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BINARIES IN OPEN STAR CLUSTERS: PHOTOMETRIC APPROACH WITH APPLICATION TO THE HYADES

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ABSTRACT

A new method has been developed to solve the star cluster membership problem. It is based on synthetic photometry employing the Black Body concept as stellar radiation simulator. Synthetic color-magnitude diagram is constructed showing the main sequence band and the positions of binary star systems of combinations of various components through different photometric tracks. The method has been applied to the Hyades. The cluster membership problem has been re-appraised for the cluster (both single and binary) stars. For the binary members, the components' spectral types have been derived by the method. The results obtained agree very well with those found in literature, The method is simpler than the others and can be developed to undertake other cases as multiple star systems.

Key words : Stars:binary-open clusters, associations (individual): Hyades, techniques: photometric

I. INTRODUCTION

Investigation of incidences of binary stars in star clusters is more beneficial for better understanding of binaries as well as clusters than individual studies of these candidates. Identification of binaries as cluster stars is as old as some sixty years when TX Cnc has been assigned as one of the Praesepe cluster members by Haffner & Heckmann (1937). These authors have stated that part of the magnitude dispersion of the main sequence stars in the cluster Color-Magnitude Diagram (CMD) can be explained by the presence of double stars among the cluster stars. According to this theory, the stars that appear to be lifted towards brighter magnitudes in the CMD are unresolved double stars. In the diagram derived by these authors there seems to be two ridge lines separated by a distance of about 0.7 magnitude of the stars that are fainter than 8.5 magnitude, about 20% belong to the upper branch, and these stars have been considered as double star systems. In making this assumption, the authors have been able to reduce the value of the cosmic dispersion in the magnitudes to a quite negligible amount of 0.03 magnitude. It was peculiar that similar effect could not be found for stars brighter than 8.5 magnitude. This was criticized by Ramberg (1941) in connection with his investigation of the CMD of the Hyades. Ramberg argued that the double star theory is not sufficient to explain the observed scatter phenomenon. He pointed out that 5 (out of 10) spectroscopic binaries observed fall on the ridgeline and the other 5 are lifted up. Ramberg also detected similar finding for the Praesepe star cluster.

Holmberg (1944) simulated the positions of binary systems on the CMD for the Hyades cluster. He adopted a primary component of $P_g = 12$ magnitude while the magnitude difference between the components ranges from zero to infinity. It has been realized that significant displacement above the Zero Age Main Sequence (ZAMS) stars may be found when the difference between the binary components' brightness is smaller than two magnitudes while it is inconsiderable for difference values larger than three magnitudes. The result would apparently be a certain separation of single stars and doubles. Holmberg found no indication for proper displacement in CMD that associated with double stars presence. He stated that "The conclusion would be, either there are no double stars among the investigated cluster members, which apparently is not true, or that the components of a narrow double system behave as one unit in the CMDs". Hence stars can be assigned as certain, probable or possible single members.

Some other studies have been done to investigate the spread of clusters' main sequence band as a result of stellar doublicity. Golay (1964) studied this effect on the CMDs for different types of binary systems considering the component's radius as a free parameter. Maeder (1968) determined the positions of 80 unresolved binary star systems in some diagrams of Geneva photometric system. Bettis (1975) has investigated sta-

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tistically the binary frequency for three well studied clusters (Hyades, Praesepe and Pleiades). His approach is based on an iterative least square fit of power series polynomial, of a pre-assigned degree, for the photometric data of these clusters. Jaschek (1976) has analyzed the color-magnitude diagrams of four open clusters (α Per, Pleiades, Coma Berenices and Praesepe) expressing the deviation above the ZAMS in terms of the binary mass ratio and determining the percentage of the binaries in these clusters. The Hyades and the Praesepe clusters have been re-examined for the same reason, by Dabrowski & Beardsley (1976), considering the lower envelope of the ZAMS as the single star locus. They adopted the mass-luminosity relation of Harris et al. (1963) to derive, for a binary system, the relation between the displacement above the main sequence band and the binary mass ratio. The formula obtained has been employed to estimate the binary frequency in these clusters. Alawy (1984) and Korany (1999) discussed the validity of these methods in comparison with what found observationally in some studies (e.g. Trimble 1974, Abt et al. 1965 and Bartholdi 1975). Couteau (1985) studied the H-R diagram for 164 visual binaries using the unit-mass brightness instead of the brightness itself, showing their positions with respect to the ZAMS.

The aim of the present work is to consider the binarity effect only on the CMD employing synthetic photometry technique.

II. THE PRESENT METHOD

(a) Approach

The present method is based on simple synthetic stellar photometry to:

1- Define the cluster main sequence by calculating the absolute visual magnitude M_v and color index (B-V) for single stars of known effective temperature T_{eff}. If instead the intrinsic color index $(B-V)$ is given the T_{eff} is derived and hence M_v follows.

2- Construct the synthetic CMD, $[M_v - (B-V)]$ and define the main sequence band, caused by the binarity effect only, that includes the cluster (single and binary) members.

3- Calculate M_v and $(B-V)$ for each component of a binary system if their effective temperatures are known, as well as the integrated magnitude and color index of the system. The magnitude and color index differences between the binary system and its primary component are also evaluated.

4- Compute the photometric tracks on the CMD for hypothetical binary systems of known primaries and different companions.

5- Compute the photometric tracks for binaries whose secondaries' temperatures are of certain percentage of the primaries.

6- Compare the outcome of the previous steps with the observed photometric data for the stars in the cluster vicinity. This is intended to identify the cluster members particularly double stars providing that the observational data are free of interstellar reddening and corrected for the Earth's atmosphere extinction as well as allowing for both observational errors and calculation precision.

