Search of variable stars in the field of NGC 1960 and DOLIDGE 14

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Abstract

Open clusters are host the several identical stars in the similar physical and chemical environment. They become interesting objects to identify the variable stars in the lower metallicity domain. In the present paper, the CCD time series observations of cluster NGC 1960 and DOLIDZE 14 are performed to search the variable stars within them. A comprehensive study of differential photometry and secondary standardization transformation is carried out to search the stellar pulsation. A total of 18 and 4 short periodic variables found in the field of NGC 1960 and DOLIDZE 14 respectively. Fast Fourier transformation techniques are utilized to compute the pulsation. The period and classification of 18 discovered variables of NGC 1960 are discussed, which consist of one Planet transit variable, one RR Lyre-d variable, one β Cep variable, one γ − Dor variable, one dual character (δ Scuti + RRC) variable, two irregular variable, two s-Cepheid variables, four δ Scuti variables and five RRC variables. In the case of DOLIDZE 14, four discovered variables consist of one Flare-type variable, one SX-Phenocs variable and two δ Scuti variables.

Keywords: Astronomy: photometric methods – database – telescopes – astronomical reduction – NGC 1960, DOLIDZE 14, stellar Variability

1. Introduction

An open cluster (OCL) is loosely bounded group of up to a few thousand stars caused by the mutual gravitational attraction of cluster members. Such objects are useful for studying stellar evolution because of the similar age and chemical composition of their members. The member stars of the OCL form from a giant molecular cloud. In this connection, a young OCL may be found within its parental molecular cloud and their mutual interaction mechanism is illuminated a process of creation of HII region [A good example of this region is NGC 2244 (Johnson, 1962)]. Such regions are active star formation sites and formed young stars with the highest metallicity. The chemical composition or metallicity are used to know the type of stellar population and stars, having high metallicity, belong to Population I (abbreviated as Pop I). As a result, OCLs are host the stars of Pop I. Analysis of observations of the Kepler data-set
confirms that the larger, potential gas giants planets are only concentrated around stars of Pop I (Buchhave et al., 2012), whereas smaller planets are found around stars of all stellar populations. Such planets are traced through the transit method, based on observing the short ($\approx 10$ hours) periodic ($P = \approx$ months to years) dips in stellar light curves caused by a planet passing in front of the star’s disk (Carpano et al., 2003). Thus, fluctuation of stellar light curves becomes an important tool to search exo-planets, however fluctuations of stellar brightness also occur due to other ongoing physical phenomena within their interior and surrounding.

The brightness fluctuations are found for some stars among members of stellar population and such stars are known to be variable stars. The stellar variability may be arise either due to intrinsic properties (pulsations, eruptions, stellar swelling and shrinking) or extrinsic reasons (eclipsed by stellar rotation by another star or planet etc.). Extrinsic reasons of stellar variability are stellar eclipsing in the binary and triplet stellar systems, properties of interstellar medium, planet transition and accretion process of surrounding matter of stars. Other hand, the change of intrinsic properties of variables are driven by the plasma transportation on the stellar surface, nucleus stellar activities in their interior parts, effect of tidal force on stellar environment due to nearby stars, their masses and ages. As a result, the variable stars are natural targets of study for any civilization due to their correlation between period and total light output, which allowed them to become the first rung in the astronomical distance ladder (Hippke et al., 2015). In this connection, Cepheids of pulsating variables are important indicators of cosmic benchmarks for scaling galactic and extra-galactic distance (Majaess et al., 2009; Freedman & Madore, 2010) due to a strong direct relationship between a Cepheid variable’s luminosity and pulsation period (Soszynski et al., 2008). Pulsating variables are most important objects due to the periodic expansion and contraction of the surface layers of the stars to maintain its equilibrium. Their census including pulsators and binaries, can provide important clues to stellar evolution and the host star clusters (Luo et al., 2012). The several classes of pulsating variables are largely found at instability strip region of the Hertzsprung-Russell (HR) diagram.

The colour magnitude diagram (CMD) is an observational HR diagram for clusters and its plots the apparent magnitude of detected stars of studied cluster against their colour. Such CMD of an OCL contains a continuous and distinctive band of stars and stars of this band are known as main sequence (MS) stars of studied cluster. In this connection, theoretical models of isochrone curve have constrained to show the stellar population of the same age. Through the visual fitting of theoretical models on observed CMDs of the cluster, we can be computed the distance, age and chemical compositions (i.e. metallicity) of stellar population of its MS. Since, pulsating variables has an associated instability strip (Dupret et al., 2004) above the MS, therefore, an OCL provides an opportunity to estimate the properties of its stellar variables through its own characteristic parameters. In addition, scientific study of variable stars are carried out by using the comparison stars, have observed with the same telescopic field of view of studied variables.

The comparison stars of a variable are have approximate similar stellar magnitudes and colours as found for that variable. Such comparison stars are easily assigned for identified variables of an OCL through their positions in an observed CMD. Thus, open clusters become excellent objects to search variable stars and their associated exo-
planets within the clusters. OCLs can also be effectively used to compute the stellar properties of detected variables within them and to modify the age-period relations of pulsating variables for precise measurements.

In this background, we are carried out analysis of the time series observations of NGC 1960 and DOLIDZE 14 to search the variable stars within them. The previous parametric studies of both clusters are given in the Section 2. The observational details of these clusters are given in the Section 3. The methodology of data reduction is discussed in the Section 4. The identification procedure of variable stars of DOLIDZE 14 and NGC 1960 is given in the Section 5.

2. Previous studies

2.1. NGC 1960

A complete $UBVRIJHKW_1W_2$ photometric catalogue has been constructed by Joshi & Tyagi (2015a) by complying the PPMXL catalogue with the obtained $UBVRI$ standard photometric magnitude of gathered data on date of 30 Nov, 2010. In this connection, constructed catalogue has been utilized as reference catalogue for searching the variable stars in the observational field of view of cluster NGC 1960. It contains ten stars of a visual magnitude brighter than 10 (Jeffries et al., 2013), one B-type Variable of 9$^{th}$ magnitude (Delgado et al., 1984), 178 down to magnitude 14 (Sanner et al., 2000) and 38 members have infrared excess (Smith & Jeffries, 2012). As a result, flux of detected stars of this cluster will be contaminated due to the presence of these brighter stars during its deep CCD photometric observations.

