ORTHOPHOTO PRODUCTION COMPARISON TEST FOR CLOSE-RANGE APPLICATIONS ON HIGHLY CURVED OBJECTS

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ABSTRACT

Orthophoto provides a significant alternative capability for the presentation of architectural or archaeological applications, especially when the product of the survey will be used as basic information for other disciplines. Although orthophoto production from airphotography of high or lower altitudes is considered to be typical, the close range applications for the large-scale survey of monuments still contain a lot of interesting issues to be investigated.
In this paper a comparison test is carried out for the production stages of large-scale (1:5) orthophotos of highly curved non-developable surfaces, in four (4) digital photogrammetric systems (DPS): the SSK of Intergraph, the SoftPlotter, the Virtuozo for Windows v.3.1 and the ADA/ORTHOMAP of Siscam. The objects are mosaics and murals on curved walls of the interior of the Byzantine Monastery of Daphni.
The possibilities and the restrictions of the four DPS for the extraction of digital surface model, manual editing and input of additional points, orthophoto production were investigated. The results were compared according to the values and accuracy of orientation parameters, the necessary editing and the density of points for the efficient orthophoto production, the quality and accuracy of orthophotos. Conclusions for the usefulness, the operation and reliability of each one of the photogrammetric systems for such special applications were derived.

1. INTRODUCTION

Orthophotography is a powerful tool for aerial photogrammetric applications, already tested with excellent results, cost effective and extremely flexible in its digital version. In terrestrial and especially in close-range applications single image rectification and the development of mathematically developable surfaces are mostly applied when monoscopic photogrammetric procedures are used. In architectural and especially in archaeological applications, however, one is very often faced with surfaces, on which these procedures cannot be applied, while at the same time the desired result is an image. In this case the production of an orthophotograph seems to be the only solution, capable of providing reliable and accurate results (Seeger, 1979).

The idea for carrying out the comparative test described in this article, was the investigation of the undisputed possibilities presented and the problems which arise when applying orthophoto techniques in difficult cases of geometric documentation of monuments. It goes without saying that this particular product is extremely valuable, especially as a coverage of a Spatial Information System, and since the digital orthophoto production, provided it works properly, is a fully automated procedure. The investigation concerns the possibilities of producing satisfactory results for close range archaeological applications on highly curved objects, using the orthophoto production software of commercial Digital Photogrammetric Systems (DPS) available to the Laboratory of Photogrammetry of NTU of Athens.

The basic test field characteristics were:

- Large scale (1:5 – 1:10) orthophoto production of high accuracy
- The use of non-metric photography taken at very close distances
- Highly curved objects with high level of detail
- Objects large in size and composed of non-developable surfaces
- The use of pre-marked control points is prohibited

2. DATA OF THE COMPARISON TEST

2.1 Test fields

Three test fields were chosen, all autonomous objects from the interior of the central Church (Katholikon) of the Byzantine Monastery of Daphni. This Monastery was built in the 11^{th} century, it is situated at the southwestern suburbs of Athens and is worldwide famous for its marvellous mosaics, which, to a certain extent, are intact to date. The strong earthquake, which struck the area in 1999 caused severe static problems to the church and endangered the mosaics. Thus the Ministry of Culture asked the Laboratory of Photogrammetry of NTUA to undertake a large project for the detailed geometric documentation of the Church with vector and raster products at scales ranging from 1:5 to 1:50. Hence a considerably large amount of relevant data is available for these tests and their evaluation.

The test fields are two mosaics and a mural. All photographs were taken with a Hasselblad camera, of 6x6 format and a 50mm lens using colour slide film from distances of 1.2 – 1.3 m. Special lighting units were used for the truthful imaging of the colours and the best possible quality of the raw data. In detail the test fields are:

a. The first test field is a mosaic of Archangel Michael (Figure 1), situated in the main altar of the church. The dimensions of the mosaic are 2.53x2.07x0.45 m. The mosaic lies on a surface which is a combination of a cylinder (lower part) and a second order surface (upper part). 8 stereomodels were taken and oriented in total. For the absolute orientations 45 control points were determined on the object with an accuracy of 5 mm.

