Application of feature-based image matching method as an object recognition method

I Gede Made Karma[1], I Ketut Darma[2]
[1]Department of Accounting, Politeknik Negeri Bali, Badung, Indonesia
[2]Department of Mechanical Engineering, Politeknik Negeri Bali, Badung, Indonesia

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ABSTRACT

In everyday life, objects are recognized based on the suitability of their characteristics to familiar objects. A feature matching process occurs when recognizing objects. This concept is what we want to apply and test in this research. Because various factors can influence the level of accuracy and success of an image matching method, the first step taken is to improve the accuracy level of the image matching method used. There are three feature-based image matching methods, which are implemented as object recognition methods. These three methods are the result of modifications of the image matching function method, normalized 2D cross correlation method and point feature matching which were later named PICMatch, NCMatch and FBMatch. As image matching methods, these three modified methods show performance with a success rate above 95%. However, when applied as an object recognition method, both individually and combined, the three methods only have a maximum accuracy of 7%. These results are obtained by matching the samples using one of the methods with the best match rate, in the order of application of the PICMatch, NCMatch, and FBMatch methods.

Corresponding Author:

I Gede Made Karma
Department of Accounting, Politeknik Negeri Bali
Kampus Bukit, Jimbaran, South Kuta, Badung, Bali 80364, Indonesia
Email: igmkarma@pnb.ac.id

1. INTRODUCTION

In the process of recognizing an object, vision plays a very important role. With their vision, humans can track, sort, separate and ultimately detect the presence of an object. Even though objects have various appearances and are in different environments, humans can still recognize them well humans recognize an object based on the shape, pattern or texture of an object. Humans do not need to observe an object in detail, but only need to observe certain points, which are then combined into a recognizable pattern. This is then known to be matched with the pattern of the previous object, as a basis for recognizing the object [1].

In image matching applications, the process of detecting and describing features has a very important role. This feature is different and distinctive, so it can be used as a reference for recognizing an object. Features can be recognized because of changes in intensity, color or texture in the image. Features can be categorized in the form of keypoint and edge features [2]. Keypoint features are indicated by different groups of pixels in the image. Meanwhile, an edge is the edge of an object, which shows its appearance and orientation. To clarify its uniqueness, features are determined locally, with relatively large numbers so that they are easy to detect or recognize. Based on location and coverage, features can be classified into local and global features. Local features describe the area around the image keypoint, while global features describe the properties of the image as a whole, involving all existing pixels [3]. This feature is a physical representation of an image that can be expressed separately and measured. Good features must be able to distinguish patterns of different classes and show similarities for the same class. In addition, ideal features must be very distinctive, so that they can be matched correctly with high probability [4].

There are 3 types of image characteristics that are often considered, namely color, texture and shape. Color features are determined from pixel properties with reference to a predefined color space. Texture features are determined based on spatially and spectrally extracted pixel groups, while shape features are determined based on contours or regions [5]. Shape features are widely used to describe the contents of an image, and are commonly used by humans to identify and recognize an object. These shape features are relatively weak, mainly related to the dimensions of 3-D objects projected onto a 2-D plane, coupled with the variable problems of noise, defects, distortion and occlusion [6]. This weakness was then tried to be overcome by a shape transformation process from a small and irregular texture area to a square texture.

Object features in the image can be extracted from the image itself. In this process, color has a very important role because color has a relatively similar and stable representation, with the degree of similarity being easily measured. Feature extraction [7] is a process for obtaining features, by calculating the mean, median, and standard deviation values of the three basic color components R (red), G (green), and B (blue) of a color [8]. This process has weaknesses related to sensitivity and difficulty in representing an image, if the image is dominated by a certain color. One anticipatory step that can be taken is to apply the multiscale structural similarity (MSSIM) index [9]. To find out information on the spatial arrangement of colors and their intensity in an image, texture analysis can be done, by applying various mathematical techniques to measure the intensity of gray levels and spatial groups of images. Various methods have been introduced, such as statistical, model and transformation based methods, and it turns out that statistical methods are more widely used because they are considered easier to calculate [10].

The various buildings, objects or images that we encounter show various harmony, both locally and globally. Because its alignment is stable and strong, it is often used as a representation or descriptive characteristic of the object. This is the reason why many object recognition and image matching processes utilize image features as the basis for their processing [11]. Image matching is the process of matching the features in the reference image and the target image. The two images are extracted to obtain features and descriptors, then matched using a certain algorithm. A relationship/correlation will be formed between the two images based on the suitability of their features [12].