2.2. DOLIDZE 14

An infrared photometric study of DOLIDZE 14 is carried out by Joshi et al. (2015). This cluster have stellar enhancement in the B-band of USNB1.0, whereas it does not show the properties of cluster in the infra-red bands (Joshi & Tyagi, 2015b).

3. Data Collection and Extraction

The time series observations of studied clusters, DOLIDZE 14 and NGC 1960, are carried out by utilizing observational facilities of 1.04-m Sampurnand telescope of ARIES, Manora Peak, Nainital. The CCD camera of 1.04-m Sampunanad telescope of ARIES covers $15\times15 \arcmin^2$ field of view of the target objects. Since, the size of both clusters is more than the telescopic field of view, therefore, we have performed an analysis of the time series observations of the core regions of both clusters. In this connection, the bias and flat frames are also observed for each observational night of studied clusters. To detect the short periodic pulsation of stars of target cluster, we need time series observation of the whole night as per availability of target in the telescopic field of view. The weather conditions (seeing, humidity, wind flow, passing clouds etc.) and declination of target object affect the receiving flux of stars. Thus, the quality of observational data is most important to perform the crucial task of identification of variables. In this connection, the selection procedure of exposure times and observational details of clusters are given as below,
Table 1: The observation details of collected data of DOLIDZe 14 and NGC 1960 for searching variable stars within them.

**1. DOLIDZE 14**

| S.No. | Date      | Observation Band (Frames) | Observation Time & Mode | No. of Frames | Exposure Time |
|-------|-----------|---------------------------|-------------------------|--------------|---------------|
| 1.    | 13-10-2014 | I                         | 3.25 hours, Slow        | 52           | 150 Sec.      |

**2. NGC 1960**

| S.No. | Date      | Observation Band (Frames) | Observation Time & Mode | No. of Frames | Exposure Time |
|-------|-----------|---------------------------|-------------------------|--------------|---------------|
| 1.    | 24-01-2012 | V                         | 3.5 hours, Slow         | 070          | 60 Sec.       |
| 2.    | 11-12-2013 | V (150 frames)            | 5.4 hours, Slow         | 050          | 05 Sec.       |
|       |           |                           |                         | 050          | 10 Sec.       |
|       |           |                           |                         | 050          | 20 Sec.       |
| 3.    | 20-12-2013 | V (080 frames)            | 7.6 hours, Slow         | 040          | 06 Sec.       |
|       |           |                           |                         | 040          | 60 Sec.       |
| 4.    | 12-01-2015 | V (200 frames)            | 7.2 hours, Slow         | 100          | 05 Sec.       |
|       |           |                           |                         | 100          | 20 Sec.       |
| 5.    | 08-02-2015 | V (140 frames)            | 5.6 hours, Slow         | 140          | 20 Sec.       |

3.1. Characteristics of observational data of NGC 1960

To identify short periodic pulsations of stars, time series observations of NGC 1960 are carried out in V-band during 5 observation nights (2012-2015). A brief description of these observations is listed in Table 1. It noted that our telescopic field of view for NGC 1960 is fulfilled by several brighter stars. We found that these brighter stars saturate during an exposure time of 5 seconds. In this regard, 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 contamination of the observed science frames through the 1.04-m telescope at ARIES, Nainital. Similarly, an exposure time of 1 second is too low value to collection the stellar information for fainter stars of NGC 1960 below 17 mag in V-band. Environmental influences (seeing, air flow, humidity, passing clouds etc.) and high declination of the target cluster from zenith further reduce the value of stellar magnitude and alter the rate of stellar detection. As a result, different number of faint stars are detected in different science frames of NGC 1960. To overcome the prescribed difficulty of faint stars, we performed the deep CCD photometric observation of 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 of night. Thus, the observations have obtained two data sets of NGC 1960 of different exposure times in the same session of observational night. In this background, the exposure time plays a major role to collect the stellar information. The details of exposure times of observed data are also given in Table 1.

3.2. Characteristics of observational data of DOLIDZE 14

DOLIZE 14 has an open cluster of fainter stars and shows stellar enhancement in B-band. Due to its faintness, the deep CCD photometric observations are needed to
stellar detection. In this connection, this cluster is observed in I-band on the date 13 Oct, 2014 through 1.04-m Sampurnanand telescope at ARIES, Manora Peak, Nainital. A total of 52 science frames are captured over a period of 3 hours 15 min. It was noted that the positions of the stars slightly shifted during exposure time of 300 seconds. Consequently, the observations of longer exposure times for open cluster has been avoided. Thus, exposure time of each frame is fixed at 150 seconds according to the pixel capacity and characteristic of CCD camera.

4. Methodology of Data reduction

The raw science frame of target contains the electronic noise, counts of nonuniform pixel sensitivity and cosmic rays. The data reduction procedures (cleaning, standardization) of observed data would required to overcome these defects from science frames of targets to search variable stars within them. The brief detail of data reduction of observed frames of studied cluster is given below.

4.1. Cleaning of raw science frames

The bias-subtraction, flat fielding and cosmic-ray reduction are compulsory steps in the cleaning procedure of raw science frames. In this connection, the bias correction and flat-fielding of observed science frames of NGC 1960 and DOLIDZE 14 have been carried out by using those bias and flat frames, which are observed in the same observational night of object. We are 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 utilized. ‘COSMICRAYS’ task of ‘IRAF’ software are used to remove cosmic rays from the science frames. Such cleaned science frames are used to compute instrumental magnitudes of detected stars in observed field of view of the targets. These instrumental magnitudes of stars may convert into the standard magnitudes by either the transformation coefficients of the standardization night or solution of linear fitting of secondary standard stars of cluster.

