An Integrated Formulation of Zernike Invariant for Mining Insect Images

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***Abstract*— This paper presents mathematical integration of Zernike Moments and United Moment Invariant for extracting printed insect images. These features are further mining for granular information by investigating the variance of Inter-class and intra-class. The results reveal that the proposed integrated formulation yield better analysis compared to conventional Zernike moments and United Moment Invariant.**

***Keywords*— Feature Extraction, Granular Mining, Inter-class, Intra-class, Pattern Recognition, United Moment Invariant, and Zernike Moment Invariant,**

I. Introduction

The mathematical concept of moments has been around since 1960s. Some of them are used for mechanics and statistics to pattern recognition and image understanding. Past few years, there were many researchers on moment functions have been explored in pattern recognition such as United Moment Invariant, Aspect Moment Invariant and etc. The techniques have been investigated to improve conventional regular moment by proposing the scaling factor of geometrical function that has been proposed by Hu [1]. However, previous studies reveal that there are weaknesses in Hu's scaling factor [2].

Table 1 shows previous studies on enhancement of Moment Invariants from year 1962 to year 2008. All the proposed techniques are based on the drawbacks of Geometric Moment Invariants. Some of the drawbacks are:

1) Not sensitivity to image noise, aspect of information redundancy and capability for image representation [6].
2) Lose scale invariance in discrete condition [7].
3) Not good in boundary condition [4].
4) Error if the data are unequally scaling data [8].

On the other hand, [3] has proposed United Moment Invariant (UMI) that was based on the Geometric Moment Invariant (GMI) [3], and it was derived to improve the moment invariants of [4]. UMI was developed to handle with the images with boundary and shape representation.

The remainder of this paper is organized as follows: Section II describes related work on Geometric Moment Invariants in pattern recognition. Section III describes an integration of Zernike moments with United Moment Invariant, while Section IV presents the sample data of the study. Section V introduces the concept of inter-class and intra-class, and provides the experimental results and analysis of the proposed approach. Finally Section VI gives the conclusion of the study.

TABLE I. Trends of Moment Invariant Derivation Based on Geometric Function

Year	Researcher	Technique
1962	Hu	Geometric Moment Invariant
1980	Teague	Zernike Moment Invariant
1980	Teague	Legendre Moment Invariant
1992	Flusser and Suk	Affine Moment Invariant
1993	Chen	Improve Moment Invariant
1994	Feng And Keane	Aspect Moment Invariant
2000	S. M. Shamsuddin	Higher Order Centralized Scale – Invariant
2001	R.Mukundan	Tchebichef Moment Invariant
2003	Yinan	United Moment Invariant
2003	Yap	Krawtchouk Moment Invariant
2007	A.K. Muda, S.M Shamsuddin, M. Darus	Higher Order United Scaled Invariants
2008	A.K Muda	Aspect United Moment Invariant

II. Related Work of Moment Invariant

Various studies have been conducted on improvement of the algorithms for United Moment Invariant and Zernike Moment Invariant. In 1934, F. Zernike introduced Zernike Moments, and later, in 1980, this technique was applied by M.Teague for digital images [5]. Consequently, there are many applications on using ZMI have been explored (Table II).

Zernike moment has been proven better in terms of offering the ability of features and sensitivity to the noisy phase low despite its complex calculation. Its representation in terms of a concentrated moment is given as follows [5]:

$$ZM_1 = \frac{3}{\pi}\left[2\left(\eta_{20}+\eta_{02}-1\right)\right]$$

$$ZM_2 = \frac{9}{\pi^2}\left[\left(\eta_{20}-\eta_{02}\right)^2+4\eta_{11}^{\ 2}\right]$$

$$ZM_3 = \frac{16}{\pi^2}\left[\left(\eta_{03}-3\eta_{21}\right)^2+\left(\eta_{30}+\eta_{12}\right)^2\right]$$

$$ZM_4 = \frac{144}{\pi^2}\left[\left(\eta_{03}-3\eta_{21}\right)^2+\left(\eta_{30}+\eta_{12}\right)^2\right]$$