(b) Assumptions

The present method is based on some acceptable assumptions as follows:

Assumption 1:- Individual stars and the binary components undertaken are MS population I stars fulfilling the standard observational data and empirical relations known.

Assumption 2:- The binary system components are neither too wide to be resolved by a telescope nor too close so mutual interactions are present. This includes non-interacting spectroscopic and eclipsing binaries.

Assumption 3:- Only the effect of binarity on the photometric observations is considered, i.e. neglecting other effects due to rotation, interaction, peculiarity etc.

Assumption 4:- Stellar energy distribution is a smooth function, i. e. neither absorption lines nor emission lines are undertaken.

Assumption 5:- Stars behave as a black body having its effective temperatures.

(c) Formulation of the Method

The circumstances of the fourth and fifth assumptions render the description of the radiation field a relatively feasible process. The intensity of such radiation at any wavelength, λ is a function only of the effective temperature, T. The spectral distribution is described by the Planck function, viz;

$$E_\lambda(T) = 2hc^2\mu^2/\{\lambda^5[e^{hc/\lambda kT} - 1]\} \tag{1}$$

where c is the light speed, μ is the refractive index of the medium (normally equals unity for most cases) and h and k are the Planck's and Boltzmann's constants respectively.

Considering an optical band A, if $E_\lambda(T)$ be the illumination generated by the star's radiation in the entry pupil of a telescope assumed to be outside the Earth's atmosphere, the flux received is given by (see Jaschek & Jaschek 1987);

$$F_A(T) = \int E_\lambda(T)S(\lambda)d\lambda \tag{2}$$

where $S(\lambda)$ is the response function of the photometric system adopted incorporating the filter and telescope transmission and the response of the receiver. From photometric point of view the filters' transmissions are the most effective parameter in discriminating between the stars. The integration is performed over the optical band adopted.According to the stellar magnitude concept, a star calculated magnitude $(\mathrm{m}_{cal})_A$ is proportional to the logarithm of integrated flux F_A via the formula (see Golay 1974),

$$m_{cal} = -2.5\log(\alpha^2) \int E_\lambda(T)S(\lambda)d\lambda + Constant \quad (3)$$

where α is the apparent diameter of the star. This can be replaced by the radius of the star since the magnitude thus calculated will be co-related with the absolute magnitude of the ZAMS stars. If two bands (A and B) are considered the computed color index can be evaluated.

(d) Pre-Calculation Steps

Some steps have to be done when considering the method assumptions given above and before carrying out the calculation procedure outlined next. These are adopting the photometric system to be used and the physical and geometric data of normal main sequence stars to be employed.

In the present work, the blue and visual (B and V) bands of the Johnson and Morgan photometric system have been adopted. The transmission functions of the filters given by Allen (1973) have been interpolated with one Angstrom step using cubic spline interpolation technique. Updated standard photometric, physical and geometric data (e.g. M_v, $(B-V)$, T_{eff} and Radius) were adopted from Cox (2000) and Schmidt-Kaler (1982) for normal main sequence stars of different spectral types in the range A0 to M0, fulfilling assumption 1. This range is as wide as to include all stars of the present case (the Hyades star cluster). Applying the piece-wise polynomial fit technique, some empirical relations have been derived to assign stellar radius (in Solar unit) corresponding to the effective temperature.

(e) Calculation Procedure

The calculation has been performed in two stages. The purpose of the first stage is to establish with highest possible accuracy the transformation equations that correlate the calculated magnitudes and color indices to the standard ones. This mode of calculation is executed only once for the photometric system and the standard data adopted. It has to be redone if another data set is chosen or the photometric system is replaced by another one. The second stage aims to compute the absolute visual magnitude M_v and intrinsic color (B-V) for the program standard MS stars. The two stages have been coded in FORTRAN following the itemized steps given below.

i) Stage One Procedure

1) For each T_{eff} entry of the standard data adopted, corresponding to A0 to M0 main sequence stars, the relevant black body radiation intensity $E_\lambda(T)$ is calculated (Equation 1) to fulfil the fifth assumption at wavelengths defined by the B and V bands.
2) For each T_{eff} adopted the stellar radius is derived using the empirical polynomials obtained in the pre-calculation steps explained above.
3) The $E_\lambda(T)$ computed is then multiplied by the corresponding response $S(\lambda)$. The product is then integrated (Equation 2) numerically over the defined band of both filters yielding the stellar flux received through the filters outside the Earth's atmosphere. The calculated magnitude is derived through equation 3 where the stellar radius star is included.
4) From the outcome of the steps 2 and 3 the total fluxes of the stars in question are computed as F_B and F_V and the calculated magnitudes b_{cal} and v_{cal} and the color index $(b-v)_{cal}$ are derived.
5) Correlating the calculated and standard photometric parameters $[v_{cal}$ - M_v and $(b-v)_{cal}$ - $(B-V)]$ leads to two polynomials that can be used to transform any calculated magnitude and color index to the corresponding standard ones.

At this point all standard data are available and empirical standardizing relationships have been derived to achieve the second stage of the present calculation.

ii) Stage Two Procedure

1) For a star of given T_{eff}, the black body radiation intensity is calculated (step 1 of stage one).
2) The integrated blue and visual fluxes are computed (step 2 of stage one).
3) The star's radius is derived from the adequate empirical polynomial obtained from the pre-calculation step.
4) The integrated fluxes (F_b and F_v) are then calculated from steps 2 and 3.
5) Then the calculated magnitude and color index are determined.
6) The absolute visual magnitude M_v and color index $(B-V)$ can be derived using the transformation formulae obtained from step 5 of stage one.