4.2. Astrometry and alignment of frames

The coordinates of detecting stars are found in the term of pixels through 2k×2k charge couple device (CCD) camera of 1.04-m telescope. Since, the pixel coordinates of identified stars are shifting due to telescopic motion and observed field of view, therefore, ‘GEOMAP’ and ‘GEOTRAN’ tasks of IRAF software are utilized to align the all science frames for analysis. In the astrometry, pixel coordinates of detected stars have been transformed into celestial coordinates (α2000, δ2000) by using a linear astrometric solution as derived by matching a set of stars in common between our reference catalogue and the 2MASS catalogue. For this purpose, the visualization of images and access to catalogues has been done by ‘SKYCAT’ tool of ESC.

1www.eso.org/sci/observing
4.3. Secondary standardization method

In order to perform consistent photometry from night to night on the aligned images (Joshi et al., 2012), we need a master list of stars from science frames of target cluster, which have the best seeing and coverage of the observed core region of both clusters. In this connection, the secondary standardization method [SSM Joshi et al. (2015)] was used to compute the absolute photometric magnitude of detected stars of core region of cluster NGC 1960 through a data-set of standardized night (30 November 2010) and the data-set of standardized night of NGC 1960 is taken to be reference catalogue for searching the variable stars within NGC 1960. This method is effective to estimate the absolute stellar magnitudes of variable of NGC 1960 through the calibrated magnitudes of its stable stars in the terms of standardized reference catalogue.

It is noted that OCL, DOLDIZE 14 have not calibrated by any standardized field at present. In this background, data set of detected stars of its first science frame of our work considered to be its reference catalogue for further analysis of stellar variability within it. Other observed science frames of DOLIDZE 14 are calibrated according to this reference catalogue by using the technique of SSM to reduce atmospheric-effect and estimation-errors of stellar magnitudes during the data collection. In this connection, we need a set of common stars of each cluster, which are available in their reference frame and science frames. We have selected 29 and 63 common stars in the observed field of DOLIDZE 14 and NGC 1960 respectively. These common stars are used to find out a linear fit between the standard magnitudes and instrumental magnitudes of each frames, assuming that most of the stars have stable magnitude. We reject those stars for linear fitting, which deviate more than 3σ limit of deviations of fitting. Resultant linear solution are used to transform instrumental magnitudes of stars of studied clusters into their absolute magnitudes.

5. Identification of variable stars

The collective information of variation of stellar magnitude with time is known to be light curve of target. If, we find the deviation of absolute magnitudes of star more than 3σ limit of mean value of its light curve, then, it will be considered a possible candidate of variable stars. As a result, the possible variable candidates identify by inspecting of their light curves (Sariya et al., 2014). In this connection, the shapes of light curves of a variable star give valuable information for examining the nature of stellar variability and underlying physical processes producing the brightness changes. The light curves of regular variables (such as Cepheids) are repeating with a constant value of time (i.e. its period). Mira variables have less regular light curves with large amplitudes of several magnitudes, while semi-regular variables are less regular with the smaller amplitudes (Samus et al., 2017). In this connection, amplitudes of light curves of irregular variables does not occur after a fixed time interval and shape of their light curves have found in an uncertain pattern. The amplitude or period of the pulsations can be related to the luminosity of the pulsating stars and shape of their light curves can be an indicator of the pulsation mode (Wood & Sebo, 1996). As a result, pulsating variables are distinguished by their periods of pulsation and the shapes of their light curves (Lata et al., 2014). For this purpose, the interesting magnitude ranges of CMD plane of NGC 1960 and DOLIDZE 14 are discussed as follow,
Figure 1: The upper and bottom panels of this figure represent CMDs for NGC 1960 and DOLIDZE 14, respectively. The blue dots on each panel represent the variable stars as identified by us through the time series photometric data while red dots represent the probable members of the studied clusters as extracted from the work of Joshi & Tyagi (2015a) and Joshi & Tyagi (2015b). The black solid lines represent the best fitted theoretical isochrones as given in the previous studies.
5.1. Instability Strips of CMDs

The instability strip is a narrow, almost vertical region in HR diagram, which contains many different type of variable stars. Most stars more massive than Sun enter the instability and become variable at least once after they have left the main sequence (MS)\(^2\). This strip intersect the MS in the region of A and F stars (have mass 1-2 \(M_\odot\)) of studied clusters and extends to G and early K bright super-giants. Joshi & Tyagi (2015a) shown the most probable members (MPMs) in \((B − V) vs V\) CMD by comprehensive analysis of photometric, kinematic and spatial probabilistic criteria. These MPMs are found along with MS of NGC 1960 and also well aligned with a well fitted theoretical isochrone as depicted in the Figure 1(A). We did not find stellar alignment along with theoretical isochrone in the magnitude range of 12.5-13.2 \(H − mag\) of \((J − H) vs H\) CMD as constructed in the Figure 1(B) by MPMs. This fact indicates contamination of fluxes of fainter stars by their nearby brighter stars. The contamination effect of brighter stars also experienced in \(W_2 − W_1 vs W_1\) CMD as depicted in the Figure 1(C). Brighter stars do not satisfy the pattern of theoretical isochrone in \(W_2 − W_1 vs W_1\) CMD while they have found along with theoretical isochrones in \((B − V) vs V\) and \((J − H) vs H\) CMDs. In this connection, we are found very high scatter data points in the light curves of brighter stars of NGC 1960 due to their unresolved centers in the present deep photometric observations. As a result, we did not analysis the time series observations of brighter and their nearby stars within the observed field of cluster NGC 1960 for stellar variability. The common area of instability strip and MS of OCL NGC 1960 seems to be important region (includes A and F stars) to understand the cluster dynamics through the stellar variability and vice-versa. In this connection, the upper and lower limit of region, have A and F stars, are found to be 13.17 mag of \(V−band\) and 16.61 mag of \(V−band\), respectively and prescribed intercepted region also least affected by the brighter stars and their neighbourhood. As a result, we are carried out time series analysis for finding stellar variability within this magnitude-range. A total of nine variables of NGC 1960 are identified in this magnitude-range.

In the case of DOLIDZE 14, we have not found such saturated brighter stars of unresolved center. As a result, there are no need of any selected range of stellar magnitudes to overcome the difficulty of contaminated stellar fluxes. The identified variables of both clusters are depicted in the various CMDs of Figure\(^1\). The red dots of each panel of Figure\(^1\) represent the previous known probable members of studied clusters.

