Nonoverlapped View Management for Augmented Reality by Tabletop Projection

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Abstract

Augmented reality (AR) by a projector allows easy association of information by using a label with a particular object. When a projector is installed above a workspace and pointed downward, supportive information can be presented; however, a presented label is deformed on a non-planar object. Also, a label might be projected in a region where it is hidden by the object, i.e., a blind area. In this paper, we propose a view management technique to allow interpretation by improving the legibility of information. Our proposed method, the Nonoverlapped Gradient Descent (NGD) method, determines the position of a newly added label by avoiding overlapping of surrounding labels and linkage lines. The issue of presenting in a shadow area and a blind area is also addressed by estimating these areas based on the approximation of objects as a simple solid. An experimental evaluation showed that the visibility of the labels was improved with this method.

1 Introduction

Augmented reality (AR) presents computational information to the real world. A large amount of work has examined desktop tasks using AR in tabletop projections [8,9,11,12,20]. Labels with a textual or graphical form are often utilized in AR to provide information. Users obtain information once after recognizing a label that corresponds to a physical object. Legible presentation is necessary to communicate a message correctly, and view management improves label visibility. Investigation on view management methods have been studied for the see-through type AR, such as through a head-mounted display or a hand-held display [1,2,5,10,14,17]. However, few studies show view management methods for projection type AR [6,15,18].

In see-through type AR, labels are presented on a display by superimposition with a video captured image. However, in projection type AR, labels are projected in the real world. In this case, the following two issues should be taken into account. First, labels are deformed when they are overlapped by objects. The linkage line that connects a label with a target object is also deformed. Second, from the user’s perspective, a label may be hidden by a tall object. In both issues, a user can only see a part of information or might even not notice the presence of the label, which prevents interpretation. This is critical in applications in which speed and correctness of associating labels with a target object are important, such as in a chemistry experiment [16]. These issues are unique to projection type AR that deals with the three-dimensional relationship between a target object, a projector, and a user. In contrast, a view management method for see-through type AR does not need to consider these issues, because all things happen in two-dimensional space. Existing see-through view management methods cannot be directly applied to projection type AR.

In this paper, we propose a new view management technique for projection type AR. Figure 1 summarizes the variations of view management that include (a) no view management, (b) the existing method, Gradient Descent (GD), for see-through type AR, (c) our proposed method, Nonoverlapped Gradient Descent (NGD), without overlap, and (d) and (e) our proposed method with gradual improvements. The core idea in our method is to determine the position of a label by changing the distance of a line to a target object, linkage line, until no overlapping is detected (c). Here, “overlapping” includes not only each label and line, but also an object with a label or line. Overlapping of the presentation with an object is regarded as projecting in a shadow area of an object. Meanwhile, a blind area of an object from a user’s perspective is estimated to avoid hidden projection from a user (d). So, estimating
both shadow and blind areas allows improved legibility of information. These areas are estimated by approximation into a cylinder or a cuboid based on the shape of the area on the surface. The approximation allows fast detection of overlapping by a two-dimensional geometric computation. As can be seen in Figure 1-(d), labels are placed without any overlapping and have high legibility of information, whereas (a), (b), and (c) do not have high legibility. Furthermore, our method recalculates label placement for an object that changes its position only (e).

The rest of the paper is organized as follows: Section 2 examines related work. Design considerations in the view management method for projection type AR are shown in Section 3. Section 4 proposes a novel view management method (NGD), which intends to avoid any overlapping as an extension of the traditional method designed for see-through type AR. The integrated view management system is presented in Section 5, followed by a basic performance evaluation of the system and future work in Section 6 and Section 7, respectively. Finally, Section 8 concludes the paper.

2 Related Work

Much work has been done to improve the visibility of label placement. Makita et al. [10] proposed a technique for a dynamic environment where target objects move. Their approach employs lines to associate information to an object in a head-mounted display. The position of information presentation is determined by minimizing the cost function represented by three factors: 1) the distance of the line, 2) the area of overlapping information with a target object, and 3) the amount of movement of the information between frames. Grasset et al. [5] investigated a label placement method for an AR browser that estimates a critical region from an image frame and avoids placing rendering information on it. Azuma et al. [1] proposed four algorithms that determine the position of a label with less overlap. In this paper, we adapt their method to a projection type AR environment.