For a binary system, the steps from 1 to 4 are carried out to get F_b and F_v for each component. Then the components' blue and visual fluxes are combined to obtain those of the system. The integrated magnitude and color index can be calculated and transformed in the same way to get M_v and $(B-V)$ for the binary system seen as one star. Of course magnitudes and color indices of both stars are already derived through steps 1 to 6. The differences δ M_v and δ $(B-V)_v$ between the binary system as a whole and its primary star are derived to locate the binary position in CMD with respect to the MS primary component.

(f) Binarity Effects on the CMDs

Regarding the fourth assumption when the two components of a physical binary can not be resolved by a

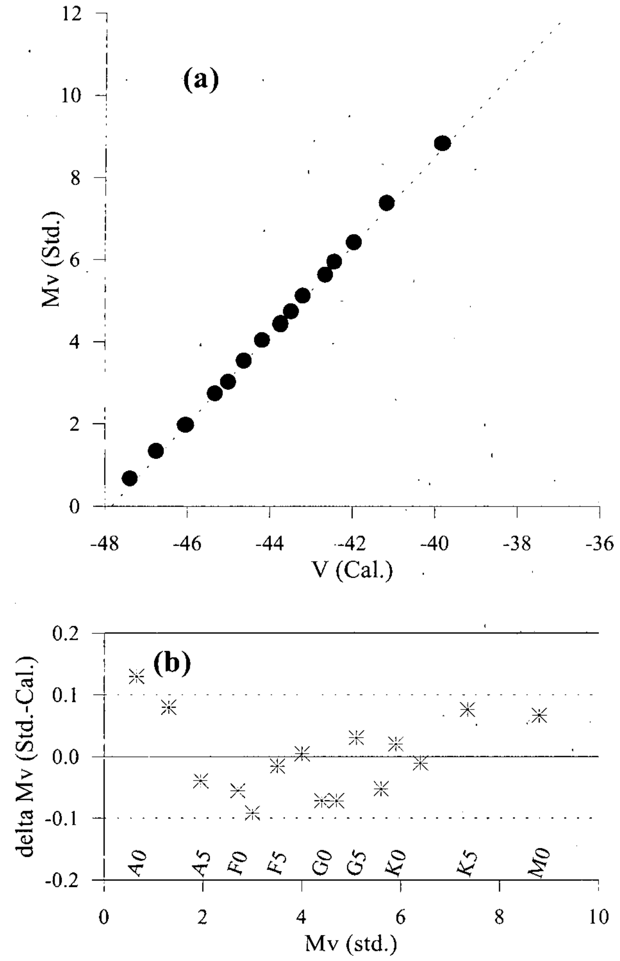

Fig. 1.— a) The correlation between M_v and V_{cal}. The linear fit is shown. and b) The dependence of fit residuals on M_v. The spectral types are indicated

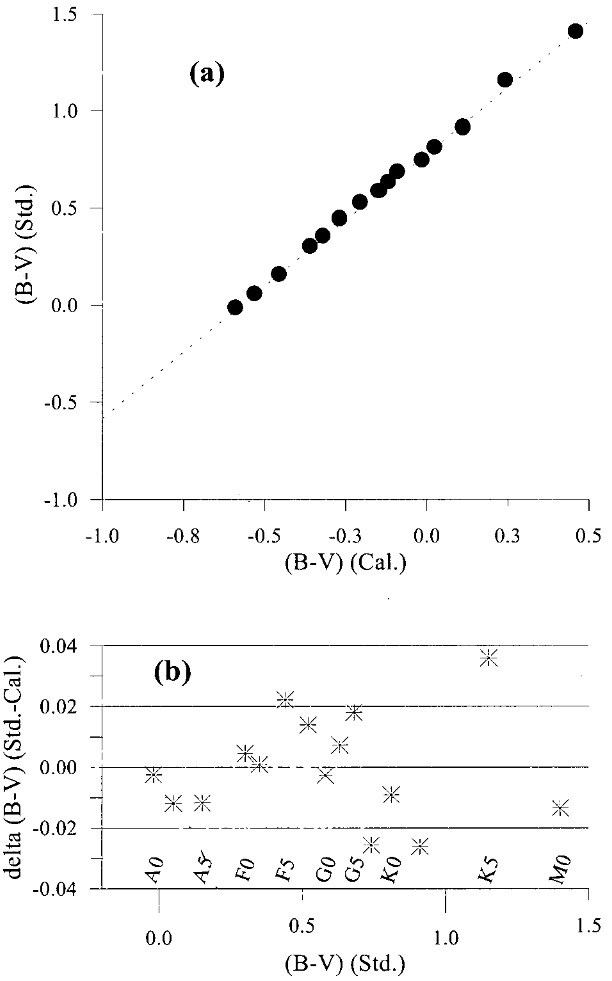

Fig. 2.— a) The correlation between standard and calculated $(B-V)$. The linear is shown. and b) The dependence of δ [$(\mathrm{B-V})_{std}$ - $(B-V)_{cal}$] on a $(B-V)_{std}$. The spectral types are indicated.

telescope the color index thus measured represents a mixture of the two energy distributions. It has been realized that binaries are located above single stars of the same spectral type in the H-R diagram. The upper limit of such location can easily be determined through the well-known Pogson formula. If M_{bin} is the integrated magnitude of a binary system composed of two similar main sequence stars each of magnitude M_{sing}, then,

$$M_{bin} - M_{sing} = -0.753 \tag{4}$$

This value defines the upper limit of the band within which the cluster binaries may be found in the CMD due to the binarity effect alone. Of course there are some other sources to widen this band (e.g. stellar rotation, peculiarity, significant mutual interaction between the components etc.).