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$$ZM_5 = \frac{13824}{\pi^4}\left\{\begin{array}{l}(\eta_{03}-3\eta_{21})(\eta_{03}+\eta_{21})\left[(\eta_{03}+\eta_{21})^2-3(\eta_{30}+\eta_{12})^2\right] \\ -(\eta_{30}-3\eta_{12})(\eta_{30}+\eta_{12})\left[(\eta_{30}+\eta_{12})^2-3(\eta_{03}+\eta_{21})^2\right]\end{array}\right\}$$

$$ZM_6 = \frac{864}{\pi^3}\left\{\begin{array}{l}(\eta_{02}-\eta_{20})\left[(\eta_{30}+\eta_{12})^2-(\eta_{03}+\eta_{21})^2\right] \\ +4\eta_{11}(\eta_{03}+\eta_{21})(\eta_{30}+\eta_{12})\end{array}\right\}$$

TABLE II. APPLICATIONS OF ZERNIKE MOMENT INVARIANT

No	Authors	Objective	Year
1.	Belkasim S.O	Handwritten Numbers Recognition	1989
2.	P.Pejnovic	Tank, Helicopter Air-Craft and Ship recognition	1992
3.	W. Y Kim *et al*	Alphanumeric Machine-Printed Character recognition	1994
4.	H.Lim *et al*	Chinese character recognition	1996
5.	J. Haddadnia *et al.*	Face recognition	2001
6.	Qing Chen,Xioli Yang,Jiying Zhao	image watermarking	2005
7.	Harikesh Singh, Dr. R. K. Sharma	online handwritten character recognition	2007
8.	R. Sanjeev Kuntee, RD Sudhaker Samuel	Kanada character recognition	2007
9.	Chong-Yaw Wee1, ∗Raveendran Paramesran1, Fumiaki Takeda2	Rice Sorting System	2007

On the other hand, United Moment Invariant which was derived by Yinan [7] in 2003, found that the rotation, translation and scaling can be discretely kept invariant to region, closed and unclosed boundary. The formulations of UMI is given [7]:

$$\theta_1 = \sqrt{\phi_2} / \phi_1$$
$$\theta_2 = \phi_6 / \phi_1\phi_4$$
$$\theta_3 = \sqrt{\phi_5} / \phi_4$$
$$\theta_4 = \phi_5 / \phi_3\phi_4$$
$$\theta_5 = \phi_1\phi_5 / \phi_2\phi_3$$
$$\theta_6 = \left(\phi_1 + \sqrt{\phi_2}\right)\phi_3 / \phi_6$$
$$\theta_7 = \phi_1\phi_5 / \phi_3\phi_6$$
$$\theta_8 = (\phi_3 + \phi_4) / \sqrt{\phi_5}$$

However, in 2007, the integration techniques of High Order Moment Invariant and United Moment Invariant were purposed by A.K. Muda *et. al* [2]. This study has been extended to other unequal scaling invariant by integrating with Aspect Moment Invariants [9].

