CCD observation of daylight crescent moon at Bosscha observatory

P. Mahasena\textsuperscript{(1,2)}, M. Yusuf\textsuperscript{(2)}, M. Irfan\textsuperscript{(2)}, E.I. Akbar\textsuperscript{(1,2)}, A.T.P. Jatmiko\textsuperscript{(2)}, D. Mandey\textsuperscript{(1,2)}, A. Setiawan\textsuperscript{(2)}, M. Sulaeman\textsuperscript{(2)}, T. Hidayat\textsuperscript{(1,2)}, D. Herdiwijaya\textsuperscript{(1,2)}, M. Raharto\textsuperscript{(1,2)}, B. Dermawan\textsuperscript{(1,2)}

\textsuperscript{1}Astronomy Research Division, FMIPA, Institute of Technology Bandung, Indonesia
\textsuperscript{2}Bosscha Observatory, FMIPA, Institute of Technology Bandung, Indonesia

E-mail: mahasena@as.itb.ac.id

Abstract. Bosscha Observatory, Institut Teknologi Bandung, has been experimenting to observe crescent moon using small telescope equipped with digital cameras since 2007. The initial motivation was to provide evidence, \textit{i.e.} digital image, of the first crescent moon visible after new moon (hilal) for moslem community in determining the first day of Ramadan and Shawwal. Initially, observation was done after sunset, following common believe that crescent moon can be detected only after glare from the Sun disappear. In early 2000’s it was shown that crescent moon can be detected using CCD camera before sunset (in daylight) with special setup. We catched up the idea in 2013. In this paper we summarize what we have learned so far. Now, detection of crescent moon with elongation $e \geq 4^\circ$ is not a problem. Detailed report will be written somewhere else.

1. Introduction

There are several islamic organizations in Indonesia who define their own (lunar) calendars, with different sets of criteria. At least, for determining the beginning of three months (Ramadan, Shawwal, and Dhul-Hijjah) some organizations require sighting of the new moon crescent to determine its first day. On the other hand, some organizations define their calendar only by (modern) calculation of relative positions of the Moon from the Sun. This occasionally results in uncomfortable situation in the country when there were two versions of the 1st of Shawwal, for example [1]. Apart from the difference in the definition for the new month, weather and inaccuracies in the sighting report contribute to the situation. Incorrect positive reports (mostly statement under oath; without hard evidence) from unaided-eye observers in “impossible” cases (\textit{e.g.} because the Sun-Moon angular distance were too small) caused efforts to reconcile the two different definitions more difficult. To improve positive sighting report, by providing digital images, was our first motivation to do experiment on observing crescent moon using digital camera [2].

Soon after we embarked with our first experiment back in 2007 we found that it was not a trivial task. Using small telescope ($D = 66 \text{ mm}$, $F/5.9$) equipped with pocket digital camera, we followed the tradition to observe crescent moon after sunset (new moon) or before sunrise (old moon). For the first five years, 2007 – 2011, we worked in video mode streaming our after-sunset observation to Internet. Mostly we failed to detect the crescent when moon age was $\leq 18$ hours,
Table 1. List of our first successful observations of crescent moon in 2012 and 2013. Observations number 1 – 5 used DSLR camera after sunset, number 6 – 8 used CCD camera (+ I filter) in daylight. Details including (contrast-enhanced) photos of these observations can be found at http://bosscha.itb.ac.id/hilal/m/data.

| No. | Place     | Date       | Time | Moon age | ∆ Alt | ∆ Az | Elongation |
|-----|-----------|------------|------|----------|-------|------|------------|
| 1   | Subang    | 22-05-2012 | 18:08 LT | +37° 14' | +14° 51' | +03° 20' | 15° 14'    |
| 2   | Subang    | 20-06-2012 | 18:06 LT | +19° 27' | +08° 42' | -02° 05' | 08° 57'    |
| 3   | Bangkalan | 20-07-2012 | 17:46 LT | +30° 13' | +13° 33' | -06° 19' | 14° 57'    |
| 4   | Kupang    | 18-08-2012 | 17:55 LT | +18° 03' | +07° 26' | -06° 36' | 09° 57'    |
| 5   | Makassar  | 18-08-2012 | 18:19 LT | +18° 24' | +07° 01' | -07° 23' | 10° 11'    |
| 6   | Lembang   | 15-09-2012 | 14:54 LT | -17° 00' | -11° 38' | -03° 17' | 11° 56'    |
| 7   | Lembang   | 16-10-2012 | 09:46 LT | +13° 23' | -08° 13' | +08° 31' | 09° 18'    |
| 8   | Lembang   | 13-03-2013 | 07:53 LT | +29° 58' | -14° 19' | -07° 47' | 16° 02'    |

or when moon illumination was \leq 1\%. The hardest challenges were (i) often not clear sky above west horizon, (ii) low contrast between the crescent and the background sky, (iii) polar alignment and pointing accuracy of our portable mounting, (iv) wind in the telescope area, and (v) low effective resolution of our low-cost video system.