(g) Constructing the Synthetic Color-Magnitude Diagram

In retrospect, according to the present method the synthesis CMD can be constructed through the next two main steps. First, for the MS band assignment, one can apply the following:

1) Define the effective temperature range according to the spectral types of the stars in question and divide this range into intervals with reasonable step (say 100 Kelvin).

2) For each value of T_{eff} find the corresponding stellar radius, compute the integrated fluxes (F_b and F_v) and derive the calculated magnitudes b_{cal} and v_{cal} and the color index $(b-v)_{cal}$ (steps 1 to 5 of stage two).

3) Transform these values into the absolute visual magnitude M_v and color index $(B-V)$ using the two polynomials obtained from step 5 of stage one. In the present work these polynomials are derived in the next

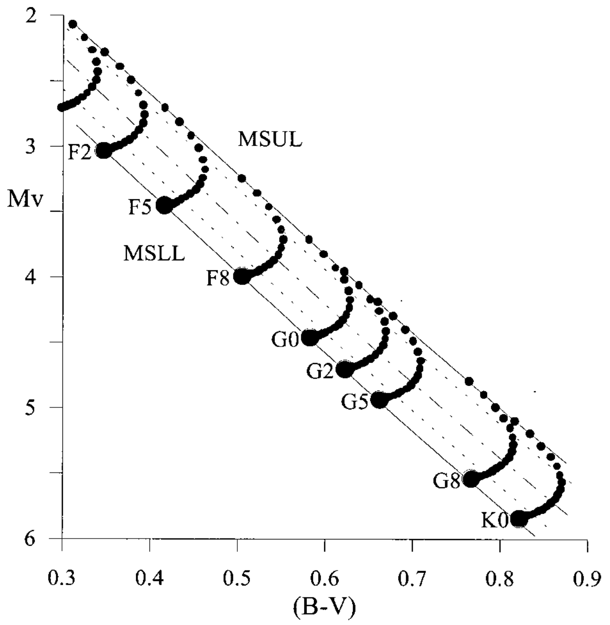

Fig. 3.— The synthetic CMD; the MS band is defined. Different binaries' tracks are plotted where the spectral types of their binary components are shown. BITR tracks of 70%, 80% and 90% temperature ratio are shown from MSLL towards MSUL. (See text)

section (Equations 5 and 6). Both absolute visual magnitude M_v and (B-V) define the Main Sequence Lower Limit (MSLL). Subtract the value of 0.753 from each value of absolute visual magnitude M_v to define the Main Sequence Upper Limit (MSUL).

Secondly, to illustrate the dependence of the binaries' positions in CMD upon the physical properties of their components, some tracks have been computed for hypothetical binary star systems. The primary components of these systems have been assigned as MS stars of spectral type from A0 to M0. In each case the secondary compaion temperature is, first, adopted similar to that of the primary and then decreased gradually to 3000 Kelvin. In any of these tracks each point represents a binary whose components' temperatures are known that lead to the mass ratio of the binary if the standard data adopted and the empirical relations derived are concerned. In addition, some photometric tracks have been constructed to represent binaries for which the temperature ratio is fixed. These tracks represent Binaries of Iso-Temperature Ratio (BITR). The resultant calculations for the binary thus formed [i.e. M_v and $(B-V)$] are plotted in the synthetic CMD (see Figure 3).

III. RESULTS AND DISCUSSIONS

(a) Synthetic Photometry Calculations' Results

The results of the present method computation are given and discussed to investigate its convenience and limitation of applicability. First the standardizing relations are considered. From STAGE ONE of the present calculation, the calculated visual magnitudes are plotted against the standard absolute ones in Figure (1a) yielding linear relation of the form,

$$M_v = 1.084(\pm 0.006)v_{cal} + 51.862(\pm 0.257) \qquad (5)$$

The probable errors are in parentheses, the Root Mean Square of the residuals, RMS, is 0.064 and the Linear Correlation Coefficient, LCC, is 99.957%. The differences between the standard and the fitted absolute visual magnitude are shown in Figure 1b, where the corresponding spectral types are indicated. All of these residuals, except one, are less than 0.1 magnitude. Similarly the relation between the standard and the calculated color indices, $(\text{B-V})_{std}$ and $(\text{b-v})_{cal}$, is given in Figure 2a; the linear fit is shown having the following form,

$$(B-V)_{std} = 1.359(\pm 0.011)(b-v)_{cal} + 0.778(\pm 0.004) \qquad (6)$$

where the RMS and LCC are 0.017 and 99.902% respectively. Figure 2b illustrates the dependence of the residual on $(B-V)$ showing that all residuals, except one, are less than 0.03 magnitude. Figures 1b and 2b are useful to estimate the errors, in absolute magnitude and color index, associated with computations corresponding to the standard $(B-V)$ (i.e. spectral type) of the stars in question. This is important in applying the present technique to verify any of its purposes. Secondly, the STAGE TWO of the calculation procedure have led to construct synthetic CMD for stars of the T_{eff} range adopted as well as the Main Sequence band due to binarity effect. The synthetic M_v and (B-V) data are plotted in Figure 3 showing both the Main Sequence Lower and Upper Limits (MSLL & MSUL). Photometric tracks are also shown for binaries of different primaries. The spectral types of these primaries are labelled at the beginning of each track. The figure shows also three photometric tracks of binary system whose secondary star's temperature is 70%, 80% and 90% of that of the primary component. Different BITR tracks have been computed but only three are plotted for clarity. The the photometric and BITR tracks divide the area between MSLL and MSUL into different segments that may define the locations of binary stars of specified primary and secondary components fulfilling the assumptions of the method. Several experimental calculations have been performed using the present method for binary systems of different components. As

TABLE 1. Deviation of Binaries Absolute Visual Magnitude Mv above Their MS Primary Components (in Mag.)

