LESSON AND LEARN OF THE ADJUSTMENT OF GAIN LEVEL SETTINGS FOR FORMOSAT-2 REMOTE SENSING INSTRUMENT

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KEY WORDS: FORMOSAT-2, Remote sensing, Image, Gain setting

ABSTRACT: The FORMOSAT-2 (FS2) is equipped of Remote Sensing Instrument (RSI) with the panchromatic (PAN) and multispectral (MS) bands. The MS bands include blue, green, red, and near infrared. There are 10 selectable gain levels for each band to optimize the dynamic range of FS2 images. The physical meaning of RSI gain can be considered as the ratio of CCD output digital counts to input radiance. For a constant range of output digital counts (8 bits for FS2 image), the images of different regions need different gain level setting due to different input radiances. Currently, the selection of gain levels is based on the global gain map provided by Centre National d'Etudes Spatiales (CNES) and SPOT Imaging. According to FS2 experience, the gain setting does not fully meet the practical implementations, for example the variation in observation from snowfall to ice melting. We also noticed that some of default gain level settings are not suitable for the imagery of islets. Therefore, it is necessary to timely adjust the gain levels for optimizing the FS2 imagery. For the simplest case, a saturated (overexposure) image can be properly adjusted by reducing the gain level before the next image acquisition. In this work, we present examples of gain adjustment, some rules, and discuss its application results as well as statistic analyses.

1. INTRODUCTION

Since 2004, FS2 has been successfully operated on 890km sun synchronous orbit. In the beginning, the FS2 imaging activity focused on Taiwan area. It was not concerned the variation of RSI gain setting on global region. Once NSPO starting the FS2 global imaging in the end of 2004, the importance and requirement of global information of gain setting gradually arose. There are 10 tunable gain levels for each band of RSI to optimize the dynamic range of FS2 images. The current selection of gain level in routine pictures is based on the gain map provided by CNES and SPOT. The RSI generally takes about 40-70 segments every day depending on the acquisition time of each segment which is scheduled based on the request of customer, status of satellite operation, and capability of ground receiving stations. Up to now there are more than 800,000,000 km^2 of image area. Rich achievements are obtained by these abundant data. However, the difficulty of gain setting still exists. The gain map cannot supply the ideal implementations in FS2 orbiting imaging. For example, the gain level default is not suitable for the imagery of oceanic islets and of some sub-polar regions. It also may not work when unexpected snowfall/freezing or ice melting occurs. It is necessary to timely adjust the gain levels based on each case. In the following, we describe the procedure of adjusting gain setting for optimizing FS2 images, the noticeable items, the classification of origins of improper image situations, and the pre-adjustment work.

2. ADJUSTMENT ON GAIN LEVEL SETTING

2.1 Stage and Performance Order

Based on response linearity, the output digital number (DN_{out}) of each CCD pixel is related to input radiance (L, in units of W/m^2/sr/μm) by $DN_{out} = A \cdot L + DN_{dark}$ (Henderson and Krause, 2004). The slop A and intercept DN_{dark}

(digital counts of dark current) are generally called the gain and offset, respectively. DN ranges from 0 to 255 for an 8-bit image data. For FS2 RSI, A(b, g, p) = K(b)G(b, g)ρ(b, p) is named as total conversion factor where (b, g, p) denote the index of band (b = PAN, Blue, Green, Red, NIR), gain level (g = 1-10) and pixel (p = 1-12000 for PAN and p = 1-3000 for MS). K(b) and ρ(b, p) are the absolute radiometric and relative response coefficients, respectively. The atmospheric scattering effect is also introduced through the on-orbit calibrations. Contribution of K(b)ρ(b, p) and DN_{dark} will be eliminated in ground processing system, but gain setting for each band is remained. The electronic gain $G = 2^{(g-1)/2}$ is used to control the whole input radiances could feed into a constant output range. For a clear picture in vision, the intensity histogram should be at its peak in the center of DN range and distribute as wide as possible but avoiding saturated and dark phenomena. Therefore, the imaging quality strongly depends on the gain level selection.