Figure 1. Test field 1- Mosaic of Archangel Michael

Figure 2. Test field 2 - Mosaic of Annunciation

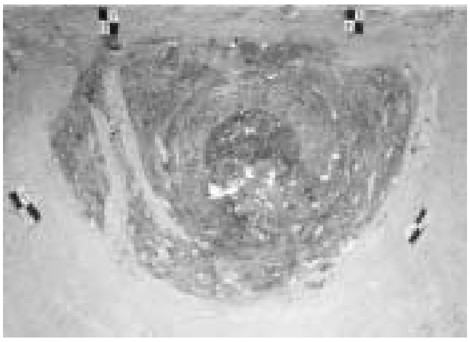

Figure 3. Test field 3 - Fresco with a portrait of a Saint

b. The second test field is a mosaic of the Annunciation (Figure2), situated at the base of the dome. Its dimensions are 2.75x1.73x0.40 m. the surface on which this mosaic lies is actually the orthogonal cross-section of two cylindrical surfaces (pendentive). The photographs taken for this mosaic form 6 steromodels and 49 control points were measured for their orientation.

c. The third test field is a mural, which depicts the portrait of a saint (Figure 3), is situated on the spherical part of a niche at the southern part of the church, but it is in a rather bad condition. Its dimensions are 0.60x0.47x0.35 m. It was covered stereoscopically with one model and 6 pre-marked control points were measured.

2.2 Digital Photogrammetric Systems available for comparison

For the orthophoto production of the three test fields four different DPS's available to the Laboratory of Photogrammetry at the time of the test were used. The cost and the automation and application possibilities of these instruments vary considerably. Thus a comparison of the various software would have no sense. The available DPS's are:

- SSK Imagestation of Z)I Imaging
- SoftPlotter v.2 of Autometric
- VirtuoZo v.3.2 for Windows of Supersoft Inc.
- ADA/New OrthoMap of SISCAM

The basic characteristics of these four instruments which directly concern the orthophoto production procedure are given in Table 1. Detailed descriptions for the possibilities of the software are to be found in the corresponding manuals, but are also briefly described in (Plugers, 2001). Of special interest for the test are:

- The possibility for automatic relative orientation or stereo viewing for measuring points during relative orientation.
- The demands for specialized hardware
- The strategies available for the collection of DTM
- The possibility for automatic DTM collection.

	SSK	SoftPlotter	VirtuoZo	ADA/New ORTHOMAP
Price	60.000 Euro	60.000 Euro	35.000 Euro	25.000 Euro
Operating system	Windows NT	UNIX	Windows NT4.0	Windows 98 NT
Special H/W	Graphic card Special mouse	No	Graphic card	Twin mouse
Stereo-view	Crystal-Eyes active shutter glasses			
Relative orientation	Automatic Stereo view	Automatic Mono view	Automatic Mono view	Semi-automatic Stereo view
Triangulation	Yes	Yes No blunder detection	No	No
Automatic DTM/Contour	Yes	Yes	Yes	Yes
Ortho/Mosaic	Yes	Yes	Yes	Yes
Restitution	Yes	Yes	No	Special module (STEREOMETRIC-PRO)

Table 1. Basic characteristics of the available DPS

3. TEST RESULTS

3.1 Model orientations

For the production of the orthophotos the procedure of independent determination of the orientation elements for each image on each different instrument was chosen. This was carried out using on each system the same control points and - of course – the same person. It turned out that the orientation results differ from each other from one instrument to another. The main quantitative results are:

- The model of test field 3 was oriented on SSK and ADA only, with small differentiations in the determined orientation elements. On SoftPlotter and VirtuoZo on the contrary the adjustment either diverged or there was considerable rest y-parallax left in the model. The most probable cause is the shape of the object and the position of the control points.
- The rest of the orientations gave satisfactory statistical measures for estimating the accuracy, i.e. linear elements accuracy better than 5mm.
- For test fields 1 and 2 the differences of the exterior orientation parameters are within 30mm for all DPS's except SoftPlotter. For the latter a displacement in space of the taking base of some models is noticed, while for the rest of the models the results are similar to those from the other DPS's. The deviations of the camera station coordinates for test field 2 and for the same images, as determined by all four DPS's, appear in Figure 4. The grid size for X axis is 50 cm and for Y and Z axes is 20 cm.
- The result of the automatic relative orientations were in all cases satisfactory.

