Correspondence between the GSD of Digital Aerial Photographs and the Scale of Maps – Japanese Case Study and Multi-Country Comparison

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SUMMARY

It has been more than a decade since digital cameras replaced film cameras as the mainstay of aerial photography. Maps are also shifting from print to digital, but our industry's main customers, local governments in Japan, have not yet abandoned the concept of traditional map scale, so we classify the specifications of digital photographs and digital maps using the term "map information level," which corresponds to map scale. The term is specified in the General Standard of Operation Specifications for Public Surveys, which is provided by the national geospatial organization. In addition, since the Standard basically inherits the historical process of printed map production practiced by using film photographs, the ground sample distance (GSD) of digital aerial photographs and the ground position accuracy of digital photos and maps assigned to each "map information level" seem too coarse from the perspective of current equipment and technology.

This study clarifies the current situation of the GSD of digital aerial photographs in public surveying in Japan and compares the results with the standards for digital aerial photography in Germany, the United Kingdom, and the United States. As a result, we perceive the difference in ideas among these countries and there seems to be no common international standard.

We will refer to these findings to plan aerial photography experiments necessary to specify the relevant GSD and ground position accuracy in the future. Then, we will compile the results obtained in a new format of specifications suitable for digital aerial photography together with a correspondence table between GSD and the traditional map scale.

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1. Introduction

The General Standard of Operation Specifications for Public Surveys (hereinafter GSOS; GSI, 2023) is provided by the Geospatial Information Authority of Japan (GSI) and served as a model for public organizations to conduct surveying and mapping. The use of GSOS is not obligatory but most of public organizations employ it as is, so it can be regarded as the national standard for public surveys in Japan. The structure and contents of the GSOS is summarized in our previous paper (Murakami, 2023).
In the recent revision of GSOS in 2023, chapters regarding aerial photographing and map production using films were removed from the part of topographic and photogrammetric surveys. However, the chapters using digital photos basically inherit the historical process of aerial photographing using films and printed map production. The quality criteria for digital photos were specified based on those for film photos. The accuracy of digital maps is defined as the same as those of printed maps.
Before updating the specification of the criteria and process that are suitable for digital photos and maps, we investigate the current situation of digital aerial photographing in public surveys as the first step.

2. Current quality criteria for digital aerial photographing

GSOS defines the inverse of a map scale as a map information level. Ground sampling distance (GSD) is specified for each map information level as in Table 1, where B/H means the ratio of the baseline B and the flight height H of aerial camera positions.

Table 1. Association of map information level with GSD.

Map Information Level	Ground Sample Distance
500	90*2*B/H – 120*2*B/H mm
1000	180*2*B/H – 240*2*B/H mm
2500	300*2*B/H – 375*2*B/H mm
5000	600*2*B/H – 750*2*B/H mm

The quality criteria above were derived from those for film cameras in condition that the height accuracy Δz is proportional to (H/B) and the horizontal accuracy, and that the horizontal accuracy equals half of the GSD, (1/2)*GSD, which means $\Delta z = 1/2*(H/B)*GSD$. Another constraint was posed that Δz should be 0.02% of flight height H of a camera with the principal distance (≈focal length) of 150 mm. Those conditions and constraint lead to Table 2, which are reflected in Table 1.

Table 2. Association of map information level with photo scale.

Map scale	Photo scale	Flight height H (m)	Δz: 0.02% of H (mm)
1:500	1:3,000 – 1:4,000	450 – 600	90 – 120
1:1,000	1:6,000 – 1:8,000	900 – 1200	180 – 240
1:2,500	1:10,000 – 1:12,500	1500 – 1875	300 – 375
1:5,000	1:20,000 – 1:25,000	3000 – 3750	600 – 750

Though quality criteria in Table 1 were cleverly made, the assumption that the horizontal accuracy equals half of the GSD and the constraint that the height accuracy should be 0.02% of flight height were not confirmed to be suitable for digital photos.
Problem comes with the dependence of B/H on camera models. Assuming the overlap of adjacent photos is 60%, DMC III model by Leica and UCFp model by Vexcel, for example, show B/H= 0.25 and 0.39 respectively. This results in the dependency of GSD on camera models.
When substituting the lower B/H, i.e., 0.25 for the lower limit of GSD and the higher B/H for the higher limit of GSD, Table 1 is transformed to Table 3.

Table 3. Association of map information level with specific values of GSD.

