig. 2) is used to simulate the measuring conditions of frescoes on a wall, to this purpose some tiles were painted on the surface wall with 4 different colours. In addition, on each tile a very thin cross was drawn to have an accurate reference about the localization of the chosen test point.

### 4.1 Tests on dimensional reconstruction accuracy

The dimensional reconstruction accuracy of the AVS was compared with that of the commercial laser scanner (VI-910) on the same reference object, namely a copy of the pharaoh Ramesses II bust framed into a reference support (see Fig.3). The reference support is made of three orthogonal planes in a corner-cube configuration and it was intended to provide the same reference frame both for laser measurements and for AVS measurements. As a first step a 3D reference model of the subject was obtained by the laser scanner operating at its maximum accuracy. The accuracy of the scanners depends on several factors, in particular on the surface reflectance, on the object distance, on the measurement direction and, for this type of scanner, also on the objective used (accuracy of the VI-910 equipped with wide-angle lenses is claimed better than +/-1.4 mm at 0.6 m).

Generally the accuracy decreases with the object distance, linearly in a plane perpendicular to the line of sight of the optics, and with quadratic law along it. Laser scanner shows also a limited depth-of-field, and scanning objects at quite different depths in a single scan can be cumbersome. Hence to build a complete 3D model several scans at different poses are generally required, followed by a registration phase to bring the scans in the same reference frame. The registration of data with different and spatial varying accuracies coming from scans at different poses leads to possible misleading interpretations of the comparison results. To avoid this problem the laser-object pose did not change during the scanning of the reference model. To be able to relate the bust data to the reference frame in a single scan both the bust and the planes must be acquired contemporary. In this case their relative distance and the limited depth-of-field of the scanner forced the object-scanner distance to be greater than 0.9 m.

Preliminary measurements were made in the working volume (about 2 $m^3$ ) on a 3D reference target to evaluate the best laser settings (actually wide-angle objective, bust distance 1m ) for which the highest accuracy (absolute error lower than 1.3 mm) can be obtained in the working volume. A reference model of the bust has been obtained averaging 5 different scans with the above mentioned laser settings (see the textured model in Fig. 4). The 3D data in the scanner reference system were expressed in the reference frame by fitting the 3D data of the planes and then by building up the reference frame representation in the scanner laser reference system. A multiscale volumetric approach based on radial basis functions has been employed to fit the 3D scan points with a volumetric function (Dalmasso 2004). The surface approximating the data is the zero level set of the volumetric function. The accuracy of the model respect to the data was evaluated from the distribution of the distances between the approximating surface and the 3D data along the normal to the surface. The distances were estimated from the gradient of the volumetric function evaluated on the surface and from the function values on the 3D data points, assuming a local linear approximation of the volumetric function. The mean distance between 3D points and the surface model was of about 0.2 mm, well below the data accuracy, hence avoiding to introduce further errors. In a second step two acquisitions of the reference object were performed and two 3D data sets were produced: one by the AVS system and the other by the laser scanner. The 3D data points were obtained by the scanner with new settings (tele objective lenses, bust distance 2.5 m), and from AVS by a stereo vision algorithm which processes the TLs image pairs of the AVS system.

3D reconstructions from stereo were performed using the graph cut algorithm (Kolmogorov 2001) which is one of the more effective present in literature. Both data sets were referred to the reference frame: the laser data by the same procedure used for the reference model, the AVS data by using the 3D position of circular targets on the reference planes (see Fig. 3). The measurement accuracy of the two data sets was evaluated by comparison with the reference model by using the same approach adopted to validate the reference model from its 3D data. 3D points outside 20 mm from the reference model were assumed outliers and filtered out. The spatial distribution of the euclidean distances of the 3D points normal to the surface of the reference model, as measured by AVS and by laser scanner, are superimposed on the surface itself in Fig. 5 and Fig. 6 respectively. The min/max values of the scale in Fig.5 are +/- 10 mm, while in Fig. 6 are +/- 20 mm. In Table 1 a quantitative comparison of the measurement accuracy of the two approaches is given by the statistics of the distance distributions.

