An Efficient Mobile AR Navigation System Using Polygon Approximation Based Data Acquisition

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Abstract. In recent years, most mobile navigation systems adopt augmented reality (AR) to provide location-aware and interactive multimedia contents for visitors' reference. Most AR navigation systems support only one target recognition and then only acquire corresponding contents from data servers for reducing storage and network costs. With the increase of multimedia navigation information, the performance of data acquisition for resource-constrained mobile devices must be improved for better user experience. In this paper, we propose not only the multi-target AR recognition mechanism but also the polygon approximation based data acquisition to improve performance of mobile AR navigation system by accelerating spatial data acquisition. In the proposed approach, the query efficiency and search precision can be well controlled according to the requirements of different applications.

Keywords: Augmented reality · Mobile navigation · *K*-means clustering
Polygon approximation · Spatial data acquisition

1 Introduction

In recent years, most mobile navigation systems supports augmented reality (AR) for better user experience [1]. In AR display, users can seamlessly interact with location-aware multimedia contents. Nevertheless, there are still several challenges in supporting location-aware AR navigation system.

The first challenge is to recognize multiple targets in AR display at a time. Most AR navigation systems can identify exhibits by recognizing a special marker (e.g. QR code) within a close range [1–5]. On the other hand, several markerless AR navigation system can identify exhibits by directly recognizing images of exhibits [6–8]. However, the above AR recognition technologies can only recognize one target at a time. Therefore, in this paper, we proposed a mobile AR navigation system supporting multi-target recognition based on the *k*-means clustering algorithm [9], which is able to simultaneously recognize multiple targets from a long distance.

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The second challenge is to improve the efficiency of multi-target recognition in resource-constrained mobile devices. Spatial data query can help to improve above multi-target AR recognition by reducing the search range from all target dataset to the targets near users. However, the distance between users and candidate targets cannot be calculated by simply using Eular distance or Haversine formula [10]. To accurately calculate the distance between two geolocations, WGS84 is widely accepted in many implementations [11]. Unfortunately, the complexity is too high to degrade the query efficiency accordingly while the number of target dataset increases [12]. Therefore, in this paper, the polygon approximation-based data acquisition [13, 14] is employed. Instead of a circle, an *n*-sided polygon is used as the use-specified search area to improve query efficiency with compromising some search precision.

The remainder of this paper is organized as follows. Section 2 introduces the system framework. Section 3 describes the proposed mobile AR navigation system supporting multi-target recognition and how the proposed polygon approximation-based data acquisition can improve the efficiency of multi-target recognition in resource-constrained mobile devices. Section 3 is system implementation and demonstration. Section 4 provides the performance evaluation of proposed polygon approximation-based spatial data query approach. Section 5 offers the conclusion of this paper.

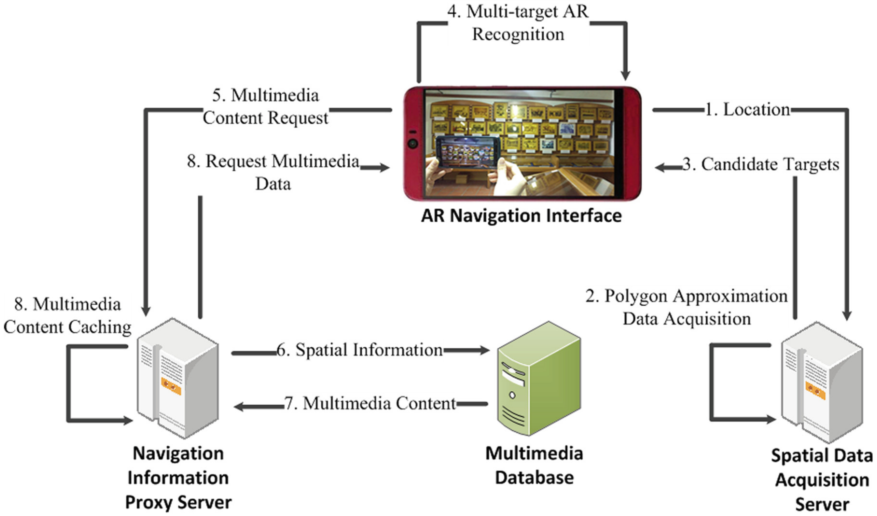


Fig. 1. Diagram of system framework.