Little work has been done on projection type AR. Projection type AR for a wearable projector was proposed by Uemura et al. [18]. Their method allows a person who performs some tasks against a wall to obtain clear wall-projected information without overlap by his/her hands. A label placement technique for a non-planar and textured surface was proposed by Iwai et al. [6]. Image distortion was also addressed. However, our assumed target objects for annotation are thin, tall, sharp objects that stand on a table, such as a test tube, a gas burner and a pipette. Objects are often made of glass, so this technique is not suitable for direct projection because the legibility of the information is degraded. The work of Siriborvomratanakul et al. [15] determines an appropriate projection area for a handheld projector without overlapping in a dynamic cluttered environment. Their approach, based on image processing, can avoid overlapping of a projected image with physical objects; however, their approach is limited to projection in a situation where the projector and the user are on the same side. In the case of projection on a table, a blind area might appear according to the height of an object and the spatial relationship between the objects and the user. Furthermore, their approach aims at finding an area for projection and does not handle label placement.
3 Design Considerations

In this section, we present the requirements for view management of projection type AR, more specifically, for tabletop projection.

3.1 Association of a label with a target object

A label is usually associated with a physical object. Direct projection of a label onto a non-planar and textured surface object, e.g., [6], seems to be natural; however, the applicability depends on the material and the shape of an object. A transparent object as well as an odd-shaped object may significantly degrade the legibility of the information. As shown in Figure 2-(a), the two labels 'D' and 'E' projected on a transparent and an odd-shaped object, respectively, cannot be read. Therefore, we project the label on the flat surface on which the object is placed. However, an issue of ambiguous presentation still exists. Here, label 'A' is presented next to a glass beaker, which is easily associated; however, in the case of label 'C' (upper left of Figure 2-(a)), a user might be confused with which of three surrounding objects the label is actually associated. Thus, we decided to project labels on a table with a line connected to the bottom of an object. We call this a linkage line.

3.2 Blind area projection

No information is hidden by objects in see-through type AR because information is computationally superimposed with a captured image on a device screen. However, it is not applicable to the case of tabletop projection. Information can be projected onto a blind area, from the user's perspective, on a table. As shown in Figure 2-(b), information for the small box (match box) is projected on an area of a table that is hidden by a large box (white cardboard box). A user can see only a small portion of the projected information. Thus, if the information is projected onto such an area, the information may not be communicated. A user may not even notice the presence of information when the projected information enters into a full blind area. Such a blind area is considered as the critical projection area. View management for tabletop projection type AR should avoid the critical projection area.

3.3 Overlapped projection

In Figure 2-(c), label ‘A’ is overlapped with a large object, while Figure 2-(d) shows a situation where a linkage line is projected on an unrelated object, i.e., a test tube rack, placed between a label and its target object. Such deformation of the label and the linkage line may degrade both the time of interpretation of the label with the object and the correctness of interpretation. This is also a uniqueness of projection type AR. Thus, a view management method for see-through type AR is not applicable to projection type AR. Instead, a label should be positioned by taking into account the shape and the size of objects near the target object. Also, the linkage line should be directly drawn between the label and the target object. Azuma et al. investigated a view management method that resolves not only the overlapping of labels but a label and an object for see-through type AR [1]. We extend their method so that it can handle the issues in projection type AR.

4 Nonoverlapped Gradient Descent Method

We introduce the method proposed by Azuma et al. [1] called the Gradient Descent (GD) method and then we present our extension. A preliminary comparative experiment on the two methods is also presented.
4.1 GD method

Azuma et al. identified the following three factors that increase the visibility of see-through type AR:

- Less overlapping of labels
- Short distance between a label and its target object
- Small amount of movement of labels between frames.

Azuma et al. proposed four algorithms: Adaptive Simulated Annealing (ASA), Greedy, Clustering, and GD. We focused on GD because it allowed the most correct association in the user study. In GD, the distance between a label and a target object is constant. The processing flow is as follows. First, the candidate position of label placement is determined every 10 degrees around a target object. Then, the cost of overlapping is calculated. Finally, the most distant candidate from other objects and labels is selected if there are more than two least-cost candidates. The cost function has four elements with different weights, as follows:

- Between labels: 10
- Between lines: 2
- Label and object: 1
- Label and line: 1.