### 4.2 Tests on colour monitoring

With reference to Figure 2, tests have been carried out as follows:

Figure 3 - Test scene for geometric measurements: a copy of Ramesse II bust kept in the Egyptian Museum in Turin

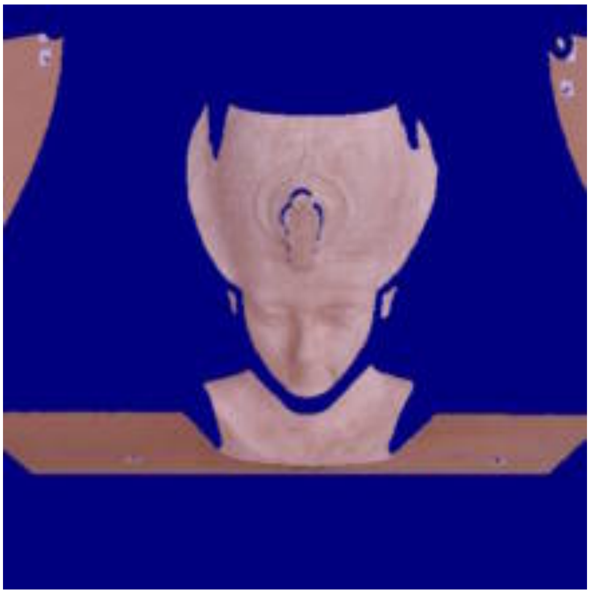

Figure 4 - The 3D reference model

a) In the first measure campaign the SVA system was set up in front of the wall at the proper distance (about 5 m) and four lamps L were placed for the best illumination. The WA image was saved as a reference (WA_R) for subsequent operations, and the spatial positions of SVA and lamps were marked for future comparisons. A barite disk (WR in Fig. 2) was used as a White Reference.

b) the relative system-to-wall position was measured by fixating the N ( N ≥ 5) artificial targets, and the position of the 4 lamps (defined by artificial targets) were computed with respect to SVA. All position parameters, that is the 3D coordinates of the N Artificial Targets (AT_R) and of the 4 lamps (L_R) were saved for reference.

c) Then the operator interactively drove the AVS to fixate in sequence the points of interest on the 4 coloured tiles plus a test point on the natural wall surface (TPi, i=1, 2, …, 5 in Fig 2), which were marked with a thin cross as described above. At last, AVS performed the colour measurement using three different spot sizes around the image centre: 33×33, 17×17 and 9×9 pixels.

d) The three-chromatic components resulting from these measures (CIE X, Y, Z and L*, a*, b*), together with the 3D co-ordinates and the left TL image of the test points, were stored together with the measuring parameters of the TL camera.

e) To get statistics on measure noise, step c and d were automatically repeated 10 times in sequence, without changing the measurement setup. Results are shown in Table 2.

| Method | Mean distance respect to reference [mm] | Standard Dev respect to reference [mm] | Max Error respect to reference [mm] |
|---|---|---|---|
| (*) Laser Scanner 2.5 m | 10 | 8 | 20 |
| Stereo Vision 2.5 m | 2 | 4 | 20 |

Table 1 – Comparison of 3D reconstruction at 2.5 m distance. Laser scanner vs. Stereo Vision Algorithm

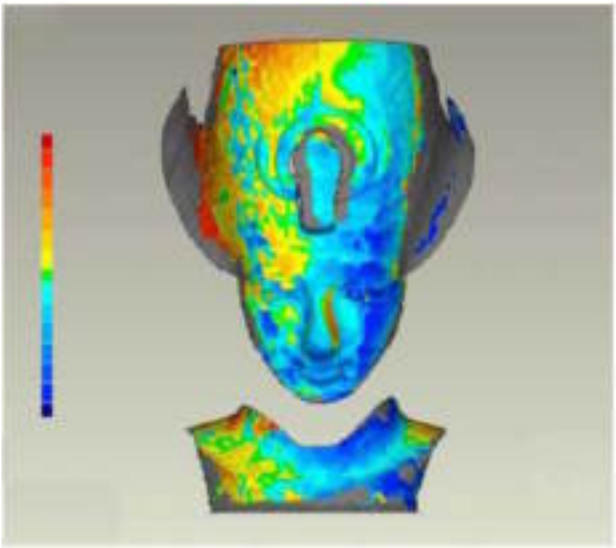

Figure 5 - False color representation of 3D measurements deviation from the model using AVS: scale ranges from - 10 mm (dark blue) to +10 mm (dark red)