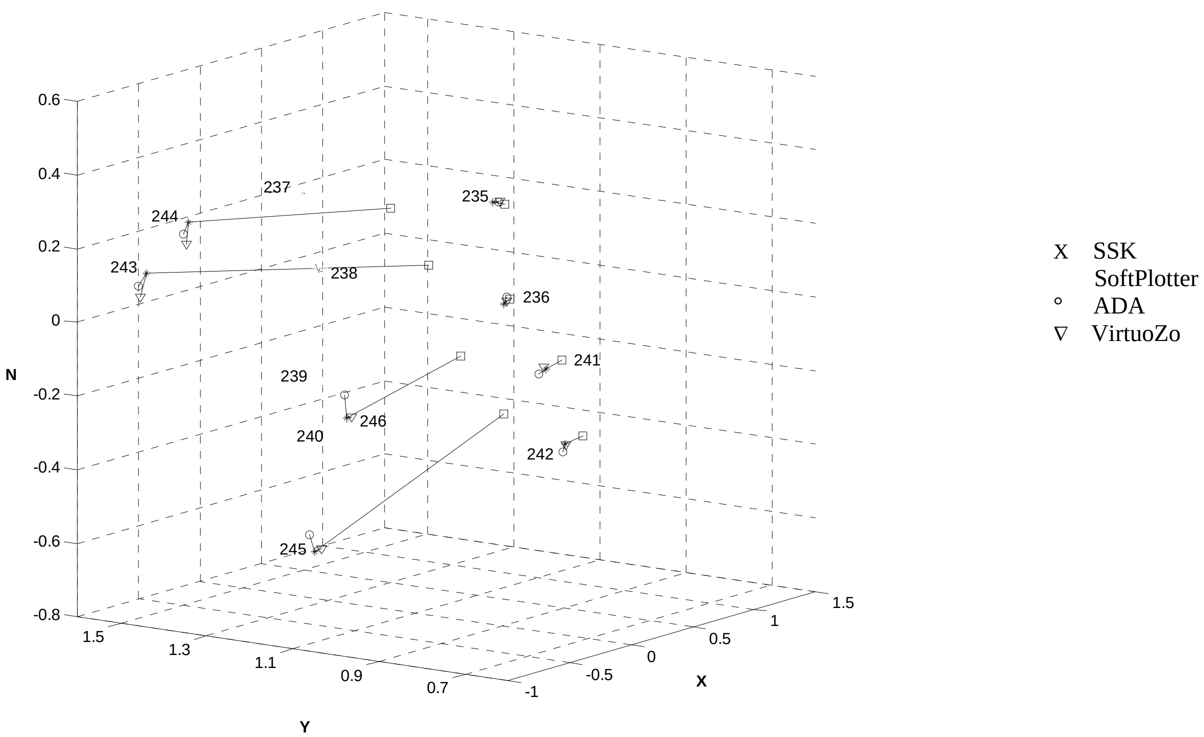

Figure 4. Test field 2 - Deviations of the camera station coordinates

The qualitative comparison of the orientation procedures on the four DPS's has shown that:

- There is a large difference in the friendliness of the various systems used, while executing the orientations. The measurement of the points is carried out in a different way on each instrument, e.g. by using buttons on the VirtuoZo, which makes the procedure tedious.
- The possibility of stereoscopic viewing during the relative orientation for cases of difficult location of control points (for all test images there were only natural control points available) is very important for faster and more reliable results.
- There is a large diversity for the kind and detail of the statistical reports for each system.

3.2 Digital Surface Model generation

The phase of collecting and editing the points for the object surface description is most important for the success of the final orthophoto production. All DPS's are equipped with a set of possibilities in this field, which varies according to the cost and the applications for which each instrument is designed. However all available DPS's are made rather with aerial applications in mind and the automatic generation of a Digital terrain Model. Their use in close-range applications is not always efficient and one should not expect high accuracy results.

A first conclusion from this test could be that VirtuoZo is not capable of collecting DSM grid, when the spacing along an axis is less than 10cm at the scale of the object. For the dimensions of the models of the three test fields this feature is prohibitive, as it would lead to single figure number of points per model. Hence this particular DPS was excluded from the rest of the comparison test. On the other hand, even if the required DSM grid is produced manually, there is a similar limitation in the software of the instrument, i.e. patch width larger than 20cm, which leads to a large pixel size for the orthophoto for scales larger than 1:10, as in these cases.

