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REMOTE SENSING RESEARCH: A User's Perspective

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ABSTRACT

Remote sensing technology has been adopted by various fields of science since the Second World War. Its research varies greatly accordingly. Basically it can be broken down into there types,i.e, (1)research using remote sensing just for data acquisition, (2) research in theoretical remote sensing, and (3) research in applied remote sensing. This article is about its differentiation.

Keywords: remote sensing, research, differentiation

INTRODUCTION

The scope of remote sensing is very wide indeed. It includes ground segment and space segment. The space segment consists of sensor, platform, and telemetry to send promptly the recorded data to the ground receiving station. The ground segment consists of data acquisition, data processing, data dissemination, and data use. In accordance to the title, this article is discussing remote sensing research from the point of view of (remote sensing) data use.

Remote sensing is a new technology which develops very quickly in the latest five decades. The adoption of this new technology by various fields of science undergoes a high speed as well. It stems from the fact that remote sensing technology records various objects in the field quickly and accurately, the location of which is almost similar to the location in the field for each object. More importantly, these spatial and comprehensive data which are recorded in digital form are readily used for GIS input. The recording mission can be undertaken at our desired interval, i.e.: every sixteen days for Landsat satellite and every twelve hours for NOAA satellite, causing remote sensing a very good tool for monitoring our environment. By and large, remote sensing has made various kinds of research work more and more efficient. No wonder that remote sensing education up to doctorate degree is established elsewhere in the world. It is also the case with the education in the Faculty of Geography, Gadjah Mada University in Yogyakarta, Indonesia. It is afforded as one major (concentration) in the Under Graduate level, as a study program in the Master level, and as one major in the Doctorate Program.

As has been stated in the Abstract, research with remote sensing data may be broken down into three types. The differentiation which is written in this article is merely the writer's opinion, taking some references into account.

Research Differentiation

1. Research using remote sensing for data acquisition

This type of research can be done by students from the study program of geomorphology, geology, hydrology, regional planning, environmental study, and many others. They can take the benefit of the quick spatial data acquisition from remote sensing image. There is no need for them to put the word remote sensing in the title of their research works, although it can also be carried out if they want to. There is no compulsory discussion on remote sensing except in the research method. Limited discussion may be undertaken in the Literature review as an arbitrary item.

2. Theoretical research in remote sensing

The main objective of this research is to improve and improve the interpretability of remote sensing image. To say it another way, it is to increase continuously the multitude benefit of remote sensing for the users, whoever they are. This objective may be successfully achieved by taking these factors into consideration; first, choice of suitable remote sensing image for the respective purpose, and second, proper choice of interpretation method.

Choice of Image

Proper choice of image is very important to attain a good result. Spatial, spectral, temporal, and radiometric resolutions should be considered in relation to interpretability and accuracy, environmental complexity, contrast, and detail level of information due to user's need. Indeed there are so many factors which play in concert to reach a good end. The decision to make a choice may differ from one analyst to another. Hence [*Lillesand et al.,* 2007] stated that remote sensing is a science and art. [*Aronoff,* 2005] even stated that remote is a science, art and technology (which convert electromagnetic energy into remote sensing image). We can also add it with converting image into useful information.

Interpretability and accuracy

Interpretability denotes reconcilability of objects recorded in remote sensing image. It depends largely on spatial resolution of the image and contrast of objects, environmental complexity, and detail information needed by the analyst. Better spatial resolution, higher contrast, simpler or more homogenous environment, and less detail information cause better interpretability.

Accuracy means the close similarity between the result of image interpretation and the fact in the field. It is known by affording an accuracy test or ground trusting. In case field check for accuracy test can not be carried out, the accuracy test can be conducted by comparing the result of image interpretation with a reliable map or with image of higher spatial resolution, namely 3-10x better [*Aronoff*, 2005] Validation of the result of image interpretation or accuracy test is indispensable for image interpretation [*Campbell*, 2002]. Accuracy consists of accuracy of the map content (type and completeness) and geometric accuracy or the position (and elevation) for each object [*Doyle*, 1984; *Naithani*, 1990; *Aronoff*, 2005].

Interpretation accuracy correlates well with spatial resolution, [*Doyle*, 1984] prepared a rule of thumb based on his experience, a formula as a guide to select a particular image resolution in relation to the scale of the expected final map. The formula is based on an assumption that the pixel size is 0, 1 mm, as follows

$$\frac{1mm}{10pixel} x \frac{1m}{1{,}000mm} xSm = Rp$$

$$Rp = 10^{-4}\ Sm \qquad (1)$$

Where:
Sm = Scale of the map
Rp = Resolution in pixel (m)

To acquire an accurate map scaled to 1: 100, 000, for instance, we need remote sensing image with a pixel size of 10^{-4} m = 10 m. This formula is meant to achieve not only mapping accuracy (geometric accuracy), but also classification accuracy or interpretation accuracy (map content).

