AUGMENTED REALITY-BASED VISITING GUIDANCE IN INDOOR ARTISTIC STATUE EXHIBITIONS BY USE OF MOBILE DEVICES

[1]*Tzu-Lung Chang* (*張子瀧*) *and* [2]*Wen-Hsiang Tsai* (*蔡文祥*)

[1]Institute of Computer Science and Engineering
[2]Department of Computer Science
National Chiao Tung University, Hsinchu, Taiwan
Emails: chang.howard@gmail.com, whtsai@cis.nctu.edu.tw

ABSTRACT

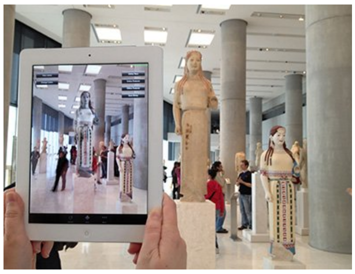
An augmented reality (AR)-based guidance system for use in indoor artistic-statue exhibitions is proposed to guide a visitor to find and appreciate statue artworks. For statue recognition, a skillful method of exhaustive matching of statue-image features is proposed, which "learns" each statue by capturing its images from different directions to construct a database, and recognizing each statue by matching its image against the database via the use of speeded-up robust features (SURFs). To improve the matching accuracy, a method of using two nearest neighbors of each matched feature point and a technique of utilizing parallel-line structure in matching feature-point pairs are proposed. For visitor positioning, a method of recognizing a nearby statue and taking the statue position as the visitor location is proposed. To guide the visitor, a method of augmenting a guidance arrow on the visitor's smart phone and updating the arrow dynamically based on the location of the visitor-selected destination statue and the reading of the digital compass of the visitor's smart phone is proposed. Good experimental results showing the feasibility of the proposed system are also included.

Keywords: *augmented reality; indoor guidance; statue recognition; SURF matching; path planning.*

1. INTRODUCTION

An art exhibition is always a peaceful and inspiring place to reset the soul. Besides, it is very educational – audiences can learn a lot from the exhibits through many ways such as read the descriptions of the exhibits; ask the staff of the exhibition for the details of the exhibits; listen to the audio guide for the details of the exhibits. However, each of them has its drawbacks and inconvenience for the audiences. For example, the descriptions of the exhibits might occupy too much space; the language used for the descriptions might not suitable for all visitors; some visitors might not be used to asking a staff for visit guidance; the audio-guide speech might be too fast for common audience; etc.

In order to provide the audience the best experience of visiting artistic exhibitions without the above problems, it is desired in this study to propose a virtual reality (AR)-based visiting guidance system for indoor artwork exhibitions by use of mobile devices, as illustrated in Fig. 1.



(a)

(b)

Fig. 1. Illustration of AR-based guidance for visiting indoor artistic statue exhibition using a mobile device. (a) An example by Keil et al. [1] using an iPad. (b) Another example developed in this study.

About AR-based indoor guidance, Keil et al. [1] presented the design of handheld AR experiences with four ways to digitally look at the exhibits: virtual reconstruction of the original aspect; placement in the original location; visual highlighting of interesting details and annotations; and recreation of mythological appearances. Lee and Park [2] proposed a museum guidance system by which a user may select an exhibit initially by a mobile device, and the system starts guiding by showing the relative orientation, distance, and visual cue to find match. When the user finds and locates the matching visual cue within a matching box of the display screen, the system provides multimedia information on the exhibit. Ran et al. [3] presented a system which enhances the user's real-world navigation experience by augmenting their reality through vocal interfaces with contextual information about their surrounding environment. Another system, named NAVIG (Navigation Assisted by Artificial Vision and

GNSS), was presented by Katz et al. [4] which relies on a geographical database and visually-identified objects to guide a user to a desired destination via specialized semantic audio rendering.

