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Evaluation of Popular Photometry Analysis Softwares Using DSLR Camera

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Abstract: The Digital Single Lens Reflex (DSLR) camera combined with a small aperture telescope is an efficient equipment for an astronomy-related lab exercise. This paper compares the different photometry softwares to provide insights on using the GUI-based photometry tool to the conventional command-line based photometry tool. The magnitude of the same point source measured within the aperture is consistent regardless of the software used although the background estimation, partial pixel treatment, and error estimation are slightly different. In a crowded field image where the aperture photometry is less reliable, the aperture photometry with varying aperture size is useful to see the qualitative trend for the magnitude. Due to the variation in ISO settings and the color dependence on the RGB Bayer system, an initial uncertainty of ~0.15mag is expected to be embedded in the magnitude derived from the DSLR images.

Keywords: observation, photometry, data analysis

Introduction

Photometry is the first step to derive the physical properties of various celestial objects through the astronomical observation. Thanks to the widely distributed cooled CCD and DSLR camera that uses CMOS sensors, it has became much easier to obtain digital astronomy images where the flux of the objects can be quantitatively measured even for amateur astronomers, to say nothing of students in high school or college level astronomy lab.

In contrast to the CCD camera, commercial DSLR cameras have several advantages such as (i) a large field of view when combined with the small (~few inches diameter) aperture telescopes, (ii) an easy accessibility due to their compact size and relatively low price compared to the cooled CCD, and (iii) an RGB Bayer filter system that is onboard in the sensor that provides at least a part of a color information even without the use of a filter. The last point could of course be regarded as a caveat of a DSLR camera compared to the monochromatic CCD since combining a specific filter (e.g., narrow-line Hα filter) with the DSLR is not as easy as the case of a monochromatic CCD, yet the simultaneous access to the red, green, and blue color images of a target is a great advantage for a limited time allowed in a lab for high school or college-level astronomy related class. Color information obtained using DSLR RGB filter system can be converted to the scientific values in match with the conventional Johnson-Cousins BVR filter system. Park et al. (2016) presented formula that can be used to transform DSLR RGB colors to Johnson-Cousins BVR colors using the DSLR image of a young star cluster. The reliability of the conversion formula is dependent on the use of the color term, thus it is naturally expected that the coefficient in each term would be varied according to the spectral types of stars. Despite such limitations, it is expected that the DSLR photometry can be used to provide a rough idea in understanding of the astronomical research process particularly in a high-school or college level class (e.g., Kim et al., 2008; Lee, 2010).

Among the 31 astronomy-related projects presented in the final of national science fair during the recent 12 years (2005-2016)[1], 12 projects (~40%) conducted

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1) https://www.science.go.kr/link.bs?cd=00109

the photometry of astronomical objects for main analysis. 8 out of 12 photometry projects were carried out using CCD while only 4 projects used DSLR. On the other hand, non-photometry projects such as projects about spectroscopy, astrometry, and measuring sizes of solar system objects did use the DSLR, which leaded the contribution of DSLR in astronomy projects to be nearly ~50% (14 out of 31). From the statistics, it is noted that DSLR camera is easily accessible especially when targeting bright objects under the heavy light pollution in cities (Lee et al., 2009), yet photometry using the DSLR is unfamiliar to most of the middle and high-school students and teachers.

The first obstacle that students and teachers who have obtained digital astronomical images (either through the CCD or DSLR camera) encounter are the lack of understanding in the process of measuring flux from the images as well as the inexperience of using photometry tools. Concepts such as magnitude and brightness of a star are mentioned repeatedly in curriculum for different grades, yet quantifying the brightness is not described in detail in textbook. Sections that describe astrophotography do not provide the meanings of pixel values, the linearity range of digital images, and the possibility of saturation. Typical photometry tools used by professional astronomers are mostly command-line based, therefore are not easily accessible by amateur astronomers, students and teachers.

Possible solution to this is to use GUI-based software that is more user-friendly. Many of the science high schools that have their own observatory equipped with large aperture telescope and commercial cooled CCD camera use commercial softwares such as MaxIm DL[2)] to operate CCD, and such software also provides recipes for image pre-processing, basic calibration, point source profile measurement and aperture photometry on multiple sources. Naturally such commercial software is a first choice to do a photometry in a high school science fair projects. For 12 astronomy projects about photometry, 4 projects used Image Reduction and Analysis Facility[3)] (hereafter IRAF; Massey and Davis, 1992) which is popularly used by professional astronomers, and 9 projects used MaxIm DL. There is one project that used both IRAF and MaxIm DL. The MaxIm DL does have a variety of functions that can be utilized in many ways. Especially its ability of doing photometry on a few objects in multiple images from a time-series observation is a great merit for amateur astronomers interested in generating light curves of variable stars (e.g., Blackwell et al., 2005).