NMAS (National Map Accuracy Standard, USA) established tolerable map accuracy with the following limit:
Position data: Sp = 0, 3 mm x map scale .... (2)
Elevation data: Se = 0, 3 x contour interval .... (3)

Where:
Sp = standard deviation of position
Se = standard deviation of elevation

The lower limit of acceptable accuracy for the map content (classification accuracy) varies with spatial resolution, environmental complexity, desired detail of information, and contrast. Higher spatial resolution of remote sensing system, more homogeneous environment, less detail of information, and higher contrast of objects tends to increase interpretability, and hence, increase the accuracy as well. The method of interpretation also contributes its role in this respect. Some examples may clarify this statement.

[*Anderson, et al,*1975], determined an acceptable accuracy of 85 % for land use land cover mapping in USA based on Landsat MSS image (80 m pixel). [*Welseness,* 1971] determined an acceptable accuracy of 88 % for rural population estimate in the Netherlands using black and white panchromatic air photos scaled to 1: 15,000. [*Mettivier and McCoy,* 1973; in *Lo,* 1986] accepted an accuracy of 80% for urban poor mapping in Lexington (USA) using black and white aerial photographs of 1: 6,000. [*Sabins,* 2007] stated that the acceptable accuracy should be less for remote sensing in geology. To the writer's opinion and experience, the interpretability of land cover is much higher than the interpretability of land use, as the latter is inferred from the former.

Ideally, each researcher in remote sensing has to decide his or her own acceptable accuracy based on the aforesaid factors and also based on sufficient references. Again, the art plays its role in this case.

Based on Formula 2, 3, and 4, *Doyle* prepared Table 1 reflecting the spatial resolution requirement to fulfill classification and mapping accuracies for particular map series.

Table 1. Requirements for image map series

Scale Number (Sm)	Spatial Resolution		Position Sp (m)	Contour interval (m)	Elevation Se (m)
	m/Line Pair	m/pixel			
1,000,000	250	100	300	100	30
500,000	125	50	150	50	15
250,000	63	25	75	25	8
100,000	25	10	30	20	6
50,000	12,5	5	15	10	3
25,000	6,3	2,5	7,5	5	1,5

Source: [*Doyle*, 1984], with modification

Notes: Sp = standard deviation in position
Se = standard deviation in elevation

To read the last line for instance, in order to acquire both sufficient accuracies for final map series of 1: 25, 000, we need air photos of 6,3m/line pair or digital image with pixel size of 2.5 m. The lowest limit of position accuracy is 0.3 mm x 25,000 = 7.5m, and the lowest limit of elevation accuracy is 0.3 x 5 m contour interval = 1.5 m.

[*Richards,* 1996] also made a rule of thumb with similar assumption and presented an almost similar table.

Table 2. Maximum map scale in relation to resolution

Map scale	Approximation of Pixel size (m)	Remote sensing system
1:50,000	5	Aircraft MSS
1:250,000	25	Spot HRV, Landsat TM
1: 500, 000	50	Landsat MSS
1: 5,000,000	500	HCMM
1: 10,000, 000	1,000	NOAA-AUHRR

Source: [*Richards*, 1996]

Differing from [*Doyle,* 1984] and [*Richards,* 1996] who assumed 1 mm for ten pixels, [*Jacobson*, 2004; in *Aronoff,* 2005] made an assumption of 1 mm for 10-20 pixels. He stated that IKONOS image, the pixel of which is 1 m, may support mapping purpose of 1: 10, 000 to 1: 20, 000. He prepared almost similar table as a rule of thumb (Table 3)

Table 3. Approximate scale factors for images of different ground sample distances (GSD) when printed at 300 image pixels per inch

GSD (m)	Scale Factor	GSD (m)	Scale Factor
0,6	7.320	15	180.000
0,7	8.400	20	240.000
1	12.000	25	300.000
1,5	18.000	30	360.000
2	24.000	250	3.000.000
2,5	30.000	500	6.000.000
5	60.000	1.000	12.000.000
10	120.000	5.000	60.000.000

Source: Jacobson, 2004; in Aronoff, 2005

To prepare thematic map in Indonesia, Table 4 may be worth to consider.