5.2. Nature of stellar light curves

We have detected 200±50 stars in each frame for DOLIDZE 14, whereas, a total of 1800-3000 stars are detected in the science frames of NGC 1960. The number of detected stars of a frame depends on the exposure time of observed science frame. The reference frame of NGC 1960 is standardized with respect to the Landolt field stars. As a result, we found absolute stellar magnitudes for NGC 1960 through the application of SSM. Other hand, the reference frame of DOLIDIZE 14 did not standardized

\(^2\)astronomy.swin.edu.au/cosmos/I/Instability Strips
Figure 2: The panels represent the light curves of variable stars within the cluster NGC 1960.
Figure 3: The panels represent the light curves of variable stars within the cluster NGC 1960.
Figure 4: The panels represent the light curves of variable stars within the cluster NGC 1960.
Figure 5: The panels represent the light curves of variable stars within the cluster NGC 1960.
Figure 6: The panels represent the light curves of variable stars within the cluster NGC 1960.
Figure 7: The panels represent the light curves of variable stars within the cluster NGC 1960.
Figure 8: (A) We represent the light curves of identified variables (ID 004, ID 088, ID 110, ID 184) and their corresponding comparison stars in the field-view of DOLIDZE 14. The HJD time of observations are shown in the x-axis whereas y-axis is shown apparent magnitudes of stars in $I$-filter. (B) The panels show light-pholded-curves or phase diagrams of identified variables. The value of phase and amplitude (mmag) of stellar variability are shown in the x-axis and y-axis respectively. (C) The frequency spectrum of identified variables of DOLIDZE 14 are depicted here. The frequency ($d^{-1}$) and amplitude (mmag) of variables are represented in x-axis and y-axis respectively.
with respect to the standard field stars. The stellar magnitudes of detected stars of each science frame of DOLIDZE 14 are transformed with respect to its reference frame, therefore, SSM methodology provides the apparent stellar magnitudes for DOLIDZE 14 by considering the uniform sky conditions for the entire session of observations. These transformed stellar magnitudes are used to generate the light curves of stars. Such light curves carry the information of stellar variability, noise and their aliases. The varying sky conditions during observations generate noise and instrumental errors, which lead to the scattering of data points in the stellar light curves. The sky conditions change with unexpectedly, the transformation coefficients also vary accordingly. It leads the irregular variation of stellar magnitudes and these variations are very close to estimated/considered standard stellar magnitudes of the reference frame. Such variation can also produce the pseudo stellar variability. Such irregular variations have the same pattern for all stars and can be narrowed down through the differential photometry. A varied sky condition alters the equal amount of stellar fluxes of all detected stars in a science frame. Due to the stars having different amount of fluxes, the different orders of variation is obtained in apparent stellar magnitudes. Such variations for the stars having different magnitudes, produce the light curves of different pattern. It indicates that the differential photometry can be performed for stars of approximately same magnitudes. Thus, the selection of comparison stars is a basic requirement in differential photometry. It is preferable to select the comparison star of any variable in such a way that the stellar magnitude and reddening of comparison star are close to the variable.

The possible candidacy of variable stars is assigned for stars, having a variation of amplitudes above the $3\sigma$ limit of its mean in light curves. After the visual inspection of light curves of detected stars of both clusters, we found a total of 4 and 18 possible variable candidates in the observed field of DOLIDZE 14 and NGC 1960, respectively. The exact confirmation of stellar variability can not possible through the light curve of a star due to unavailable information of the obtained stellar variability. It may possible that a selected comparison star have also contained the stellar variability. As a result, its differential photometry further increase the scattering of data points and lead to a weak information of stellar variability. As a result, the practice of selecting a single comparison star for a potential variable has been avoided. In the present analysis, we have selected two comparison stars for each potentially variable star as depicted in Figure 2 to 8. The pixel coordinates and differences of stellar magnitudes of identified variables and their comparison stars are listed in the Table 2. To distinguish the instrumental variations from stellar light curves, the stellar magnitudes are subtracted from each other and resulting curves are defined as comparative light curves. The light curves for each variable and its selected comparison stars (set of three stars) have shown in the different panels of these figures. In this connection, each set of stars have four panels. Top panel shows the light curve of potential variables and middle panels show the light curves of selected comparison stars. The fourth panel of each set have three lines of blue, red and black colour for representing the comparative light curves. The blue and red lines are shown the field subtracted light curves of variable through comparison stars, whereas black line represents the difference of stellar magnitudes of selected comparison stars. A constant spacing of comparative light curves is obtained for stable comparison stars, while the varied spacing of these curves confirms the sig-
Table 2: Variable IDs for cluster are listed in first column. The pixel coordinates for variable and its two comparison stars are given in second, third and fourth columns. Fifth, sixth and seventh columns indicate the difference of magnitudes for potential variable and its comparison stars.

| Va. | Pixel coordinates for Variable V | Pixel Coordinates for I$^o$ com. C1 | Pixel coordinates for I$^{II}$ com. C2 | $\Delta I$ | $\Delta I$ | $\Delta I$ |
|-----|----------------------------------|--------------------------------------|---------------------------------------|----------|----------|----------|
| 1:  | DOLIDZE 14                       |                                      |                                       |          |          |          |
| $V_1$ | (206.40, 060.40)                  | (403.50, 867.50)                     | (372.00, 575.00)                      | -0.370   | -0.483   | -0.113   |
| $V_2$ | (026.20, 315.80)                  | (243.50, 224.50)                     | (743.50, 688.50)                      | 0.011    | 0.013    |        |
| $V_3$ | (920.80, 274.00)                 | (586.50, 599.50)                     | (314.00, 527.50)                      | 0.003    | -0.006   | -0.009   |
| $V_4$ | (1001.00, 988.80)                | (085.50, 891.50)                     | (400.00, 247.50)                      | 0.032    | -0.001   | -0.033   |