The gain map consists of 12 files which are corresponding to 12 months of a year. In each file, the earth ellipsoid is decomposed into 141344 grids distributed from Antarctic to Arctic. In region of latitude ≤ -85°, each grid occupies ~6.2° in longitudinal direction. In regions on two sides of equator, the grid is a square with size of 0.54°×0.54°. A kid code is used to compute the corresponding grid by input of the latitude and longitude of an image. One set of gain level setting for one grid. Each set consists of 5 values of gain level (named by "g-value" throughout this paper) in an order of PAN, blue, green, red and NIR. After receiving data on ground station, raw data is processed (including radiometric correction) to generate image catalog for web querying purpose. Also we could examine the quick-look image in catalog and process the g-value adjustment. Both the examining of image and predict-correct adjusting of suitable g-value are based on the histogram of DN values. After updating gain map file, the adjusted g-value can be used for next acquisition.

In examining the histogram of an image, we firstly look for the existence of saturation situation and more bright/dark areas. Information of overexposed pixels cannot be recovered by any post processing technique. Also a dark image losses much detailed information. A good FS2 image generally has histograms (of PAN and MS) peaked in range of DN = 100-150 (for 8-bit image). In particular the range may be extended to 50-200 after g-value adjusting work, for example, the main peak been shifted to a lower DN to accommodate special bright dots or area. We further check the color cast of MS image providing no brightness problem occurs. The visible images usually exhibit blue cast due to the higher contribution from atmospheric Rayleigh scattering for the shorter wavelength. It should be eliminated by radiometric correction. But color cast situations still survived in FS2 images and need be further processed. In addition, some unreasonable default g-value of BGR bands in gain map are observed. Serious color cast situation can be eased off by raising or reducing some g-value. On the other hand, the default g-value of NIR band will not be changed unless receiving special request from customer.

2.2 Illustrations of Brightness and Color Cast Variations

We look a series of the Antarctic imageries near Flask glacier. Figure 1(a) shows the record of g-value adjustment. Each table is adopted from web system. In each time of adjusting g-value, we manually note the check/correction date, the numbering grid in gain map and the tuned g-value. The target ID (first column) 13202, 13203, 14376 and 14375 locate at same grid (#6073). In March 2010, the default g-values on grid #6073 are (g_{PAN}, g_B, g_G, g_R, g_{NIR}) = (8, 8, 8, 8, 10, 7). The remark on both 3/7 and 3/8 describes the condition of image is white without black spot, that is, all pixels in an image occurred saturated DN. It is originated from either 100% cloud or the glisten in snowy area. Fortunately other images nearby are visible with a setting of (g_{PAN}, g_B, g_G, g_R) = 4444. Hence we try to tune g-value from 88807 to 44447. Figure 1(b) shows the MS quick-look acquired on 3/29. A color histogram of the local flat (dashed rectangular area) is attached. The other bright and shadow regions cannot be simultaneously resolved by adjusting g-value since only one set of g-value be applicable in whole image. Anyway the image looks good. Figure 1(c) shows another image acquisition (target ID 14375) in same month of next year. It can be seen that 44447 had been modified to 33337 in advance. The record on "2011/3/0" means a pre-adjustment (further described in section 4) by referencing the result in February, 2011. The dashed lines on histogram further indicate the peak shifts of BGR bands in our prediction of tuning (g_B, g_G, g_R) from 333 to 444. Furthermore it is found that same g-value may take various result in different year.

Another illustration of how the g-value adjustment recovering the color cast situation is presented in Figure 2. In Figure 2(a), the image on 2010/8/1 shows bluish violet cast in using (g_B, g_G, g_R) = 667. In general, the urban area (dashed rectangular) is expected to be white and the vegetation area should be green (or with blue tone) but not purple. It is found that the raise of g_G and g_R ($g_Bg_Gg_R$ = 667 to 678) in this case just catch up the deviation between peaks of BGR bands. The bright urban area in 2010/8/30 image shows a good histogram matched status although a wider distribution occurs in red band and leads to slight orange tint. On the other hand, the farmland and forest indeed show a normal green and are easier to be classified compared with situation on 2010/8/1.