Table 4. Ideal thematic map scales in relation to spatial resolution, Indonesia

Thematic map scale	Pixel size (m)	Remote Sensing System***
National* 1 : 1,000,000	100	Aster Band 10-14 (90 m), Landsat MSS (80 m), Landsat-7 (60 m), CBRS-1 IRMS (80 m), IRS-1 (75 m), etc.
Regional* 1 : 250,000	25	Landsat-7 ETM (30 m), SPOT-HRV (20 m), IRS LIS-III (24 m), EO-1 MSS (30 m), CBRS-2 (20 m), Monitor-E-1 (20 m), DMC UK (32 m), DMC Beijing-1 (32 m), etc.
Regency* 1:100,000 – 1:25,000	10-2,5	EO-1 Pan (10 m), SPOT-5 HRG Pan (2,5 – 5 m), SPOT-5 HRG Band 1-3 (10 m), IRS ResourceSat-1 Liss IV (6 m), DMC Vinsat-1 (4 m), IRS ResourceSat-2 (6 m), CBRS-3+4 (5 m), CBRS-4 (5 M), REISS (6,5 m), IKONOS-MSS (4 m), Quic Bird ASS (2,4 m) , ORB-View-3 MSS (4 m), airphotos 1 : 25.000 – 1:80.000, etc.
City* 1:50,000-1:10,000	5-1	SPOT-5 HRV (2,5 – 5 m), DMC Vinsat-1 Pan (4 m), CBS 3+4 (5 m), IKONOS (1 – 4 m), EROS-A (1,9 m), QuickBird (0,61 – 2,4 m), OrbView-3 (1-4 m), GeoEye-1 (0,41 – 1,64 m), WorldView II MSS (1,84 m), etc.
More detail level** 1 : 5,000	0,5	QuickBird-Pan (0,61 m), GeoEye-Pan (0,41--> 0,5 m), Airphotos of 1 : 15.000 – 1 : 20.000
1 : 2,500	0,25	Airphotos of 1 : 2.500$^{1)}$
1 : 1,000	0,10	Airphotos of 1 : 5.000$^{1)}$, Airphotos of 1 : 4,000 – 1 : 6,000$^{2)}$

* = Government Regulation No. 10 of 2010, Republic of Indonesia
** = Law Design on Geographic Information Setting, of Indonesia
*** = To the writers opinion based on references
1) = *Kennie and Matthews* (1985)
2) = *Aronoff* (2005)

What happens, then, if the rule of thumb is neglected, as it is often the case in the field? Three experts put forth their arguments in this respect?

It was promoted in the late eighties that SPOT image can replace air photos of 1:50,000 to prepare topographic map series of 1: 50,000. As we know, the pixel size of SPOT-P is 10 m. Based on the rule of thumb, it is appropriate for final map of around 1: 100,000. For a map of 1: 50,000,000, however, some small features which are normally presented in topographic map of this scale, are not discernable in SPOT-P image [*Naithani,* 1990]. A twofold exaggeration from the rule of thumb means a loss of some small features for the map.

[*Petric and Liwa,* 1995] had similar argument. For topographic mapping scaled to 1:50, 000 in Dar and Norogwe areas (Africa), they compared the accuracy in terms of completeness of features extracted from small scale air photos and from SPOT-P image, as seen in Table 3.

Table 5. Percentage completeness of information extracted from small scale aerial photographs and SPOT-P Images.

	Aerial Photograph		SPOT-P	
Features	Dar 1:65,000	Korogwe 1:75,000	Dar	Korogwe
Communications				
Hard-surfaced roads	100	100	100	100
Unsurfaced roads	100	100	100	100
Motorable track	100	100	75	60
Streets	100	100	50	10
Footpaths	80	80	5	60
Bridges	50	50	0	0
Railway lines	100	100	60	100

Source: [*Petrie and Liwa* ,1995], with modification

Even with aerial photographs of smaller scales than 1:50,000, the accuracy of map contents is much better as compared to SPOT- P.

It is worth to note one more example of disobeying the rule of thumb. It was presented by [*Kennie and Matthews,* 1985] on the use of Landsat MSS image of 80 m pixel (size) for topographic mapping scaled to 1: 250, 000 in Africa. This choice was quite reasonable as viewed from the unavailability of topographic map for most of the very large continent. This huge project took the benefit of the availability of various remote sensing images to prepare topographic map series of 1: 250, 000 for the whole continent, 1:100, 000 for selected areas, and 1: 50, 000 for populated areas. On the other side, however, the choice of 80 m pixel size for topographic map of 1: 250, 000 is not an ideal one. Although the mapping accuracy may be achieved, it is not the case with the classification accuracy [*Kennie and Matthews,* 1985; *Petric and Liwa,* 1995]. Table 4 may convince this statement.