| Va. | Pixel coordinates for Variable V | Pixel Coordinates for I$^o$ com. C1 | Pixel coordinates for I$^{II}$ com. C2 | $\Delta V$ | $\Delta V$ | $\Delta V$ |
|-----|----------------------------------|--------------------------------------|---------------------------------------|----------|----------|----------|
| 2:  | NGC 1960                         |                                      |                                       |          |          |          |
| $V_1$ | (326.39, 371.36)                  | (330.42, 136.68)                     | (591.11, 108.45)                      | 0.032    | 0.017    | -0.015   |
| $V_2$ | (569.17, 491.82)                  | (443.96, 350.19)                     | (447.95, 306.69)                      | -0.029   | -0.044   | -0.015   |
| $V_3$ | (320.79, 236.69)                  | (537.44, 628.87)                     | (840.54, 176.63)                      | 0.047    | 0.011    | -0.029   |
| $V_4$ | (569.16, 455.81)                 | (647.30, 237.98)                     | (484.63, 809.77)                      | -0.036   | -0.019   | -0.055   |
| $V_5$ | (637.19, 853.38)                 | (573.39, 374.35)                     | (450.51, 967.25)                      | 0.000    | -0.007   | -0.007   |
| $V_6$ | (558.23, 316.76)                 | (897.74, 312.71)                     | (866.07, 073.17)                      | 0.001    | -0.004   | -0.005   |
| $V_7$ | (481.46, 890.25)                 | (872.18, 373.21)                     | (365.48, 075.02)                      | 0.013    | 0.008    | -0.005   |
| $V_8$ | (266.90, 435.15)                 | (225.75, 295.63)                     | (558.63, 768.81)                      | 0.042    | -0.011   | -0.053   |
| $V_9$ | (284.21, 488.30)                 | (743.37, 037.84)                     | (768.63, 768.81)                      | 0.005    | -0.022   | -0.017   |
| $V_{10}$ | (766.26, 144.03)               | (660.10, 216.48)                     | (330.21, 960.67)                      | 0.034    | -0.011   | -0.045   |
| $V_{11}$ | (354.26, 490.63)              | (257.50, 399.39)                     | (767.47, 741.93)                      | -0.089   | -0.091   | -0.002   |
| $V_{12}$ | (112.94, 160.52)            | (546.62, 058.62)                     | (546.62, 058.62)                      | 0.001    | -0.031   | -0.032   |
| $V_{13}$ | (287.39, 424.57)            | (784.75, 180.53)                     | (943.23, 490.50)                      | 0.017    | -0.001   | -0.018   |
| $V_{14}$ | (247.05, 069.18)            | (652.48, 558.88)                     | (641.41, 863.99)                      | 0.002    | -0.016   | -0.018   |
| $V_{15}$ | (278.49, 425.25)            | (440.69, 644.26)                     | (462.34, 572.85)                      | 0.002    | -0.041   | -0.019   |
| $V_{16}$ | (669.95, 151.53)           | (419.01, 544.23)                     | (301.97, 842.46)                      | 0.007    | -0.022   | -0.029   |
| $V_{17}$ | (617.01, 490.98)           | (513.65, 218.19)                     | (458.72, 856.76)                      | 0.007    | -0.006   | -0.013   |

6. FPF of variables and their Pulsations

The light curves of stars contain aliases frequencies due to the interaction of pulsation of variables and the noise or instrumental errors. Such summation of noise and nature of stellar variability. Since, obtained information of stellar variability changes rapidly with the sky and weather conditions, therefore, we can not find stellar variability of the order of mmag during session of bright moon and observational nights, having fog and high humidity. As a result, we have selected smoother light curve to compute the period of identified variable after the visual inspection of individual light curve of each observational night. This procedure becomes more reliable to evaluate the stellar variable nature within studied clusters.
Figure 9: The left panels represent the phase-folded-diagrams of identified variable stars within the cluster NGC 1960, whereas their corresponding DFT represent in the right panels.
Table 3: The first column shows variable ID of variables within studied clusters. The second and third columns represent RA and DEC respectively. The values of period of detected variable stars are estimated through the PERIOD04 and PerSea Software as listed in fourth and seventh columns respectively.

| Variable ID | RA      | DEC      | Period (days) | Amplitude (mmag) | Power [PERIOD04] | PerSea Period (days) |
|-------------|---------|----------|---------------|------------------|------------------|----------------------|
| V₁          | 05 : 36 : 25.11 | 34 : 06 : 10.2 | 0.3057±0.0815 | 102              | 66.948           | (2.4949 ± 0.0173)    |
| V₂          | 05 : 36 : 17.85 | 34 : 09 : 14.8 | 0.2246±0.0599 | 165              | 56.576           | 0.6250±0.0274        |
| V₃          | 05 : 36 : 33.33 | 34 : 06 : 05.4 | 0.3598±0.0001 | 086              | 99.261           | 0.4000±0.2086        |
| V₄          | 05 : 36 : 20.05 | 34 : 09 : 14.6 | 0.3115±0.1168 | 062              | 35.608           | 0.2857±0.0706        |
| V₅          | 05 : 35 : 55.79 | 34 : 10 : 07.6 | 0.3182±0.0848 | 248              | 34.752           | 0.2857±0.0454        |
| V₆          | 05 : 36 : 28.54 | 34 : 09 : 05.8 | 0.1528±0.0194 | 069              | 24.174           | 0.1538±0.0369        |
| V₇          | 05 : 35 : 53.49 | 34 : 08 : 09.6 | 0.1747±0.0254 | 065              | 23.504           | 0.1695±0.0154        |
| V₈          | 05 : 36 : 21.20 | 34 : 05 : 25.4 | 0.2864±0.0007 | 073              | 65.225           | 0.2857±0.0947        |
| V₉          | 05 : 36 : 17.96 | 34 : 05 : 38.7 | 0.2667±0.0006 | 095              | 48.289           | 0.4629±0.0399        |
| V₁₀         | 05 : 36 : 39.17 | 34 : 11 : 42.8 | 0.1886±0.0003 | 074              | 31.753           | 0.2404±0.0226        |
| V₁₁         | 05 : 36 : 17.84 | 34 : 06 : 31.8 | 1.1053±0.0007 | 124              | 185.267          | 1.098±0.1033         |
| V₁₂         | 05 : 36 : 37.89 | 34 : 03 : 27.5 | 0.8538±0.0004 | 084              | 93.789           | 0.6667±1.0505        |
| V₁₃         | 05 : 36 : 21.85 | 34 : 05 : 40.9 | 0.3057±0.0815 | 076              | 35.455           | 0.2857±0.0762        |
| V₁₄         | 05 : 36 : 43.52 | 34 : 05 : 08.8 | 0.2665±0.0711 | 077              | 13.036           | 0.2222±0.0775        |
| V₁₅         | 05 : 36 : 21.81 | 34 : 05 : 34.1 | 0.3039±0.0810 | 072              | 23.669           | 0.2041±0.0105        |
| V₁₆         | 05 : 35 : 44.69 | 34 : 03 : 03.4 | 0.3005±0.0801 | 087              | 22.739           | 0.2941±0.0171        |
| V₁₇         | 05 : 36 : 38.67 | 34 : 10 : 29.8 |               |                  |                  |                      |
| V₁₈         | 05 : 36 : 17.92 | 34 : 09 : 51.1 |               |                  |                  |                      |
pulsation signal of variable is removed through the utilization of comparison star during differentiate photometry and becomes an effective method to reduce 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 (Lomb, 1976; Scargle, 1982), Box-fitting Least Squares or “BLS” (Kovacs et al., 2002) and Plavchan (Plavchan et al., 2008). Standard and advanced Fourier transform techniques are useful in the analysis of astrophysical time series of very long duration (Ransom et al., 2002) due to their better computing ability. The Lomb-Scargle algorithm is a variation of the Discrete Fourier Transform (DFT), in which a time series is decomposed into a linear combination of sinusoidal functions. This algorithm has been implemented by us to detect pulsation of variables and constructed the Fourier-Discrete- periodogram (FDP). In this connection, the 'PERIOD-04' and 'PerSea' software are utilized to estimate the period of new 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. Other hand, ‘PerSea’ is based on the analysis of variance (ANOVA) algorithm. In the Table 3, we listed the resultant estimated period of variables through the both software. The phase-folded diagrams of detected regular variables are constructed by utilizing the values of pulsation period as per ’Period04’. The phase-folded light curves of variables of DOLIDZE 14 have been depicted in the Figure 8(B), whereas these curves of variables of NGC 1960 are shown in the Figure 9. In these diagrams, the phase values of any variable at time $t$ is defined to 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 value of $JD$ is 2455951.11037 and 2456943.35851 for NGC 1960 and DOLIDZE 14 respectively.