For user positioning in indoor environment, existing techniques may be classified into two categories: radio-based and non-radio-based. The former includes the techniques of using WiFi, Bluetooth, RFID, visible light, sound waves, and NFC, etc.; and the latter includes the techniques of using magnetic information or inertial measures; marker-based or markerless image analysis, and so on. Gherghina et al. [5] proposed a marker-based tracking system which detects QR-codes on the image captured by a camera capture and overlays rich media obtained from a server on the image. Kim et al. [6] proposed a system which can automatically recognize a location from an image sequence taken of an indoor environment, and realizes the AR function by overlaying the location information on the user's view. The image sequence is obtained by a wearable mobile PC with a camera, which transmits the acquired image to a remote PC which performs marker detection, image sequence matching, and location recognition. Wu and Tsai [7] proposed a novel approach using omni-directional vision with circular landmark information to estimate the location for autonomous vehicle navigation in indoor environments.

In this study, we focus on the study of AR-based guidance for visiting *artistic-statue* exhibitions via the use of smart phones. A core problem of constructing a system for this purpose is recognition of artistic statues from a 360º view range of a visitor so that correct AR information can be retrieved from the database and overlaid on the user's smart-device screen. Another core problem is generation of an optimal path from the visitor's current location to a user-selected artwork as well as step-by-step AR-based guidance of the visitor to the destination. Effective methods have been proposed in this study to solve these two major problems.

In more detail, to implement such a system, first of all, we use the camera of a smart phone to capture statue images and provide the guidance information on its screen to the visitor. Second, we need a server which has a database for storing all the feature points of every image of each exhibited statue taken from any possible visitor's view angle. Besides, CPU-intensive and high memory-usage tasks such as feature extraction and feature matching are carried out on the server instead of on the much less powerful smart phone to achieve the real-time requirement of the system.

Also, relevant software based on the proposed computer vision and augmented reality techniques have been proposed for use by the system to achieve the following functions: (1) taking an image of an interesting statue and sending it over to the server for recognition; (2) conducting feature extraction and matching to recognize the statue; (3) locating the user using the statue recognition result, and finding the best route so as to guide the user to the destination statue he/she selects; (4) augmenting the information of the recognized destination statue on the screen of the smart phone.

It is mentioned here that although a common approach to user positioning and guidance in AR applications is to track QR-codes as done in [5], our method for this purpose is to recognize the statue image as a substitute of the QR-code image. At least, two merits of this alternative approach may be pointed out: (1) no extra marker (namely, the QR-code) need be prepared and deployed; (2) the image of a statue may be taken from any direction for decision of the user's orientation while the QR-code can only be recognized right from the front (i.e., with no pan angle).

The remainder of this paper is organized as follows. In Sec. 2, the architecture and components of the proposed system as well as the system processes are presented. In Sec. 3, a status recognition method is proposed. In Sec. 4, a method for speeding up the feature matching work for statue recognition is described. In Sec. 5, path planning and AR-based guidance processes based on the proposed methods are presented. In Sec. 6, some experimental results showing the feasibility of the proposed methods for indoor guidance in artistic statue exhibitions are presented. Finally, conclusions and some suggestions for future works are included in the last section.

2. SYSTEM CONFIGURATION AND PROCESSES

As shown in Fig. 2, the hardware used in the proposed system includes a smart phone and a server. The smart phone used in this study is an iPhone 5S produced by Apple Inc. The server is a MacBook Pro Retina manufactured by Apple Inc. as well. The tools and configurations used to build the app/software are Xcode 6.2 on MacBook Pro Retina, the Objective-C programming language, and OpenCV libraries v2.4.6 for feature extraction and matching.

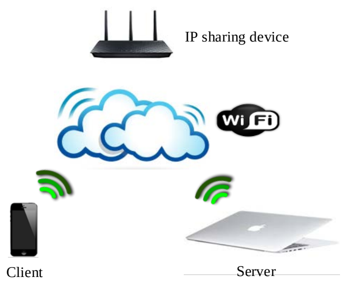


Fig. 2. Configuration of proposed system.