Table 6.Detestability and interpretability of topographic details of Landsat image of Kartoum area, Sudan

Elements mapped on 1: 250, 000 scale maps	Landsat-2 MSS	
	Detected on imagery	Identified on imagery
Lines of Communications		
Hard surfaced roads	Sometimes	Not
Unsurfaced roads	Not	Not
Tracks	Not	Not
Footpaths	Not	Not
Streets	Not	Not
Bridge Location	Not	Not
Ferry location	Not	Not
Railroods	Sometimes	Not
Railrood stations	Not	Not

Source: *Kennie and Matthews*, 1985

Line of communication is man made features of linear ones, both of which lend them easier to recognize on the image. We can imagine, then, what happens with natural features of small size in the form of point and area ones. With this in mind, it is worth to note the RePPProT (Regional Physical Planning Program for Transmigration) map in Indonesia. This map was prepared based on Landsat MSS image (80 m pixel) with a scale of 1:250, 000. A threefold exaggeration from the rule of thumb means the lost of information concerning small features which should be plotted in such a scale. More importantly, this map was prepared without filed check. We can imagine how low the reliability of the map content is.

This lengthy discussion is meant to highlight the importance of the rule of thumb in selecting appropriate pixel for particular purpose in remote sensing research. It is indeed not fixed value, but, a considerable difference from this value is not recommended. If for some reasons we have to do it, we should be prepared to add the unacquired information from remote sensing image with information from other sources.

Mapping Application

What has been stated earlier concerning the accuracy test is referred from the US National Map Accuracy Standard (NMAS) which was revised in 1947, since then it was adopted widely elsewhere? The accuracy is calculated in two ways, through the standard deviation (Formula 2 and 3), and with maximum position and elevation errors. For maps scaled to 1 : 20,000 or smaller, position errors in the map should be less than 1/50th of one inch for 90% (or more) of well defined test points, and 1/30th of an inch for larger scales. The maximum elevation error should be half of the contour interval [*Aronoff*, 2005; *Doyle,* 1984]. These formulas are used to achieve classification and mapping accuracies in general.

For mapping application, however, *Aronoff* advocates the use of another mapping accuracy standard prepared by US Federal Geographic Data Committee in 1998 termed National Standard for Spatial Data Accuracy (NSSDA). Differing from NMAS where the mapping accuracy is calculated with 90% confidence level, hence it is called The Ten Percent Accuraty; NSSDA is calculated based on 95% confidence level.

Spatial or positional accuracy is assessed by selecting a number of well defined points (20 or more), their positions of which are compared to their true or reference positions. These true positions are acquired through ground survey measurement, or from independent source of higher accuracy (from three to ten time's higher accuracy). Positional accuracy is assessed using root mean square error (RMSE), the square root of the average of the squared discrepancies between the test and the reference points, defined in terms of errors at the ground scale.

$$\mathrm{RMSE} = \frac{\sqrt{\sum_{i=1}^{n} d^{2}}}{n} \quad \ldots\ldots\ldots\ldots \quad (4)$$

Where:

d = the distance between the test and the true points.
i = the ith test point
n = the number of test points

Positional accuracies are assessed as follows

CE 90 = 1.5175 x RMSE for 90% confidence level .... (5)
CE 95 = 1.7308 x RMSE for 95% confidence level .... (6)

Where:

CE = circular error or the distance between the test and the reference point
RMSEr = root mean square error of the radial distance discrepancies.

or:

CE 90 = 1.5175 x SQRT $[(\mathrm{RMSE}_x)^2 + (\mathrm{RMSE}_y)^2]$ .... (7)
CE 95 = 1.7305 x SQRT $[(\mathrm{RMSE}_x)^2 + (\mathrm{RMSE}_y)^2]$ .... (8)

Vertical accuracy is assessed in similar manner as follows:

LE 90 = 1.6449 x RMSE_z .... (9)
LE 95 = 1.9600 x RMSE_z .... (10)

where:

LE = linear error
Z = elevation

Environmental Complexity

Small area of heterogeneous feature tends to decrease the contrast between objects and hence, it decreases image interpretability [*Welch,* 1982]. Urban land use, for instance, looks much more complex as compared to the rural one. Therefore, urban land use needs much better resolution of the image. For similar rural land use of Indonesia, the agricultural land use needs much better spatial resolution than agricultural land use map of rural United States of America.