A clear drawback of the MaxIm DL is the price. In addition to that, the MaxIm DL operates only in Microsoft Windows platform therefore less flexible to be installed in a various machines. Recently, Collins et al. (2017) presented an astronomical image analysis software AstroImageJ by implementing useful plugins suited for the astronomy specific functions onto the ImageJ[4)]. The code is java-based thus is compatible with computers running Mac OS X, Linux, and Microsoft Windows. Since the AstroImageJ provides almost all function that can be done with the MaxIm DL, the program can be used to do a photometry on a time-series images of variable stars, multi-aperture photometry of a star cluster to construct the color-magnitude or color-color plot, etc. After the release, the program is most widely used among researchers studying the light curves of transiting exoplanets, since the program offers built-in transit curve fitting algorithm (e.g., Jeong, 2016). Digital images obtained with not only CCD but also DSLR camera can be used as an input by converting RAW format camera files into typical FITS (Flexible Image Transport System) format file normally used in observational astronomy, thus can be used as important class material to understand the process of astronomy research.

In this work, in order to ensure the possibility of

2) http://diffractionlimited.com/product/maxim-dl/
3) http://iraf.noao.edu/
4) https://imagej.nih.gov/ij/

using the astronomical images taken with the DSLR camera in the photometry, the comparison between the three different photometry tools -the professional IRAF, widely used commercial MaxIm DL, and recently developed freeware AstroImageJ- is presented. In addition to the comparison between the softwares, initial photometric uncertainties embedded in the DSLR images due to the CMOS sensor properties are discussed.

Data and Analysis Method

Properties of the DSLR camera used

The ISO system that indicates the film speed in the film photography, i.e., the sensitivity of a photographic emulsion to light, still remains in the setting of a digital camera. The ISO value in DSLR camera is closely related to the amount of photons that is converted to the electrical voltage, i.e., the gain in CCD (Kitchin, 2013). Since the astrophotography in general targets to capture very faint light from the objects, either the high sensitivity (i.e., the large ISO number) or the long exposure time is required to guarantee the detection of the interested source. Many photography guides mention that a high ISO setting naturally results the noise increase over the entire field of view. Then should we avoid or choose high ISO setting for astrophotography if the purpose of taking pictures would be the photometry?

Since the ISO settings in DSLR camera is relevant in charge reading process, the change of the ISO number would change the gain and the read-out noise. The digital astronomical images used in the followed analysis are obtained using the entry-level DSLR camera Canon 450D. The camera is 14-bit camera that delivers the minimum pixel value of 0 and the maximum pixel value of 16383ADU. According to the data provided by the collection of digital camera sensors[5], the read-out noise and the saturation well depth decrease as the ISO number increases (Fig. 1).

In order to calculate the gain of a sensor for a specific ISO setting, two bias (zero) images and two flat images are needed. Bias images were obtained using the shortest exposure time (1/4000 second in case of Canon 450D) with the lens cap being shut, flat images were obtained by shooting the white wall when the light is evenly illuminated. Images were taken in RAW format, then converted to FITS format using the open source software *dcraw*[6]. The gain in image sensor can be calculated using the following formula presented in Howell (2006),

$$\mathrm{Gain}=\frac{(\overline{F_1}+\overline{F_2})-(\overline{B_1}+\overline{B_2})}{\sigma^2_{F_1-F_2}-\sigma^2_{B_1-B_2}} \tag{1}$$

where the B_1 and B_2 are two bias images and the F_1 F_2 and are two flat images. B_1-B_2 and F_1-F_2 represent the difference between two bias and two flat images respectively. The variances in these two images are $\sigma^2_{B_1-B_2}$ and $\sigma^2_{F_1-F_2}$. The $\overline{B_1}$, $\overline{B_2}$, $\overline{F_1}$, $\overline{F_2}$ are the mean values measured in central 100×100 pixels of each image while the original image size is 4272×2848pixels. The numerator and the denominator in Eq. (1) is plotted as the x- and y-axis of the bottom panel of Fig. 1, thus the slope presented is equivalent to the gain factor for each ISO setting.