	M0	K5	K2	K0	G8	G5	G2	G0	F8	F5	F2	F0	A5	A2	A0
A0	.001	.002	.005	.009	.012	.020	.025	.032	.048	.078	.114	.150	.292	.477	.753
A2	.001	.004	.009	.016	.021	.037	.046	.057	.086	.138	.198	.259	.482	0.753	
A5	.002	.007	.016	.029	.038	.065	.080	.099	.159	.236	.332	.427	.753		
F0	.004	.015	.033	.059	.077	.131	.160	.197	.290	.443	.603	.753			
F2	.006	.020	.044	.078	.102	.173	.211	.258	.375	.563	.753				
F5	.008	.029	.065	.114	.148	.246	.298	.361	.515	0.753					
F8	.013	.047	.105	.181	.233	.380	.455	.544	.753						
G0	.021	.071	.157	.268	.341	.540	.638	.753							
G2	.026	.089	.193	.325	.412	.642	.753								
G5	.032	.109	.235	.391	.492	.753									
G8	.055	.183	.382	.612	.753										
K0	.072	.236	.481	.753											
K2	.126	.393	.753												
K5	.270	.753													
M0	.753														

TABLE 2. Deviation of Binary (B-V) from MS Primary Component (in Milli-Mag.)

	M0	K5	K0	G5	G0	F5	F0	A5	A0	B5
B5	0.00	0.01	0.04	0.07	0.12	0.26	0.41	0.65	0.91	0.00
A0	0.22	3.46	9.94	16.17	26.14	48.59	58.69	56.05	0.00	
A5	0.38	5.93	15.83	24.37	36.56	55.69	48.26	0.00		
F0	0.69	10.18	24.39	34.11	44.42	42.70	0.00			
F5	1.16	16.14	33.37	40.11	40.09	0.00				
G0	2.70	33.35	48.63	35.75	0.00					
G5	4.68	50.86	44.33	0.00						
K0	7.72	65.99	0.00							
K5	16.12	0.00								
M0	0.00									

an illustration of these computations some are given in Tables 1 and 2. The former gives the difference between the binary integrated absolute visual magnitude and that of its primary component. The latter lists the color index deviation of these binaries from that of their primary components. From these tables, the maximum deviation of M_v is about 0.753 mag. for binaries of similar components. The calculations showed that the deviation of the color index $(B-V)$ reaches its maximum value of about 0.066 mag.; the value that agrees well with that given by Barrado et al.(1996) as 0.07 mag. and is very close to that found by Golay (1964) as 0.05 mag. The tables' entries and the observations' accuracy define the limits of the method applicability.

(b) Application Results

The present approach has been applied to the Hyades star cluster where the cluster members have been identified from photometric point of view only. The criterion for selecting the cluster single and binary stars is their position on the synthesized CMD allowing for observational errors and computational precision. As described above, synthetic absolute visual magnitude, M_v, and color index, (B-V), were calculated for single stars of different spectral types from A0 to M0. Also, photometric tracks have been computed for different binary systems. As known, in star clusters' studies, the absolute and the de-reddened visual magnitudes are interchangeable. In other words, any of them can be used to construct CMDs characterizing the cluster under study. It is known that, the accuracy of M_v de-

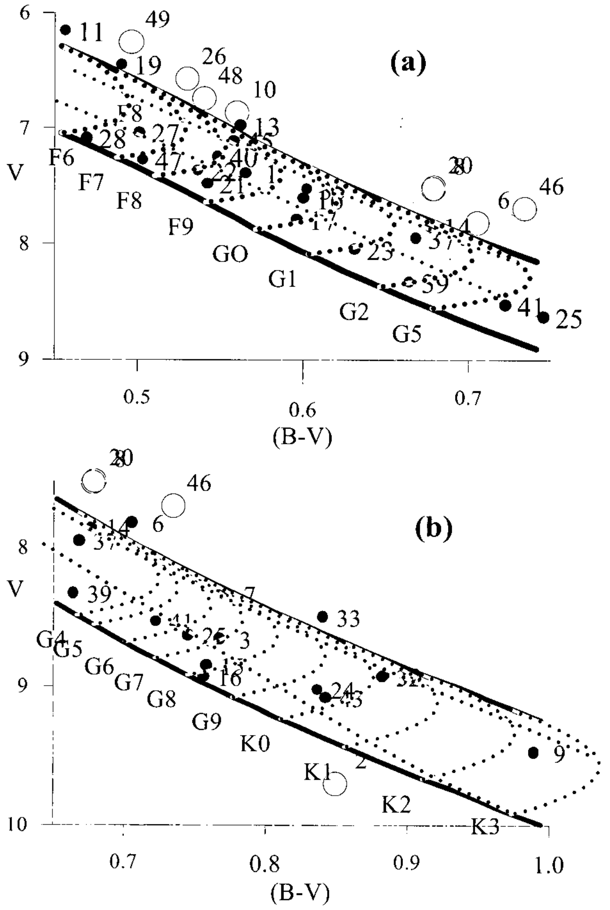

Fig. 4.— The CMD of the Hyades for two color index ranges. a) 0.4 - 0.7 and b) 0.6 - 1.0 . Filled circles are the cluster binary stars identified. The ID numbers are those of Table 3. (see text).

pends on those of photometry, interstellar reddening correction and distance derived. Errors of the later are generally the largest. Hence, in this work, the intrinsic apparent visual magnitude, V*o*, has been used instead of M*v* by adopting the distance modulus as 3.40 magnitude given by Schwan (1991) based on 145 cluster stars and the color excess as 0.0 magnitude derived by Gilroy (1989). The modified synthetic CMD is then superimposed on that of the stars in the cluster vicinity. Points located within, or close to, the Main Sequence Lower and Upper Limits (MSLL & MSUL) can be considered as cluster members taking into account the observational errors and the computational precision. The photometric tracks curves are, in principal, used to estimate approximate assignment of the binary components' spectral types. Identifying the closest track to the data point adopts the spectral type of the primary component.