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

There is too much of a scattering of data points in the original phase diagrams to investigate and shape the nature of stellar variability. Such scattered data points in the curves are occurred due to instrumental errors and noise, due to which, it is not possible to accurately classify the nature of stellar variability. To overcome this problem, we adopt the average moving procedure for construction of these diagrams. In this procedure, data points are arranged in increasing order according to their phase values from 0 to 1. In this connection, the average values are determined for sets of five data points such as 1-5, 2-6, 3-7 and so on. This procedure is repeated until we are not computed the average of last remaining five data points. However, a sufficient fraction of the amplitude of light curve also decreases during adoption of this procedure. The resultant phase-folded curves of variables are found to be smooth in comparison of original diagrams. As a result, we conclude that amplitude of stellar pulsation decreases with

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3exoplanetarchive.ipac.caltech.edu/docs/pgram
4www.univie.ac.at/tops/Period04
5www.home.umk.pl/ gmac/SAVS/soft.html
Table 4: The detail of amplitude change in identified variables of DOLIDZE 14 and NGC 1960. Amplitude of the stellar Pulsation of variable stars computed through are listed in fourth column, as computed through the visual inspection of Phase-curve of variables.

1:- DOLIDZE 14

| Variable ID | I-Magnitude (mag) | Normalized Amplitude [PERIOD04] | Amplitude (mmag) [Phase Curve] | Normalized Amplitude [Phase Curve] | Structural Index | Variable Type |
|-------------|-------------------|---------------------------------|---------------------------------|-----------------------------------|-----------------|---------------|
| $V_1$       | 13.784            | 19.588                          | 052                             | 03.772                            | 0.193           | $\delta$ – $\delta$ $Scuti$ |
| $V_2$       | 17.385            | 27.265                          | 082                             | 04.716                            | 0.173           | $\delta$ – $\delta$ $Scuti$ |
| $V_3$       | 17.804            | 17.468                          | 352                             | 19.771                            | 1.132           | Flare         |
| $V_4$       | 18.501            | 17.675                          | 381                             | 20.593                            | 1.165           | SX-Phenocs    |

2:- NGC 1960

| Variable ID | V-Magnitude (mag) | Normalized Amplitude [PERIOD04] | Amplitude (mmag) [Phase Curve] | Normalized Amplitude [Phase Curve] | Structural Index | Variable Type |
|-------------|-------------------|---------------------------------|---------------------------------|-----------------------------------|-----------------|---------------|
| $V_1$       | 14.007            | 07.282                          | 120                             | 08.567                            | 1.176           | $\gamma$ – Dor |
| $V_2$       | 14.020            | 11.768                          | 096                             | 06.847                            | 0.581           | RRC           |
| $V_3$       | 14.127            | 06.088                          | 089                             | 06.299                            | 1.035           | RR Lyrae d    |
| $V_4$       | 14.215            | 04.362                          | 111                             | 07.808                            | 1.790           | $\beta$ – Cep |
| $V_5$       | 14.674            | 16.901                          | 254                             | 17.309                            | 1.024           | Planet Transit |
| $V_6$       | 15.060            | 04.582                          | 087                             | 05.777                            | 1.261           | $\delta$ – $\delta$ $Scuti$ |
| $V_7$       | 15.155            | 04.289                          | 071                             | 04.685                            | 1.092           | $\delta$ – $\delta$ $Scuti$ |
| $V_8$       | 15.345            | 04.757                          | 139                             | 09.058                            | 1.904           | RRC           |
| $V_9$       | 15.497            | 06.130                          | 123                             | 07.937                            | 1.294           | RRC           |
| $V_{10}$    | 15.592            | 04.746                          | 099                             | 06.349                            | 1.334           | $\delta$ – $\delta$ $Scuti$ + RRC |
| $V_{11}$    | 15.668            | 07.914                          | 204                             | 13.020                            | 1.645           | s-Cepheid     |
| $V_{12}$    | 15.711            | 05.347                          | 154                             | 09.802                            | 1.833           | s-Cepheid     |
| $V_{13}$    | 15.769            | 04.820                          | 118                             | 07.483                            | 1.553           | RRC           |
| $V_{14}$    | 15.969            | 04.822                          | 089                             | 05.573                            | 1.156           | $\delta$ – $\delta$ $Scuti$ |
| $V_{15}$    | 16.197            | 04.445                          | 097                             | 05.989                            | 1.347           | $\delta$ – $\delta$ $Scuti$ |
| $V_{16}$    | 16.279            | 05.344                          | 224                             | 13.760                            | 2.574           | RRC           |
| $V_{17}$    | 16.369            | –                               | –                               | –                                 | –               | Irregular     |
| $V_{18}$    | 16.673            | –                               | –                               | –                                 | –               | Irregular     |
the increment of smoothness of the phase-folded diagram of variables due to the moving average procedure. In the Figures 8(B) and 9(A), the phase diagrams of variables constructed through the resultant data points as per the average moving procedure.