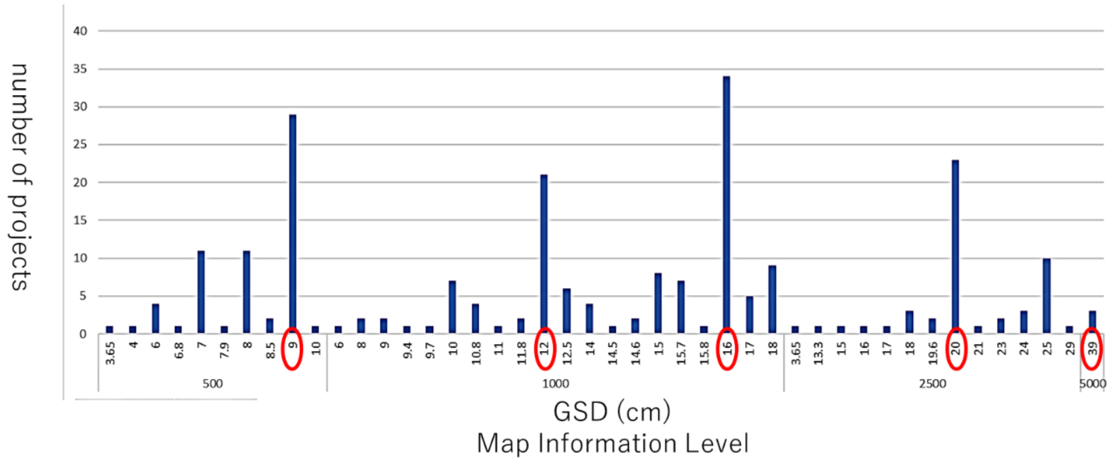
Map Information Level	Ground Sample Distance lower limit (B/H=0.25)	Ground Sample Distance upper limit (B/H=0.39)
500	4.5 cm	9.4 cm
1000	9 cm	18.7 cm
2500	15 cm	29.3 cm
5000	30 cm	58.5 cm

Variation of GSD is doubled for each map information level, which may result in an ambiguous horizontal accuracy of maps.

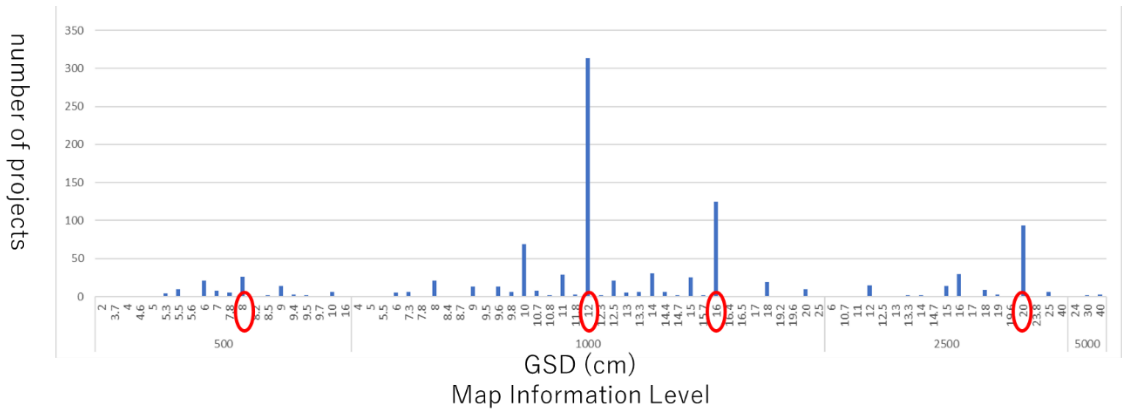
3. Current situation of digital aerial photographing in public surveys

We analyzed two sets of data of digital aerial photographs obtained in public surveys:
A) Data from photos brought by surveying companies contracted for the public sector to Japan Association of Surveyors for its inspection, including 234 projects from 2016 to 2022,
B) Data from photos submitted by the public sector to GSI for its review, including 1055 projects from 2019 to 2021.

Part of dataset A may overlap with B.
Analysis of data set A and B about the correspondence between map information level and GSD shows the resemblance (Figure 1 (a) and (b)), and typical GSDs are prominent for each map information level despite ambiguous criteria shown in Table 3.



(a)



(b)

Figure 1. Correspondence between map information level and GSD.
(a) for data set A; (b) for data set B.

From Figure 1, we summarize the typical GSDs for each map information level (Table 4). We will compare these GSDs with other countries' in Section 4.

Table 4. Typical GSDs derived from the public survey data in Japan

Map Information Level	Ground Sample Distance
500	8 or 9 cm
1000	12 or 16 cm
2500	20 cm
5000	40 cm

Data set A includes camera models used in the public surveys, from which we can find the tendency of B/H employed in the surveys (Figure 2). The figures show the preference for large B/H in Japan. This may be one of the reasons why GSDs show certain values (Table 4) despite ambiguous criteria.