The overlapping detection in the approach of Azuma et al. is divided into five pairs: 1) between labels, 2) between a label and an object, 3) between linkage lines, 4) between a label and a linkage line, and 5) between an object and a linkage line. Their method classifies both a label and an object as rectangles. This classification simplifies the overlapping detection with the geometric calculation of line vs. rectangle, rectangle vs. rectangle, or line vs. line. Note that their technique does not focus on the overlapping between a label and an object, as the weight of “1” suggests. Although, the increase of the weight of “label and object” might improve the overlapping in such a case. As pointed out in Section 3, a label is deformed and degrades its legibility when it is overlapped with an object. We suppose overlapping has the most impact on projection type AR. Thus, we extend GD with variable distance between a label and an object to eliminate overlapping, which we call NGD.

4.2 Nonoverlapped Gradient Descent (NGD) method

As described above, the key idea is the variable length of the linkage line. Similar to GD, candidate label positions are set around a target object by 10 degrees once overlapping is detected (A and B in Figure 3). If there is no area without overlap around the object (C), the distance of the linkage line is increased (D). This process is repeated until no overlapping is found. The selection rule in the case of multiple label positions with the same distance follows that of GD (E). Steps A, B, and E are identical to those of GD, which is also true for the cost function.

Figure 3: Processing flow of NGD. The processes ‘A’ and ‘B’ are identical to those of GD.

Figure 4 shows the resultant views of the two methods. As shown, the distance of the linkage line is constant, and overlapping of lines and objects (rectangles) is observed in GD (Figure 4-(a)). In contrast, NGD with variable length shows no overlapping (Figure 4-(b)).

Figure 4: Resultant views of GD (a) and NGD (b). Rectangles indicate objects, while the labels in red are what the subjects of comparative study in Section 4.3 were asked to read in the experiment.

4.3 Comparative study of GD and NGD

We carried out a comparative study on the correctness and legibility of association, as well as on the speed of association. Fourteen university students in their
20s (ten men, four women) participated in the experiment. We followed the experimental scheme of Azuma et al. [1]. However, one exception is that we utilized tabletop projection rather than see-through AR. This is because we intended to compare the two methods under the possible deformation of lines and labels caused by overlapping. Here, the critical projection areas, i.e., the shadow and the blind areas, are not considered; they can be regarded as the bottom of an object when they are handled.

Figure 5 shows a snapshot of the experimental projection. Twenty cubes were placed on a table (W 66 × D 50 [cm]). The cubes were small enough (2 [cm] square) to avoid the critical projection area. Each cube has a label that consists of alphanumeric words. The label is linked to the center of a dedicated object. Subjects were asked to read a pair of red words and the number on the cube they thought that were associated with the words. They read four pairs in one trial, and a total of 20 trials were conducted for each subject. To avoid order bias, the subjects were divided into two groups: one group were tested with GD for the first 10 trials and with NGD for the latter 10 trials, while the other group started with NGD followed by GD. The position of the cubes did not change; however, the positions of the labels and numbers were randomly determined for each trial to avoid memory effects. The words were also changed for each trial to avoid habituation, although the length of the words was equalized to seven.

Three performance metrics were collected in this experiment: the time to association, the correct association rate, and the correct reading rate. The time to association, i.e., task completion time, was measured by differentiating the start time of a particular trial from the last word of the fourth pair, i.e., number. The difference between the correct association rate and the correct reading rate is that the correct association rate just checks whether the association is successful regardless of the failure of reading the words. In contrast, the correct reading rate shows a more rigid performance of association by counting only the successful readings.

4.4 Result

The average task completion time of a subject with GD and NGD was 10.1 sec and 8.0 sec, respectively (Figure 6-(a)). The result of a paired t-test for the two groups with a significance level of 5% showed that the NGD completion time was significantly shorter (t(26) =6.9×10^{-5}, p<0.05). Although individual differences were seen in the reading speed, we consider that this does not have a major impact on the outcome because all subjects were tested with both GD and NGD.

The average correct association rate of a subject for GD and NGD was 90.0% and 99.0%, respectively (Figure 6-(b)). Similar to the task completion time, the result of the paired t-test showed that the correct association rate of the NGD method was significantly higher (t(26) =2.4×10^{-5}, p<0.05). In contrast, the correct reading rate for GD and NGD was the same at 97.9%.

4.5 Discussion

As shown above, NGD is superior to GD in the speed and the correctness of association. These results suggest that avoiding overlapping played a key role. Makita et al. [10] defined a cost function by the length of the linkage line and the overlapping for view management of a head-mounted display. However, our result indicates that the impact of the length on the legibility is smaller than that of overlapping. In other words, we can ignore the negative impact of the length of a linkage line and proceed with NGD unless we intend to develop a room-size application.
5 View Management with NGD

A view management system is proposed based on NGD. The system considers various object properties.

