Comments

Page 1. Photometric search for variable stars in the field of the northern open cluster NGC 1960

Abstract: The aim of the present work is to extract and analyze the light curves of the stars in the field of the cluster NGC 1960. The photometric calibration is performed by a comprehensive secondary standard method. transformation and differential photometry using two comparison stars per candidate variable star. The resultant light curves for each potential variable star are displayed, and their periods are analyzed by two different methods. The period and classification of the 18 discovered short periodic type variable stars of NGC 1960 are discussed, which consist of four known variable stars and fourteen new variable stars. In the case of NGC 1960, the 12 selected comparison stars appear to be likely candidates for long periodic variability, and four stars may be standard stars. The variation in brightness of the other twenty comparison stars is non-pulsating with an irregular pattern. Membership analysis of variable stars is performed using their distance, kinematic probability, and location in (U − B) vs. (B − V) TCD. C-M diagrams were constructed to confirm the evolutionary state of thenew variable stars

Comment [Bs1]: Reformulate this statement

Comment [Bs2]: Rewrite your abstract by showing your main findings

Introduction

OCLs are the stars of Pop I. The fluctuations in brightness were found for some stars amongmembers of the stellar population, and such stars are known as variable stars. The stellar variabilityarise either due to intrinsic properties (pulsations, eruptions, stellar swelling, and shrinking) or due toextrinsic reasons (eclipsed by stellar rotation by another star or planet, etc.). Their census, includingPulsators and binaries can provide important clues to stellar evolution and the host star clusters [1]. The several classes of pulsating variables are found extensively in the instability strip region of theHertzsprung-Russell (HR) diagram Since pulsating variables have an associated instability strip [2]. Above the MS, therefore, a star cluster provides an opportunity to estimate the properties of its stellar variables through its own characteristic parameters.

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Since the detection and magnitude estimation of the fainter stars are primarily affected by their nearby brighter stars, knowledge of the flux contamination of the stars in the science frame of any cluster is useful for probing the nature of instrumental pseudo-variability. For such a study, a cluster region consisting of bright stars is required, and NGC 1960 has been found to be a likely candidate for such a study.

In this background, the time series observations of NGC 1960 have been analyzed to search the variable stars within them. The previous parametric studies of clusters are given in Section 2. The observational details of the cluster are given in Section 3. The methodology of data reduction is discussed in Section 4. The identification procedure for variable stars in NGC 1960 is given in Section 5. Fast-Fourier analysis of variables discussed in Section 6. Mean-proper motions and kinematics Membership probabilities are described in Section 7. A comparative study of variable stars with the parameters of clustering are discussed in Section 8. A detailed description of the identified stars in the cluster NGC 1960 is given in Sections 9. The results, discussion, and Conclusion are described in Sections 10 & 11.

This cluster is located in the Constellation Auriga and has been studied by many authors in the past. The Center coordinates (α, δ) for this cluster have been calculated by Sharma et al. (2006) [3] and Cantat& Anders (2020) [4] as (05h: 36m : 20.8s, +34o: 08′ : 31") and (05h: 36m : 20.2s, +34o:08′: 06"), respectively. Its angular size is computed by Cantat& Anders (2020) [4] and Joshi & Tyagi, (2015) [5] as 10.3 arcmin and 16 arcmin, respectively. Previously, this cluster was studied by various research groups [[3, 6–14]].

