

THEORETICAL GROUND ACCURACY ANALYSIS DERIVED FROM TODAY'S AIRBORNE DIGITAL FRAME CAMERAS AND DIRECT GEOREFERENCING

Mohamed M.R. Mostafa and Joe Hutton

APPLANIX Corporation
85 Leek Cr., Richmond Hill
Ontario, Canada L4B 3B3

E-mail: mmostafa@applanix.com

Phone (905) 709-4600 ext 274

ABSTRACT

Airborne Digital Frame Camera Systems have been used in the last few years in various mapping projects around the world. Although they have proved to be a viable replacement to the traditional film cameras, their theoretical accuracy estimates have not been published, except occasionally by camera vendors who have demonstrated system accuracy and practical capabilities under certain flying conditions.

This paper introduces a comprehensive theoretical accuracy assessment for most of the airborne digital frame cameras currently available in the market. The direct georeferencing method has been used in this analysis to demonstrate the capability of each camera geometric configuration when coupled with a GNSS/INS system to produce a precision mapping product. Various models of Direct Georeferencing Systems have been used in this accuracy assessment to illustrate the effect of the direct georeferencing system accuracy on the final mapping accuracy. A number of elements in the photogrammetric process have been analysed to show their effect on the final mapping accuracy. One of these parameters is the Ground Sample distance GSD (which implies the photo scale and flying height). The accuracy assessment results are also compared to the National Mapping Standards of the United States for each digital frame camera used in this accuracy assessment.

INTRODUCTION

For almost a decade, airborne digital frame camera systems have been used in various mapping projects around the world. A number of publications have addressed the design of such systems (c.f., Hinz et al, 1999, Gruber et al, 2003, Mostafa, 2003). Generally speaking, airborne digital frame cameras have proved to be a viable replacement to the traditional film cameras. Their usability, productivity, and superiority in many aspects have been demonstrated by service providers and system vendors. However, their theoretical accuracy estimates have not been published, except occasionally by camera vendors who have demonstrated system accuracy and practical capabilities under certain flying conditions (c.f., Leberl, 2004, Heier and Hinz, 2002, Thurgood and Gruber, 2004, Mostafa, 2003, Madani and Mostafa, 2004). On the other hand, the digital frame camera vendors have properly designed the integration of a GNSS/INS in all the currently available commercial digital cameras. This is done to allow the users to make use of the different advantages of using GNSS/INS systems in the airborne mapping process. Note that it is not necessary to integrate a GNSS/INS system in a digital frame camera since such cameras basically produce a frame image that could simply be used in a traditional photogrammetric sense to be georeferenced in a block fashion.

However, frame camera users have demonstrated numerous advantages of such integration. To name a few, productivity and cost saving, not to mention the capability to aid in rapid response applications and to allow for mapping remote areas where the necessary image acquisition configuration especially conditioned for traditional photogrammetric georeferencing becomes an obstacle (c.f., Molander et al, 2005, Al-Hanbali et al., 2009.) For introduction on direct georeferencing theory, see Schwarz et al, 1993. For details on the theoretical and practical aspects, see Mostafa and Hutton, 2001, Casella et al, 2006, Ip et al, 2004, 2006, and 2007.

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accuracy assessment to illustrate the effect of the direct georeferencing system accuracy on the final mapping accuracy. A number of elements in the photogrammetric process have been analysed to show their effect on the final mapping accuracy. One of these parameters is the Ground Sample distance GSD (which implies the photo scale and flying height). The accuracy assessment results are also compared to the National Mapping Standards of the United States for each digital frame camera used in this accuracy assessment.