2 System Overview

Figure 1 shows the framework of proposed system. When visitors recognize images through AR navigation interface on a mobile device, the location is first sent to spatial data acquisition server to obtain the candidate targets near visitors with using the proposed polygon approximation based data acquisition. With this information, AR navigation interface can efficiently perform multi-target AR recognition and then directly show the related navigation information of the recognized image targets. In the absence of multimedia content of user-specified targets, the system will request the navigation information proxy server to obtain the multimedia content from multimedia database. In order to improve the performance, the multimedia contents of other candidate targets can be pre-fetched at the same time.

With the use of multi-target AR recognition technology, this system completes feature detection and clustering of multiple image targets in advance, and then, uses a mobile device to shoot and recognize the photos displayed in the exhibition area in order to further display the corresponding 3D and multimedia navigation information. When the camera of a mobile device shoots image target with AR navigation information, the system will process the images into gray scale images, detect and recognize the image feature points and their distribution, and search the corresponding 3D and multimedia navigation information of individual images according to the recognition results of the clustering image targets, which will be further shown in the navigation interface. To improve the search efficiency, the proposed polygon approximation-based spatial data query is applied.

2.1 Multi-target AR Recognition

As shown in Fig. 2, the processing flow of multi-target AR recognition in this paper mainly includes 5 steps: (1) calculate the recognition rating and relative location of individual targets; (2) determine the representative target from the targets with high recognition rating; (3) calculate the distance between all the targets and the representative target, and complete preliminary clustering according to the k-means clustering algorithm; (4) optimize the preliminary clustering result into multi-target clustering images with a length-width ratio suitable for image recognition; (5) at the time of AR recognition, complete the image recognition of all the targets and AR navigation information displays via the optimized multi-target clustering result.

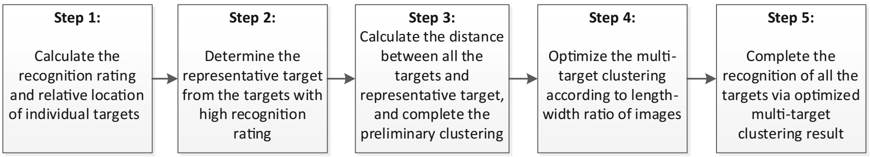


Fig. 2. Diagram of the processing flow of multi-target AR recognition.

The revised k-means clustering algorithm, as proposed in this paper for multi-target AR image clustering, is $\underset{S}{argmin} \sum_{i=1}^{k} \sum_{x \in S_i} ||x - \mu_i||^2$ where S_i represents Cluster i; μ_i represents image targets with a rating of high recognition in S_i cluster, which can be used as the representative target of Cluster i; x refers to other image targets with low ratings of recognition, and is the affiliated target in Cluster i. The shortest distance between all the targets and representative targets is calculated to complete the preliminary clustering of all the images; finally, the preliminary clustering results are optimized into clustering images with a length-width ratio suitable for image recognition, which is used for AR image recognition.

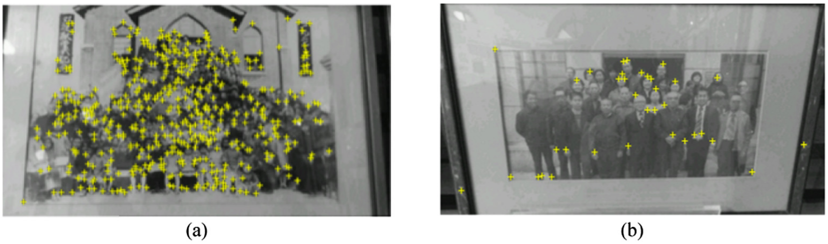

(a) (b)

Fig. 3. Diagram of the feature point analysis of image recognition. (a) The image with many feature points. (b) The image with few feature points.