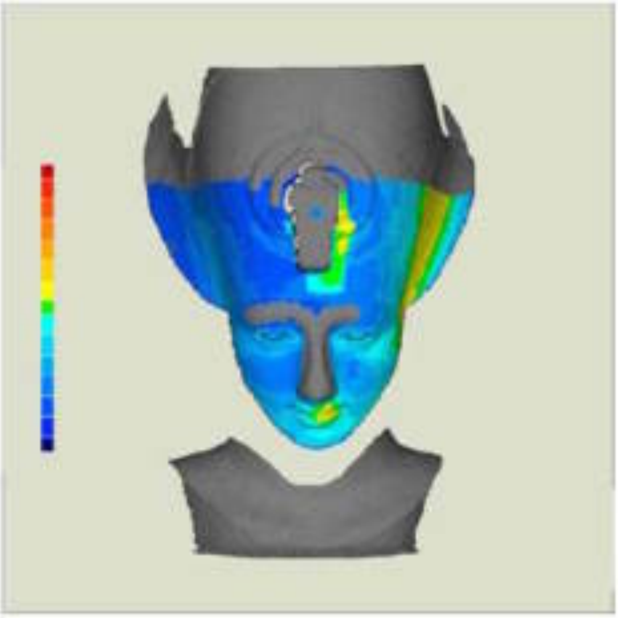

Figure 6 - False color representation of 3D measurements deviation from the model using Laser Scanner: scale ranges from - 20 mm (dark blue) to +20 mm (dark red)

In the subsequent measuring campaigns the above procedure was split into two steps: the system setup, in order to test the repositioning accuracy, and the colour measurement, to test measure repeatability.

**Setup test:**

a) AVS and lamps were moved away from the reference position, then AVS system was roughly repositioned in front of the wall by comparing the WA_R reference image with the current WA;

b) the spatial position of the N artificial targets (AT) were measured and the roto-translation RT between the reference position and the present position of SVA was computed as the transformation that takes the N points AT into the reference ones AT_R;

c) a good approximation of the reference position of AVS was easily recovered in one step only (using RT) with a repositioning error lower than 50 mm;

d) the residual roto-translation were computed again and used to correct the reference 3D coordinate into the new setup;

e) the 4 lamps were repositioned by fixating their artificial targets by SVA and the one step repositioning error was well below 50 mm.

**Measure:** measures were repeated following the Report:

a) TL cameras were automatically driven to fixate each test points (after conversion into the present co-ordinate system), and TL were set to the corresponding parameters;

b) colour measures (CIE X,Y,Z and L*a*b*) were automatically executed, and the fixation error $\Delta x$ and $\Delta y$ evaluated as the displacement between the present and the reference TL image of the test point, in pixel. The new results were recorded while a comparison with previous ones was immediately displayed to allow for new actions, if required. Results are shown in Table 3.

In Table 3 the mean values and standard deviation, computed over five different measuring campaigns for each test point, are shown together with the maximum error in terms of ΔCIE Lab units, with respect to the Reference Value of Table 2. The fixation error in pixel, $\Delta x$ and $\Delta y$, is also reported.

The same set of measures have been carried out, independently, using the commercial tristimulus colorimeter PR650 (label C in Fig. 2) and results are reported in Table 4.

In this Table ΔCIE Lab represents the maximum deviation with respect to the mean value.

| Spot size | | Test Point 1 | | | Test Point 2 | | | Test Point 3 | | | Test Point 4 | | | Test Point 5 | | | Mean on row |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* | |
| 16 mm | mean | 74.22 | -26.21 | 41.70 | 76.13 | 18.73 | 75.8 | 49.83 | 54.92 | 46.30 | 61.53 | -26.68 | -34.06 | 73.04 | 1.96 | 5.46 | |
| | st.dev. | 0.12 | 0.39 | 0.17 | 0.13 | 0.40 | 0.21 | 0.13 | 0.20 | 0.21 | 0.14 | 0.26 | 0.21 | 0.14 | 0,38 | 0.27 | **0.22** |
| 8 mm | mean | 74.02 | -24.69 | 41.20 | 76.82 | 19.71 | 76.04 | 49.37 | 52.77 | 44.44 | 61.43 | -26.88 | -37.02 | 72.82 | 3.30 | 5.50 | |
| | st.dev. | 0.07 | 0.39 | 0.16 | 0.06 | 0.48 | 0.21 | 0.06 | 0.38 | 0.17 | 0.08 | 0.32 | 0.24 | 0.22 | 0,74 | 0.24 | **0.25** |
| 4 mm | mean | 74.25 | -24.92 | 41.60 | 76.90 | 19.58 | 76.23 | 49.16 | 52.02 | 43.79 | 61.54 | -26.94 | -36.69 | 72,71 | 6.16 | 5.51 | |
| | st.dev. | 0.10 | 0.23 | 0.18 | 0.21 | 0.59 | 0.27 | 0.12 | 0.43 | 0.19 | 0.20 | 0.56 | 0.21 | 0.23 | 0.69 | 0.27 | **0.30** |