Comment [Bs4]: Remove unnecessary square brackets

A complete UBV RIJHKW1W2 photometric catalog~~ue~~ has been represented by Joshi & Tyagi (2015) [5] by complying with the PPMXL catalog~~ue~~ with the obtained UBV RI standard photometric magnitude of data collected on November 30, 2010, and the~~date of 30 Nov, 2010 and same~~ data set was further analyzed by JO20 for their absolute or ~~/~~standard photometric analysis. By utilizing catalog~~ue~~s of various data-sets, a comprehensive photometric analysis of this cluster with the long-term variability is shown by them. A total of 76 variable stars from~~of~~ NGC 1960 have been identified by JO20, and their analysis confirmed 72 periodic variables, 59 of which~~among them~~ are short period ($P < 1$ d). They have used absolute ~~phtometry~~photometry to detect variable stars, to~~in~~ which instrumental errors are surely added due to magnitude transformation. In the case of dataset ~~of~~ J20, there are only three data strings of continuous time series observations with a gap of more than 1 year and~~there are only three data strings of continuous time series observation with a gape of more than 1 yr and~~ length of each data string is less than 3.5 hours (i.e. $\simeq$ 0.146 d). time gap~~e~~ of more than 1 year leads ~~more than 1 yr leads~~ additional aliases. Mostly, other observational nights have only 1-3 frames with irregular exposure time as well as time interval, which do not seem suitable for the detection of short periodic variable stars. Thus, it is impossible to determine a ~~short periodic variable stars~~short periodic variable star.

In the case of this cluster, the flux of nearby fainter and brighter stars would be contaminated during its deep CCD photometric observations~~flux of nearby fainter stars of brighter stars would be contaminated during its deep CCD photometric observations~~. Such circumstances surely lead to an overestimation in the detection of short periodic variable stars. In view of the above antecedent, the author is also motivated to perform time series observations of this cluster with short exposure times of 05, 06, and 10 seconds.~~Such circumstances surely lead an over estimation in the detection of short periodic variable stars. In the view of above antecedent, author is also motivated to perform time series observations of this cluster with short exposure times of 05, 06 and 10 seconds.~~

3. Data Collection, Extraction and Characteristics of observational data of NGC 1960

To detect the short periodic pulsation of stars in the ~~of~~ target cluster, we need time series observation of the whole night as per the availability of the target in the telescopic field of view. The time series observations of the studied cluster NGC 1960~~,~~ are carried out using the observational facilities of the 1.04-m Sampurnand telescope of ARIES, Manora Peak, Nainital. The CCD camera of the 1.04-m Sampunanad telescope of ARIES covers 15×15 arcmin2 field of view of the target objects. To identify short periodic pulsations of stars within the core region of NGC 1960, time series observations were~~are~~ carried out in V-band during five~~5~~ observation nights (2012-2015). It contains ten stars of a visual magnitude brighter than 10 [9], one B-type Variable of 9th magnitude [15], 178 down to magnitude 14 [13], and 38 members with~~have~~ infrared excess [16]. Thus, there are several bright stars in our telescopic field of view for NGC 1960. The author found that these bright stars became nearly saturated during an exposure time of 5 seconds. As a result, the value of exposure time of 5 seconds in V-band becomes too high for saturation counts of the brighter stars of NGC 1960 and leads to flux contamination for nearby fainter stars of bright stars in the observed science frames using the ~~facility~~ 1.04-m telescope at ARIES, Nainital. Similarly, an exposure time of 1 second is too low ~~value~~ to collect~~ion~~ the stellar information for fainter stars in~~of~~ NGC 1960 below 17 mag in V-band. Environmental influences (seeing, air flow, humidity, passing clouds, etc.) and the high declination of the target cluster from zenith further reduce the value of stellar magnitude and alter the rate of stellar detection. Therefore, different numbers of faint stars are detected in different science frames of NGC 1960. To overcome the detection problem of faint stars, the author performed a~~the~~ deep CCD photometric observation of the core region of NGC 1960~~,~~ with exposure times of 10, 20, and 60 seconds. We need continuous observations of 4-6 hours or more, therefore, the science frames of NGC 1960 have been captured in the alternating order of low (5 or 6 seconds) and high (10 or 20 or 60 seconds) exposure times during the observation session at~~of~~ night. Thus, ~~the~~ exposure time plays a major role in collecting~~to collect~~ the stellar information. The visual picture of science frames for exposure times of 10 and 60 seconds for NGC 1960 are shown in the right and left panels of Figure 1. In these figures, flux contamination of nearby bright stars is found more often in the science frame with exposure times of 60 seconds than that of 10 seconds. The details of exposure times and a brief description of the present data are given in Table 1. After inspecting the light curves of the studied variable stars and their comparison stars in Figures 4–9, the quality of these curves dated January 24, 2012, and December 20, 2013 is too low to identify the nature of stellar variability. An exposure time of 60 seconds has been kept during the above observations. Thus, the author concludes that observations with exposure times of 0–20 seconds are suitable to analyze the nature of stellar variability within NGC 1960. In observational sets of 43 nights, JO20 has 1, 1, and 19 observational nights with exposure times of 40, 200, and 60 seconds, respectively. It is noted that the data strings for dates 02/11/2011, 03/11/2011, and 24/12/2012 include observations with an exposure time of 60 seconds. In this background, the classification of variable stars within NGC 1960 by JO20 seems very suspicious.In these figures, flux contamination of nearby stars of bright stars are found more for science frame with exposure times of 60 seconds than that of 10 seconds. The detail of exposure times and brief description of present data is given in Table 1. After inspecting light curves of studied variable stars and their comparisonstar in Figures 4-9, the quality of these curves dated 24/01/2012 and 20/12/2013 is too low to identify the nature of stellar variability. An exposure time, 60 seconds, has kept during above observations. Thus, author concludes that observations with exposure times, 05-20 seconds, are suitable to analysis the nature of stellar variability within NGC 1960. In observational sets of 43 nights, JO20 have 1, 1 and 19 observational nights with a exposure time 40, 200 and 60 seconds, respectively. It is noted that data strings for dated 02/11/2011, 03/11/2011 and 24/12/2012 include observation with exposure time 60 seconds. In this background, the classification of variable stars within NGC 1960 by JO20 is seems to be very suspicious.