METHODOLOGY

The standard variance-covariance propagation is used to compute the theoretical accuracy of a ground object during map compilation. Two cases have been analysed in this project, namely:

- Stereo imagery for map compilation purposes
- Single photo plus DEM for orthophoto production

In each of the above mentioned cases, variance covariance propagation standard modeling approach has been used to compute the ground coordinates of an object. A number of camera systems have been used in this project, namely:

- DMC
- RMK-D
- DSS 439 - 40 mm lens
- DSS 439 - 60 mm lens
- DSS460
- UltraCamD (UCD)
- UltraCam L (UCL)
- UltraCam X (UCX)
- UltraCam Xp (UCXp)
- Pictometry

Each camera configuration is listed in each of the corresponding plot presented in the Results section. The assumptions made in this project can be summarized as follows:

- DEM elevation = 10.0 m.
- DEM Accuracy:
 - DEM accuracy (m) = 0.1, 0.5, and 1.0 m.
 - DEM accuracy (ft) = 0.33, 1.0, and 5.0 ft.
- Image Coordinate Measurement SD = $\frac{1}{2}$ pixel
- Direct Georeferencing System
 - POSAV 410
 - POSAV 510
- Accuracy Standards: ASPRS accuracy standards for large scale maps for both metric and feet units
- Flight Heights
 - 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, and 5000 m.
 - 600, 1800, 3000, 4200, 5400, 6600, 7800, 9000, 10200, 11400, 12600, 13800, and 15000 ft.

RESULTS

This Section is dedicated to present a sample of the results obtained when applying the assumptions made in this project. First, a sample of the medium format camera theoretical horizontal accuracy results using single photo plus a Digital Elevation Model is shown in

Figure 1 for the RMK D Digital System when using a 1/3 foot DEM accuracy data. It is therefore implied that the DEM data has been acquired using a LiDAR system to achieve such elevation accuracy. Note that ASPRS RMS red bars represent the NSSDA horizontal mapping accuracy standards for different map scales.

For example, if a service provider flies an RMK D camera integrated with a POS AV 510 system at AGL of up to 4,200 Ft, the resulting horizontal accuracy will meet the NSSDA accuracy of 1:1,200. This accuracy statement is based on the assumptions listed above assuming that the system has been calibrated and all systematic errors have

been modeled, which is normally the case in the airborne mapping projects.