The image matching process is declared accurate if it is able to extract and compare all information related to image features and the environment. In the image matching process, the two images are matched based on the correspondence of the features detected and described in the two images [13]. Image feature detection and description play an important role in this process [14], and must be done relatively quickly.

In general, image matching will be related to two main things, namely the characteristics or patterns of the image to be matched, and the method or strategy used to carry out the matching. The image matching process will begin by extracting features from both images, matching them, and calculating the level of correspondence [15]. Image matching methods can be classified into two groups, namely area-based methods and feature-based methods. In the region-based method, the matching process is carried out based on the similarity of pixels in the two images, without paying attention to existing features. In its application, many obstacles are encountered related to the condition of the two images which are greatly influenced by differences in intensity, illumination and geometric deformation due to noise [16]. Feature-based methods are methods that build correspondence based on similarities between points that have similar descriptors. In this method, the matching process is carried out by establishing a relationship or correspondence between features in one image and features in other images. This method first carries out a feature extraction process for the two images, so that they can be compared and corresponded between the two [17]. In this method, image similarity can be measured based on image intensity values, spatial distribution of features, or symbolic descriptions of features applied in various methods.

This research aims to test the concept of object recognition in everyday life, which is done by matching an object with other known objects. This research will test the ability of the image matching method as an object recognition method. Because image matching methods sometimes give wrong or failed results, the research began by improving the performance of image matching methods, and applying 3 (three) different methods. These three methods are feature-based image matching methods.

2. METHOD

The three feature-based image matching methods compared are implemented in the MATLAB R2017b program. Comparison of the three methods is carried out based on the results shown on sample testing, especially with regard to the success rate and matching accuracy.

2.1. PICMatch method

PICMatch is an edge detection-based image matching method developed based on the image matching function algorithm [18]. In an image, these edges contain information about the presence of an object, its shape, size and texture. This information can then be used to extract features from the image using various operators such as Roberts, Prewitt, Sobel, and so on. Edge detection is a process for identifying points in an image that experience sharp changes in intensity [19]. Detecting edges is basically a relatively difficult process, because many factors influence its success. The image matching process is carried out by comparing the white and black points in the two segmented images using the edge method with the Roberts operator. The comparison results will produce a level of similarity between the two images, and both images are considered the same if they have a similarity percentage above 50%.

PICMatch algorithm

```
{Checking whether two input images match or not based on the level of similarity of the
white points in the two images}
Declaration:
   - WhitePoint1, WhitePoint2: number of white points in image1 and image2.
   - MatchedWhitePoints: the number of white points that match in both images.
   - percentageMatch1, percentageMatch2: comparison of MatchedWhitePoints with WhitePoint1
     and WhitePoint2.
Steps:
  1. Input image1, image2
  2. Perform edge segmentation method on both images
  3. Count WhitePoint1 and WhitePoint2
  4. Calculate the MatchedWhitePoints
  5. Calculate the percentageMatch1 and percentageMatch2
  6. Is percentageMatch1>50 or percentageMatch2>50?
       - Yes: Match
       - No: Not match
  7. End
```

2.2. NCMatch method

NCMatch is an image matching method using the normalized 2-D cross-correlation method, which was developed by modifying the template matching image matching algorithm using the MATLAB command 'normcorrx2' [20]. In the field of statistics, to determine the relationship between two variables can be measured using the Pearson correlation coefficient:

$$\rho_{X,Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \tag{1}$$

The Pearson correlation has a value range of -1 to 1, with a value of 0 indicating there is no relationship between the two variables. A value greater than 0 indicates a positive relationship, while a smaller value 0, indicates a negative relationship. Based on the range of values, the relationship strength will be further categorized into small (±0.1 - ±0.3), medium (±0.3 - ±0.5) and large (±0.5 - ±1.0).

Signal correlation can be used to compare the similarity of two signals [21]. An image which is an arrangement of pixels can be analogous to a series of signals in a 2D plane. The matching process is carried out by establishing correspondence between the two images, so that a measure is obtained that shows the level of similarity between the two images [22]. In the 2D-based face recognition process, normalized cross correlation (NCC) is widely used, considering that the calculation process is relatively fast in accordance with the demands of time-sensitive applications [23]. The cross correlation value of the two signals can be calculated using (2). The larger the value obtained, the more similar the two signals are [24].

$$R_{xy}(\tau) = \sum_{i=0}^{N-1} x_i(t).y_i(t-\tau) \tag{2}$$

The application of this function to two images will result in a level of similarity between the two images. In this study, the two images are declared match if they have a minimum correlation value of 0.45.