Next, the closest BITR track aids in determining the temperature ratio that leads to the secondary component's spectral type. In addition, if the MS standard

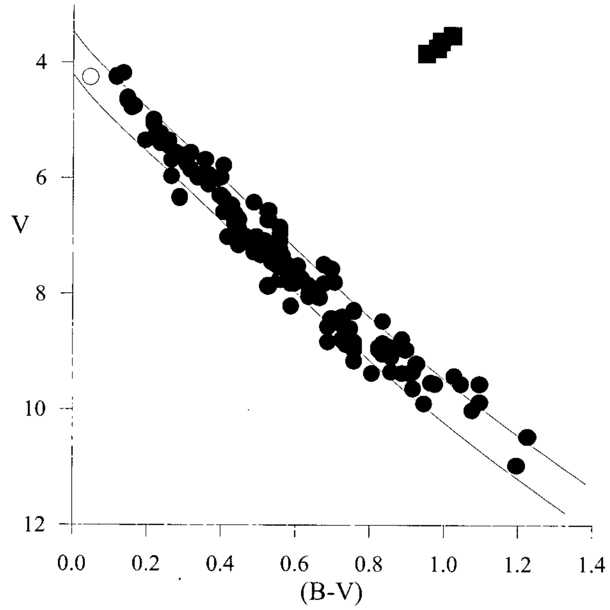

Fig. 5.— The CMD of the Hyades for the data of Table 4; filled circles are the cluster members identified, open circle is the blue straggler and open squares are the cluster giant stars.

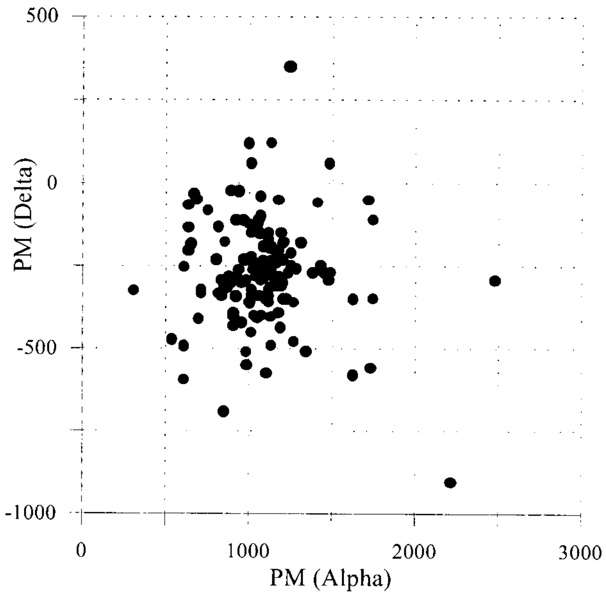

Fig. 6.— The Vector Point Diagram of the Hyades for the data of Table 4; units are 0.01"/century (see text).

TABLE 3.

The Hyades Stars Investigated; Given are a Sequential Numbers, Star Identification (vB: van Bueren, 1952, J: Johnson et al. 1968, vA: van Altena, 1969), Spectral Types of the Binaries' Components Assigned by Barrado et al. 1996 and the Present Method

SN	ID	Primary Barrado	component Present	Secondary Barrado	component Present
1	vB1	F9V	F8/F9V	M1V	K1/K2V
2	v471Tau	K2V		WD	
3	vB9	G6V	G7V		K5V
4	vB14	F2V		K8V	
5	BD23635	K3.5V		K9V	
6	vB162	G4V	G5V	G9V	G5V
7	vB22	G6V	G7V	K3V	K2V
8	vB23	G3V		G6V	
9	BD22669	K2V	K2/K3V	K5V	K6V
10	vB29	F8V		G5V	
11	vB34	F5V	F6V	F6V	F6V
12	vB38	F0V		G9V	
13	vB40	F9V	F9V	K4	F9V
14	vB39	G5V	G1/G2V		K0V
15	vB42	G8V	G8V	M2V	M1V
16	vB50	G0V	F9/G0V	K6V	K2V
17	vB52	G0V	G0V		K5/K6V

data are considered, reliable estimate can be obtained for the binary mass ratio. Contrary to the above, points located noticeably above the MSUL are more likely foreground stars. However, if they are cluster members based on other criteria, these large deviations may be attributed, beside the binarity effect, to one or more of the following reasons:

1) Rotation effect.
2) One component (at least) is not a main sequence star.
3) The system is multiple one (i.e. there are more than two components).
4) Peculiar component(s).
5) The components are so close to each other that photometric mutual interaction becomes pronounced.