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4. Methodology of Data reduction

Bias correction and flat-fielding of observed science frames of NGC 1960 have been performed using bias and flat frames that were observed in the same observational night of the object. The author also utilized bias and flat frames of nearby nights for the science frames of NGC 1960 due to the lack of these frames in the observed data. For this purpose, the 'ZEROCOMBINE' and 'FLATCOMBINE' tasks of the IRAF' package are used. The COSMICRAYS' task of the IRAF' software is used to remove cosmic rays from the science frames.Bias correction and flat-fielding of observed science frames of NGC 1960 have been performed using bias and flat frames, that were observed in the same observational night of object. Author also utilized bias and flat frames of nearby night for the science frames of NGC 1960 due to the lack of these frames in observed data. For this purpose, the 'ZEROCOMBINE' and 'FLATCOMBINE' tasks of 'IRAF' package are used. 'COSMICRAYS' task of 'IRAF' software are used to remove cosmic rays from the science frames.

The GEOMAP' and 'GEOTRAN' tasks of the IRAF software are used to align the all-science frames for analysis. In the astrometry, the pixel coordinates of detected stars are transformed into celestial coordinates (2000, 2000) using a linear astrometric solution derived by matching a set of common stars between the present reference catalog and the 2MASS catalog with an rms value of about one arcsec in RA and DEC. A total of 63 common stars have been selected in the observed field of NGC 1960. For this purpose, the visualization of images and access to catalogs have been done by the SKYCAT' tool of ESO. The CCMAP and CCT-RAN tasks of IRAF were used for these transformations.'GEOMAP' and 'GEOTRAN' tasks of IRAF software are used to align the all science frames for analysis. In the astrometry, the pixel coordinates of detected stars are transformed into celestial coordinates ($\alpha 2000$, $\delta 2000$) using a linear astrometric solution, derived by matching a set of common stars between present reference catalogue and the 2MASS catalogue with the rms value of about one arcsec in RA and DEC. A total of 63 common stars have been selected in the observed field of NGC 1960 respectively. For this purpose, the visualization of images and access to catalogues has bee