For the other three DPS's the possibility of producing the DSM automatically was also investigated. The result was a failure in all three test fields, as

- The percentage of the well defined points, as produced by the automatic collection was in all cases smaller than 10% of the total necessary points. In SSK and SoftPlotter, which offer the possibility for selecting the collection strategy the results are a little better than in the case of ADA, where no user intervention is allowed. The description of the surface with these points is not bad, with accuracy, however, unsatisfactory for the scales of the application. In the case of the mosaics with a large area with evenly coloured tessarae this problem is enhanced.
- A large percentage of 'good points' given by the instruments, turns out to be wrongly determined, thus resulting to low reliability products.

As a result of the above, the DSM collection was carried out manually for all three test fields for the rest of the test. Approximately 1000 points per model were digitized for each test field and each DPS. Breaklines were not introduced.

The 3D axonometric views of the DSM for all three test fields as they were produced by ADA appear in Figures 5(a), 6(a) and 7(a). The other two systems produce absolutely similar results.

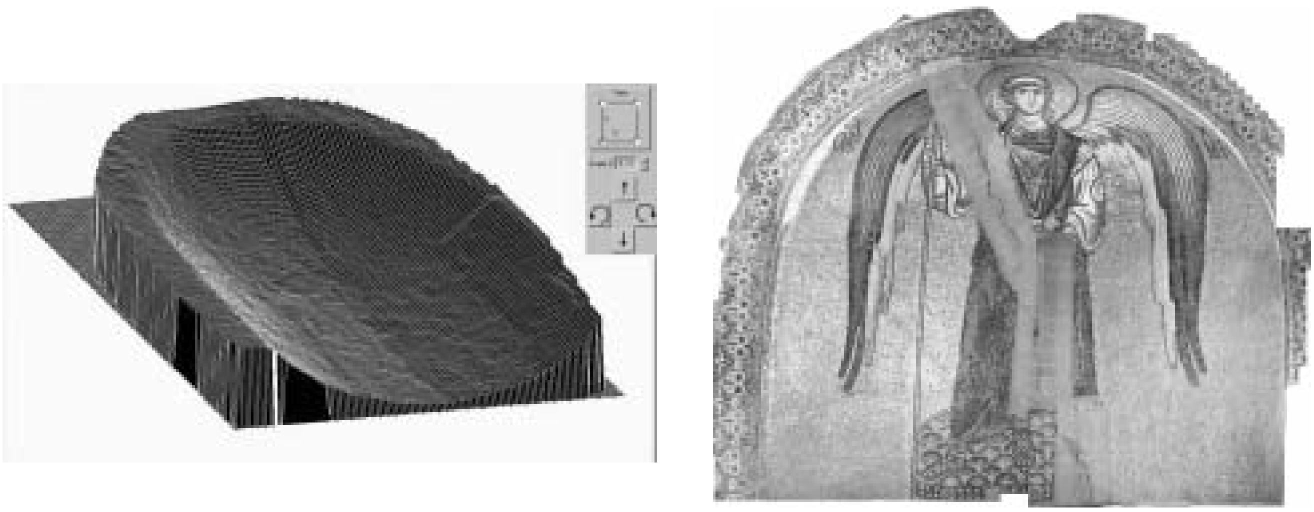

Figure 5. Test field 1: (a) 3D axonometric view of the DSM grid and (b) Orthophoto-mosaic