5.1 Handling various shapes and sizes of objects by models

NGD uses various object properties such as position, shape and size to avoid overlapping of a label. In the experiment of Section 4.3, the objects were uniform. Also, they were small enough so that we could ignore the shadow and blind areas described below; however, to be applicable to real-world applications, we need to take into account the object properties.

An object is modeled into either a cuboid or a cylinder that is circumscribed to the object to allow fast overlapping detection. An alternative method is to represent a target object with a cloud of points, point cloud, from a depth camera. The point cloud approach can lead to precise estimation of the critical projection area and efficient use of the desktop real estate; however, we consider that this approach requires more computational power than the model-based one due to predominantly large number of points to represent the contour of the object. So, we decided to take the modeling approach.

Basically, an object can be modeled into a cylinder (Figure 7 left); however, a long, thin object on the surface, such as a fork or a pen, is modeled as a rectangular solid (Figure 7 right). The cylindrical approximation requires a large base area with a diameter of the length of the object. This consumes more area, as the critical projection area cannot be used to place a label. Therefore, the candidate positions for a label near a target object decrease, and the search time increases due to incrementing the search range. Furthermore, a critical situation may occur when a small object is placed inside a large circle defined by a long, thin object (see Figure 8). Here, the label for the small object will not be placed anywhere because the linkage line between the center of the small object and its label crosses the base circle for a cylinder, which means overlapping cannot be avoided. Thus, cuboid approximation addresses this issue.

To focus on overlap handling rather than 3D object recognition and shape measurement, we applied a visual marker approach, where necessary information is retrieved by the ID of a marker from an external database. The types of information linked to an ID are as follows: 1) the type of applicable model, i.e., cylinder or cuboid; 2) the size of the base surface of the object; and 3) the height of the object. We assume that these information are input into the database in advance. The two-dimensional position on the surface is obtained by a camera, which is regarded as the center of gravity of an object, and the linkage line is drawn toward a label.

5.2 Finding the shadow area and the blind area

A shadow area appears due to the shade of an object from the projector’s light source. In other words, light is overlapped with an object. Thus, avoiding a shadow area in projection leads to projection without overlapping of a label with the object. A number of studies proposed the hard shadow technique to estimate the shadow area based on a point light source [3, 4, 13, 19]. We adopted the planar projection shadow method [3], because it can calculate the shadow area very quickly when a shadow is cast on a planar surface and the number of objects is small. In the model approximation approach, the shadow area is drawn by connecting the feature points of an object projected on the surface from the light source. Here, the feature points of a particular model are analytically calculated.

For cylindrical modeling, two points, which are on the diameter of the upper surface of a cylinder, are obtained. The line segment formed by the two points is
perpendicular to a line connecting the light source with the center of the upper surface of the cylinder. Then, the two points on the cylinder are projected on the surface, i.e., table, by calculating the intersections of the surface and the lines that connect the light source and the points. The projected points constitute the diameter of a circle, which is combined with the rectangular area that corresponds to the body of the cylinder. Here, although the shadow is actually a part of an ellipse, we regard it as a circle for simplicity of calculation. The right-hand part of Figure 9 illustrates an example. Note that we assume that the shape of the shadow of the cylinder’s body is a rectangle for the ease of computation. The points forming the silhouette of the cuboid are obtained in a similar way to those of the cylinder. Here, four vertices of the upper surface of the cuboid are projected on the surface. Thus, overlapping of a projected label with an object (see Figure 2-(c)) can be avoided by placing the label at a position outside the shadowed area on the tabletop coordinates.

5.3 Detecting overlap by geometric computation

Labels and linkage lines are projected on a planar surface, i.e., a table, which allows us to limit the calculations to two-dimensional coordinates. The shadow area and the blind area of a cuboid is represented by a polygon, whereas that of a cylinder is a combination of a circle and a rectangle. In addition, a label is represented as a rectangle. Now, we can focus on detecting the overlapping of lines, rectangles, and circles. The detection consists of the following processes:

- Between labels: The containment of a vertex of one rectangle in the other
- Label and object: The containment of a vertex of a label’s rectangle in a polygon or a circle of an object
- Between linkage lines: The intersection of one line segment with the other
- Between a label and linkage line: The intersection of one of four sides of a rectangle of a label with a line segment
- Between an object and linkage line: The intersection of a side of a polygon for an object with a line segment or that of a circle with a line segment.