NCMatch algorithm

```
{Checking whether two input images match or not based on the Pearson correlation value of
the two images}
Declaration:
   - CorrelationValue: pearson correlation value of the two images.
   - MaxValue: the largest value of the pearson correlation value of the two images.
Steps:
  1. Input image1, image2
```

```
2.  Calculate the CorrelationValue of image1 and image2
3.  Set the MaxValue of the CorrelationValue
4.  Is the MaxValue>0.45?
      - Yes: Match
      - No: Not match
5.  End
```

2.3. FBMatch method

FBMatch is an image matching method using the point feature matching method, the result of a modification of the object detection image matching algorithm in Cluttered Scenes using point feature matching. Each feature is described in a certain way and then compared to the whole image, to get similar features. In the image matching process, a number of feature pairs (x1, y1) in one image and (x2, y2) in another image can be found, which have a match or similarity, based on their description [25]. It is suitable for objects that have unique features, do not repeat and do not have a uniform color [26]. Both images are considered to match if they have at least 3 points of correspondence.

FBMatch algorithm

```
{Checking whether two input images match or not based on the number of feature point pairs
that have similarities in both images}
Declaration:
   - NumberofFeaturePoints1, numberofFeaturePoints2: the number of feature points in the
     image that are similar to feature points in other images.
Steps:
1.  Input image1, image2
2.  Detect object feature points in both images
3.  Extract and describe the feature points of both images
4.  Count the number of matching feature points in both images
5.  Estimate the geometric transformation of the feature point matches
6.  Count the numberofFeaturePoints1 and the numberofFeaturePoints2
7.  Is the numberofFeaturePoints1>=3 or the numberofFeaturePoints2>=3?
      - Yes: Match
      - No: Not match
8.  End
```

The number of samples used in this research was 1,190 image files with a total of 40 object categories, 39 object categories with 30 samples each and 1 object category with 20 samples. Samples were obtained from http://www.vision.caltech.edu/ImageDatasets/Caltech101/. Sample categories and their numbers can be seen in Table 1. The entire sample is used in 3 (three) types of testing, namely:

- Each sample image is matched to itself. This test is intended to check the suitability of each method as a method for matching object images as expected.
- Each sample image is matched with images that have the same category. This test is intended to check the ability of each method to match similar objects (one category).
- Each sample image is matched with a sample image that is not in the sample category. This test is intended to determine the level of failure carried out by each method in matching or recognizing an object.

Table 1. Categories and number of samples

#	Category	N	#	Category	N	#	Category	N	#	Category	N
1	Dog	30	11	Sunflower	30	21	Shell	30	31	Penguin	30
2	Air balloon	30	12	Owl	30	22	Coin	30	32	Aircraft	30
3	Tire	30	13	Cup	30	23	Horse	30	33	Radio tape	30
4	Stork	30	14	Elephant	30	24	Butterfly	30	34	Ant	30
5	Duck	30	15	Greyhounds	30	25	Chair	30	35	Strawberries	30
6	Beaver	20	16	Watch	30	26	Fly	30	36	Bag	30
7	Bear	30	17	Cactus	30	27	Mandolin	30	37	Binoculars	30
8	Starfish	30	18	Kangaroo	30	28	Washing machine	30	38	Tomato	30
9	Bonsai	30	19	Bat	30	29	Palm	30	39	Camel	30
10	Buddha	30	20	Crab	30	30	Umbrella	30	40	Zebras	30
Total=1,190											

3. RESULTS AND DISCUSSION

In initial testing, each method had a relatively fast processing time for matching two images. The processing time for the PICMatch method is 0.01 seconds, the NCMatch method is 0.13 seconds and the FBMatch method is 0.14 seconds.

3.1. Results of the feasibility test of the image matching method

As previously explained, to carry out this test, each sample is matched to itself using the three image matching methods tested. The results obtained are presented in Table 2. Of the 1,190 samples available, the PICMatch method was able to match 1,145 samples, the NCMatch method was successful in matching all samples, while the FBMatch method was able to match 1,187 samples. The NCMatch method has a success rate of matching samples with itself of 100%, the FBMatch method is 99.75%, while the PICMatch method is 96.22%. In general, the three methods have a fairly high success rate, namely above 95%, so they can be considered worthy as image matching methods. The NCMatch method has the best performance, followed by the FBMatch and PICMatch methods.