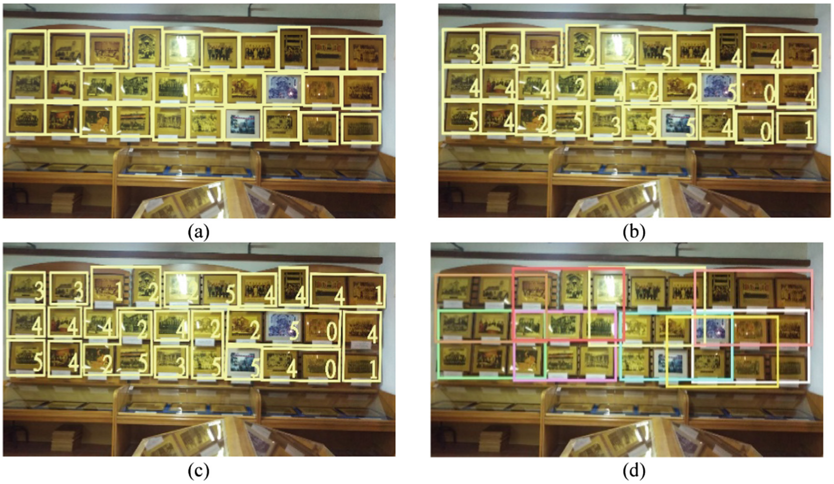

(a) (b) (c) (d)

Fig. 4. Diagram of the test results of multi-target clustering. (a) Image segmentation. (b) Analysis of recognition rating. (c) Preliminary clustering results. (d) Final clustering results.

Regarding research into the recognition ratings of images, this paper applies Vuforia SDK to analyze the recognize features of all images, which are saved in the Unity package format, and used to recognize images; afterwards, the corresponding navigation information can be accessed in real time according to the records in the database. Figure 3 shows the preliminary test results of this paper: the symbol ("+") in the figure represents the feature points that can be used for image recognition; the more the ("+") symbols, the higher the recognition rating of this image as shown in Fig. 3a; otherwise, the fewer the ("+") symbols, the lower the recognition rating of this image, and in such a situation, it is difficult to complete image recognition as shown in Fig. 3b. Accordingly, the rating for the rating of recognition can be given, ranging from 1 star to 5 starts, as based on the quantity of feature points, in order to distinguish the level of difficulty regarding the rating of recognition. The recognition rating of images is positively correlated to the quantity of starts: 5 stars denote that the image is the easiest to be recognized, 4 stars denote that the image is the second easiest to be recognized, 1 star denotes that the image is extremely difficult to be recognized, and no starts denote that the image cannot be recognized.

The relevant tests are as shown in Fig. 4, among which, Fig. 4a is a diagram of individual image segmentation; while Fig. 4b shows the analysis of the recognition rating of individual images. According to the recognition rating of the images, this system applies the proposed multi-target clustering algorithm, chooses targets with higher recognition ratings as the representative targets, and then, calculates the distance between other targets and the representative targets; finally, preliminary clustering is completed on the principle of the shortest distance as shown in Fig. 4c. It can be found only from Fig. 4c that the shape of the preliminary clustering result is irregular, meaning its shape is inconsistent with the rectangle picture shot by the camera, which goes against image recognition. Preliminary testing found that the length-width ratio of most mobile phones is 3:2, thus, the best ratio of cluster image recognition should be 3 photos in width and 2 photos in height, namely 6 photos. Therefore, this paper further merges the preliminary clustering results into a cluster image with 6 photos in one group, where the length-width ratio is 3:2, in order to facilitate image recognition as shown in Fig. 4d.

2.2 Polygon Approximation-Based Data Acquisition

Users can select the number of n-sided polygon for approximating a circle search area according to their requirements. The users who demand high search precision can select a large n. However, the query efficiency will be degraded. On the contrary, the users who demand high search efficiency can select a small n. However, the query precision can be degraded.