There are two main processes in the proposed system, namely, *learning* and *guidance*. In the learning process, all exhibited statues are "learned" by extracting the features of the statue images and saving them into a database. The type of feature used is speeded-up robust feature (SURF) [8]. The features are organized into a K-d tree to speed up feature matching in the statue recognition process. Moreover, the locations of the exhibited statues are also included in the database with a graph created accordingly as a map for path planning in the AR-based guidance process.

In the guidance process, a visitor uses the app developed in this study to select a *target statue* as the destination and the client system plans an optimal path from the visitor's current location to the target statue. The visitor's current location is determined by recognizing an image of a nearby statue taken by the user under the assumption that the position of the recognized statue is just where the visitor is located.

3. STATUE RECOGNITION

3.1 Ideas for Conducting Statue Recognition

Recognition of an artistic statue, which is 3D in nature, is challenging because the feature points of the images taken of it from different angles are all different. Moreover, the lighting condition also affects the matching result significantly. In this study, it is assumed that the lighting is under control in the indoor exhibition environment by fixing the lighting direction and luminance.

To solve the challenge of 3D object recognition from different views, it was observed that the smaller the difference between two view angles from which two images are taken of the same statue, the greater the similarity between the two acquired images. Also, it is realized that the 3D models of exhibited statues are usually unavailable so that only 2D images can only be taken of the exhibited statues exhaustively from different view angles for statue recognition.

In order to minimize the image-taking effort in the learning stage, we have conducted a series of experiments on recognizing statue images taken of a statue from different view angles by increasing and decreasing the angle intervals in order to find out which angle interval value to use during image taking is the most appropriate under the criteria of minimizing image-taking efforts and maximizing the statue recognition rate. The details of statue image recognition will be described in the next section. Some experimental results are shown in Tables 1 and 2, where Table 1 shows the rates of statue recognition against images taken with three different angle intervals of 5°, 10°, and 15°; and Table 2 shows the average angle deviations of the erroneous recognitions listed in Table 1 from the ground truths for 5°, 10°, and 15° intervals, respectively.

Table 1. Statue recognition rates of 3 angle intervals (5°, 10°, and 15°).

	No. of database images	*Correct counts*	*Error counts*	*Recognition rate %*
5°	108	106	2	98.15
10°	55	53	2	96.36
15°	38	34	4	89.47

Table 2. Average angle deviations of erroneous recognitions listed in Table 1 from ground truths for 5°, 10°, and 15° intervals, respectively.

	Average angle deviations in erroneous recognition results
5°	2.95°
10°	2.85°
15°	4.05°

These results indicate that taking an image every 5 to 10 degrees has the highest recognition rate. As a trade-off between the number of images that should be taken for a single statue and the resulting recognition rate, it is decided to use the interval of 10 degrees in this study. Fig. 3 shows the images taken of a single statue from different view angles with 10^o intervals in a 180^o range in the learning process.

3.2 Statue Recognition by SURF Matching

In the beginning of the guidance process, the visitor takes an image of a nearby statue with resolution 480×320. The system extracts the features of the image using an SURF extractor as done in the learning process. Figs. 4(a) and (b) show an example of such feature extraction results. It is seen that some feature points from the background are extracted as well. But they need not be eliminated while SURF matching is conducted against the statue-image database; they will be ignored during the matching process, i.e., no feature point in the images of the database will correspond to them because each database image is taken against a clean background with no feature point extracted, as shown in Figs. 4(c) and (d).

Fig 3. Images taken of a single statue from different view angles with 10 degrees interval in a 180^{o} range.