Finally derived gains are 2.7, 1.2, 0.8, 0.35, and 0.2 e^-/ADU when the number followed by ISO is 100, 200, 400, 800, and 1600 respectively. It is clearly seen that the increase of an ISO value leads to the decrease of the number of electrons needed for recording data, which means that the high ISO setting can compensate the lack of photons in a situation for the astro-photography. On the other hand, in high ISO number settings, the maximum data number value (16383 in 14-bit DSLR) could be reached more easily than in low ISO number setting since the rate of a value increasing as a function of exposure time is much higher. This means that the magnitude range that is free of saturation decreases in case of high ISO settings. This may not be a big problem if only a single target is of interest for a photometry (e.g., variable star, star that hosts exoplanet, etc.) but would

5) http://www.sensorgen.info/
6) https://www.cybercom.net/~dcoffin/dcraw/

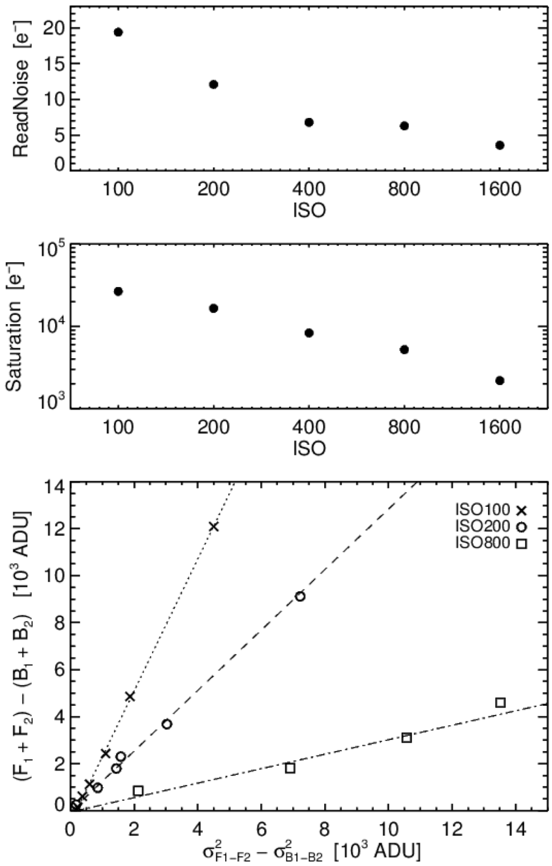

Fig. 1. CMOS sensor properties of Canon 450D camera. (Top) Read noise variation for different ISO settings. (Middle) Full saturation limit variation for different ISOs. (Bottom) Plot that shows gain difference for different ISOs. See text for details.

be a drawback if the observer intends to do a photometry for many objects over a large magnitude range (e.g., star clusters).

Observation

A large open cluster M44, a bright globular cluster M2, and a pulsating variable star RR Lyr are targeted with the DSLR camera. The digital images used in following analysis were obtained by 'prime focus' method by attaching the DSLR camera (Canon 450D) body directly to the Takahashi FC-76DS f/7.5 reflector. Combined to a small diameter (~76 mm) telescope, the DSLR camera provides a relatively wide field of view of ~$2^{o}\times1.5^{o}$ which is favorable for observations

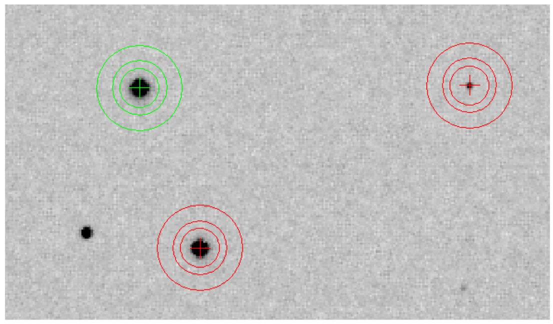

Fig. 2. The aperture for flux measurement (innermost circle), and the inner and outer annuli for background sky measurement overlaid on the DSLR camera image.

of large size objects including open star cluster. However due to the large pixel size (~1.87"/pixel), point sources are easily under-sampled which means that the magnitude can be affected by the relative positions of point sources in respect to the pixel center.

Typical seeing during the observation dates was 5-6", considering the high relative humidity (in summer nights) and non-negligible wind (in winter nights). The site for observation was the rooftop of a building in a downtown area of a metropolitan city, therefore it is difficult to expect better seeing which ironically reduces the risk of PSF under-sampling with DSLR images.