We gave up working in video mode and then experimenting in picture mode using DSLR camera, with better results. At about the same time we tried a technique used by Martin Elsasser [3] and Thierry Legault [4] to photograph crescent moon using CCD camera and Johnson/Bessel I filter (to increase contrast; referred to as I filter hereafter), in daylight. We list in Table 1 our first positive results using DSLR and CCD camera (+ I filter), which are comparable regarding their elongation. The smallest elongation was \sim 9°.

In the followings we will show why I filter is essential for contrast enhancement, describe our current instrument setup, briefly describe our observation procedure and software algorithm, and show some latest results.

2. Wavelength dependence of contrast

To see in which wavelength crescent moon is most contrast with its sky background, in visual range, we took some CCD spectral images with slit orientation shown in Figure 1 (inset). The spectra of waning crescent were taken using Shelyak Lhires III spectrograph attached to an 8-inches reflecting telescope when the sky background was relatively blue.

Using spectroscopy data reduction packages within IRAF we extract spectra from two segments of the slit indicated by “Sky + Moon” and “Sky.” We then plot the ratio between the two spectra as a function of wavelength in Figure 1. We can see that contrast between the crescent and its sky background is higher at the red-end of the spectra, above 740 nm. Since response profile of I filter also peaks around 740 nm, daylight crescent moon will be easiest to be recorded using CCD + I filter, in visual range. Note that quantum efficiency of visual CCD usually has decreased to about 40\% at 740 nm.

3. Instruments setup

In order to increase crescent image contrast, apart from utilising I filter, we use a homemade yet very effective baffle to reduce stray light. The baffle is a cylinder, extension of the original telescope baffle of same diameter, made from black cardboard. The cylinder is about 1 meter long, and at every 4 cm we put black cardboard rings (inside). The effectiveness of this baffle had been judged by pointing the telescope to different angular distances from the Sun while taking
Figure 1. Ratio of spectra extracted from slit segments indicated by “Sky + Moon” and “Sky” (in the inset) as a function of wavelength. Inset: slit orientation with respect to crescent arc. Shelyak Lhires III spectrograph had been used to obtain the spectra.

images of the sky. In moderately blue sky we do not see significant sky brightness increase even if the telescope is pointing to only ∼3° from the Sun.

We use William Optics 66 mm (F/5.9) telescope and Celestron Skyris 445M (or ImagingSource DMK 41AU02.AS) CCD camera. With this configuration full moon is about 100% (or 80%) of the short axis of the CCD and the sampling is ∼2″/pixel (or ∼2.4″/pixel). The camera can take images up to 30 fps (or 15 fps) and its variable shutter speed (0.0001 s−30 s) is very convenient for taking bright sky images near the Sun where saturation usually is a problem.

In order to have good pointing to and tracking of the Moon we use fixed mounting AstroPhysics 1600 GTO with pointing accuracy of ∼3″. This mounting can track the Moon both in the right ascension and declination direction. With this mounting we are confident that the crescent would stay on the same pixels for few minutes.

4. Observation procedure and software algorithm

Before taking images of the sky in the crescent direction, it is very important to create “flat image” from an adjacent direction (estimation: far enough to exclude the crescent). Experience shows that pattern of flat image changes if we move too far from crescent direction, which makes subsequent image reduction less effective. The pattern changes with elongation as well, so we need to renew our flat image from time to time.

With the above instruments setup, we point the telescope to the direction where the crescent is supposed to be. We then create a stacked image (call it S) from N individual frames, each of which is processed with the following steps: (i) divide the frame with current best flat image, (ii) do histogram equalization to the resulted image to increase contrast, and (iii) put the resulted image into the stack. Contrast of the final stacked image is further enhanced using Contrast Limited Adaptive Histogram Equalization (CLAHE) method proposed in [5] and summarized in [6]. The resulted image is the image S.
Figure 2. Upper panels: before sunset. Lower panels: after sunset.
The repetition of image acquisition and processing are done by a software that we have developed. For example, if \( N = 50 \) then we will get one image \( S \) every 2 seconds, because the camera can work at maximum 30 fps. We can thus see a near-real-time video observation of crescent moon. At this point, it is easy to broadcast/stream the observation to Internet (to youtube.com, for example).

5. Results
In 15 August 2015 we succeeded in tracking crescent moon from Bosscha Observatory. The tracking started at around 07:30 LT when illumination was 0.2\% and elongation was 05° 46′, and ended at around 18:10 LT when the moon set at the horizon with illumination of 0.7\% and elongation of 09° 44′. We were surprised that our system works even if there are considerable amount of cloud. We show images of before- and after-sunset crescent moon in Figure 2. Now we are confident that, provided the sky is moderately blue, crescent moon with elongation \( e \geq 4° \) will be detectable using our system.

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