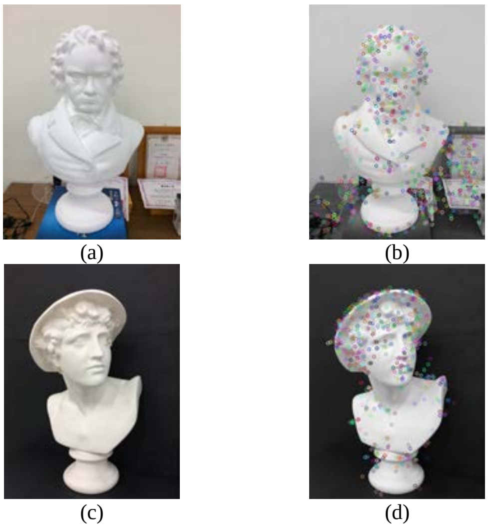


Fig. 4. Examples of feature extraction results. (a) An input image with background also included. (b) Extracted features of (a). (c) A database image with clean background. (d) Extracted features of (d).

Initially, a common matching algorithm, FLANN Matcher (fast approximate nearest neighbor matcher), was used with the SURF extractor for statue recognition in this study. An input image taken by a visitor is matched against all the images of *each* statue in the pre-constructed database. A distance is calculated for each match. After the matching process is finished, the *minimum* distance Md_i among the distances yielded by all the matches with *each* statue S_i in the database is picked out, and only matches with distances *smaller* than $2 \times Md_i$ are regarded as *good matches* with S. Then, the number of good matches, N_i, is counted for each S_i. Final the statue S_i that has the largest N_i is taken the recognition result.

It is mentioned by the way that we assume the smart phone is held by the visitor "vertically" with no tilt angle. If the phone is not so held, when it is tilted for about 10^{o}, erroneous statue recognition results will be yielded by the proposed system.

3.3 Improvement on Feature Matching Accuracy

In the previous SURF-matching method, only one *nearest neighbor* (*NN*) is considered during the *feature-point* matching process, and so it is prone to yielding recognition errors when the uniqueness of the closest feature point is not enough. Therefore, an improving method utilizing information of two nearest neighbors is proposed in this study.

In more detail, in the feature-point matching process, we pick out the two nearest neighbors, say C_1 and C_2, for each matched feature point after the matching process is completed. Then, we check all the matched feature points and put them into two groups, a *good-match* group and a *bad-match* group. The criteria used for grouping the matched feature points F_1, F_2, … F_n is the ratio $r = D_1/D_2$ of the distance D_1 between the matched feature point F_i and its 1st nearest point C_1 over the distance D_2 between F_i and its 2nd nearest point C_2. If r is larger than 1.25, then F_i is put into the good-match group; otherwise, into the bad-match group. The reason for adopting this criterion is to check if F_i has a relatively unique correspondence. If C_1 and C_2 have *similar* distance values, it implies that there exists *uncertainty* to accept F_i as a good-matching point; and so F_i is put into the bad-match group. By doing so, we can assure that every matched feature point in the good-match group is sufficiently *unique* as well as *good* to be used afterwards. As our experiments show, the recognition rate is greatly improved by this two nearest-neighbor (2NN) method.

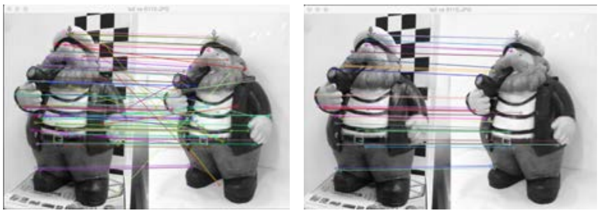
Besides, a *parallel-line structure* technique is proposed further to eliminate the incorrect matches to improve the recognition accuracy. Specifically, statues are rigid bodies, and so it can be figured out that under the condition that images of the statue are taken at roughly the same distance, if we draw a line segment to connect every pair of well-matching feature points (one in the database image and the other in the input image), the directions of these lines are *roughly mutually parallel*. An example is shown in Fig. 5 to illustrate this phenomenon. This property of *parallel-line structure* in good-matching feature-point pairs can be utilized to discard bad matches and improve the recognition correctness, as is done in this study. Fig. 6 shows an example of using the parallel-line structure property to improve the recognition result, in which Fig. 6(a) shows an erroneous recognition result using the 1NN method and no parallel-line structure; Fig. 6(b) shows another erroneous recognition result using the 2NN method and no parallel-line structure; and Fig. 6(c) shows a correct recognition result of using both the 2NN method and the parallel-line structure. The effectiveness of the 2NN method and the parallel-line structure can be seen from this example.