Aperture photometry

To measure the flux and estimate the magnitude in an aperture of a given radius, the center of the star should be determined first and three circles centered on it should be defined. In Fig. 2, the innermost aperture defines the boundary where the photon counts from the star (i.e., point source) are measured, and the two outer circles define the ring where the sky background value is calculated.

IRAF daophot package (Davis, 1994) and the AstroImageJ (Collins et al., 2017) explicitly mention that the flux, magnitude, and the magnitude error is calculated based on the so-called 'the revised CCD equation' presented in Merline and Howell (1995). MaxIm DL does not explicitly mention how the magnitude and the magnitude errors are calculated in the users' manual. If the total counts in the photometry aperture is *sum* and the mean average value for sky is *msky*, the counts value from the source only is calculated by $sum - msky \times n_{pix}$ while the n_{pix} is the number of pixels within the measuring aperture. This is equivalent to the flux F of the object, therefore the instrumental magnitude m can be estimated following the equation $m = \mathrm{zp} - 2.5\log_{10}F$. The zeropoint zp should be calibrated using the standard star exposures, accounting for the integration time and the atmospheric extinction. The relative photometry which is more frequently attempted by the DSLR camera users is less complicated than the absolute photometry since the separate standard star observation is not strongly required for this purpose.

The estimation of the magnitude error *merr* is directly relevant to the estimation of the flux error *Ferr*, i.e., $merr = 1.0857\frac{Ferr}{F} = 1.0857\left(\frac{S}{N}\right)^{-1}$. The signal-to-noise ratio $\frac{S}{N}$ is described as the Eq. (25) from the Merline and Howell (1995),

$$\frac{S}{N} = \frac{N_*}{\sqrt{N_* + n_{pix}\left(1 + \frac{n_{pix}}{n_{sky}}\right)(N_{sky} + N_{dark} + N_{read}^2 + G^2\sigma_f^2)}} \tag{2}$$

where the N_*, N_{sky}, N_{dark}, and N_{read} (in unit of electrons) represents total counts from the stars, counts from the background sky per pixel, counts from the dark current per pixel, and read-out noise. n_{pix} and n_{sky} is the number of pixels within the measuring aperture and the sky annulus. The last term $G^2\sigma_f^2$ indicates the combination of the squared CCD gain G and the standard deviation in the background sky σ_f. Since in most CCD images the fluctuation of the background is the dominant source for photometric errors, the above Eq. (2) can be re-written as in unit of ADU, not electrons:

$$\frac{S}{N} = \frac{1}{\sqrt{\frac{sum - msky \times n_{pix}}{G} + n_{pix}\sigma_f^2 + \frac{n_{pix}^2\sigma_f^2}{n_{sky}}}} \tag{3}$$

which is used in the IRAF *daophot* package for magnitude error estimation. The magnitude error (as well as the flux error) derived this way is always the lower limit for the true error.

The differences in three different aperture photometry tools -IRAF, MaxIm DL, and AstroImageJ- are the formula used to estimate outputs, the calculation of a sky background, and the treatment of partial pixels that rise with the circular boundaries. IRAF daophot uses Eq. (3) while the AstroImageJ uses Eq. (2). Note that if the dark current per pixel per exposure time is not measured (since the dark current was subtracted simultaneously while taking images) and the read noise of a few electrons (Fig. 1) is a marginal value, the Eq. (2) is more or less consistent with the Eq. (3). The sky background *msky* is calculated by taking average of the pixel values within the sky annulus in AstroImageJ. In IRAF, user can decide the method to calculate *msky* among the mean, median, mode, etc. MaxIm DL does not provide any formula or specific comments on how the magnitude and the magnitude error is calculated, yet the sentence "*… a careful background subtraction using median-mean techniques, and also takes partial pixels into account when integrating the light inside the measurement aperture.*" in the on-line users' manual[7] implies that the background subtraction is likely to be done by calculating mode instead of median or mean, and partial pixels are taken into account when calculating the total counts. The accounting of a partial pixel is supported in the most recent version (after the version 3.2.1) of AstroImageJ, while the previous versions adopted the standard method the same as IRAF counting only for the complete pixels while integrating in the aperture. More flexible treatment on the partial pixels would be advantageous for DSLR photometry, considering the under-sampling of the PSF in DSLR images. The differences between three photometry softwares are summarized in Table 1.