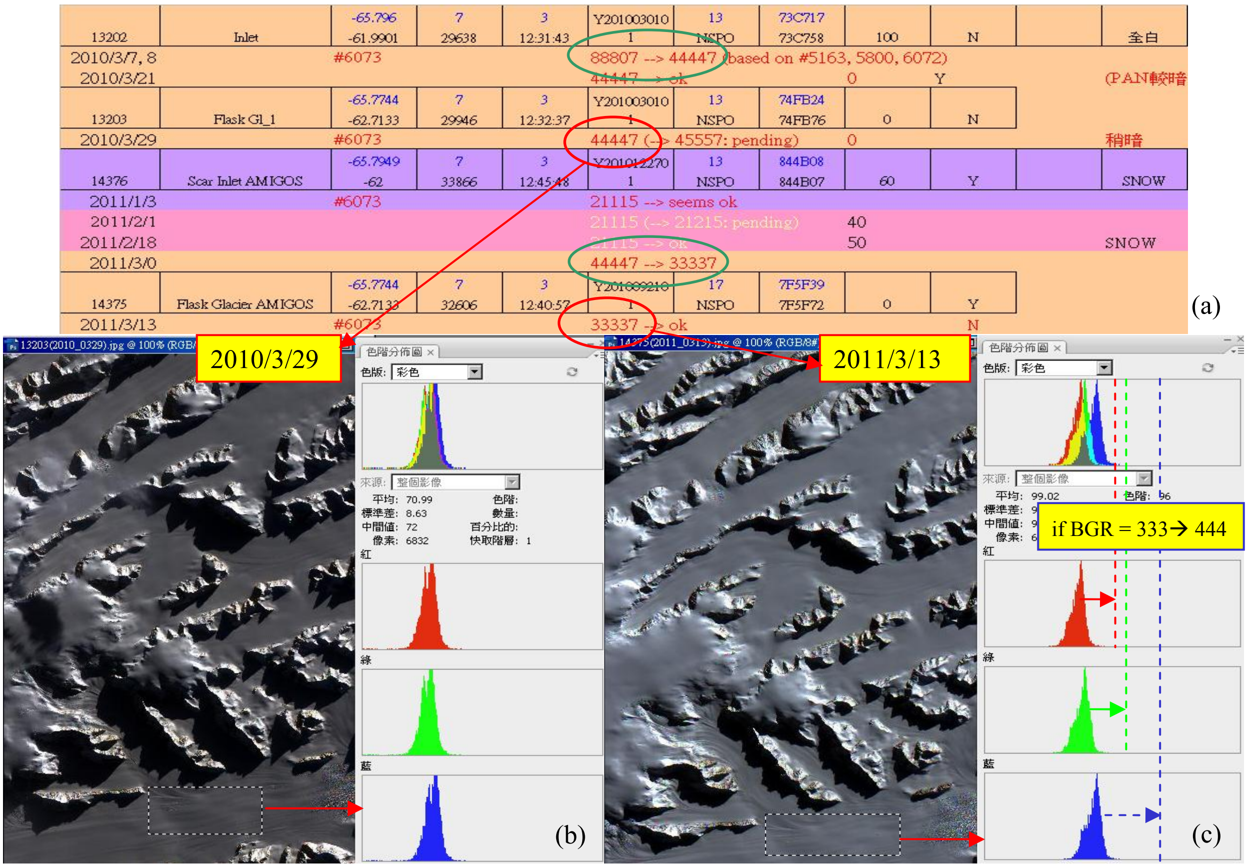

Figure 1. The Antarctic Flask glacier images in March. (a) A series of checking images and adjusting g-value is recorded. A attempt of significant adjusting of (g_{PAN}, g_B, g_G, g_R, g_{NIR}) from (8, 8, 8, 10, 7) to (4, 4, 4, 4, 7) is done on 2010/3/8. (b) The image acquired on 2010/3/29 shows the action is effective. (c) Another image (through the pre-adjusting g-value based on images in February, 2011) on 2011/3/13 implies that same gain setting may have different effect in different year.