4. SPEEDING UP FEATURE MATCHING

In order to provide better user experience of visiting artistic statue exhibitions, speedy responsiveness is a must for the proposed system. Among the processes related to statue recognition, feature matching takes the largest amount of time. Three approaches to speedup of the feature matching process to improve the system response time are adopted in this study: (1) by use of a K-d tree; and (2) by use of a client-server model; and (3) by reduction of the image size. The details of these three approaches are given in the following.

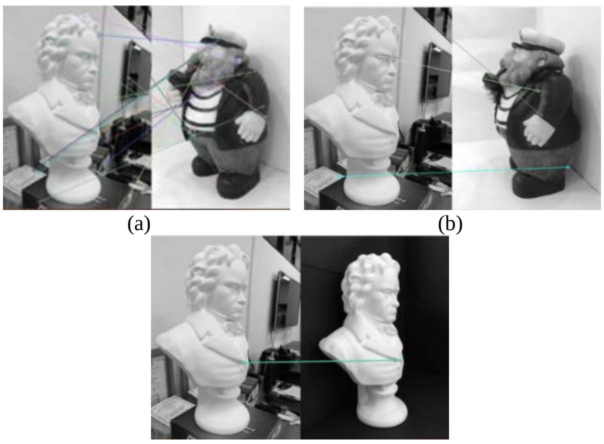
4.1 Speeding Up by Use of K-d Tree

In the proposed system, the features of all the images of the exhibited statues in the database are organized into a K-d tree. Upon receiving an image taken by a visitor, the features of the input image are extracted and used to match against the K-d tree. The K-d tree is constructed once and can be used forever as long as the learned images in the database are not changed. Taking the advantage of the binary-space partitioning characteristic of the K-d tree, the speed of the feature matching task is improved greatly. Specifically, for a feature matching process without using the K-d tree, whenever an image for recognition comes in, the feature matching step will be executed X times to find out the best-match image where X is the number of the learned images in the database. However, with the use of the K-d tree, the matching is done *only once*.



(a) (b)

Fig. 5. An example of statue matching results. (a) Feature matching result of using no parallel-line structure. (b) Feature matching result of using parallel-line structure.



(a) (b) (c)

Fig. 6. Another example of statue matching results. (a) Erroneous recognition result using the 1NN method and no parallel-line structure. (b) Erroneous recognition result using the 2NN method and no parallel-line structure. (c) Correct recognition result of using the 2NN method and parallel-line structure.

4.2 Speeding Up by Use of a Client-Server Model

The most time-consuming process in statue recognition is feature matching as mentioned. Though we have already used the K-d tree to speed up feature matching, we can improve it even further by use of a client-server model, as is done in the proposed system. A system that does not adopt the client-server model will put all the burden of image processing on the visitor's smart phone. Although smart phones nowadays are getting more and more powerful, they are still inadequate to handle CPU-intensive and high memory-usage tasks such as image processing which mostly take large amounts of time. Therefore, the use of a remote server which takes care of computational tasks is necessary. In this study, a client-server model as shown in Fig. 2 is adopted.

4.3 Speeding Up by Reducing Image Size

An image taken by the iPhone 5S is 2448×3264 in size which has 8M pixels and requires 1.3M bytes of storage. The larger an image is, the longer time it takes to extract its features; and the bigger an image file is, the longer time it takes to transmit it to the server for statue recognition. Therefore, the image resolution is reduced to be 360×480 in this study, which is 23 times smaller in size.

4.4 Experimental Results of Speeding Up Feature Matching

Table 3 shows a comparison between featuring-matching times of using the above-mentioned techniques of speeding up. The speedup is larger than 5 times, and the resulting speed, which requires less than a second for each image recognition work (specifically, 0.72 sec.), is practical for realtime applications.