7) https://diffractionlimited.com/help/maximdl/MaxIm-DL.htm

Table 1. Differences in photometry recipes among the three different photometry tools

	sky subtraction	partial pixel treatment	magnitude error estimation
IRAF (daophot)	mean, median, mode, user-value	not implemented	Eq. (3)
MaxIm DL	not specified	implemented	not specified
AstroImageJ	mean	implemented	Eq. (2)

Results

Photometry on the non-crowded field

First, we conducted a multi-aperture photometry on the image of the M44 open cluster using three different photometry tools: IRAF (ver. 2.16), MaxIm DL (MaxIm DL Pro Demo), and AstroImageJ (ver. 3.0.0). In case of IRAF, *daophot* package was used to select point sources over 4σ detection automatically and to perform aperture photometry simultaneously. In MaxIm DL and AstroImageJ, stars were visually inspected and selected for a flux measurement. In all tools, re-centering of point sources was done within the ~5pixel box and the aperture size, inner and outer annulus for background sky measurement were set to 10, 14, 22pixels respectively. The aperture size used is larger than ~3 times the FWHM, thus the aperture correction is not necessary. In the IRAF, the background sky estimation was set to 'mean' to match with the calculation in AstroImageJ. Using the same zeropoint, we compared the differences in the derived instrumental magnitudes in Fig. 3.

In Fig. 3., the magnitude error marked as a vertical line is dominated by the Poisson photon noise, thus should be considered as a lower limit of a true magnitude error. At S/N greater than 20, magnitudes measured using the different photometry tools are in a very good agreement with each other. The deviation from the IRAF magnitude is slightly larger in MaxIm DL than in AstroImageJ, which appears to be generated from the different way of estimating the background sky. In any case, there is no systematic offset between the magnitudes measured using the different tools. Amateur astronomers, high-school or college-level students may choose any GUI-based photometry tools of their convenience and budget

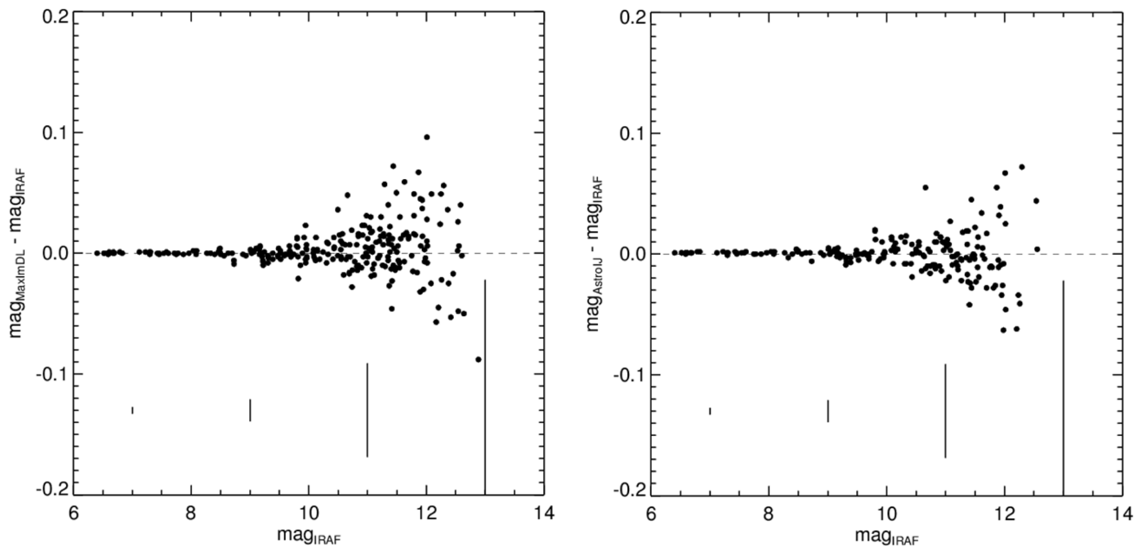

Fig. 3. Comparison between the instrumental magnitudes measured with IRAF and MaxIm DL (Left), IRAF and AstroImageJ (Right). The x-axis represents magnitude measured with IRAF and the y-axis indicates magnitude difference between the two photometry tools. Vertical lines show the scale of a typical magnitude error at the given magnitude range.