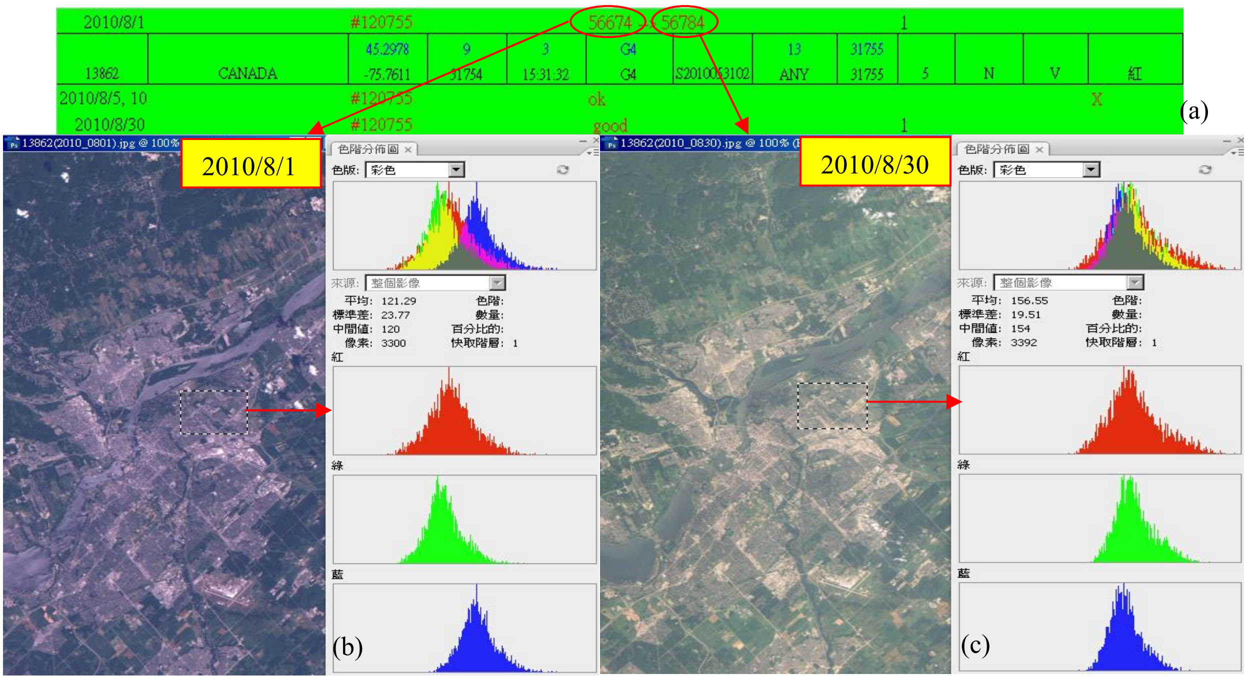

Figure 2. An illustration of correction of color cast by adjusting g-value. The bluish violet tint in the 2010/8/1 image is resolved in later acquisitions by rising g_B and g_R. The urban area (dashed rectangular) in 2010/8/30 image shows more bright with orange tone. The farmland and forest indeed shows a normal green.

2.3 Empirical Rules of g-value of BGR Bands

As mentioned above, BGR bands having same g-value usually lead to an image with slight blue tone. The displayed BGR peaks in color histogram range in an order of $DN_{blue} > DN_{green} > DN_{red}$ on DN-axis. Blue cast may be worsened in some terrain. It is frequently found that default g_R is larger than g_B and g_G in gain map. For example, (g_B, g_G, g_R) = (N, N, N+1), where N is some integer. It usually lead to peak of red histogram can just catch up the blue one. But the implemented imaging would display a purple tint due to the drag of g_G. In region of |latitude| > 40°, the blue cast becomes more severe and the setting of (N, N+1, N+2) can be observed in area without urban. Buildings are always more bright than the surrounding vegetation. Urban prefers same g-value in BGR bands. (The result in Figure 2(c) is not often seen.) Also the bright desert and ice/snow exhibit same behavior as urban.

Based on the FS2 experience, two rules between the variations of BGR g-value are concluded as (1) $g_B \le g_G \le g_R$ and (2) $g_G \le g_B+1$, $g_R \le g_G+1$. Rule 1 wishes to eliminate the tendency of $DN_{blue} > DN_{green} > DN_{red}$. In fact, $g_B < g_G < g_R$ is expected but no more gain levels could support a precise adjusting. The g-value adjustment always causes a certain DN jump in contrast to the post data processing wherein any wished shift of DN can be achieved. The further constrain of rule 2 is based on the $G = 2^{(g-1)/2}$ specification. (It is turned to $g_G \le g_B+1/2$, $g_R \le g_G+1/2$ for $G = 2^{(g-1)}$.) Rule 1 and 2 can be expressed in an alternative form: (A) $g_B \le g_G \le g_B+1$ (B) $g_G \le g_R \le g_G+1$. The validity of g-value rules is performed experimentally. From the adjusting record, g-value without complying rules would lead to poor histogram.