Table 2. The results of the feasibility test of the image matching method

Sample		Method		
		PICMatch	NCMatch	FBMatch
N	1,190	1,145	1,190	1,187
%	100%	96.22%	100.00%	99.75%

3.2. Image matching test results in one category

This test aims to check the capabilities of each method whether it is able to recognize similar objects or not. Testing is carried out by matching each sample with samples of the same category. Each sample is matched with other samples in one category, and the results obtained are presented in Table 3. In Table 3 it can be seen that of the 35,550 samples in all categories, the PICMatch method was able to match only 1,149 pieces (3.24%), the NCMatch method 14,282 pieces (40.23%) and the FBMatch method 4,724 pieces (13.31%). In matching object images in one category, the NCMatch method appears to have the best performance, followed by the FBMatch and PICMatch methods.

3.3. Image matching test results with images outside the category

This test is intended to check the ability of each method to match sample images with sample images that are not in its category. This ability will indirectly indicate the failure or inability of the method to recognize an object. Of the 1,190 samples, 100 samples were randomly selected to be compared with samples outside their category. The results obtained are presented in Table 4.

Table 3. Image matching test results in one category

Sample		Method		
		PICMatch	NCMatch	FBMatch
N	35,500	1,149	14,282	4,724
%	100%	3.24%	40.23%	13.31%

Table 4. Image matching test results with images outside the category

Sample		Method		
		PICMatch	NCMatch	FBMatch
N	330,600	0	72,528	11,615
%	100%	0.00%	21.94%	3.51%

Of the three methods tested, it appears that only the PICMatch method failed to match a single sample with a sample image outside its category, while the NCMatch method was 21.94% and the FBMatch method was 3.51%. That means, the PICMatch method has very good abilities in distinguishing object categories, while the NCMatch method and FBMatch method have weaknesses, which means they have the possibility of wrongly distinguishing one object category from another. The NCMatch method has a greater chance of error than the FBMatch method.

3.4. Discussions

Based on the results of the three tests related to the three image matching methods discussed previously, the following results were obtained:

- All three methods have very good abilities in matching images, although the PICMatch and FBMatch methods have experienced failures in matching the same image. With a capability level above 95%, the three methods can be considered suitable for use as image matching methods.
- In matching images in one category, the NCMatch method has the best ability compared to other methods. The FBMatch method is quite capable, while the PICMatch method is practically incapable.
- In matching images that are not categorized, the PICMatch method was not successful in matching a single existing sample, while the NCMatch and FBMatch methods were relatively successful. This shows that the PICMatch method is very capable of distinguishing objects, while the NCMatch and FBMatch methods are relatively not.

Based on the performance shown by the three methods, the object recognition process is not appropriate if it is only done with one method. Object recognition must be carried out using all three methods simultaneously in turns. The question is, what is the order of implementation. Based on the results described previously and the demands for accuracy, the most suitable series of image matching processes for object recognition are the PICMatch, NCMatch and FBMatch methods.

To find out how it performs, further testing is carried out. Testing was carried out using a random sample of 100 from 1,190 data. In this test the sample data will not be matched to itself. Each sample is matched using three methods, with different treatments, namely:

– Each sample is matched to each data using each method in turn. If one method is declared suitable, then the other method is no longer used.
– Each sample is matched with all the data using each method to find the object match with the best match level. If one method is successful, then the other method is not used.
– Samples were matched to each data set using all three methods sequentially. If the sample is declared to match method 1, the matching process is stopped. However, if it is declared suitable with method 2 or 3, then the matching process continues with the next data using methods 1 and 2 or 1, 2 and 3. If in the next process it is declared suitable with the same method, then the match is selected based on the better match level. This treatment is repeated until it is declared suitable for method 1 or the data is exhausted.

In these three types of testing, the three methods are applied in two types of order, namely: i) PICMatch, NCMatch, and FBMatch; and ii) PICMatch, FBMatch, and NCMatch. From these six tests, the results obtained are as shown in Table 5.

Table 5. Method testing results and level of accuracy

Testing		Match		%
#	Type	True	False	Accuracy (%)
1	a	0	100	0
	b	2	98	2
2	a	7	93	7
	b	5	95	5
3	a	4	96	4
	b	5	95	5

4. CONCLUSION

Image matching methods based on picture matching function, normalized 2-D cross-correlation and point feature matching after being modified into PICMatch, NCMatch, and FBMatch, have a success rate above 95%. This makes all three worthies of consideration as object recognition methods. The test results show a maximum accuracy rate of only 7%, obtained from applying the method in the order of PICMatch, NCMatch, and FBMatch. Both processes actually have the same working concept, namely comparing the features of the two images/objects. Because its performance as an object recognition method is not good, it raises the question, what is wrong or lacking in the three. This is certainly interesting to study further, in an effort to make it worthy as an object recognition method.