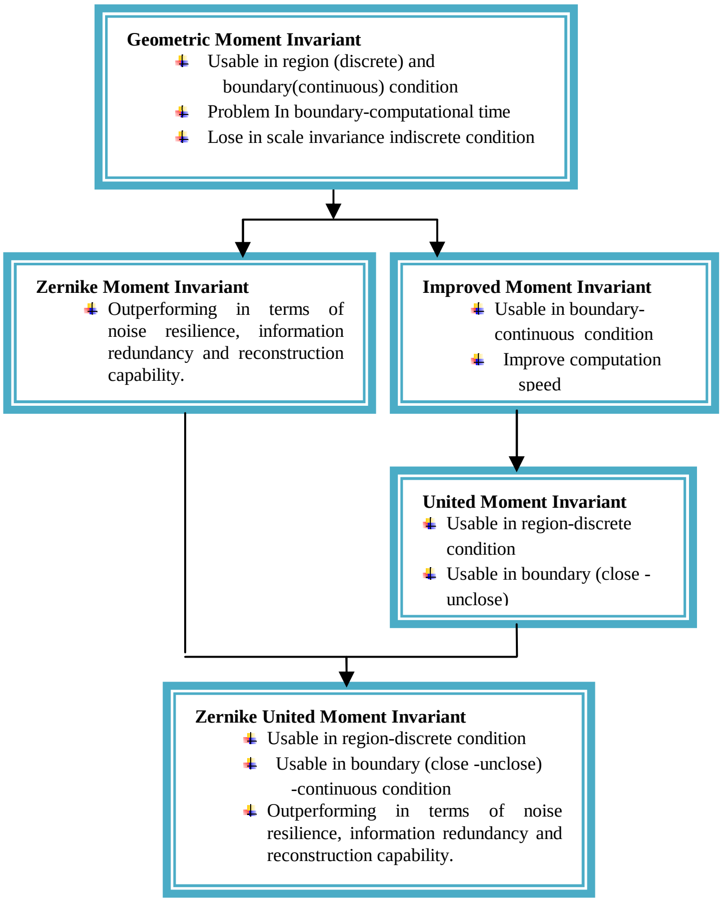

Figure 1. Chronology of Zernike United Moment Invariant

III. ZERNIKE UNITED MOMENT INVARIANT

UMI was derived from Geometric Moment Invariant and Improve Moment Invariant (IMI) [3] (refer to Figure 1). GMI is usable for region representation in discrete condition; however it is high in computational times for boundary representation [4]. Thus, Chen proposed IMI that practical for boundary and increased the computation speed. However, Yinan proposed a new technique that was effectively the shape of image on both region and boundary in discrete and continuous condition [3].

The combination of Zernike and United Moment is implemented to get better formulations that will yield good representation for boundary, region, discrete and noise resilience, information redundancy and reconstruction capability. UMI formulation is based on geometrical representation that taken into consideration the Normalized Central Moment of GMI and Boundary Representation of IMI[4] .

The integration formulation of ZMI and UMI is given as below. We define standard scaling equation as below:

$$\eta_{pq} = \frac{\mu_{pq}}{(\mu_{00})^{\frac{p+q+2}{2}}}$$

$$\eta'_{pq} = \rho^{p+q}\eta_{pq} = \frac{\rho^{p+q}}{(\mu_{00})^{\frac{p+q+2}{2}}}\mu_{pq}$$

$$\eta''_{pq} = \frac{\mu_{pq}}{(\mu_{00})^{p+q+1}}$$

From the above equations, we find that, each term has μ_{pq}. Yinan [3] said that if we can contemporary avoid the influence of μ_{00} and, the united formula can be materialized. Hence, the eight formulas for United Moment Invariants (UMI) is presented as:

$$\begin{aligned}
\theta_1 &= \sqrt{\phi_2} / \phi_1 \\
\theta_2 &= \phi_6 / \phi_1\phi_4 \\
\theta_3 &= \sqrt{\phi_5} / \phi_4 \\
\theta_4 &= \phi_5 / \phi_3\phi_4 \\
\theta_5 &= \phi_1\phi_5 / \phi_2\phi_3 \\
\theta_6 &= \left(\phi_1 + \sqrt{\phi_2}\right)\phi_3 / \phi_6 \\
\theta_7 &= \phi_1\phi_5 / \phi_3\phi_6 \\
\theta_8 &= (\phi_3 + \phi_4) / \sqrt{\phi_5}
\end{aligned}$$

However, in this integration, the ϕ values are substituted by Zernike's moments as shown below.

$$ZM_1 = \frac{3}{\pi}\left[2(\eta_{20} + \eta_{02} - 1)\right]$$

$$ZM_2 = \frac{9}{\pi^2}\left[(\eta_{20} - \eta_{02})^2 + 4\eta_{11}^{\ 2}\right]$$

$$ZM_3 = \frac{16}{\pi^2}\left[(\eta_{03} - 3\eta_{21})^2 + (\eta_{30} + \eta_{12})^2\right]$$

$$ZM_4 = \frac{144}{\pi^2}\left[(\eta_{03} - 3\eta_{21})^2 + (\eta_{30} + \eta_{12})^2\right]$$

$$ZM_5 = \frac{13824}{\pi^4}\left\{\begin{array}{l}(\eta_{03} - 3\eta_{21})(\eta_{03} + \eta_{21})\left[(\eta_{03} + \eta_{21})^2 - 3(\eta_{30} + \eta_{12})^2\right] \\ -(\eta_{30} - 3\eta_{12})(\eta_{30} + \eta_{12})\left[(\eta_{30} + \eta_{12})^2 - 3(\eta_{03} + \eta_{21})^2\right]\end{array}\right\}$$

$$ZM_6 = \frac{864}{\pi^3}\left\{\begin{array}{l}(\eta_{02} - \eta_{20})\left[(\eta_{30} + \eta_{12})^2 - (\eta_{03} + \eta_{21})^2\right] \\ +4\eta_{11}(\eta_{03} + \eta_{21})(\eta_{30} + \eta_{12})\end{array}\right\}$$