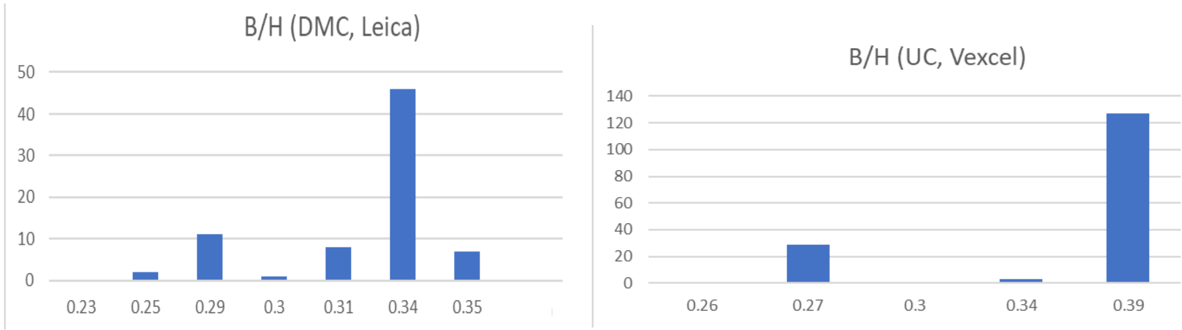


Figure 2. Tendency of B/H employed in public surveys. (left) Leica; (right) Vexcel.

4. Comparison of the specification of aerial photographs among countries

We refer to other countries' standards: Germany (AdV, 2023), United Kingdom (RICS, 2010; 2023), and United States (ASPRS, 2023).

4.1 Comparison with AdV standards

Arbeitsgemeinschaft der Vermessungsverwaltungen der Laender der Bundesrepublik Deutschland (AdV) published several kinds of standards but we could not find any description about the corresponding relation between GSD and map scale.
In PQS-DL (Produkt und Qualitätsstandard für Digitale Luftbilder des amtlichen deutschen Vermessungswesens, Version 4.1.) (AdV, 2023) published by AdV, we find the statements in section 3.6.3., which describes as follows:

> "Die Qualität der äußeren Orientierung muss sicherstellen, dass die Standardabweichung der La-gekoordinaten berechneter Bodenpunkte nicht größer als das 0,5-fache der festgelegten Stan-dardabweichung σ_{XY} der georeferenzierten Lagekoordinaten des Orthophotos ist." with footnote, "Aus AK GT-Dokument [897Rx], Produkt- und Qualitätsstandard für Digitale Orthophotos, Geometrische Genauigkeit: σxy (DOP40): ± 0,8 m σxy (DOP20): ± 0,4 m."

(The quality of the external orientation must ensure that the standard deviation of the position coordinates of calculated ground points is not greater than 0.5 times the specified standard deviation σ_{XY} of the georeferenced position coordinates of the orthophoto. *Footnote*: From AK GT document [897Rx], Product and Quality Standard for Digital Orthophotos, Geometric accuracy: σxy (DOP40): ± 0.8 m σxy (DOP20): ± 0.4 m.)
Therefore, the description is formalized as follows:
Planimetric accuracy = 0.5*σxy=1*GSD, for GSD=20 cm and 40 cm.
We will compare among countries the relationship between positional accuracy and GSD in a later subsection.

4.2 Comparison with RICS standards

Royal Institution of Chartered Surveyors (RICS) published its guidance note for vertical aerial photography and digital imagery in 2010 (RICS, 2010) and its standards for earth observation and aerial surveys in 2023 (RICS, 2023).
The former describes corresponding relation among photo scale, GSD, map scale, and RMSE (Table 5).

Table 5. RICS standards excerpted from the table in section 5.1 of RICS (2010).

Photo scale	GSD	Mapping scale	Hz RMSE
1:3000	4 cm	1:500	+/-0.100 m
1:5000	7.5 cm	1:1250	+/-0.225 m
1:10000	15 cm	1:2500	+/-0.500 m

The latter describes corresponding relation among platform (UAV/Helicopter/Fixed wing), height, accuracy, and GSD without relating map scale. An excerpt is given in Table 6. Note that, as described in RICS (2023), the table is based on high-end equipment and that values quoted can only be referenced as achievable. This can be easily confirmed comparing Table 5 and Table 6.

Table 6. RICS standards excerpted from Table 5 of RICS (2023).

Height (m)	Achievable accuracy for plan X, Y (m)	Resolution – GSD (m)
2250	±0.11	0.08
4500	±0.23	0.15
7500	±0.38	0.25

We compare the relationship between GSD and map scale of Table 4 with that of Table 5, and the result is shown in Table 7.