Interpretability of object of low contrast may be overcome by using image of higher radiometric resolution, or, image of higher spectral resolution. As the former is not always available, the latter is more often accomplished by choosing greater spectral difference in multispectral images. For example, if we use Landsat TM image for urban land use mapping, we use to adopt the combination of:

a) $TM_2 + TM_3 + TM_4$, or
b) $TM_3 + TM_4 + TM_5$, or
c) $TM_3 + TM_4 + TM_7$

The reasons are:

a) roads are well discerned in band 1, band 2, or band 3,
b) vegetation can be casily interpreted in band 4, and,
c) Differentiation of vegetation is casily conducted in band 5 or band 7 [*Lillesand, et al.,* 2007].

In case we use air photos for urban land use mapping, panchromatic black and white air photos of 1: 10,000 has almost similar interpretability with color infrared air photos of 1: 15, 000. The latter is more preferable because vegetation which looks red in the photo will not disappear easily from the observer. As we know, vegetation is a minor feature in urban area.

One more example given by [*Jacobson*, 2004; in *Aronoff,* 2005] is worth to note in the selection of image in remote sensing research. He stated that to map urban areas and to create vector line data for GIS and LIS (Land Information System) applications in USA and Canada typically uses map of 1: 1,200. For similar purpose, UK uses map of 1: 1, 250, all of wich are generated from air photos of 1: 4, 000 – 1: 6, 000.

Method of interpretation

Proper method of interpreting image or digital data is quite in need in order to achieve satisfactory result. An example is given here.

[*Lo and Choi,* 2004] adopted a hybrid approach to urban land use/ cover mapping using Landsat ETM + data. This approach is aimed at increasing the interpretability of the ETM + data. Besides, he undertook three more approaches for comparison of the result. These four approaches indicated the following accuracies: (a) 91.50% for hybrid approach, (b) 90.25 % for isodata clustering, (c) 77.75 % for supervised fuzzy classification, and (d) 76.75 % for maximum likelihood classification.

Research in Applied Remote Sensing

Differing from research in theoretical remote sensing, the main objective of applied research in remote sensing is to make this research work more efficient. The other difference is on the focus of discussion. The dissuasion is focused on the applied discipline. In order to differentiate the latter from other research using remote sensing for data acquisition, there should be enough discussion on theoretical remote sensing. This discussion may involve the selection of remote sensing data, method of interpretation, validation of the result of interpretation, etc.

To the writer's knowledge, the differentiation between these there types of research may even be carried out since the very beginning of the research proposal, as seen in their titles. These following examples may clarify this differentiation.

Research in theoretical remote sensing

The Interpretability of Landsat TM data for Physical Urban Expansion
The Case of Surakarta City, Central Java

The whole discussion is on theoretical remote sensing. It starts with why physical urban expansion and why Landsat TM data is selected. The greatest bulk of discussion is on the interpretability of TM data which may cover: (1) the ease of interpretation, (2) the speed, (3) the cost, and (4) the accuracy of the result, etc. There is no discussion on the physical urban expansion, as it is used just as an object for interpreting TM data. The importance of physical urban expansion is presented only in the Introduction.

Research in applied remote sensing

Physical Urban Expansion in 1988-2000 Based on Landsat TM Data The Case of Surakarta City Central Java

The discussion is on both theoretical remote sensing and applied subject, with its focus on the latter. The discussion on the former may include: (a) why TM data is selected, (b) which bands to use and why, (c) how is the rate of urban expansion spatially and temporally. The discussion on the applied subject may cover: (a) why the expansion rate and its pattern occur that way, (b) how is the prediction for the next ten years, twenty years, etc, and (c) how to control it.

Other research using remote sensing

Physical urban expansion in 1988 – 2000 for Surakarta City Central Java

There is no need to put the word remote sensing in the title. It is put only in the method of research for data acquisition, similar to statistics for data analysis, both of which are not written in the title. The discussion is fully on the respective discipline.

If the researcher wants to put the word remote sensing in the title for the reason of more marketable job, the most that he or she can do is to put the words WITH THE AID OF REMOTE SENSING, following the stated title.

Differentiation of these three types of research can be undertaken by differentiating the type of discussion, as can be seen in Table 5.

Table 6.Type of discussion representing the difference between these three types of research

Item	Remote sensing research		Other research using remote sensing
	Theoretical	Applied	
Introduction	++x	++xx	000
Research questions	+++	+xx	000
Research objective	+++	+xx	000
Literature review	+++	+xx	000
Theoretical framework	+++	+xx	000
Research method	+++	+xx	00+
Discussion	+++	+xx	00+
Conclusion	+++	+xx	000

Information of the symbols

+ = small discussion on remote sensing
++ = sufficient discussion on remote sensing
+++ = numerous discussion on remote sensing
x = small discussion on applied subject
0 = small discussion on other subject

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