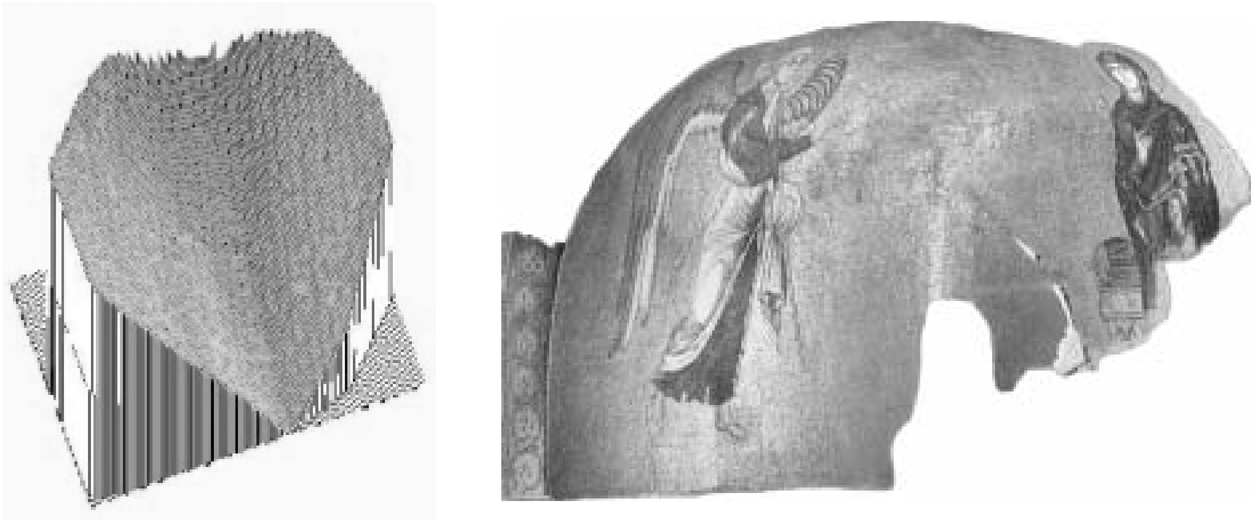

Figure 6. Test field 2: (a) 3D axonometric view of the DSM grid and (b) Orthophoto-mosaic

Figure 7. Test field 3: (a) 3D axonometric view of the DSM grid and (b) Orthophoto-mosaic

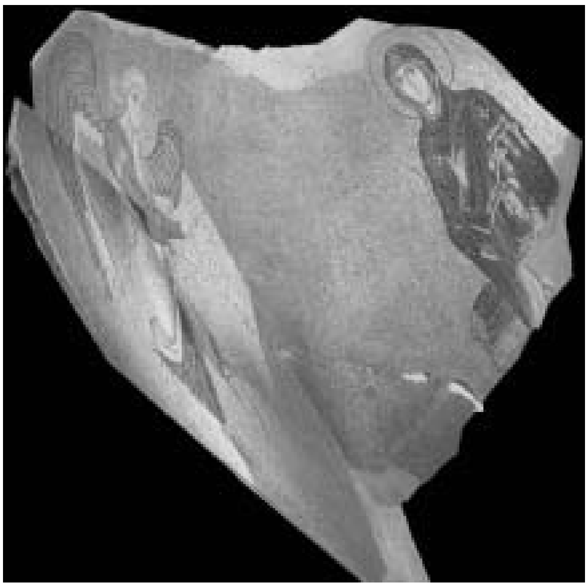

Figure 8. 3D view of the orthophoto-mosaic of the test field 2 overlayed on DSM

3.3 Orthophoto Mosaicking

The last phase of the test was the production of orthophotos and the creation of a single orthophotomosaic for test fields 1 and 2. the procedure is fully automatic for all three DPS’s and the results for the three test fields appear in Figures 5(b), 6(b) and 7(b). Moreover there is the possibility for producing 3D views of the orthophotomosaics overlayed on the DSM (draping). Such a 3D view for test field 2 appears in Figure 8. All orthophotos were produced with a pixel size of 1mm, as larger sizes (2 or 3 mm) resulted in worse qualitative results.

A comparative quality control test of the orthophotomosaics, produced by the three DPS’s, was also carried out. Large deviations were observed among the various products, especially in areas, where the object surface was highly curved. The best qualitative results, during the projection of the objects on the orthophoto, were given by SSK, while the SoftPlotter products presented various problems. Characteristic parts of the orthophotomosaics from the curved surfaces of test fields 1 and 2 are given in Figures 9 and 10 respectively. The deformation and the introduction of tilt in the heads of the two persons depicted in the mosaic as produced by SoftPlotter is clearly apparent. The ADA/New OrthoMap system, although of smaller nominal possibilities and of considerably lower cost, gives rather satisfactory qualitywise results even in difficult, highly curved, areas of the object surface.