6.2. **Structure Index for Stellar Variability**

We have computed period of identified variables by two different programs PerSea and PERIOD04. In this connection, we also computed the amplitudes of variables through the visual inspection of phase-folded diagrams as listed in the table 3 and table 4. Since, the amplitudes of identified variables are varied to observational night to night due to observational conditions and aliases frequencies of noise, therefore, we are purposed to a parameter ‘Structure index’ $S_{in}$ to verify the stellar variability and it is expressed as $S_{in} = \frac{A_{phase}}{A_{fc}}$, where $A_{phase}$ is the amplitude of stellar variability as computed through the resultant phase-folded diagrams. Similarly, $A_{fc}$ is the amplitude of stellar variability as per Lomb-Scorgle periodigrams by using PERIOD04. Present analysis indicates that the computed values of structure indexes for variables are independent from the stellar magnitudes, power of periodograms and amplitude of stellar variability. Normalized stellar amplitudes are also independent from the stellar magnitude for similar group of variables. The value of structure index for variables found to be more than one (except $\delta$-Scuti variables). It indicates that average moving procedure effectively increase smoothness of stellar variability and provides clear shape and characteristics to identify type of their stellar variability.

7. **Results and Discussion**

7.1. **Detected Variables in DOLIDZE 14**

There are a total of 4 detected stars in the observed field of DOLIDZE 14.

7.1.1. $V_1$ and $V_2$

They may be $\delta$-Scuti variable stars. Based on PERIOD04 code analysis, the periods of $V_1$ and $V_2$ are found to be $0.0599 \pm 0.0067$ d and $0.0939 \pm 0.0195$ d respectively.

7.1.2. $V_3$

It poses a spike of Flux in light curve. The computed period is $0.1349 \pm 0.0359$ d and close to observation session for DOLIDZE 14. So, $V_3$ may be Flare type variable.

7.1.3. $V_4$

It poses character of SX-Phenocs variables with period of $0.0674 \pm 0.085$ d.

7.2. **Detected Variables in NGC 1960**

In this paper, eighteen variables were detected in the observed field of NGC 1960. According to the behavior of the light curves and the period analysis, classification of detected variables were made. Among the eighteen detected variables of NGC 1960, one as $\gamma$ DOR type star, one as $\beta$ Cephe type star, one as RRC type or $\delta$ Scuti star, two as irregular variable stars, two as S-Cepheid variables, four as $\delta$ Scuti stars and five as RRC variables.
7.2.1. \( V_1 \) (Star ID 600 of NGC 1960)

The double-peak is found in light curve of 08 February 2015 as depicted in Figure 2. Similarly, a peak of the phase diagram is clear with the period of 0.3057±0.0815 \( d \). It may be \( \gamma \) Dor star.

7.2.2. \( V_2, V_8, V_9, V_{13} \) and \( V_{16} \)

Their phase curves possess the character of Lyre C (RRC), asymmetrical, increasing rapidly and decreasing slowly as depicted in Figure 9. The values of period for \( V_2, V_8, V_9, V_{13} \) and \( V_{16} \) may be 0.2246±0.0599 \( d \), 0.2864±0.0007 \( d \), 0.2667±0.0006 \( d \), 0.3057±0.0815 \( d \) and 0.3005±0.0801 \( d \) respectively.

7.2.3. \( V_3 \) (Star ID 649 of NGC 1960)

It is likely a \( RR \) Lyre \( d \) with period of 0.3598±0.0001 \( d \).

7.2.4. \( V_4 \) (Star ID 688 of NGC 1960)

This star may be a \( \beta \) Cepheid with period of 0.3115±0.1168 \( d \).

7.2.5. \( V_5 \) (Star ID 900 of NGC 1960)

The light curves of \( V_5 \) are depicted in Figure 3. Full phase of planet transit is found in the light curve of 20 December 2013 and a portion of planet transit also detected in the light curve of 12 January 2015. The transit period for \( V_5 \) is computed to be 0.3182±0.0848 \( d \) through PERIOD04 code. The amplitude of transit up to 248 mmag.

7.2.6. \( V_6, V_7, V_{14} \) and \( V_{15} \)

These stars may be \( \delta - Scuti \) variable stars. The probable periods of \( V_6, V_7, V_{14} \) and \( V_{15} \) are computed to be 0.1528±0.0194 \( d \), 0.1747±0.0254 \( d \), 0.2665±0.0711 \( d \) and 0.3039±0.0810 \( d \), respectively.

7.2.7. \( V_{10} \)

Author analyzed the frequencies of this star with Fourier analysis, and determined two periods \( P_1 = 0.1886±0.0003 \) and \( P_2 = 0.2404±0.0226 \) and \( P_1/P_2 = 0.78 \). So it suggested that \( V_{10} \) is a multiply periodic oscillations \( \delta - Scuti \) star with RRC characteristic.

7.2.8. \( V_{11} \) and \( V_{12} \)

These stars are classified as \( s-Cepheid \) in this paper. Based on PERIOD04 code analysis, author obtained probable periods for \( V_{11} \) and \( V_{12} \) to be 1.1053±0.0007 \( d \) and 0.8538±0.0004 \( d \) respectively.