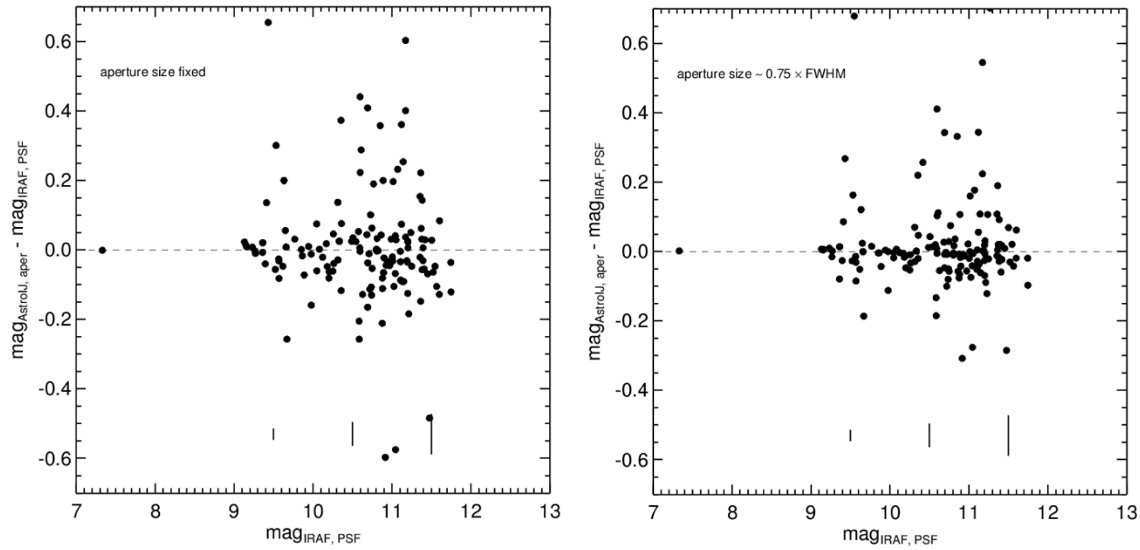

Fig. 4. Comparison between the instrumental magnitudes measured with the IRAF (PSF fitting photometry) and AstroImageJ (aperture photometry). In the left panel, aperture size in the AstroImageJ was fixed to a single value, while the aperture size is varied according to the FWHM size of each star in the right panel. Like in Fig. 3, vertical lines show typical magnitude errors at the corresponding magnitude bins.

(such as AstroImageJ) to conduct either the time-series or multi-aperture photometry on a non-crowded field.

Photometry on the crowded field

The estimation of a sky background is greatly hampered by the presence of nearby stars especially in case of the globular cluster images. To overcome such an issue, PSF fitting method is favored than the simple aperture photometry for photometry over the crowded field. The first step of the PSF fitting photometry is to construct a well-defined PSF that represents characteristics of point sources over the field that can be described in an analytic form (e.g., gaussian function). When the PSF is determined, the function is fitted to each point source with the fitting factor to be the flux of an object.

The *daophot* package in IRAF provides tasks for PSF construction, PSF matching, and subtracting the fitted PSF to check the reliability of photometry performed. Unfortunately GUI-based photometry tools have limited ability for a PSF fitting. In AstroImageJ, there is a function that enables the variation of an aperture size used in photometry according to the object's FWHM size. Especially in the DSLR images that is easily under-sampled, the FWHM sizes would be largely variable in the crowded field. Therefore compared in Fig. 4 are the magnitudes derived from the PSF fitting (IRAF) and the aperture photometry (AstroImageJ) with either the fixed or the varying aperture size. The mean FWHM was less than ~3pixels, therefore we used either fixed aperture radius of 5pixels (Left panel of Fig. 4) or varying aperture equivalent to 0.75 times the FWHM of the object (Right panel of Fig. 4). The aperture magnitudes were aperture-corrected using the single correction factor that matches PSF size to the total aperture size.

According to Fig. 4, the difference between the magnitudes derived from the PSF fitting and the aperture photometry is larger than the typical photometric error if the aperture size is fixed. The magnitude difference is significantly reduced if the varying aperture is used. The scatter is still large therefore obtaining crowded field images (e.g., globular cluster) with DSLR camera and conducting photometry over the image (e.g., to produce a color-magnitude diagram for the old globular star cluster)