Any of these factors (beside computational uncertainty and observational errors) can be the reason for the larger deviations found for these binaries. The present method has been applied on two data sets in order to assign the cluster binary stars determining their spectral types and re-investigate the cluster (single and binary star systems) members. The first data set is that compiled by Barrado et al. (1996). It contains photometry of 49 visual, spectroscopic and photometric Hyades binaries. These authors applied the photometric de-convolution technique for these systems to assign the spectral types of all primary and most secondary components of these binaries. The observed V and $(B-V)$ of these binaries have been plotted on the modified synthetic CMD as shown in Figures 4a & 4b. In these figures different photometric tracks and BITR for temperature ratio 0.75 and 0.90 are shown. A total of 35 (out of the 49) data points are located between, or close to, the main sequence limits implying the cluster membership probability for these binaries. Applying the procedure given above the spectral types of the binaries' components have been assigned. Table 3 gives the present results together with those derived by Barrado et al. (op cit.). Very good agreement is evident between both results. Besides, the present approach provides spectral types for some binaries' secondary components (vB9, vB39, vB52, vB113 and vA677) while the other approach could not. The rest of the data points are considerably outside the MS region. One point is well below the MSLL. It represents the contact binary system V471 Tau whose secondary component is a white dwarf star. Few points are above the MSUL. Three of them represent triple systems, which are vB75 and vB124 (Dabrowski 1984 and Griffin et al. 1985) and BD 23°635 (Griffin & Gunn 1981). Some other points are for stars (e.g. vB23, vB29, vB38, vB58 and vB122) whose V magnitudes are affected by nearby visual companions (see Barrado et al. 1996). It is to be stated that the findings of these authors for these cases are questionable because the photometric de-convolution adopted is based on the ZAMS relation and binary star systems concept. The authors gave no explanation or comments on these stars. These cases

TABLE 4. Hyades Members, (See Text)

NSch	μ_α	μ_δ	V	B-V	M_v
Hyades members					
4	706.	-414.	4.64	.15	.86
5	2488.	-298.	5.81	.41	3.16
6	1485.	-298.	5.97	.34	2.74
8	843.	-345.	5.10	.22	1.48
9	619.	-598.	5.99	.27	2.10
10	645.	-71.	5.42	.24	1.70
11	1492.	55.	5.72	.36	2.81
12	1014.	-366.	5.65	.28	1.86
14	1074.	-156.	5.03	.22	1.60
15	1057.	-128.	4.27	.12	.96
16	948.	-29.	5.39	.26	1.91
17	864.	-181.	4.69	.15	.91
18	691.	-52.	5.37	.20	1.28
19	1419.	-62.	6.38	.41	3.19
20	1174.	-245.	6.33	.40	2.90
21	1216.	-182.	5.59	.28	2.29
22	1131.	-202.	5.26	.23	1.80
24	1143.	-240.	5.72	.31	2.34
25	1464.	-275.	7.86	.68	4.95
26	1123.	-174.	5.64	.30	2.15
27	1134.	-318.	4.80	.16	1.39
28	1125.	-345.	5.98	.37	2.53
29	1135.	-407.	4.22	.14	.73
30	1197.	-442.	5.27	.24	1.91
32	1050.	-253.	6.46	.49	2.92
33	1059.	-413.	5.72	.27	2.16
36	1092.	-239.	4.78	.17	1.37
37	1072.	-247.	5.48	.26	2.05
38	1135.	-193.	5.40	.26	2.12
39	1075.	-295.	6.02	.34	2.64
40	1095.	-292.	7.54	.61	4.30
41	934.	-286.	5.78	.31	2.20
42	1113.	-578.	7.53	.58	4.27
43	984.	-119.	5.40	.25	2.07
44	876.	-322.	6.75	.45	3.44
45	1635.	-584.	7.30	.49	3.70
46	1755.	-353.	8.89	.84	5.70
47	1635.	-354.	9.37	.92	6.13
48	1035.	-265.	7.05	.42	3.16
49	1351.	-514.	8.08	.66	4.83
50	1216.	-355.	7.84	.71	4.39
52	1126.	-365.	6.80	.44	3.27
53	1081.	-405.	8.85	.76	5.28
54	1021.	-455.	7.18	.45	3.44
55	1276.	-484.	7.13	.52	3.92
56	1111.	-345.	7.38	.54	3.85
57	991.	-516.	9.19	.76	5.44
58	1066.	-345.	8.59	.74	5.08
59	1141.	-495.	6.05	.39	2.73
60	721.	-327.	9.40	.81	5.15
61	916.	-436.	9.07	.84	5.56
62	993.	-555.	9.59	1.05	6.18
63	858.	-696.	9.90	1.10	6.49
64	543.	-477.	8.59	.69	4.31
65	1500.	-274.	8.99	.90	5.80
66	1260.	-215.	7.85	.59	4.43
67	1440.	-254.	6.02	.40	2.92
68	1290.	-264.	6.62	.42	3.26
69	1215.	-235.	8.46	.70	5.09
70	1185.	-55.	8.06	.64	4.64
71	1200.	-155.	7.12	.51	3.76
72	1125.	-265.	8.32	.76	4.79
73	1170.	-295.	7.53	.68	4.07
74	1245.	-275.	9.59	.98	6.31
75	1186.	-395.	8.63	.74	5.22
76	1155.	-205.	8.43	.73	4.94
77	1185.	-285.	6.89	.56	3.52
78	1231.	-355.	7.47	.57	4.14
79	1215.	-305.	6.13	.37	2.77
80	1170.	-235.	6.81	.44	3.36
81	1125.	-155.	6.61	.41	3.15
83	1320.	-184.	6.99	.56	3.88
84	1036.	-405.	9.40	.91	5.80
85	1276.	-364.	10.50	1.23	7.38
86	1215.	-185.	9.11	.86	5.85
87	1185.	-205.	7.62	.60	4.32
88	1035.	-245.	8.24	.59	4.63
89	1051.	-285.	6.97	.44	3.40
90	1260.	-254.	7.80	.60	4.59
91	1201.	-315.	7.53	.68	4.22
92	1111.	-285.	7.48	.54	4.09
94	1170.	-245.	8.03	.65	4.69
95	1155.	-285.	8.10	.67	4.76
96	1065.	-115.	9.46	1.03	6.01
97	1140.	-265.	7.42	.54	4.09
98	1080.	-105.	7.51	.55	4.09
99	856.	-316.	11.00	1.20	7.04
100	1005.	-126.	9.02	.84	5.42
101	1095.	-195.	5.89	.32	2.48
102	1051.	-345.	8.63	.75	5.08
103	1171.	-315.	7.85	.60	4.57
104	1020.	-225.	6.59	.53	3.01
105	1111.	-355.	7.04	.50	3.68
106	1111.	-355.	6.91	.45	3.54
107	1126.	-325.	8.96	.83	5.60
108	1066.	-275.	9.10	.86	5.64
109	1021.	-325.	7.10	.47	3.50
110	975.	-236.	8.94	.85	5.31
111	1066.	-275.	6.51	.43	3.08
112	930.	-116.	7.04	.47	3.37
113	931.	-346.	8.94	.88	5.32
114	946.	-266.	8.65	.74	5.01
115	841.	-296.	9.41	.89	5.55