4.1. standardization Details for NGC 1960

To perform consistent photometry from night to night on the aligned images [17], there is a need for a master list of stars from the science frames of the cluster that have the best seeing and coverage of the observed core region of the cluster, NGC 1960. By using the prescribed telescope in Section 3.1, the photometric observations of the open star cluster NGC 1960 were obtained on the night of November 30, 2010. The bias and twilight flat frames were acquired during the observational night for the normalization of the CCD pixels. The two Landolt standard fields SA95 and P G0231 + 051 [18] were also observed on the same observational night. A total of ten frames of the cluster, with two frames each in U, B, V, R, and I filters, with exposure times of 300, 300, 200, 200, and 60 seconds, were obtained. All observations were taken in 22 binning mode to improve the signal-to-noise ratio.he basic steps of image processing, such as bias subtraction, flat fielding, and cosmic-ray removal, were performed through IRAF † . Photometry analysis was done using DAOP HOT II profile fitting software [19]. To quantify the difference between aperture and profile-fitting magnitudes, an aperture growth curve was constructed by the DAOGROW program [20]. The instrumental magnitude was translated into standard magnitude using the following transformation equation:~~To perform consistent photometry from night to night on the aligned images [17], there is need a master list of stars from the science frames of cluster, which have the best seeing and coverage of the observed core region of cluster, NGC 1960. By using prescribed telescope in Section 3.1, the photometric observations of the open star cluster NGC 1960 were obtained on the night of 30 Nov, 2010. The bias and twilight flat frames were acquired during the observational night for the normalization of the CCD pixels. The two Landolt's standard fields SA95 and P G0231 + 051 [18] were also observed on the same observational night. A total of ten frames of the cluster with 2 frames each in U , B, V , R and I filters with exposure times of 300, 300, 200, 200 and 60 sec were obtained. All observations were taken in 2 × 2 binning mode to improve the signal-to-noise ratio. The basic steps of image processing such as bias subtraction, flat fielding and cosmic-ray removal were performed through IRAF † . Photometry analysis was done using DAOP HOT II profile fitting software [19]. To quantify the difference between aperture and profile-fitting magnitudes, an aperture growth curve was constructed by DAOGROW program [20]. The instrumental magnitude was translated into standard magnitude using the following transformation equation:~~

4.2. Secondary standardization method for NGC 1960

In the case of NGC 1960, to translate the stellar magnitudes (as extracted from data on the remaining nights) into absolute magnitudes, ~~the~~ differential photometry was performed using the UBV RI catalogue of secondary stars. For this purpose, the author used a linear fit between the standard and instrumental magnitudes on each science frame, assuming that most of the stars are non-variables (these non-variable stars are also called stabe stars~~nonvariable stars also called stable stars~~). This procedure is defined as the secondary standardization method [SSM [21]]. It is effective to estimate the absolute stellar magnitudes of NGC 1960 through the calibrated magnitudes of its stable stars. The magnitudes of variable stars are rapidly varying compared to other stars, and the identified variable stars were not utilized for such calibration. In this connection, the master list of stable stars of the observed core region of NGC 1960 is prepared.

Identification of variable stars The shapes of light curves of a variable star provide valuable information for investigating the nature of stellar variability and underlying physical processes that generate brightness changes. Consequently, the potential variable candidates identify by inspecting of their light curves [22]. If, we find the 7 UNDER PEER REVIEW deviation of absolute magnitudes of star more than 3σ limit of mean value of its light curve, then, it would be considered a possible candidate for variable stars. The amplitude or period of the pulsations can be related to the luminosity of the pulsating stars and the shape of their light curves can be an indicator of the pulsation mode [23]. As a result, pulsating variables are distinguished by duration of their pulsation and the shapes of their light curves [24]. For this purpose, the applied procedure for searching variable stars is discussed as below.~~,~~