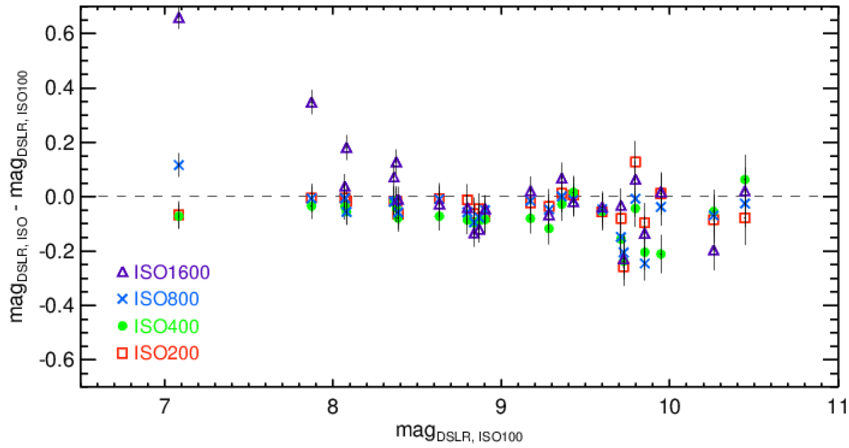

Fig. 5. Magnitude difference for a same point source in different images with different ISO setting. A DSLR image with ISO setting of 100 is used as a reference, y-axis shows the magnitude difference between ISO 100 image and other images.

seems to be challenging. However by adjusting the factor between the measuring aperture radius and the FWHM of the individual object, at least it is expected to distinguish between the color-magnitude diagrams of the open and globular clusters qualitatively.

Cautions for DSLR photometry

Despite the large pixel scale that leads to the under-sampling of the PSF, aperture photometry on DSLR images generates a stable result on the magnitudes of the point sources in a non-crowded star field. Even in a crowded field, DSLR images provide an easy way to extract flux information that is enough for a qualitative study. However, the limited dynamic range of a 14-bit DSLR camera compared to the 16-bit cooled CCD and the uncertainty of converting RGB Bayer-filter colors and magnitudes to the conventional Johnson-Cousins BVR or other filter colors suggest that the users of DSLR image in a photometry should be cautious and should understand such a characteristics before interpreting the result.

In the previous subsection, it is mentioned that the different ISO setting in DSLR camera reflects the different gain in the CMOS sensor. Images of the M44 open cluster have been obtained by changing the ISO number and the integration time. Theoretically the increase of ISO from 100 to 200 requires half of the integration time to get the same number of photons, therefore the exposure was adjusted accordingly. For images with ISO of 100, 200, 400, 800, and 1600, Fig. 5 shows the magnitude difference between images with different ISO settings. At magnitudes brighter than ~8.5 mag, the magnitude measured in ISO 1600 image is fainter than the magnitude measured in ISO 100-400 images. The magnitude difference increases as the source gets brighter, which is because the magnitude in the ISO 1600 image is fixed to a certain value while the magnitude in the ISO 100 image varies. The reason that the magnitude is fixed in high ISO numbers is that the sensor has reached its maximum limit that can be sensitive to the light exposure, i.e., the saturation limit. Similar phenomenon is seen in the brightest magnitude range for ISO 800 image. Narrow dynamic range of the DSLR camera cause frequent saturation of bright objects that could be of interest, therefore the high ISO number should be avoided in the DSLR imaging with the purpose of photometry. Though the magnitudes measured in ISO 100-400 images are roughly consistent with each other, the scatter in the magnitude differences is large especially if the S/N of the source decreases. This invokes the need for not changing the ISO setting to avoid the additional uncertainties in magnitudes and the users should be aware that the 0.1 to 0.2mag uncertainties is embedded due to the analog-to-digital conversion properties (related to the ISO) of the

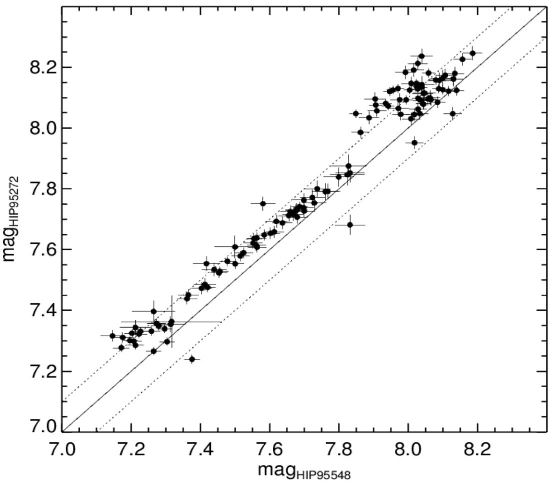

Fig. 6. Comparison of the DSLR 'green' magnitudes of the RR Lyr for two different choices of a comparison star. The x-axis and y-axis represent the magnitudes of the RR Lyr with use of the HIP95548 and HIP95272 as a comparison star, respectively. There is a slight offset (~0.1 mag) in the estimated magnitude, caused by a neglection of a color term in the magnitude conversion.