A suitable setting of (g_B, g_G, g_R) must be one of the forms of (N, N, N), (N, N, N+1), (N, N+1, N+1) and (N, N+1, N+2) according to above rules. Here (N, N, N+1) is equivalent to (N-1, N-1, N) and it means that g_R is larger than g_B and g_G with one level. Due to the limit of integer g-value, it can be expected that a certain extent of color cast with either blue, violet, green and orange tone would happen in types of (N, N, N), (N, N, N+1), (N, N+1, N+1) and (N, N+1, N+2), respectively. The types of (N, N, N) and (N, N, N+1) are usually used in regions of |latitude| < 30° and types of (N, N+1, N+1) and (N, N+1, N+2) are more suitable in regions of |latitude| > 40°. In mid region between 30° and 40°, 4 types are probable. But higher g_R is not satisfied in the usual bright area such as urban, desert, ice/snow and glistened lake surface. For example, bright area within |latitude| < 30° prefer (N, N, N) but those within |latitude| > 40° prefer (N, N, N), (N, N, N+1) and (N, N+1, N+1). These findings will be applied in 4.2.

3. SOURCE OF IMPROPER GAIN SITUATIONS

The improper gain situations occurred in FS2 images can be classified as originated from the following reasons. List of four sources is sorted by the significance of situations on image display. The significance means the necessity of adjusting g-value (or magnitude of needed value change). But it is fortunate that numbers of FS2 images occurring these situations are just in a reverse order.

3.1 Temporal Variation

Here we focus on the change of ground illumination due to short term weather variation, seasonal variation and long term global climate change. The most significant case of improper gain situation that image occurs overexposure due to an unexpected snowing. The suitable gain levels before and after snowfall (or melting) may have a jump up to 5. In observation of same location, the rapid variation of weather states including snowy/freezing and ice melting will cause large change in ground illumination. The snowing and melting periods may change year by year. Sometimes it is present that short snowing and then melting in few days occurred in same month. The unique way is to timely adjust g-value based on careful checking and verification together with surrounding images. Even for snowless area, the local g-value may need to be changed in next year. On the other hand, the monthly change is gradual. The jump of suitable g-value between the continued months is occasionally up to 2.

It is also noticed that bad weather state may lead to failure on diagnosing the improper gain situation. The problem of saturated pixel output can be proper resolved by improving device to extend the input dynamic range. But other important effects coming from cloud, haze/fog and sand dust are difficult to be cleared up in visible bands. They may lead to either dark or color cast in images. Figure 3 shows an example of variation resulted from cloud/haze/dust. Panel (b) is an image of target 12686. Panels (c) and (d) show capturing of target 12687 on different days. Three images use same MS g-value. Image on 12/22 seems to display a blue tint. At a shifted location, image on 12/23 looks good. Anyway they are clear and acceptable. Image on 12/24 exhibits dark red although the cloud only occupies few parts area. If images during 12/22,23 were absent, that on 12/24 would indeed be categorized as improper gain. In particular, the g-value on grid #38858 would be modified, for example, by changing (g_B, g_G, g_R) from 556 to 666. Hence an image with cyan tone will appear in next capturing.