For example,

$$\begin{aligned}
\varphi_2 &= \left(\frac{3}{\pi}\right)^2 \times \left[(\eta_{20} - \eta_{02})^2 + 4\eta_{11}^{\ 2}\right] \\
&= \frac{9}{\pi^2} \times \left[\frac{1}{(\mu_{00})^4} \times (\mu_{20} - \mu_{02})^2 + 4\mu_{11}^2\right]
\end{aligned}$$

and

$$\begin{aligned}
\varphi_1 &= \frac{3}{\pi} \times \left[2(\eta_{20} + \eta_{02}) - \eta_{00}\right] \\
&= \frac{3}{\pi} \times \left[2\left(\frac{1}{(\mu_{00})^2} \times (\mu_{20} + \mu_{02})\right) - 1\right]
\end{aligned}$$

so,

$$\begin{aligned}
\theta_1 &= \frac{\sqrt{\varphi_2}}{\varphi_1} \\
&= \frac{\sqrt{\frac{9}{\pi^2} \times \left[\frac{1}{(\mu_{00})^4} \times (\mu_{20} - \mu_{02})^2 + 4\mu_{11}^2\right]}}{\frac{3}{\pi} \times \left[2\left(\frac{1}{(\mu_{00})^2} \times (\mu_{20} + \mu_{02})\right) - 1\right]} \\
&= \frac{\sqrt{\frac{9}{\pi^2} \times \left[\frac{(\mu_{20} - \mu_{02})^2}{(\mu_{00})^2} + 4\mu_{11}^2\right]}}{\frac{3}{\pi} \times \left[2\left(\frac{(\mu_{20} + \mu_{02})}{(\mu_{00})} \times\right) - 1\right]}
\end{aligned}$$

Using the same approach as above, we get:

$$\begin{aligned}
\theta'_1 &= \frac{\sqrt{\left(\frac{3}{\pi}\right)^2 \times \left[(\eta'_{20} - \eta'_{02})^2 + 4\eta'_{11}{}^2\right]}}{\frac{3}{\pi} \times \left[2(\eta'_{20} + \eta'_{20}) - \eta'_{00}\right]} \\
&= \frac{\sqrt{\frac{9}{\pi^2} \times \left[\frac{\rho^4}{(\mu_{00})^4} \times \frac{(\mu_{20} - \mu_{02})^2}{(\mu_{00})^2} + 4\mu_{11}^2\right]}}{\frac{3}{\pi} \times \left[2\left(\frac{\rho^2}{(\mu_{00})^2} \times \frac{(\mu_{20} + \mu_{02})}{(\mu_{00})^2}\right) - 1\right]} \\
&= \frac{\sqrt{\frac{9}{\pi^2} \times \left[\frac{(\mu_{20} - \mu_{02})^2}{(\mu_{00})^2} + 4\mu_{11}^2\right]}}{\frac{3}{\pi} \times \left[2\left(\frac{(\mu_{20} + \mu_{02})}{(\mu_{00})} \times\right) - 1\right]}
\end{aligned}$$

$$= \frac{\sqrt{\frac{9}{\pi^2}\times\left[\frac{\rho^4}{(\mu_{00})^4}\times\frac{(\mu_{20}-\mu_{02})^2}{(\mu_{00})^2}+4\mu_{11}^2\right]}}{\frac{3}{\pi}\times\left[2\left(\frac{\rho^2}{(\mu_{00})^2}\times\frac{(\mu_{20}+\mu_{02})}{(\mu_{00})^2}\right)-1\right]}$$

$$= \frac{\sqrt{\frac{9}{\pi^2}\times\left[\frac{(\mu_{20}-\mu_{02})^2}{(\mu_{00})^2}+4\mu_{11}^2\right]}}{\frac{3}{\pi}\times\left[2\left(\frac{(\mu_{20}+\mu_{02})}{(\mu_{00})}\times\right)-1\right]}$$

and

$$\theta''_1 = \frac{\sqrt{\left(\frac{3}{\pi}\right)^2\times\left[(\eta''_{20}-\eta''_{02})^2+4\eta''^{2}_{11}\right]}}{\frac{3}{\pi}\times\left[2(\eta''_{20}+\eta''_{20})-\eta''_{00}\right]}$$

$$= \frac{\sqrt{\frac{9}{\pi^2}\times\left[\frac{1}{(\mu_{00})^6}\times(\mu_{20}-\mu_{02})^2+4\mu_{11}^2\right]}}{\frac{3}{\pi}\times\left[2\left(\frac{1}{(\mu_{00})^3}\times(\mu_{20}+\mu_{02})\right)-1\right]}$$

$$= \frac{\sqrt{\frac{9}{\pi^2}\times\left[\frac{(\mu_{20}-\mu_{02})^2}{(\mu_{00})^2}+4\mu_{11}^2\right]}}{\frac{3}{\pi}\times\left[2\left(\frac{(\mu_{20}+\mu_{02})}{(\mu_{00})}\times\right)-1\right]}$$

From the above derivation, we found that $\theta''_1 = \theta'_1 = \theta_1$. Hence, this has proven that θ_1 can be applied for both region and boundary in discrete and continues condition.