TABLE 4. - Continued

NSch	μ_α	μ_δ	V	B-V	M_v
Hyades members					
116	975.	-116.	6.62	.43	3.05
117	991.	-296.	8.49	.84	4.99
118	811.	-236.	9.67	.92	5.73
119	961.	-306.	7.89	.64	4.34
120	856.	-326.	9.38	.86	5.64
121	901.	-306.	6.65	.44	3.00
123	990.	-235.	7.96	.66	4.53
124	1020.	-155.	10.04	1.08	6.68
127	916.	-396.	9.58	.97	6.13
128	916.	-406.	8.53	.72	5.09
129	961.	-426.	8.99	.83	5.66
130	886.	-286.	7.74	.58	4.24
131	1006.	-365.	7.11	.56	3.89
133	826.	-336.	7.29	.50	3.71
134	825.	-136.	6.77	.53	3.19
135	646.	-207.	7.89	.53	3.75
137	721.	-337.	6.37	.29	2.49
138	660.	-187.	8.89	.74	4.94
139	645.	-137.	9.00	.76	5.07
140	616.	-257.	8.82	.73	4.82
141	1725.	-54.	7.39	.57	4.22
142	1020.	55.	8.93	.76	5.39
143	1140.	115.	6.38	.41	3.20
144	1080.	-45.	7.26	.56	4.19
145	675.	-37.	9.92	.95	6.25
147	316.	-328.	7.60	.70	3.61
149	1755.	-114.	7.77	.62	4.64
150	1258.	345.	9.60	1.10	6.35
Hyades possible member					
162	1392.	-275.	5.88	.32	2.57
164	1740.	-563.	8.82	.89	5.25
166	618.	-497.	8.85	.69	4.62
170	2224.	-909.	9.23	.93	7.50
171	1021.	-345.	5.59	.32	2.11
172	900.	-26.	7.77	.56	3.95
174	760.	-86.	7.26	.53	3.39
179	1243.	345.	8.98	.88	5.63
181	1005.	114.	7.36	.51	3.81

do not fulfill the assumptions of the present method and hence no spectral type decomposition can be performed. The second list has been given and investigated by Schwan (1991, Table 1) and has been adopted to re-investigate the cluster membership for both single and binary stars. It is a compilation of proper motion, radial velocity and BV photometry for 181 stars. Schwan was able through the kinematic study to assign 145 cluster members, 5 possible members and 11 probable members. In addition the study disproves the membership for 20 stars previously assigned as cluster stars by van Bueren (1952). Among the cluster stars assigned, 19 binary systems and one blue straggler star whose data have been listed in Table 4 of Schwan (op cit.). The modified CMD has been superimposed on the BV photometry of the 181 stars as depicted in Figure 5. All points that deviate considerably from the MS band have been rejected leading to 140 stars (apart from the blue straggler and the giant stars) as cluster members. Table 4 lists the present results; given are, according to Schwan, the sequential number proper motion components (in 0.01"/century), BV photometry and the absolute visual magnitude. It is worth stating that the present finding agree very well with the 72 cluster stars derived by one of us (Korany 1999) from accurate kinematic approach. Considering our finding and that of Schwan's one can conclude that:

1) The first 128 stars are certain members from photometric approach and from the kinematic criterion applied by Schwan.

2) The membership of the three possible stars (No's 147, 149 and 149) assigned by Schwan has been confirmed.

3) The non-membership for the eleven stars (numbers from No. 151 to 161) found by Schwan has been supported by the present study.

4) Cluster membership support is found from the present study for the 9 stars (at the end of Table 4) out of the 20 ones defined by van Bueren (1952) and disproved by Schwan.

The vector point diagram of the present members is shown in Figure 6 where an apparent clustering is evident. Nevertheless, few points are located slightly outside the centre. The data of these points need to be re-determined.

IV. CONCLUSIONS

From the present application on the Hyades and that done by one of us on NGC188 (Haroon 2002) one may see that reliable cluster membership can be derived for both single and double stars. The results of this method agree very well with those of other investigators. It has been feasible to assign, under the method assumption, spectral types of the components of clusters' binary stars. Moreover, some binaries have not been resolved both photometrically and spectroscopically while the present method succeeded to do so. This substantiates the method applicability and usefulness. The method proposed is so simple that can be modified to undertake multiple photometric systems. It is highly recommended to invoke better stellar radiation modelling (as Model Atmosphere) instead of the one adopted here (viz. Black Body concept). Also, it is appreciated to adopt better photometric systems providing to be filter-defined system as the Stromgren 4 color and H-Beta systems.

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