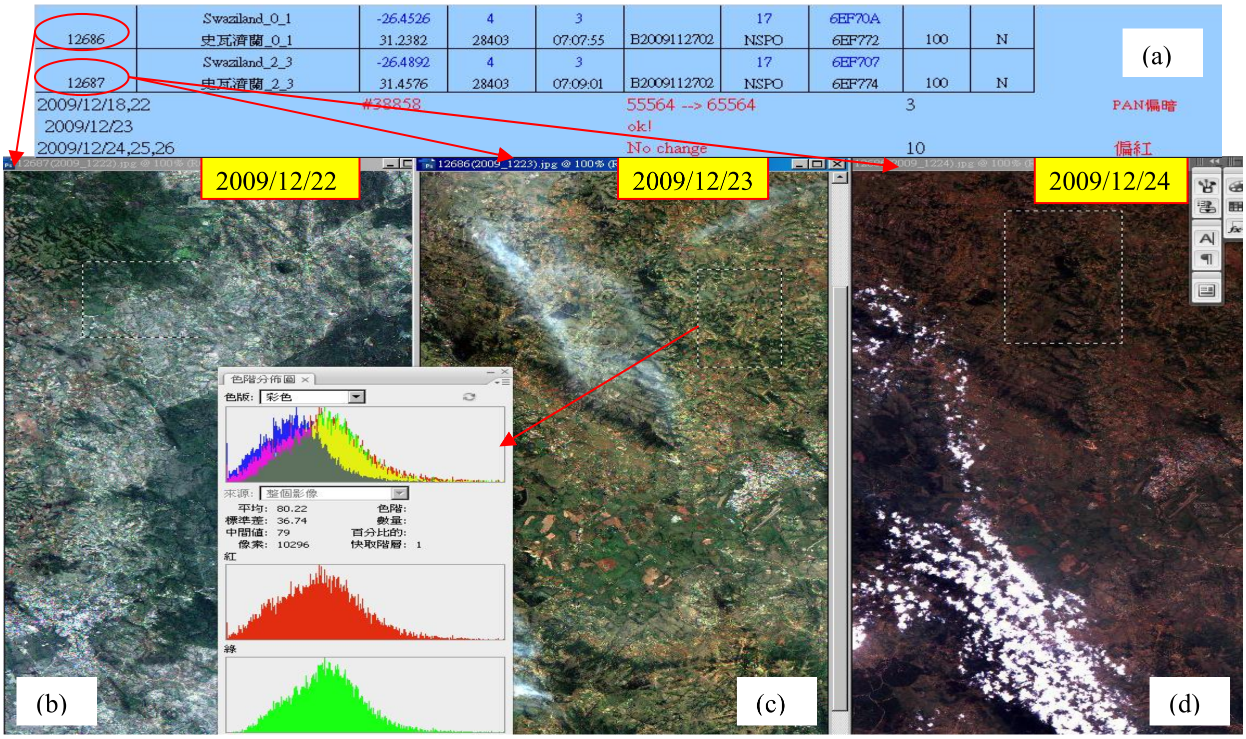

Figure 3. An illustration of effect from cloud and haze. (a) Targets 12686 and 12687 locate on same gain map grid and use same setting of (g_B, g_G, g_R) = 556. (b) Image on 12/22 displays slight blue tint. (c) Image on 12/23 looks good (or some orange tint as shown in attached histogram). (d) Image on 12/24 is dark red.

3.2 Unreason of Default g-value

Some default g-value sets are much unsuitable and may persist several months. It can be frequently found that presence of underestimated g-value leads to dull black imaging on the islets (e.g., atolls belonging to French Polynesia, islands of Solomon and Maldives). We usually need rise the g-value with a jump of 2-3 and even up to 5. Overestimate are in turn present in some sub-polar regions. The second point is concerned the rules in 2.3. It can be observed that default g-value of (g_B, g_G, g_R) = 443 or 343 occurred in summer deserts. It seems attempt to reduce the red blaze but often leads to a cyan or green desert. We usually correct it as 444 or 333. Far from desert area, many regions are also found having missed (g_B, g_G, g_R) form such as 675. By comparing g-value before and after adjustment, it seems that some gain map default miss order of (g_B, g_G, g_R) to be (g_G, g_R, g_B). Another case is the presence of over one increment between g_G and g_R such as (g_B, g_G, g_R) = 668. It is usually corrected to be 667 or 678. The most serious cases happen in sea area again. For example, the reefs of New Zealand, atolls of Maldives, Tonga, and Johnston island have abnormal (g_B, g_G, g_R) form such as 115 or 661. They need adjusting case by case.

3.3 Variation of Terrain Type

In general, the default g-value on each gain map grid is an average to meet all terrain in grid covering area or a lower limit to accommodate the largest input radiance. Once some grid covers much complicate terrain, the default will not satisfy localized image acquisition. The most significant case is that grid simultaneously covers the bright and dark area, such as wooded mountain versus urban and desert, the snowy peak versus dark valley, the floe and ice field versus melting (or without snow) area. In particular, the FS2 imaging often takes a long segment across several gain map grids but use unitary g-value to maintain the identity in topography or other usages. The presence of improper gain situations is usually unavoidable in these cases. Also the adjusted g-value is not expected to be effective in next program wherein the segment has a different acquisition length.