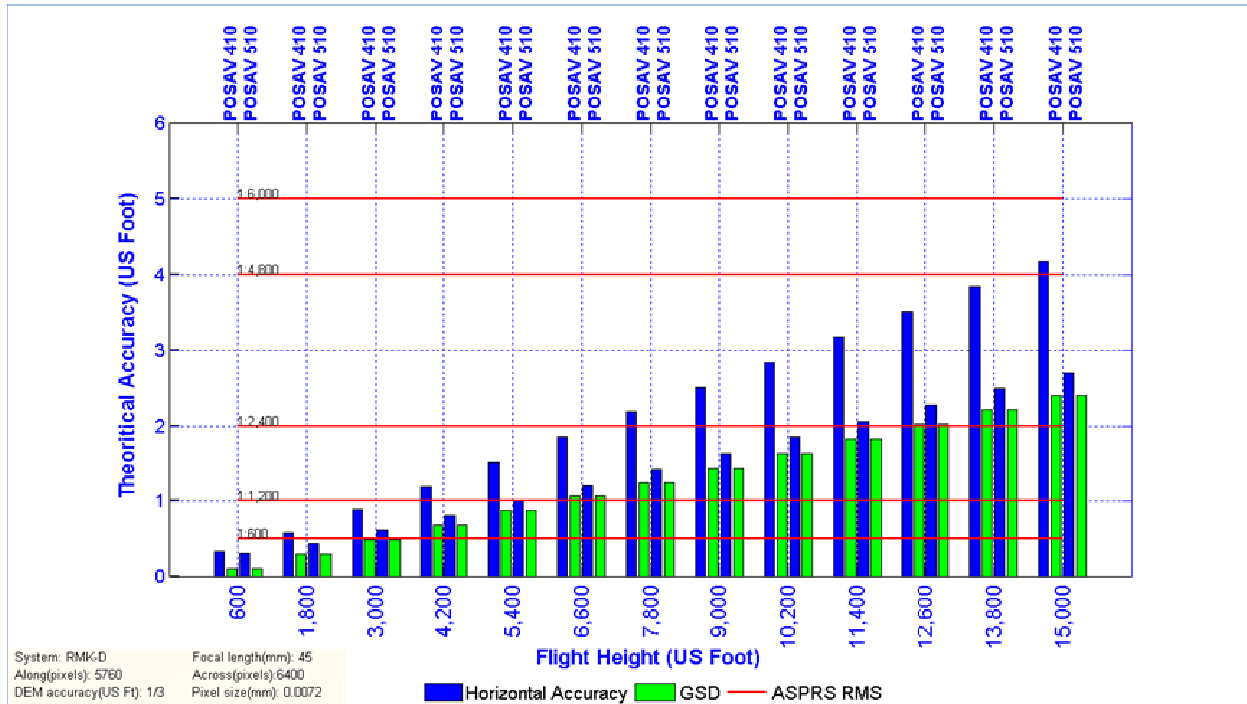


Figure 1. Horizontal Theoretical Accuracy for RMK-D (DEM Accuracy of 1/3 US Foot).

Another example of the medium format camera theoretical horizontal accuracy results is shown in

Figure 2 for the DSS 439 coupled with a 40 mm lens and in

Figure 3 for the DSS439 coupled with a 60 mm lens when using a 1/3 foot DEM accuracy data. A number of observations could be extracted from the medium format figures shown so far. For example, the effect of the direct georeferencing accuracy is evident in some cases such as for smaller image scale (i.e., larger GSD) the higher direct georeferencing accuracy affects the ground object accuracy more significantly than that of the smaller GSD.

In other words, the impact of using POS AV 510 instead of POS AV 410 for small GSD applications at low flight altitudes will be minimal when compared to that of the higher flight altitudes. Also, note that the DSS 439 60 mm lens results produced higher horizontal accuracy than that of the 40 mm DSS439 for the same flight altitude. This is due to the fact that the 60 mm lens will produce smaller GSD than that of the 40 mm and as a result the horizontal accuracy will be higher.