7.2.9. \( V_{17} \) and \( V_{18} \)

Author did not find any regular pulsation for \( V_{17} \) and \( V_{18} \) variables. A speck of stellar variability for both variables was detected on date 11 December 2013 as depicted in Figure 9. In the case of \( V_{17} \) (ID 2451), the comparison stars are ID 2439 and ID 2479. The comparative light curves indicate that spacing of light curves are varying night to night as depicted in the middle Set of Panels of Figure 9. It may be due to long periodic
variability of \( V_{17} \). In the case of \( V_{18} \) (ID 2875), the comparison stars are ID 2868 and ID 2889. The black comparative light curve of filed stars does not show any noticeable fluctuation in flux, whereas, comparative light curves of \( V_{18} \) variable and filed stars confirm the long term stellar variability of \( V_{18} \) as depicted in the lower set of panels of Figure 9. The period of both variables can not computed by code of PERIOD04 and PerSea in the present work. So both variable suggested to be irregular type variable.

8. Conclusion

The SSM method for the transformation of stellar magnitude may also include aliases for different sky conditions as well as estimation errors of transformation coefficients. To overcome these difficulties, we are applied the differential photometry is used over absolute photometry and the process is defined as differential-absolute photometry. The effective reduction of the effects of sky conditions of observational night is the major advantage of this applied procedure. The present analysis is done to find the short periodic variables, having period less than 1 day. To find such small periodic variables, time series data for DOLIDZE 14 and NGC 1960 have been collected from one and five night observations, respectively. In this regard, the stellar light curves for NGC 1960 and DOLIDZE 14 are extracted from these time series data. By deep investigate of stellar light curves, a total of 18 and 4 variable stars have been identified in the field of view of cluster NGC 1960 and DOLIDZE 14 respectively. Among of 18 variables of NGC 1960: five were classified as \( RRc \) systems \( (V_2, V_8, V_9, V_{13}, V_{15}) \), four \( \delta - \text{Scuti} \) variables \( (V_6, V_7, V_{14}, V_{15}) \), two irregular type variables \( (V_{17}, V_{18}) \) two \( s \)-Cepheid variables \( (V_{11}, V_{12}) \), a transit variable \( (V_5) \), a \( \gamma \) Dor variable \( (V_1) \), a \( RR \) Lyre \( d \) variable \( (V_3) \), and a \( \beta \) Ceph variable \( (V_4) \). Variables of DoLIDZE 14 consist of two \( \delta \) Scuti variables, a flare type variable and a \( \text{SX-Phoenicis} \) variable.

Due to the observational limitations of CCD camera of 1.04 m telescope at ARIES, a telescope equipped with a very high-capacity CCD camera is needed to carry out the task of searching for sign of variability in the brighter stars of NGC 1960.

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References

Buchhave, L. A., Latham, D. W., Johansen, A., et al., 2012, Nature, 486, 375
Carpano, S., Aigrain, S., Favata F., 2003, A & A, 401, 743
Delgado, A. J., Alfar o, E. J., Garrido, R., Garcia-Pelayo, J. M., 1984, Information Bulletin on Variable Stars (IBVS), 2603, 1

Dupret, M. A., Grigahcene, A., Garrido, R., Gabri el, M., Scuflaire, R., 2004, A&A, 414(2), L17

Freedman, W. L., Madore, B. F., 2010, Annual Review of Astronomy andAstrophysics, 48, 673

Hippke M., Learned J. G., Zee A., Edmundson W. H., Lindner J. F., Kia B., Ditto W. L., and Stevens I. R., 2015, ApJ, 798, 42

Jeffries, R. D., Naylor, T., Mayne, N. J., Bell, C. P. M. and Littlefair, S. P., 2013, MNRAS, 434 (3), 2438

Johnson, H. L., 1962, AJ, 136, 1135

Joshi, Gireesh C., CPMSED-2015, Krishi Sanskriti Publications (New Delhi) ISBN: 978-93-85822-07-0, page no.: 22-27

Joshi, Gireesh C. & Tyagi, R. K., 2015a, Mathematical Sciences Int Research Journal, 4, 384

Joshi, Gireesh C. & Tyagi, R. K., 2015b, PCME-2015 (ISBN: 978-81-930585-8-9), 37

Joshi, Gireesh C., Joshi, Y. C., Joshi, S., Tyagi, R. K., 2015, New Astronomy, 40, 68

Joshi, Y. C., Joshi, S., Kumar, B., Mondal, S., Balona, L. A., 2012, MNRAS, 419, 2379

Kovacs, G., Zucker, S., Mazeh, T., 2002, A&A, 391, 369

Lata S., Yadav R. K., Pandey A. K., Richichi A., Eswaraiah C., Kumar B., Kappelmann N. and Sharma S., 2014, MNRAS, 442, 273

Lomb, N., 1976, AP&SS, 39, 447.

Luo Y. P., Zhang X. B., Deng L. C., and Han Z. W., 2012, ApJ Letters, 746, L7

Majaess, D. J., Turner, D. G., Lane, D. J., 2009, MNRAS, 398(1), 263

Plavchan, P., Jura, M., Kirkpatrick, J. D., Cutri, R. M., Gallagher, S. C., 2008, The Astronomical Journal Supplement Series, 175, 191

Ransom, S. M., Eikenberry, S. S., & Middleditch, J., 2002, AJ, 124, 1788

Samus, N. N., Kazarovets, E. V., Durlevich, O. V., Kireeva, N. N., Pastukhova, E. N., 2017, Astronomy Reports, 61, 80

Sanner, J., Altmann, M., Brunzendorf, J., Geffert, M., 2000, A&A, 357, 471

Sariya, D. P., Lata, S., Yadav, R. K. S., 2014, New Astronomy, 27, 56

Scargle, J. D., 1982, ApJ, 263, 835
Smith, R., Jeffries, R. D., 2012, MNRAS, 420(4), 2884
Soszynski, I., Poleski, R., Udalski, A. et al., 2008, Acta Astronomica, 58, 163
Wood, P. R. and Sebo, K. M., 1996, MNRAS, 282(3), 958