Table 2- Colour measure statistics for three different spot sizes using AVS

| Spot size | | Test Point 1 | | | Test Point 2 | | | Test Point 3 | | | Test Point 4 | | | Test Point 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* |
| 16 mm | Ref. Value | 74.22 | -26.21 | 41.70 | 76.13 | 18.73 | 75.08 | 49.83 | 54.92 | 46.30 | 61.53 | -26.68 | -34.06 | 73.04 | 1.96 | 5.46 |
| | st. dev. | 0.19 | 0.33 | 0.25 | 0.27 | 0.75 | 0.34 | 0.21 | 0.50 | 0.23 | 0.31 | 0.55 | 0.40 | 0.29 | 0.96 | 0.38 |
| | Max ΔCIE Lab | 0.69 | | | 0.92 | | | 0.78 | | | 1.16 | | | 0.98 | | |
| Repositioning error [mm] | | Δx=0.3; Δy=0.3 | | | Δx=0.3; Δy=0.7 | | | Δx=0.7; Δy=0.7 | | | Δx=0.6; Δy=0.1 | | | Δx=1; Δy=1 | | |

Table 2- Colour measure statistics for three different spot sizes using AVS

| Spot size | | Test Point 1 | | | Test Point 2 | | | Test Point 3 | | | Test Point 4 | | | Test Point 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* | L* | a* | b* |
| 45 mm | Ref. Value | 72.88 | -29.40 | 39.94 | 75.05 | 20.54 | 81.75 | 49.35 | 51.30 | 48.70 | 61.49 | -27.76 | -32.22 | 71.65 | 2.07 | 5.79 |
| | st. dev. | 0.59 | 1.27 | 0.94 | 0.81 | 1.24 | 1.46 | 0.29 | 1.06 | 1.18 | 0.53 | 0.95 | 2.13 | 0.29 | 0.26 | 0.33 |
| | Max ΔCIE Lab | 2.35 | | | 2.85 | | | 2.26 | | | 3.73 | | | 0.73 | | |
| Repositioning error [mm] | | less than 30 mm | | | | | | | | | | | | | | |

Table 4 - Colour monitoring using PR650 colorimeter

### 4.3 Analysis of results

**4.3.1 Repositioning:** Before analysing the geometric and colorimetric aspect, it must be outlined the effectiveness of the procedure for the recovery of the reference position of the AVS system. Indeed, the visual comparison of the current WA image with the reference one (step a of the setup procedure) allows an initial good estimation of the spatial position (less than 1m offset at 5 m distance is easily obtained), then the roto-translation computation (step c of the setup procedure) allows reducing the residual offset to less than 5 cm in a single step. The same considerations hold for lamps repositioning. Concerning the repeatability of the test points fixation, tests were carried out both during the different colour measure campaigns (as shown in Table 3) and by starting from very different SVA offsets chosen on purpose up to 1 m in any direction to get more critical conditions. Repeatability was quite good in both cases: less than o equal to 1 pixel (equivalent to ≈1 mm on the scene).

**4.3.2 Geometric tests:** Results of Table 1 show a bias in both the data (mean distance) which can be explained by the influence of some nonlinearity in the measurements that propagates when referring the 3D data to the reference system. In general the results show a better performance of the stereo approach respect to scanner laser. It must be pointed out that the stereo approach generally produces more 3D outliers (≈10%) than the scanner laser approach (≈3.5%), but it is able to cope better with depth-of-field constraints and the acquisition process is simpler and more flexible. Furthermore the bias of the data is lower, probably because of a better measurement linearity.