REFERENCES

[1] V. Ayzenberg and M. Behrmann, "Development of visual object recognition," *Nature Reviews Psychology*, vol. 3, no. 2, pp. 73–90, 2024, doi: 10.1038/s44159-023-00266-w.
[2] Y. Yu *et al.*, "Techniques and Challenges of Image Segmentation: A Review," *Electronics (Basel)*, vol. 12, no. 5, p. 1199, Mar. 2023, doi: 10.3390/electronics12051199.
[3] S. K. Sharma, K. Jain, and A. K. Shukla, "A Comparative Analysis of Feature Detectors and Descriptors for Image Stitching," *Applied Sciences*, vol. 13, no. 10, p. 6015, May 2023, doi: 10.3390/app13106015.
[4] X. Li, Z. Li, H. Qiu, G. Hou, and P. Fan, "An overview of hyperspectral image feature extraction, classification methods and the methods based on small samples," *Applied Spectroscopy Reviews*, vol. 58, no. 6, pp. 367–400, Jul. 2023, doi: 10.1080/05704928.2021.1999252.
[5] Y. Chen, R. Xia, K. Zou, and K. Yang, "FFTI: Image inpainting algorithm via features fusion and two-steps inpainting," *Journal of Visual Communication and Image Representation*, vol. 91, p. 103776, Mar. 2023, doi: 10.1016/j.jvcir.2023.103776.
[6] M. K. Alsmadi, "Content-Based Image Retrieval Using Color, Shape and Texture Descriptors and Features," *Arabian Journal for Science and Engineering*, vol. 45, no. 4, pp. 3317–3330, Apr. 2020, doi: 10.1007/s13369-020-04384-y.
[7] N. Varish *et al.*, "Image Retrieval Scheme Using Quantized Bins of Color Image Components and Adaptive Tetrolet Transform," *IEEE Access*, vol. 8, no. 1, pp. 117639–117665, 2020, doi: 10.1109/ACCESS.2020.3003911.
[8] I. G. M. Karma, I. K. G. Darma Putra, M. Sudarma, and L. Linawati, "Image Segmentation Based on Color Dissimilarity," 2022, *Informatica (Slovenia)*, vol. 46, no. 5, pp. 1–10, 2022, doi: 10.31449/inf.v46i5.3645.

[9] K. Ding, K. Ma, S. Wang, and E. P. Simoncelli, "Image Quality Assessment: Unifying Structure and Texture Similarity," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 44, no. 5, pp. 2567–2581, 2020, doi: 10.1109/TPAMI.2020.3045810.

[10] J. L. Xu and A. A. Gowen, "Spatial-Spectral Analysis Method Using Texture Features Combined with PCA for Information Extraction in Hyperspectral Images," *Journal of Chemometrics*, vol. 34, no. 2, 2020, doi: 10.1002/cem.3132.

[11] Z. Zhao, Q. Liu, and S. Wang, "Learning deep global multi-scale and local attention features for facial expression recognition in the wild," *IEEE Transactions on Image Processing*, vol. 30, pp. 6544–6556, 2021, doi: 10.1109/TIP.2021.3093397.

[12] R. A. Hamzah *et al.*, "A Study of Edge Preserving Filters in Image Matching," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 1, pp. 111–117, 2021, doi: 10.11591/eei.v10i1.1947.

[13] Q. Wang, X. Zhou, and K. Daniilidis, "Multi-image Semantic Matching by Mining Consistent Features," in *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2018, pp. 685–694. doi: 10.1109/CVPR.2018.00078.

[14] J. Kim and K. Grauman, "Asymmetric Region-to-Image Matching for Comparing Images with Generic Object Categories," in *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2010, pp. 2344–2351. doi: 10.1109/CVPR.2010.5539923.

[15] Y. Dufournaud, C. Schmid, and R. Horaud, "Matching Images with Different Resolutions," in *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition*, 2000, pp. 612–618, doi: 10.1109/cvpr.2000.855876.