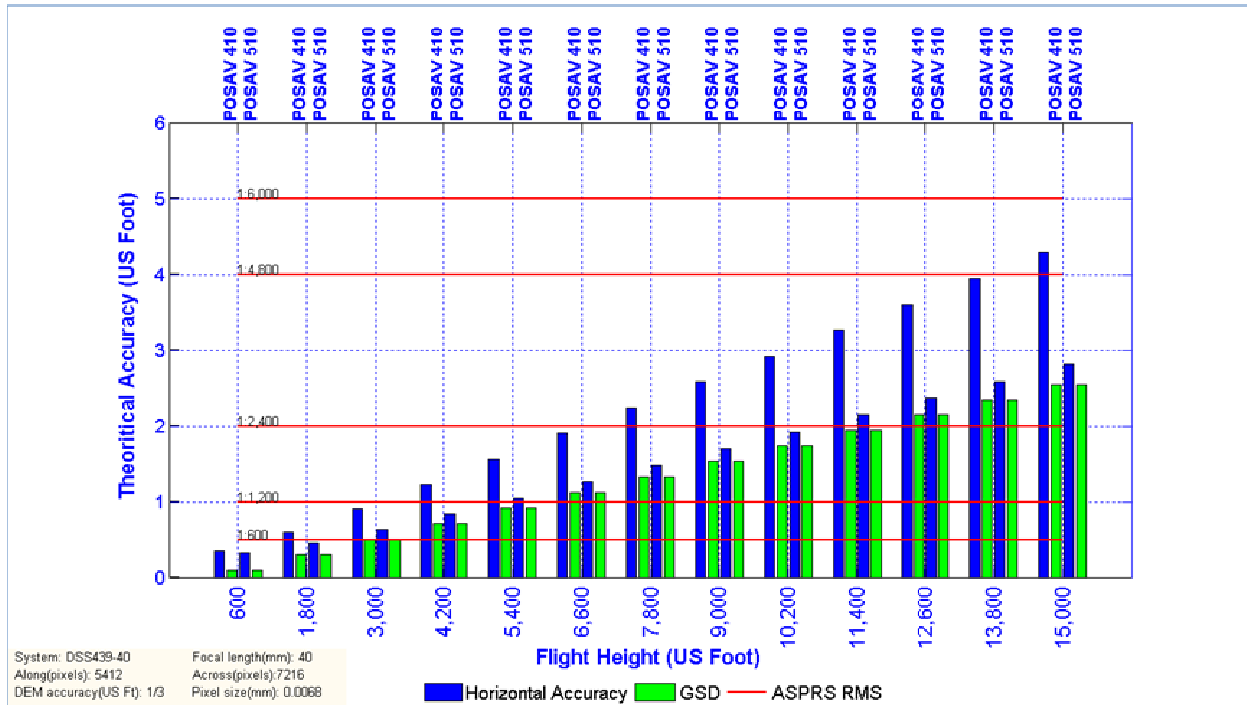


Figure 2. Horizontal Theoretical Accuracy for DSS439 using a 40 mm lens (DEM Accuracy of 1/3 US Foot).

Figure 4 shows the results for the DSS 439 coupled with a 60 mm lens using a 1 foot DEM accuracy data. Note that the effect of the DEM accuracy is dominant in the error budget of the ground coordinates of an object. This is evident when comparing the 1/3 ft DEM accuracy plots shown in

Figure 3 to the 1 Ft DEM accuracy shown in **Figure 4**, especially compared to the GSD size.

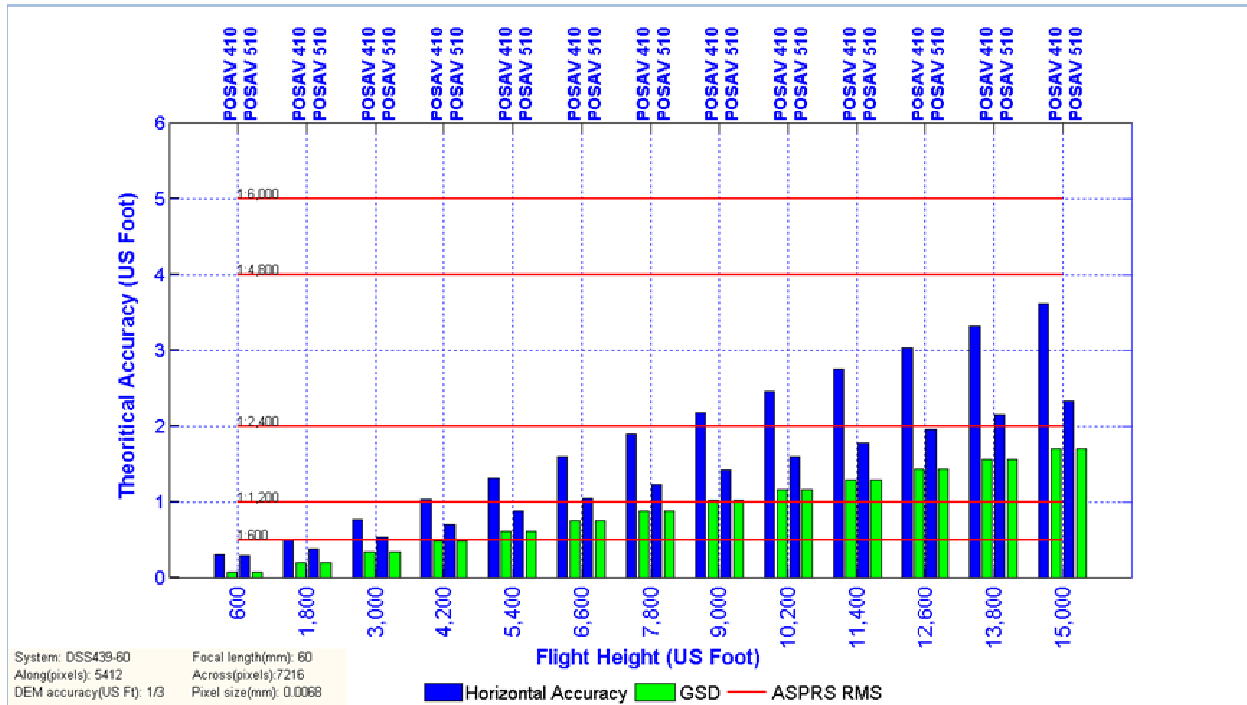


Figure 3. Horizontal Theoretical Accuracy for DSS439 using a 60 mm lens (DEM Accuracy of 1/3 US Foot).