Table 3. Comparison between featuring-matching times of using a K-d tree and using no K-d tree.

	Using *K-d* tree	***Using no K-d tree***
Test 1	578.22 ms	3477.62 ms
Test 2	1025.37 ms	3696.63 ms
Test 3	717.34 ms	4284.64 ms
Test 4	615.63 ms	3654.79 ms
Test 5	932.18 ms	5934.55 ms
Test 6	821.83 ms	4528.91 ms
Test 7	602.56 ms	3157.74 ms
Test 8	474.26 ms	2708.97 ms
Average	720.92 ms	3930.48 ms

5. AR-BASED VISITING GUIDANCE

5.1 Idea of Proposed AR-based Visiting Guidance

In an AR-based guidance system, guiding a visitor from his/her location to a destination is the major function. For this, firstly the system has to conduct *user positioning*, i.e., to find out the current location of the user as the starting location. Secondly, the heading direction of the user must be calculated in each guidance cycle. Lastly but not the least, the system should find out the best route from the starting point to the destination and show the user the planned path by augmenting an arrow on the screen of his/her smart phone in every guidance cycle.

5.2 User Positioning by Recognizing a Nearby Statue

When a visitor is looking for a specific statue *S* in a statue exhibition, he/she selects it at first as the destination. Then, the system needs the current position of the user as an initial location in order to plan a shortest path and show it on the screen of the user's smart phone as the guidance information. In this study, this *user positioning* problem is solved by recognizing the nearby statue right beside the visitor and taking accordingly its positon as that of the visitor.

More specifically, whenever user positioning is to be conducted, the visitor is asked to take an image of a nearby statue. Then, the system conducts statue recognition by SURF matching as described previously. The recognition result indicates which statue is in taken the image as well as the view angle from which the image was taken. The position of the recognized statue in the exhibition environment is then fetched from the database. With such information ready for use, the system can conduct the above-mentioned path planning task now as described later.

5.3 User Direction Detection by Use of Digital Compass Readings

In this study, we utilize the digital compass equipped within the smart phone to detect the heading direction of the visitor. The client system on the smart phone was designed in this study to include the information of the locations and descriptions of the statues as mentioned before. After the AR-based guidance is started, the client system keeps getting the heading direction of the visitor by use of the digital compass readings of the visitor's smart phone. The guidance arrow of the path planned is then calculated dynamically according to the heading direction and the location of the target statue, and is periodically updated and augmented on the screen of the visitor's smart phone while the visitor is moving.

5.4 Path Planning by Use of the Dijkstra Algorithm

Before an optimal path can be planned from the user's current position to the selected destination statue, we need the following information: (1) a graph drawn according to the placements of the statues in which an edge exists between any two nodes with a "line-of-sight;" and (2) the distance measured between every two adjacent statues with a line-of-sight for use as the weight of the edge. Such information has been constructed into the database in the learning stage. Here, by a "line-of-sight," we mean that the two statues connected by the line can "see" each other without any obstacle in between. With the above information available, the shortest path from any statue/node to the destination statue could be found by use of the well-known Dijkstra algorithm, as is done in this study.

After the path is generated, a guidance arrow pointing to the next statueor the target statue directly is generated as described in the last section, and displayed on the screen of the user's smart phone as the AR-based guidance information for the visitor.

6. EXPERIENMENTAL RESULTS

In this section, the experimental results of the two main functions, visiting guidance and statue information augmentation, conducted by use of the proposed system are presented in Sec. 6.1 and Sec. 6.2, respectively. The experimental environment is a simulated statue-exhibition space in the Computer Vision Lab. at National Chiao Tung University. Although the number of the statues used in this study is only four, it is sufficient to simulate the real scenario in an exhibition by placing the statues at appropriate locations.