[16] C. Leng, H. Zhang, B. Li, G. Cai, Z. Pei, and L. He, "Local Feature Descriptor for Image Matching: A Survey," *IEEE Access*, vol. 7, pp. 6424–6434, 2019, doi: 10.1109/ACCESS.2018.2888856.

[17] M. Cao, Q. Yan, Y. Yu, H. Zhao, and Z. Lyu, "MLV: Robust Image Matching via Multilayer Verification," *IEEE Sensors Journal*, vol. 24, no. 9, pp. 14454–14470, May 2024, doi: 10.1109/JSEN.2024.3373817.

[18] F. A. Abbasi, "Picture Matching Function," MATLAB Central File Exchange. [Online]. Available: https://www.mathworks.com/matlabcentral/fileexchange/5456-picture-matching-function. Accessed: Jan. 15, 2024.

[19] R. Bausys, G. Kazakeviciute-Januskeviciene, F. Cavallaro, and A. Usovaite, "Algorithm Selection for Edge Detection in Satellite Images by Neutrosophic WASPAS Method," *Sustainability (Switzerland)*, vol. 12, no. 2, 2020, doi: 10.3390/su12020548.

[20] A C Johnsy, "Template Matching in MATLAB." Available: https://www.imageeprocessing.com/2011/06/template-matching-in-matlab.html. Accessed: Feb. 10, 2024. [Online].

[21] J. Dou, Q. Qin, and Z. Tu, "Robust image matching based on the information of SIFT," *Optik*, vol. 171, pp. 850–861, Oct. 2018, doi: 10.1016/j.ijleo.2018.06.094.

[22] S. N. H. S. Hanapi, S. A. A. Shukor, and J. Johari, "Normalized Cross Correlation Template Matching for Oil Palm Tree Counting from UAV image," *Journal of Physics: Conference Series*, 2021, p. 012036. doi: 10.1088/1742-6596/2107/1/012036.

[23] A. Kaso, "Computation of the Normalized Cross-Correlation by Fast Fourier Transform," *PLoS One*, vol. 13, no. 9, 2018, doi: 10.1371/journal.pone.0203434.

[24] L. da F. Costa, "Comparing Cross Correlation-Based Similarities," *arXiv preprint*, 2021, doi: https://doi.org/10.48550/arXiv.2111.08513.

[25] D. Tyagi, "Introduction to Feature Detection and Matching," Data Breach. [Online]. Available: https://medium.com/data-breach/introduction-to-feature-detection-and-matching-65e27179885d. Accessed: Jan. 16, 2024.

[26] MathWorks, "Object Detection in a Cluttered Scene Using Point Feature Matching," The MathWorks, Inc. [Online]. Available: https://www.mathworks.com/help/vision/ug/object-detection-in-a-cluttered-scene-using-point-feature-matching.html. Accessed: Feb. 19, 2024.

BIOGRAPHIES OF AUTHORS

I Gede Made Karma is an Associate Professor at the Politeknik Negeri Bali, completing his undergraduate education in Industrial Engineering at ITB in 1987. After completing college and working part time, he joined the Udayana University Polytechnic (now the Politeknik Negeri Bali) as a Mathematics/Data Processing lecturer in the Accounting Department. He has held positions as Head of the Computer Center (1992-1998), Assistant Director for Academic and Student Affairs (1998-2002), and Editor in Chief of the Journal of Applied Sciences in Accounting, Finance and Tax (JASAFINT) (2018-2022). In 2005 he obtained a Master's degree in Information Systems from ITB and in 2022 he completed his Doctoral education in Engineering Science at Udayana University, Bali. Apart from actively teaching, he also develops several information systems for banking and tourism service companies. Interested in research activities and writing articles in the field of computer science and its application in the fields of business and education. He can be contacted at email: igmkarma@pnb.ac.id.

I Ketut Darma completed the Undergraduate Program from the Faculty of Teacher Training and Education, Mathematics Education Study Program, Mahasaraswati University Denpasar in 1986. Joined as a lecturer in Mathematics and Statistics in the Engineering Field, Bali State Polytechnic since 1990. Completed the Postgraduate program in the Research Study Program and Educational Evaluation in 2005, and in 2018 completed the Doctoral Program in Educational Sciences at the UNDIKSHA Singaraja Postgraduate Program, Bali. Active as a researcher in the field of Mathematics Assessment and Education. Has published a number of articles and books entitled "Competency-based Applied Mathematics" and "Applied Mathematics for Polytechnic students majoring in Mechanical Engineering". He can be contacted at email: ketutdarma@pnb.ac.id.