5.1. Limitation of Differential Photometry in present study

It is also noted that effect of contamination depends on exposure times as well as stellar distances from the bright stars. Since, the observed field of NGC 1960 is highly contaminated by the presence of bright stars in its core region, therefore, magnitude variation for nearby stars of these bright stars is varied as per physical distance and stellar orientation. Furthermore, exposure time of its science frames is not constant during observation, which further leads to different amount of flux contamination for them. Even for same exposure time, the flux contamination varies with the distance of cluster from Zenith. As a result, difference of instrumental magnitudes of nearby similar comparison stars is not found approximately constant for detected variables of NGC 1960. Since, DOLIDZE 14 is observed in I-band only, therefore, the comparison stars of its variables are searched in such a way that their I-magnitudes may closer to corresponding variables. Such detected comparison stars were found to be physically distant from their variable. As a result, detected comparison stars are not suitable for variables of DOLIDZE 14.

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Table 5. The first column shows the variable ID of variables within the studied cluster, NGC 1960. The second and third columns represent RA and DEC respectively. The values of the period of detected variable stars are estimated through the PERIOD04 and PerSea software, as listed in the fourth and seventh columns, respectively.

5.6. Comparative Analysis of SSM with essential conditions of Differential Photometry

The major characteristics of the comparative light curves of the present comparison stars of variable stars in NGC 1960 are obtained as below: (1) The shifted and varied magnitude differences are found in the comparative light curves of comparison stars V1,, V2, and V12. (2) A constant value of magnitude difference is found in the comparative light curves of comparison stars V6,, V8, and V11 during observations of individual nights. However, shifting of magnitude differences is altered from night to night. (3) A constant value of magnitude differences is found in the comparative light curves of comparison stars of variables V3, V4, V9, V14, and V17 during the observations on January 24, 2012, December 11, 2013 and December 20, 2013. Similarly, a shifted and constant value of magnitude differences was obtained in the light curves of these stars during the observations on January 12 and February 8, 2015. (4): A constant value of magnitude differences is found in the comparative light curves of comparison stars of variables V5, V9, V10, V13, V15, V16, and V18 during the observations.

Thus, the detected variable stars of NGC 1960 are listed in four different groups as per the comparative light curves of their comparison stars. After deep investigation of Table 6 and Table 4, we did not find any criteria for the geometric distribution of comparison stars and their color-difference values for separating variable stars of NGC 1960 into these obtained groups. It indicates that there is no need for comparison stars for any variable star after the implication of the SSM approach. In a nutshell, the present SSM approach seems to be reliable for evaluating the stellar variable nature within studied clusters.

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observations on date 24-01-2012, 11-12-2013 and 20-12-2013. Similarly, a shifted and constant value of magnitude differences is obtained in light curves of these stars during the observations on date 12-01-2015 and 08-02-2015. (4) A constant value of magnitude differences is found in comparative light curves of comparison stars of variable V5, V9, V10 , V13 , V15 , V16 and V18 during the observations. Thus, detected variable stars of NGC 1960 are listed in four different groups as per comparative light curves of their comparison stars. After deep investigation of Table 6 and Table 4, we did not find any criteria of geometric distribution of comparison stars and their colour difference values for separating variable stars of NGC 1960 into these obtained groups. It indicates that there are no need of comparison stars for any variable star after implication of SSM approach. In nutshell, the present SSM approach is seems to be reliable for evaluating the stellar variable nature within studied clusters.