6.1. Results of Visiting Guidance

Fig. 7 shows the step-by-step results of a visiting guidance process conducted by use of the proposed system. Fig. 7(a) shows the user interface constructed in this system which allows the user to select a target statue as the destination. The next action is to conduct user positioning by asking the user to take a snapshot of a nearby statue and send it to the server for statue recognition as shown in Fig. 7(b). With the target statue selected by the user and the user's current location obtained from the statue recognition result received from the server, a shortest path is then calculated by use of the Dijkstra algorithm. An arrow pointing to the next brief-stop statue is augmented on the screen of the user's smart phone in order to guide the user to move forward in the correct direction. The heading direction of the arrow is calculated by use of the reading of the built-in digital compass, the user's current location, and the location of the next-stop statue.

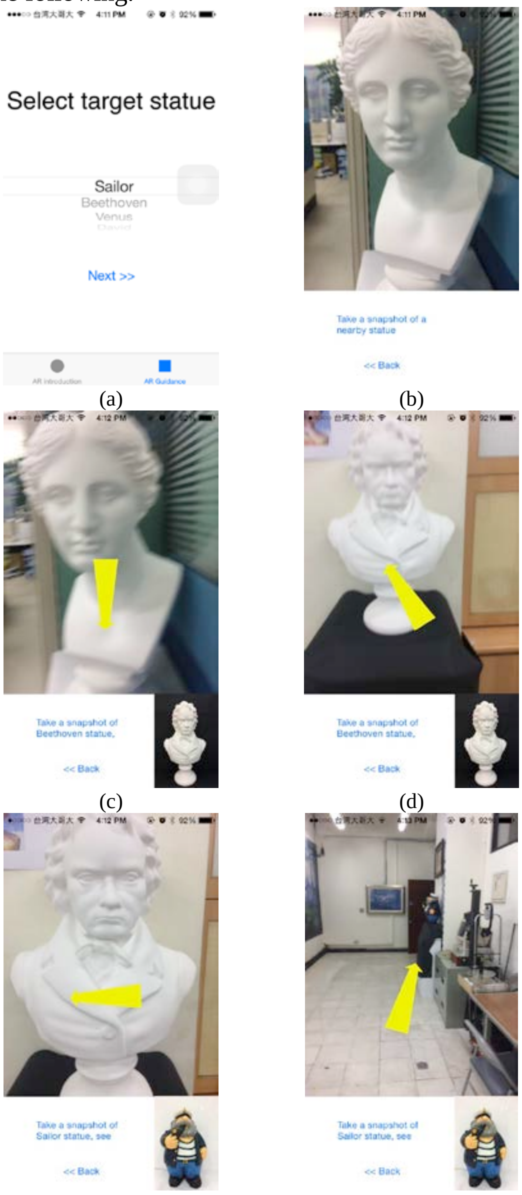
Besides, a thumbnail of the next-stop statue appears at the bottom-right corner of the user interface to indicate what the next-stop statue looks like so as to prevent the user from missing it as shown in Fig. 7(c). When the user reaches the next-stop statue as shown in Fig. 7(d), a snapshot of the statue is required to update the user's current location. The heading direction of the arrow is updated as well to point to the target statue according to the found shortest path as shown in Fig. 7(e). The heading direction of the arrow is dynamically updated even during the movement of the user as shown in Fig. 7(f). Once the user arrives at the target statue, the information of the target statue is augmented as shown in Fig. 7(g).

6.2. Results of Statue Information Augmentation

Fig. 8 shows three examples of the experimental results of statue information augmentation. In each of the results, the left figure (a), (c) or (e) is the taken snapshot of a statue, and the corresponding right figure (b), (d), or (f) is the image augmented with the information of the statue. The recognition result of the taken image is shown as a small image at the right-bottom corner of the figure.

7. CONCLUSIONS

An AR-based visiting guidance system for use in indoor artistic-statue exhibitions has been proposed. The system is implemented as an APP for use on a smart phone held by a visitor. In order to design such a system, several techniques have been proposed as summarized in the following.