Table 7. Comparison of this study with RICS (2010).

Japan in this study		RICS (2010)	
map information level	GSD (cm)	GSD (cm)	map scale
500	8 or 9	4	1:500
1000	12 or 16	6.3	1:1000
2500	20	15	1:2500
5000	40	30	1:5000

The values of GSD in the lines of map information levels 1000 and 5000 are converted by interpolation and extrapolation to match the map scale to the corresponding map information level. Japan's GSDs in this study show larger values than RICS's for equivalent map scale.

4.3 Comparison with ASPRS standards

American Society for Photogrammetry and Remote Sensing (ASPRS) published its standards for digital geospatial data in 2023 (ASPRS, 2023). It classifies specifications into horizontal accuracy class and describes the corresponding horizontal RMSE, recommended GSD, and equivalent map scale for each class (Table 8). It must be noted, as ASPRS (2023) describes, that the range of the approximate GSD of source imagery is only provided as a general recommendation, based on the current state of sensor technologies and mapping practices, and that it should not be used to reference product accuracy.

Table 8. ASPRS standards excerpted from Table B.4 of ASPRS (2023).

ASPRS Edition 2 (2023)			Equivalent to map scale in
Horizontal accuracy class	$RMSE_H$ (cm)	Approximate GSD of source Imagery (cm)	ASPRS 1990 Class 1
12.5	12.5	6.3 to12.5	1:500
25.0	25.0	12.5 to 25.0	1:1000
60.0	60.0	30.0 to 60.0	1:2400
75.0	75.0	37.5 to 75.0	1:3000
100.0	100.0	50.0 to 100.0	1:4000
150.0	150.0	75.0 to 150.0	1:6000

We compare the relationship between GSD and map scale of Table 4 with that of Table 8 and get the result in Table 9.

Table 9. Comparison of this study with ASPRS (2023).

Japan in this study		ASPRS (2023)		
map information level	GSD (cm)	GSD_L (cm)	GSD_U (cm)	equivalent map scale class 1
500	8 or 9	6.3	12.5	1:500
1000	12 or 16	12.5	25	1:1000
2500	20	31.3	62.5	1:2500
5000	40	62.5	125.0	1:5000

The values in ASPRS (2023) in the bottom two lines in Table 9 are converted by interpolation to match the equivalent map scales to map information level. Japan's GSDs in this study show smaller values than ASPRS's except for map information level 500.

4.4 Summary of comparison among four countries

We compare the relationship between GSD, accuracy, and map scale among standards of Japan, Germany, United Kingdom, and United States. German standards seem not to indicate the corresponding map scale. Relations between GSD and map scale among three countries are summarized in Table 10. There seems to be no common relationship between GSD and map scale among three countries.

Table 10. Comparison of the relation between GSD and map scale.

	Japan in this study	AdV (2023)	RICS (2010)	ASPRS (2023)	
map scale	GSD (cm)	GSD (cm)	GSD (cm)	GSD_L (cm)	GSD_U (cm)
1:500	8 or 9	Not related	4	6.3	12.5
1:1000	12 or 16		6.3	12.5	25
1:2500	20		15	31.3	62.5
1:5000	40		30	62.5	125.0

Relations between GSD and planimetric accuracy among four countries are summarized in Table 11. Aside from this study and RICS (2010), other standards show some common relationship that indicates planimetric accuracy is in the range from one to two times of GSD. The relation σxy=1/2*GSD in this study is an assumption when the formulas in Table 1 were derived and need to be confirmed or revised based on the analysis of real digital photos.

Table 11. Comparison of the relation between GSD and planimetric accuracy.

	Japan in this study	ASPRS (2023)		Upper: RICS (2010) Lower: RICS (2023)	AdV (2023)
σxy	1/2*GSD †	$2*GSD_L$	$1*GSD_U$	2.5*GSD – 3.3*GSD 1.4*GSD – 1.5*GSD	1*GSD (cm)

† the value is an assumption when the formulas in Table 1 were derived.

5. Conclusion

The multi-country comparison was made with an attempt to find common relationship between GSD, map scale, and accuracy but we perceive the difference in ideas among the countries and there seems to be no common international standard. We need to investigate the theoretical and practical background of the relationship.
We will refer to the findings to plan aerial photography experiments necessary to specify the relationship between GSD and ground positional accuracy. Then, we will compile the results obtained in a new format of specifications suitable for digital aerial photography together with a correspondence table between GSD and the traditional map scale.

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BIOGRAPHICAL NOTES

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