CMOS sensor.

Park et al. (2016) noticed that the color conversion from the DSLR RGB filter system to the Johnson-Cousins BVR system is dependent on the initial colors of the objects and claimed the need for color term in the transformation equation. Fig. 6 shows how the 'color' dependence of DSLR photometry is reflected in the 'magnitude' measured. DSLR images of the RR Lyr variable star have been obtained covering the entire phase of the light curve. In order to construct the light curve, the magnitude of the RR Lyr at each epoch was measured by using a nearby comparison star as a reference. Two comparison stars were selected, HIP95548 of which (B-V) color is close to that of the RR Lyr and HIP95272 whose (B-V) color is significantly bluer than that of the RR Lyr. At the same epoch, two magnitudes differ by ~0.05-0.1mag systematically which is a reflection of the effect using the comparison star of different spectral type. Based on the conversion formula presented in Eq. (2) of Park et al. (2016),

$$V_J = G_{B,ZP} + G_B + C_{V,BG}(B_B - G_B) + C_{V,GR}(G_B - R_B) \tag{4}$$

where the B_B, G_B, R_B, and V_J represent DSLR (Bayer) Blue, Green, Red and Johnson-Cousins V-band magnitudes while the $G_{B,ZP}$, $C_{V,BG}$, and $C_{V,GR}$ are the instrumental zeropoint and the two color terms. Through the iterations, two color terms converge to $C_{V,BG}$ ~0.5 and $C_{V,BG}$ ~ −0.06. According to the Fig. 4 of Park et al. (2016), (B-V) colors of RR Lyr, HIP95548, and HIP95272 that are 0.3, 0.32, and 0.02 mag corrspond to (B-G) colors of +0.1 and -0.1 mag. Combining the color difference Δ(B-G) of ~0.2 mag and the dominant color term of ~0.5 results ~0.1 mag difference in the calibrated magnitudes. Such ~0.1 mag of magnitude uncertainty could be considered as the source of 'intrinsic' uncertainty in the magnitude for DSLR photometry.

Summary

The popularity of DSLR cameras provides more chances of easily obtaining astronomical images to astronomy non-majors, amateur astronomers, and high-school or college students who are interested in stars and the Universe. Photometry, measuring the strength of light from the distant celestial object, is the stepstone to understand how the astronomy knowledge is constructed. A GUI-based software that is suited for aperture photometry is an easily accessible tool for students, enriching the activities that can be explored in the observational astronomy lab.

A simple aperture photometry measures the integrated flux of a source within the defined aperture by subtracting the estimated background sky values. A conventional photometry tool for professional astronomers IRAF *daophot* package, commercial software MaxIm DL, and recently released freeware AstroImageJ follow similar photometry technique in principle. Despite there are slightly different points regarding the background estimation, error estimation, and treating partial pixels for a circular aperture, the final product (magnitudes) is consistent with each other regardless of the photometry tool used. There is no systematic offset of a specific tool compared to the other two, and the magnitude differences entirely arise from the random errors. However, this is limited to the case for the non-crowded field. In the crowded field such as globular star clusters, magnitudes measured by the aperture photometry technique with the GUI-based AstroImageJ showed non-negligible scatters with the magnitudes measured by the PSF fitting method. Such a large scatter could be clearly reduced by adopting variable aperture size for different point sources, suggesting that the aperture photometry over the crowded field is not very robust, yet still the qualitative result can be derived at one's own risk.

Additionally, users who plan to use DSLR images in observational astronomy lab should recognize the effect of using different ISO settings (i.e., gain for the CMOS sensor) while taking images since the dynamical range decreases significantly at high ISO numbers. Changing ISO setting for the same target results the magnitude uncertainty up to ~0.1 mag though the integration time is adjusted to achieve the same photon counts. The choice of photometric comparison star to do a relative photometry also contribute ~0.1 mag uncertainty due to the color dependence on the DSLR magnitudes resulted from the large color overlap between Bayer filters. Summed in quadrature, ~0.15 mag of magnitude uncertainty is expected in the magnitude measured from the DSLR camera images. Those who wish to conduct a photometry on DSLR images should be aware of such intrinsic uncertainties.

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