**4.3.3 Colorimetric tests:** Concerning colour measurements we observe at first that measurement accuracy and repeatability increases as the measuring spot size increases (see st.dev. in Table 2) since repositioning uncertainty is averaged over a bigger area. On the other hand small spot sizes allow the system to deal with more complex textures. From this point of view, AVS allows both to choose the most suitable resolution (spot size) for the specific problem and to get a map of colour measurement at the same time. This task is impossible using conventional colorimeters. About measure repeatability in different campaigns, Table 3 shows that repeatability stays inside 1.16 ΔCIE Lab units and so it remains well below the human perception threshold which has been evaluated around 5 ΔCIE Lab units. On the contrary, repeatability obtained by using the colorimeter PR650 is inside 3.73 ΔCIE Lab units, despite of its large measuring area (45 mm). Obviously this is not due to the measurement uncertainty of the device, which is x = ±0.005, y= ±0.005 in Y,x,y coordinates, but it is essentially due to the repositioning uncertainty. This confirms the importance of good repositioning capability for colour monitoring and can justify our approach.

## 5. CONCLUSIONS

The Artificial Vision System was designed to perform monitoring tasks on architectural surfaces and frescoes. It allows to carry out integrated colorimetric and geometric measurements. The tests described in this paper have shown that AVS is able to perform both these measures with a given accuracy and that it performs monitoring tasks better or at least with the same accuracy of commercial devices. Thanks to these features, in addition to the possibility of performing 3D and colorimetric survey of large surfaces at pixel resolution level and of carrying out in field analysis and comparison of results, the AVS system seems to be suitable for a systematic monitoring of different subject, both in indoor and outdoor environment. In the tests described above, results on colour measurements repeatability have been carried out using Artificial Targets (AT) only as a reference points. Undoubtedly, this allows better performances than using Natural reference Targets (NT) since the localization error of AT amounts to some hundredth of pixel against some tenth of pixel for NT. On the other hand, fixed AT are used in photogrammetry for long time monitoring. The influence of the use of NT on colour measurements repeatability will be investigated in next steps. About geometric measurements, we think that this test is just a first attempt to evaluate and compare performances of these kind of 3D measuring devices. Further analysis and tests are required, for example, to deepen the influence of surface reflectance, kind of texture and surface curvature and to model the dependence of the measurement accuracy on the 3D point position into the working volume. This will allow a better accuracy in the change of reference frame and hence in the final reconstruction. This can be important also in multiple scan registration by traditional methods (e.g. ICP algorithm). The main drawback of AVS system is intrinsic to its passive stereo approach to 3D reconstruction which needs textured surfaces, but this can be overcome, for example, by using structured light. Future development will be addressed at the use of structured light.

## REFERENCES

Balsamo, A., Chimienti, A., Desogus, S., Grattoni, P., Meda, A., P., Nerino, R., Pettiti, G., Rastello, M.L., Spertino, M. A Portable Stereovision System for Cultural Heritage Monitoring. Accepted for publication by The Annals of the CIRP.

Chimienti, A., Grattoni, P., Nerino, R., Pettiti, Spertino, M., 2004. An Active Vision System for the Acquisition and Monitoring of Architectural Surfaces and Frescoes. In: Int. Workshop on Vision techniques applied to the Rehabilitation of City Centre, 25-27 October 2004, Lisbon, Portugal.

Dalmasso, P., Nerino, R., 2004. Hierarchical 3D surface reconstruction based on Radial Basis Functions. In: II Int. Symposium on 3D Data Processing, Visualization and Transmission, Thessaloniki, Greece, September 6-9 2004.

Grattoni, P., Nerino, R., Pettiti, G., 2002. Works of Art Monitoring by an Active Vision System. In: International Conference on Science and Technology in Archaeology and Conservation 12-18 August 2002, (Amman- Zarqa- Petra) Jordan, The Hashemite University

Grattoni, P., Spertino, M., 2003. A Mosaicing Approach for the Acquisition and Representation of 3D Painted Surfaces for Conservation and Restoration Purposes. Machine Vision and Applications, Vol 15, pp 1 – 10, 2003

Kolmogorov. V., Zabih, R., 2001. Computing visual correspondence with occlusions using graph cuts. In: International Conference on Computer Vision, Vol. II, pp. 508–515, Vancouver, Canada, July 9-12, 2001.