3.4 Insufficiency of Gain Levels

By rough estimating, there are only near 20% of FS2 improper gain images belonged to the much bright/dark cases (with over/under-estimated g-value) and the other 80% cases are in color cast. Miss of the g-value rules brings a few color cast events. But most cases are originated from the limited gain levels. For example, the Taiwan images are usually display a little blue tint in using (g_B, g_G, g_R) = 666 and a purple tint in switching to 667, for both the bright urban/river and dark mountain. A probable best choice of (g_B, g_G, g_R) = (6, 6.3, 6.4) is estimated but it is impossibly implemented on RSI. The precise adjusting of color cast can only be done in post processing.

4. PRE-ADJUSTMENT OF GAIN LEVEL SETTING

4.1 Follows Last Month's Result

We initially tried to pre-adjust the next-month g-value in end of February 2010 due to a series of imaging near the Antarctic Circle. It is asked to continue the suitable g-value to following captures in March. All the good default or adjusted g-value during the monthly latest 5 days is continued. Others before 5-day are treated as a reference to average next month's g-value. The attempt is done again in the end of June. Both jobs take good result. We add the pre-adjustment in routine from September, 2010. In a statistic of Table 1, the modified grids mean total number of grids wherein g-value is pre-adjusted. Four classified results of examining images are counting. Here result A indicates the obtained image is good. In result B, the not bad image shows the adjusting be in right direction but need of fine tuning. It is usually happened in an averaging g-value case when a big gap existing between default and reference g-value. Result C means it is an excessive adjusting, but the default is also not good. Result D is that default g-value should be better than adjusted. Total number of 4 results is much less than modified grids due to most last month's programs are stop. The success (failure) rate is sum of counts of result A and B (C and D). The success ratio doubles the failure part in average.

Table 1. A statistic of number of grids wherein the g-value is pre-adjusted by referencing on last month's result.

Year/Month	2010/10	2010/11	2010/12	2011/1	2011/2	2011/3	2011/4	2011/5	2011/6
Modified grids	253	294	265	313	351	196	175	200	215
Result A	9	11	7	0	5	4	6	1	3
Result B	16	25	15	13	20	14	11	13	16
Result C	7	4	6	4	7	1	5	7	5
Result D	4	6	2	2	3	5	4	3	4
Success (A+B)	9.88%	12.2%	8.30%	4.15%	7.12%	9.18%	9.71%	7.00%	8.84%
Fail (C+D)	4.35%	3.40%	3.02%	1.92%	2.85%	3.06%	5.14%	5.00%	4.19%

4.2 Follows Empirical Rules

In evaluating the number of gain map grids where g-value violates the rules in 2.3, it shows averaged 40,000 grids existing in monthly gain map file. Nearing 15% of them distribute in the vast ocean and be rarely used. The pre-adjustment on these missed type grids is done together with work in 4.1. The choice of valid g-value forms depends on terrain and latitude. In Table 2, the probability of image acquisition located on these grids is very low. But the fact of absence result D shows again that any imaging by using a missed type g-value never captures a good color.

Table 2. Statistic of counting of modified grids and their results.

Year/Month	2010/10	2010/11	2010/12	2011/1	2011/2	2011/3	2011/4	2011/5	2011/6
Modified grids	400	773	4870	7425	9565	9136	14344	13556	16255
Result A	1	1	0	4	1	3	7	1	4
Result B	1	5	15	7	8	14	19	14	11
Result C	1	3	7	4	3	5	11	3	5
Result D	0	0	0	0	0	0	0	0	0
Success (A+B)	0.50%	0.78%	0.31%	0.15%	0.09%	0.19%	0.18%	0.11%	0.09%
Fail (C+D)	0.25%	0.39%	0.14%	0.05%	0.03%	0.05%	0.08%	0.02%	0.03%

5. SUMMARY

The diagnostic of health state shows FS2 can continue keep working well over its mission life. The timely adjustment and pre-adjustment of g-value can optimize the image quality. Some notes are summarized as follows.

(1) The significance of adjusting improper gain situations is sorted as saturation > bright/dark > color cast.

(2) In an acquisition of long segment across several gain map grids, the improper gain situation usually occurs. It is suggested to adopt the averaged or the lowest g-value on those grids.

(3) Pre-adjusting based on last-month results can efficiently prevent the improper gain situations originated from the mid- and long- term climate changes, abnormal gain map default and others. Pre-adjusting based on rules can usually lead to a better imaging than that using an unreasonable default.

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