In addition, users can also select to use (1) inner-type or (2) outer-type of polygon approximation as shown in Fig. 5. The n-sided polygon will be placed into the circle search area in inner-type polygon approximation. In outer-type polygon approximation, the circle search area will be placed into the n-side polygon. The different types of polygon approximation will incur different errors as shadow area in Fig. 5. Since the *n*-sided polygon will be placed into the search area in inner-type polygon approximation, the error is false negative that indicates some data in the search area may be excluded in the search results. On the contrary, outer-type approximation incurs false positive that indicate some data not in the search area may be included in the search results. In this paper, we use the case of $n = 4$ as an example because the query efficiency can be simple in a reasonable degradation of search precision [15].

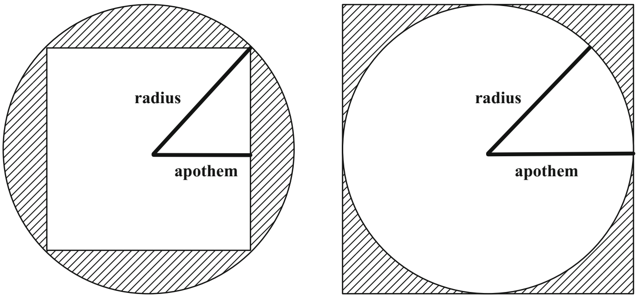


Fig. 5. Types of polygon approximation. (a) Inner-type. (b) Outer-type.