(a) product of SSK (b) product of ADA (c) product of SoftPlotter

Figure 9. Visual comparison of orthophotos – Detail of test field 1

(a) product of SSK (b) product of ADA (c) product of SoftPlotter

Figure 10. Visual comparison of orthophotos – Detail of test field 2

4. COMPARISONS

4.1 Accuracy

The accuracy test was carried out in the final products, i.e. the orthophotomosaics, using check points whose co-ordinates were determined with very high accuracy (better than 5 mm) with terrestrial geodetic methods. Intermediate (i.e. orientation results, DSM production) accuracy tests were not carried out, because on one hand it was rather difficult to ensure the considerably high accuracy required for the reference values – “true” values – and on the other hand the final accuracy was of practical interest and not the contribution of each procedure to it. Characteristic check points, 30 for test fields 1 and 2 and 10 for the smaller in size test field 3, were determined. The accuracy of their co-ordinates was ensured using multiple terrestrial geodetic methods in local reference systems – one for each test field. These points were digitized on the final orthophotomosaics:

- 3 orthoimages for test fields 1 and 2 from the SSK, SoftPlotter and ADA systems
- 2 orthoimages for test field 3 from SSK and ADA systems, since the stereomodel was not oriented properly on SoftPlotter.

	Test field 1				Test field 2				Test field 3			
	28 check points				25 check points				10 check points			
	DX(mm)		DZ(mm)		DX(mm)		DZ(mm)		DX(mm)		DZ(mm)	
	r.m.s.	max	r.m.s.	max	r.m.s.	max	r.m.s.	max	r.m.s.	max	r.m.s.	max
SSK	12	-23	6	-11	15	26	9	12	9	16	6	-10
ADA	13	-24	6	-14	14	-24	6	13	9	20	8	-16
SoftPlotter	31	-69	11	27	29	48	12	-26	-	-	-	-

Table 2. Deviations of check points coordinates

The results are given in Table 2. Two check points for test field 1 and 5 for test field 2 were rejected, because they produced blunders for at least one of the systems. The observations for the accuracy test results are:

- the deviations from the real values are a little larger than the expected ones for scale 1:10 in all three test fields. In particular for the X orthophoto axis (parallel to the object) the deviations are larger than 12 mm, while for the Z axis (heights) are smaller with an rms 6-12mm.
- the errors in the orthophotos from SoftPlotter are clearly bigger compared to the ones from the other two systems. Severe problem appears in certain areas of the test fields, thus confirming the observations of the qualitative test for the deformations in the highly curved areas of the objects. Errors of the order of 5cm or bigger may only be justified by an erroneous determination of the exterior orientation parameters of the images.
- the products from SSK and ADA are of similar accuracy and especially for test field 3, where they are almost identical.

4.2 Procedure assessment for orthophoto production

The whole evaluation of the sequence for producing orthophotos on the three DPS's gave the following results:

- *For the friendliness of the system*: SSK was proven to be friendlier in all work phases, the point observation for the orientations, the editing of the DEM, the determination of the parameters for the orthophoto production, the management and imaging of the products (i.e. 3D views). Friendly enough for most of the procedures was ADA system, with the exception of editing the automatically produced DEM. On the contrary, SoftPlotter presents some difficulties and requires complicated actions for certain functions (especially for the DEM), while it is most friendly in executing other procedures (e.g. orthophoto production).
- *For the orientation observations*: The inability of stereoscopic viewing whle executing the relative orientation causes, as already mentioned, severe problems in the case of SoftPlotter. Considerable enhancement is offered by the use of automatic relative orientation in SSK and in VirtuoZo.
- *For DTM automation*: The results in all three DPS's were lower than expected and practically useless.
- *For speed of production*: All instruments gave satisfactory results, with minor differences, negligible for the whole of the project.

5. CONCLUSIONS

Carrying out comparative tests for the accuracy and functionality of the production procedures of digital orthophotos from aerial imagery (Baltsavias et al., 1996) established their usage in a wide range of applications. At the same time the use of orthophoto in architectural and archaeological applications has proven useful even since the time of analytical orthophoto production (Seeger, 1979) and, of course, it has increased with the application of SIS (Baratin et al., 2000). The results of the present comparative test show that it is possible to use orthophoto even in complicated close-range applications with large probability of success, if certain problems, which might arise, are confronted in time. The choice of the suitable DPS is a factor, which may severely influence the result and the solution of a costly system is not always appropriate. The right use of the available automations is another factor, which mainly concerns the DSM collection. In general the functionality of the DPS's is not yet at the desired level and most systems do not offer to the user the ease of accessing all the possibilities theoretically available. Moreover all DPS's are clearly made for aerial applications, which makes the various problems worse in cases such as the one presented in this paper.

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