IV. Sample Data

The insect images will be used in this research. Initially, the insect images are scanned with 300 dpi (dot per inch) and 150 dpi resolutions. Figure 2 depicts sample of insect's images and Figure 3 illustrates various orientations of insect images in the same class.

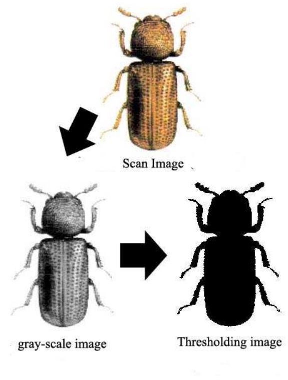

Figure 2. Insect Images

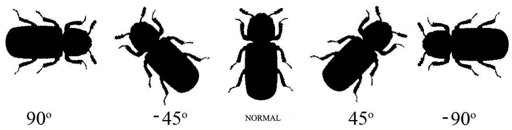

Figure 3. Insect Images (Orientation)

V. Result and Analysis

In this study, the invarianceness of the proposed integrated formulations are validated using intra-class and inter-class by calculating the MAE (Min Absolute Error) as shown below:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|(x_i - r_i)\right|,$$

where n is number of image, x_i is the current image and r_i is the reference image. The first image is the reference image. Intra-class is the process that defines the similar images with the small value of MAE. However, inter-class is the process of defining the difference images with high MAE value.

A. Intraclass Analysis

For intra-class analysis, we used eight sample insect images to get the invariance's of the techniques. All the images have different orientation with same class. The random samples of images are bactrocera maculigera (BM), bean bruchid (BB), chocolate moth (CM), dried current moth (DC), grain weevil (GW), indian meal moth (IM), rusty grain beetle (RG), and saw-toothed grain beetle (ST).

Figure 4 shows example of intra-class analysis/ Bactrocera maculigera(BM) insect images are used in this study with different orientations.

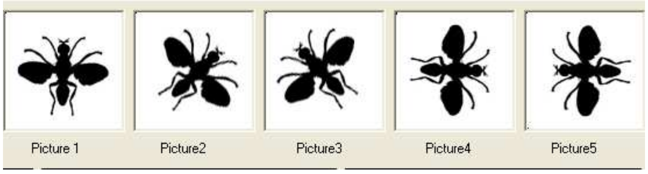

Figure 4. Sample insect image for intra-class analysis

From Table III, intra-class distance of ZUMI has smaller value for seven insect images and one insect image in UMI (saw-toothed grain beetle).

TABLE III. RESULT OF INTRA-CLASS ANALYSIS

	ZUMI	UMI	ZMI
BB	0.915747	1.615862986	15.22766
BM	0.392484	1.705341657	3.969996
CM	1.108088	2.120735	1.634658
DC	0.919749	1.315753805	27.96692
GW	1.046265	1.881051745	27.3219
IM	0.969856	1.996245217	9.254302
RG	1.251929	2.426967495	31.0565
ST	1.913044	1.846069911	65.39193

Figure 5 illustrates that Zernike Moment Invariant (ZMI) gives higher value of MAE compared to other techniques.

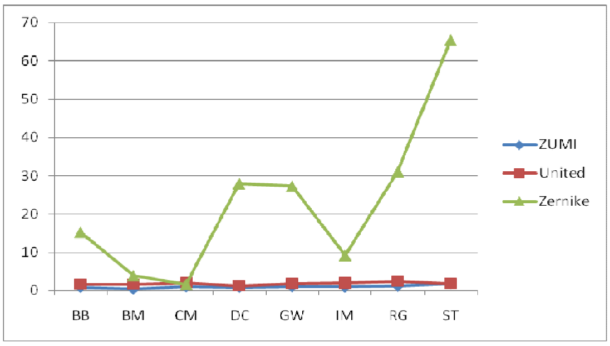

Figure 5. Intraclass Analysis of Insects' Images.