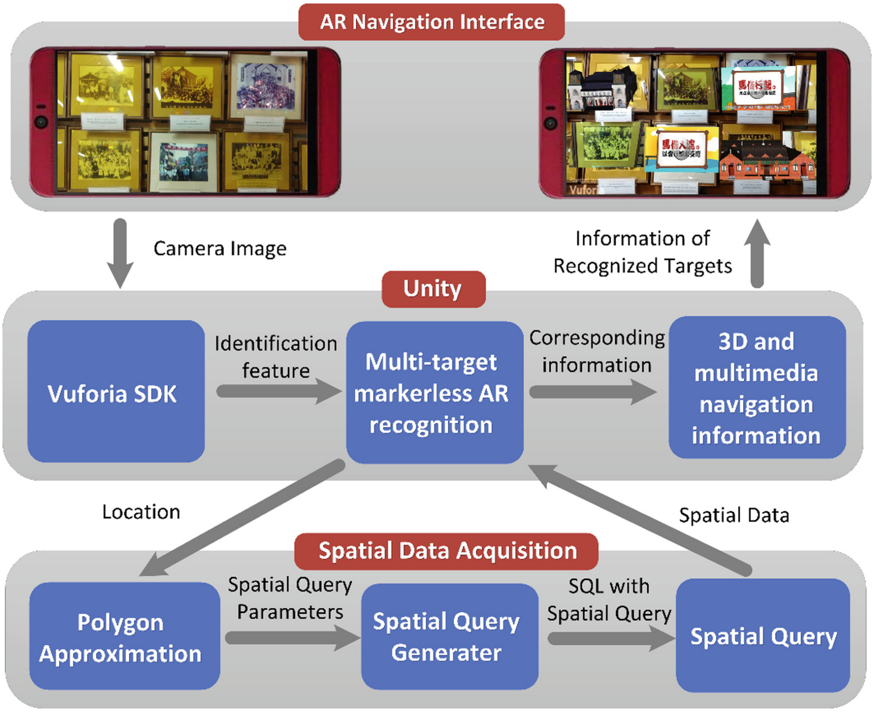


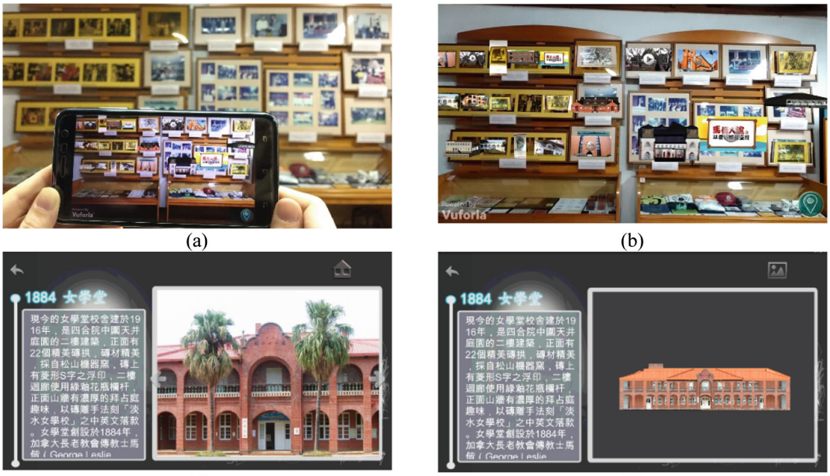
Fig. 6. The implementation flow of multi-target AR recognition and the display.

3 Implementation and Demonstration

Figure 6 shows the implementation flow of multi-target AR recognition and the display of this system. During system implementation, Unity is used to develop the user interface of mobile AR navigation system and integrate the functions of location awareness, network transmission, etc. First, Vuforia SDK is used to analyze the recognition feature of the image target to be saved in the Unity package format, which can be used to access the corresponding navigation information of individual image targets in real time according to the records in the database. In addition, during the period of real-time imaging, according to the distance and the angle between the images and the camera lens are used to show the corresponding 3D objects or multimedia information of individual image targets at the right location and angle; finally, they are combined with the real-time images, as captured by the camera, to be shown on the screen by mixing virtual and reality as shown in the results shown in the upper right of Fig. 6.

In order to improve the efficiency of multi-target recognition, the proposed spatial data acquisition is invoked in the step of multi-target AR recognition as shown in Fig. 6. In the step of polygon approximation, the coordinates of corners of n-sided polygon will be calculated. Then, a spatial query statement can be generated based on the coordinates of corners of n-sided polygon. Finally, the candidate targets can be obtained by submitting spatial query. Only the candidate targets will be searched in above multi-target AR recognition.

Figure 7 shows the test results of this system. As shown in Fig. 7a, b, this system can simultaneously detect and recognize multiple photos/targets on a large scale, and from a long distance, and accurately display the corresponding navigation information of individual targets. Moreover, users can click any AR target from all the interfaces to further acquire the navigation information related to this target. For instance, users can click the Tamsui Oxford College in the lower right corner of Fig. 7b and then view more navigation information, such as the navigation photo shown in Fig. 7c and navigation video shown in Fig. 7d.



現今的女學堂校舍建於1916年，是四合院中國天井庭園的二樓建築，正面有22個精美磚拱，磚材精美，採自松山機器窯，磚上有菱形S字之浮印，二樓迴廊使用綠釉花瓶欄杆，正面山牆有濃厚的拜占庭趣味，以磚雕手法刻「淡水女學校」之中英文落款。女學堂創設於1884年，加拿大長老教會傳教士馬偕（George Leslie

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Fig. 7. Diagram of system on-site test results. (a) Usage scenario. (b) Screen capture of navigation interface. (c) Display navigation photo. (d) Display 3D model

4 Performance Evaluation

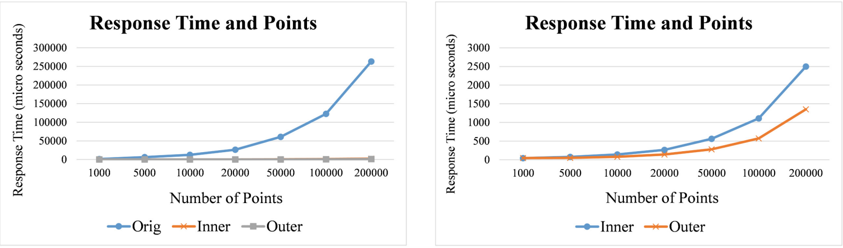
In this section, we will evaluate the proposed polygon approximation-based spatial data query approach in both numerical analysis and experimental investigation.