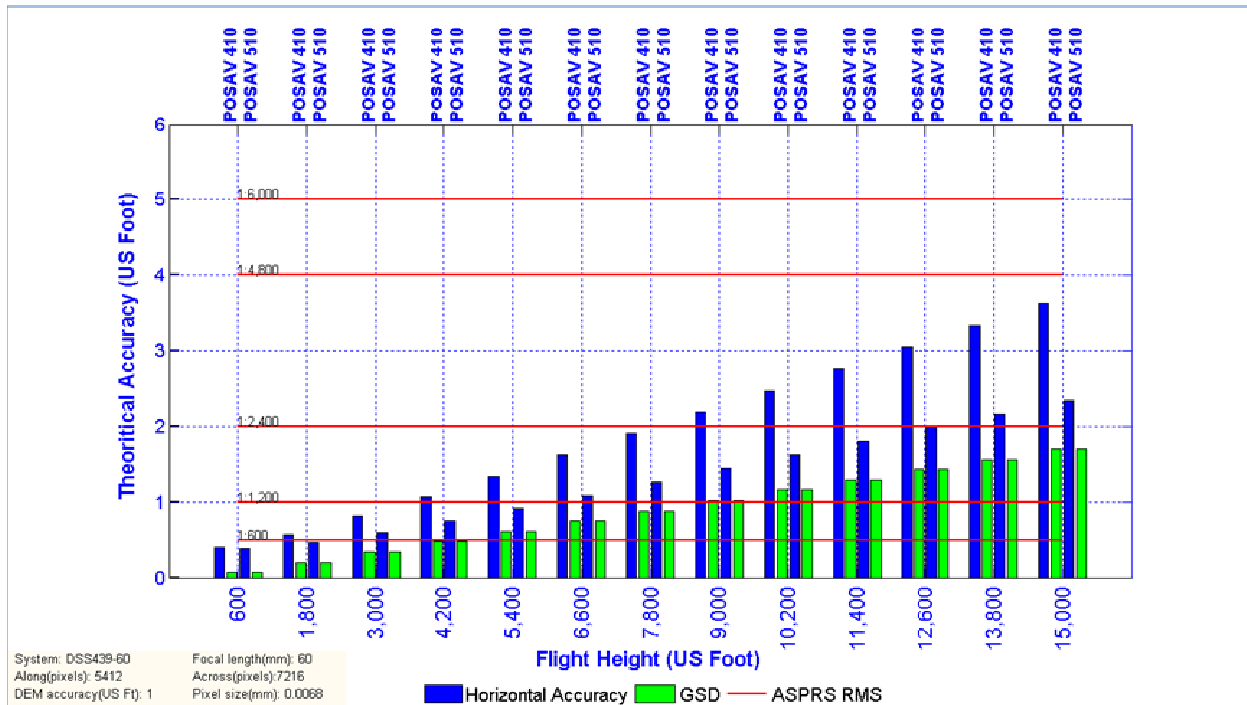


Figure 4. Horizontal Theoretical Accuracy for DSS439 using a 60 mm lens (DEM Accuracy of 1 US Foot).

SUMMARY AND OUTLOOK

Theoretical Accuracy Analysis has been conducted for a number of digital cameras. The results for the case of orthophoto production using a single photo plus DEM have been presented for two medium format cameras namely the RMK D and DSS 439. During the ASPRS conference, the presentation will include the results for large format cameras such as the DMC and UltraCam. Additionally, the stereo results will be presented as well.

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