6. Fourier Transform of variables and their Pulsations

Aliases frequencies occur in the light curves of stars due to the interaction of the pulsation of variables and the noise or instrumental errors. Such summation of noise and pulsation signal of variables is removed through the comparison star during differentiated photometry and is an effective method for reducing the uncertainty of detected pulsation signal in the scattered data points of light curves of variables. After confirming the pulsation signal of stars, we need a periodogram to estimate the spectral density of a signal during the pulsation signal processing. Now days, the periodogram is computed from the stellar light curves through the implementation of algorithms such as Lomb-Scargle folding [25, 26], Box-fitting Least squares, or BLS," [27], and Plavchan [28]. Standard and advanced Fourier transform techniques are useful in the analysis of astrophysical time series of very long duration [29] due to their better computing abilities. The Lomb-Scargle algorithm is a variation of the Discrete Fourier Transform (DFT), which decomposes a time series into a linear combination of sinusoidal functions. This algorithm is implemented by us to detect the pulsation of variables and construct the Fourier [1] discrete periodogram (FDP). In this connection, the PERIOD-04 and PerSea software are used to estimate the period of newly identified variable stars. 'Period04' is dedicated to the statistical analysis of large astronomical time series with gaps and offers tools to extract the individual frequencies from the multi-periodic content. On the other hand, 'PerSea' is based on the analysis of variance (ANOVA) algorithm. In Table 5, the author has listed the resultant estimated period of variables through both programs. The phase-folded diagrams of detected regular variables are constructed using the values of the pulsation period as per Period 04." The phase-folded light curves of variables of NGC 1960 are shown in Figure 10(A). In these diagrams, the phase values of any variable at time t are defined as the decimal part of $(t - JD)/P$, where JD and P represent the Initial Julian Date and Period of the variables. In this connection, the JD values for NGC 1960 are 2455951.11037.Aliases frequencies occur in the light curves of stars due to the interaction of pulsation of variables and the noise or instrumental errors. Such summation of noise and pulsation signal of variable is removed through of comparison star during differentiate photometry and is an effective method for reducing the uncertainty of detected pulsation signal in the scattered data points of light curves of variables. After confirming the pulsation signal of stars, we need a periodogram to estimate the spectral density of a signal during the pulsation signal processing. Now days, the periodogram are computed from the stellar light curves through the implemented of algorithms such as Lomb-Scargle folding [25, 26], Box-fitting Least Squares or "BLS" [27] and Plavchan [28]. Standard and advanced Fourier transform techniques are useful in the analysis of astrophysical time series of very long duration [29] due to their better computing ability. The Lomb-Scargle algorithm is a variation of the Discrete Fourier Transform (DFT), which decomposes a time series into a linear combination of sinusoidal functions‡ . This algorithm is implemented by us to detect pulsation of variables and to construct the FourierDiscrete periodogram (FDP). In this connection, the 'PERIOD-04'§ and 'PerSea'¶ software are used to estimate the period of new identified variable stars. 'Period04' is dedicated to the statistical analysis oflarge astronomical time series with gaps and offers tools to extract the individual frequencies from the multi-periodic content. Other hand, 'PerSea' is based on the analysis of variance (ANOVA) algorithm. In Table 5, author has listed the resultant

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6.1. Smoothness of phase diagrams and change in amplitude of pulsation

here is too much scatter of data points in the original phase diagrams to probe and shape the nature of stellar variability. After applying the moving average procedure, the resultant phase-folded curves of variables are found to be smoother than the original diagrams. As a result, it is concluded that the amplitude of stellar pulsation decreases with the smoothness increment of the phase-folded diagram of variables during the moving average procedure. In Figure 11(A), the phase diagrams of variables are constructed through the resultant data points as per the average moving procedure. The signal-to-noise ratio (SNR) is defined as SNR = A eA, where A and eA are the amplitude of the light curve and the mean estimation error in stellar magnitude, respectively. The SNR values of variable stars are listed in Table 6.There is too much scatter of data points in the original phase diagrams to probe and to shape the nature of stellar variability. After applying moving average procedure, the resultant phase folded curves of variables are found to be smoother compare than original diagrams. As a result, it is concluded that amplitude of stellar pulsation decreases with the increment of smoothness of the phase-folded diagram of variables during the moving average procedure. In the Figures 11(A), the phase diagrams of variables are constructed through the resultant data points as per the average moving procedure. The signal-to-noise ratio (SNR) is defined as SNR = A eA , where A and eA are amplitude of light curve and mean estimation error in stellar magnitude respectively. The SNR values of variable stars are listed in Table

Comments: It will be better if all figures are included in the text document rather than in the appendix.