4.1 Numerical Analysis

In Fig. 5, radius of circle is denoted by r. The apothems of polygons in inner-type and outer-type polygon approximation are denoted by a_i and a_o, respectively. First, the query performance will be the same for two types of polygon approximation because they both determine whether a geolocation is in a square. Then, to compare the search precision of two types of polygon approximation, we need to calculate the shadow areas in Fig. 5. For inner-type polygon approximation, the error as the shadow area in Fig. 8a can be calculated by $e_i = \left(\pi r^2 - 4a_i^2\right)$ where $a_i = r/\sqrt{2}$. Thus, $e_i = \left(\pi r^2 - 2r^2\right)$. On the other hand, for outer-type polygon approximation, the error as the shadow area in Fig. 8b can be calculated by $e_i = \left(\pi r^2 - 4a_i^2\right)$ where $a_o = r$. Thus, $e_o = \left(4r^2 - \pi r^2\right)$. The difference of e_i and e_o is then given by

$$e_i - e_o = \left(\pi r^2 - 2r^2\right) - \left(4r^2 - \pi r^2\right) = 2\pi r^2 - 6r^2 > 0$$

Thus, outer-type polygon approximation has better search precision than inner-type polygon approximation. The numerical analysis in case of $n = 4$ is shown in Fig. 8.



(a) (b)

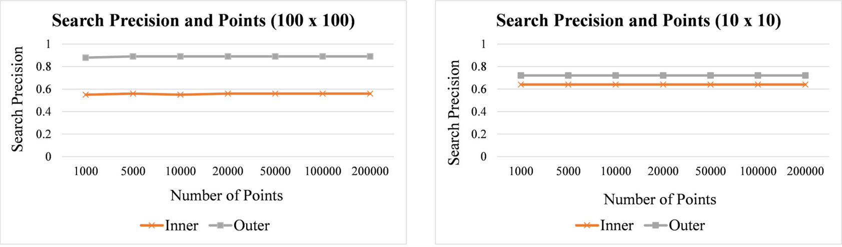
Fig. 8. Response time of different approaches. (a) Original, inner-type, and outer-type. (b) Inner-type and outer-type only.

4.2 Experimental Investigation

In the experiments, we will randomly deploy points in a square area that is the square of outer-type polygon approximation. The search center and search radius are set as the center and the apothem of this square, respectively. The original approach will calculate the distance between search center and each point based on WGS84. The inner-type and outer-type polygon approximation approaches will check if each point is inside the squares as shown in Fig. 5. The comparison of response time for different approaches is shown in Fig. 9. Because the complexity of distance calculation based on

WGS84, the original approach takes a long time to finish a request. In addition, we can see that outer-type polygon approximation outperforms inner-type polygon approximation because it requires a square root computation to find the four points of square of inner-type polygon approximation.

Although the inner-type and outer-type polygon approximation approaches can improve query efficiency, the search precision can be decreased. The search precision is defined as $1 - (P - P_{ori}/P_{ori})$ where P_{ori} and P are the number of points found by original approach and the number of points found by the polygon approximation approach, respectively. As shown in Fig. 9, the search precision of outer-type polygon approximation always outperforms inter-type polygon approximation no matter the square size is 100 × 100 or 10 × 10. However, the search precision will be lower if the search area is too small.



(a) (b)

Fig. 9. Search precision of different approaches with square sizes: (a) 100 × 100 and (b) 10 × 10.

5 Conclusion

This paper presents a mobile AR navigation system that supports multi-target recognition and adopts polygon approximation based data acquisition to improve system performance. The proposed system can simultaneously recognize multi-target with the k-means clustering algorithm as proposed in this paper and then acquire and display the corresponding 3D and multimedia navigation information from data servers. For resource-constrained mobile devices, a polygon approximation based data acquisition is proposed to accelerate spatial data query. By selecting the number of sides of n-sided polygon and the types of polygon approximation, the users can control query efficiency and search precision according to application requirements. The experimental results show that the proposed polygon approximation approach can efficiently improve the query efficiency with compromising search precision. However, the search precision can be still near 90% in the case of that the sides of polygon is 4 and the outer-type polygon approximation is selected.

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