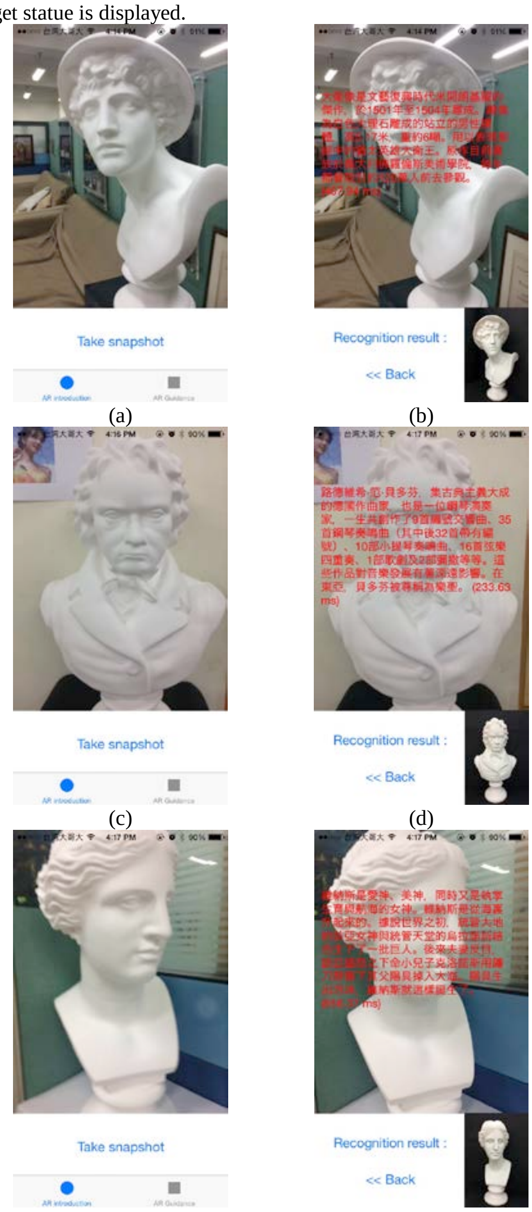
(a) (b)

(c) (d)

(e) (f)

(g)

Figure 7. An example of intermediate results of the guidance process conducted by the proposed system. (a) Target statue selection interface. (b) Initial location detection interface. (c) An arrow pointing the direction to the next brief-stop statue. (d) An updated arrow when the user moves. (e) An updated arrow pointing to the target statue after the user reaches the next brief-stop statue. (f) An image showing the user is approaching the target statue. (g) An introduction of the target statue is displayed.



(a) (b)

(c) (d)

(e) (f)

Fig. 8 Examples of results of statue-information augmentation. (a), (c) and (e) Images before statue information augmentation. (b), (d) and (f) Images with statue information augmented.

(1) A method for recognizing statue images by SURF extraction and matching has been proposed, by which the system can recognize statue images to obtain the information of desired statues, and to compute accordingly the position and orientation of the user.
(2) A method for speeding up the process of feature matching by using a K-d tree has been proposed, by which the system can recognize a statue against a large number of statue images in the database in realtime for practical applications.
(3) A 2NN method for improving the feature matching accuracy has been proposed, by which the system can recognize a statue more accurately to satisfy the requirements of correctness in real visiting guidance applications.
(4) A structural matching method using the parallel-line structure for improving the feature matching accuracy has been proposed.
(5) A method for AR-based guidance for statue information retrieval in indoor statue exhibitions by overlaying statue information on scene images has been proposed, by which a user can get to know the statues in an AR way on the user’s smart phone screen.
(6) A method for indoor AR-based guidance in indoor statue exhibitions by overlaying a guidance arrow on the floor in the acquired scene image has been proposed, by which a user can follow the arrow displayed on the screen of the user’s smart phone to reach the desired statue.

Future studies may be directed to developing a statue/background separation algorithm which can be used in the learning process, as well as seeking a method to improve the correctness of statue recognition results when the tilt angle of the user-held smart phone is taken into account.

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