From Figure 5, it shows that ZUMI gives smaller value of MAE for all images. However, Figure 6 shows that UMI gives smaller MAE compared to ZUMI for saw-toothed grain beetle (ST) images. The difference MAE value is about 0.0066974089.

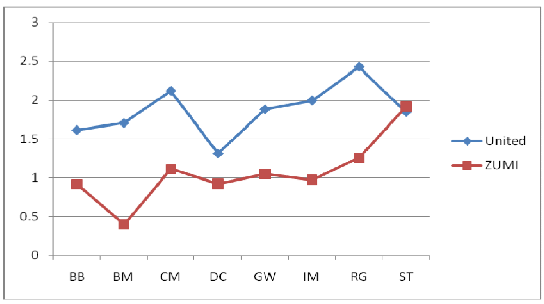

Figure 6. Comparison result between ZUMI and UMI.

B. *Interclass analysis*

The samples of images for interclass analysis are shown in Figure 7. There are 4 experiments for defining interclass analysis, and these include:

1) Interclass distance between saw-toothed grain beetle (ST) and rusty grain beetle (RG).
2) Interclass distance between chocolate moth(CM) and cocoa pod pentatomid(CP).
3) Interclass distance between bactrocera maculigera(BM) and natal fruit fry(NF).
4) Interclass distance between 6 and 9 (for testing only).

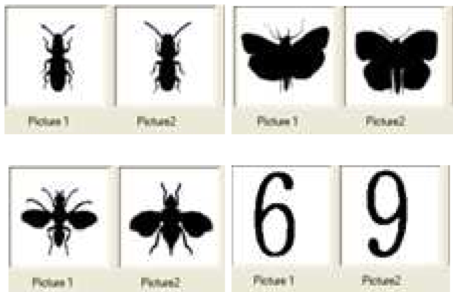

Figure 7. Sample insect images of inter-class analysis

Table IV depicts the comparison between three Moment Invariants (ZUMI, UMI, and ZMI). We label the experiments as below:

1) B1: the comparison between saw-toothed grain beetle (ST) and rusty grain beetle (RG).
2) B2: the comparison between chocolate moth(CM) and cocoa pod pentatomid(CP).
3) B3: the comparison between bactrocera maculigera(BM) and natal fruit fry(NF).
4) B4: the comparison between 6 and 9 (for testing only).

TABLE IV. RESULT OF INTER-CLASS ANALYSIS

	B1	B2	B3	B4
U	0.289149	0.591789	2.705702	0.07581
Z	0.747368	55.49137	11.68222	4.54826
ZU	0.760303	0.311496	0.589317	2.371722

From Table IV, experiment B1 for inter-class shows that ZUMI gives the higher MAE values than others. However, for other experiments (B2, B3, B4), it shows that ZMI gives the highest MAE values compared to others. Experiment B3 shows that UMI gives smaller MAE values than others. However, in the last experiment for interclass analysis, the ZUMI gives higher value of MAE compared to UMI. Besides that, ZMI gives higher MAE values for all experiments compared to others as shown in Figure 8.

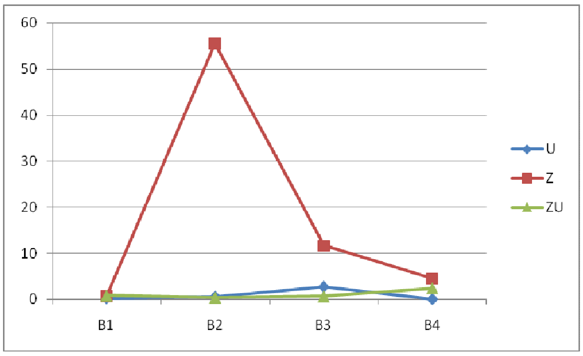

Figure 8. The graph of inter-class anylisis result.

VI. CONCLUSION

From this study, we found that the proposed integrated formulations yield promising results compared to the conventional Zernike Moment Invariant and United Moment Invariant. The summary of the results are presented in Table V. As a whole, our proposed method is better in giving invarianceness of insect images in terms of inter-class and intra-class.

TABLE V. SUMMARIZATION OF THE RESULT

Technique	Invarianceness	Decision
The proposed Integrated Formulation (Zernike United Moment Invariant)	Intra-class	Good
	Inter-class	Better
Zernike Moment Invariant	Intra-class	Bad
	Inter-class	Good
United Moment Invariant	Intra-class	Better
	Inter-class	Bad

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