Containment checking of a vertex is actually realized as follows. In the case of a circle for cylinder approximation, the intersection is checked based on the distance between a vertex and the center of the circle. Meanwhile, a cuboid represented by a polygon is decomposed into line segments. So, the existence of the intersection between a segment of a label and a segment of the polygon proves the fact of overlapping of a label by an object. The overlapping detection method even works in the case that all four vertices of a label are contained in a critical projection area by a large object. This is because the linkage line between one of the vertices and the center of the target object should cross the border of the area. An exception is that the target object itself is contained in the critical projection area, which is examined in terms of the effect of the cuboid approximation in Section 6.2.

5.4 System configuration and Implementation

Now that we have designed the major system functionalities, they can be integrated into a system. Figure 10 shows a block diagram of label placement from image acquisition to label rendering, which also shows the relationship between major functionalities. A captured
image frame is sent to the component responsible for object identification and localization (marked as ‘A’ in Figure 10). Object and label information DB (‘F’) is updated by the extracted information. As described in Section 4.1, Azuma et al. [1] suggested that a small amount of label movement between frames increased the visibility. However, to avoid the frequent change of label positions, the system checks whether there is sufficient movement in any object (‘B’), in which 10 pixels of displacement of an object triggers a new process of label placement. Otherwise, the position of the label is not changed, but the length of the linkage line changes (Figure 1-(e)). This is, of course, applicable if no overlapping is detected. In ‘C’, the shadow and blind areas for all objects are estimated by the method described in Section 5.2. Then, NGD is applied to a moved object (‘D’), which allows the reduction of computation. Finally, the position of a label and the center of mass of a target object are used to draw the linkage line as well as the label itself (‘E’). This flow is iterated about every 7.33 [msec]. We used ARToolkit as a tool for extracting the position and ID of an object and OpenCV for rendering labels and lines.

As shown in Figure 1, NGD with shadow and blind area consideration (d) significantly improves the legibility of information compared with the presentation without view management (a) or with just resolving the overlap with labels (b). In (e), an object to which label ‘C’ is linked moved to the right from the position in (d); however, the position of the label is not changed to avoid degradation of the comprehension of information. An internal image of the shadow and blind estimation is shown in Figure 11, where the white and the black colored areas indicate the shadow and the blind areas, respectively. The system finds an appropriate position for a label by avoiding these areas.

Figure 10: Block diagram of view management system based on NGD

Figure 11: Internal image of shadow and blind area estimation. Note that the white and the black colored areas indicate the shadow and the blind areas for the objects, respectively.

6 Evaluation

We carried out evaluations of the processing speed of major functionalities and the effect of model approximation.

6.1 Processing time

The elapsed time for major functionalities was measured in a prototype system running on a PC (OS: Windows 7 64 bit, CPU: 2.8 GHz Intel Core 2 duo, RAM: 4 GB). Five objects (a test tube clamp, a pipette and a matchbox as cuboids and a spirit lamp and a beaker as cylinders) were used. The average elapsed time was calculated over 20 trials. Table 1 shows these average times, in which the elapsed time for estimating shadow and blind areas is for one object, while the elapsed time for overlapping detection includes that for all objects. The total elapsed time was less than 1.0 [msec], which is due to the simple containment and the intersection checking method described in Section 5.3.

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Elapsed time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimating shadow and blind areas</td>
<td>0.57 (cylinder) 0.01 (blind area) 0.05 (label with an object)</td>
</tr>
<tr>
<td>Overlapping detection</td>
<td>0.97</td>
</tr>
</tbody>
</table>

6.2 Effect of cuboid approximation

As described in Section 4.2, NGD utilizes the area defined by a model of an object to remove overlapping.
The aim of introducing the cuboid approximation is to reduce the critical projection area for a long, thin object, and to allow an object and a label to be placed near such an object. Here, we examine the effect of the cuboid approximation in comparison with the cylindrical approximation. Five subjects moved the three types of objects, i.e., a test tube clamp, a pipette, and a matchbox, as they chose. These objects were modeled as both cylinders and cuboids. The number of times that the centroid of an object was placed within an area of the model was counted. Five subjects tried 20 times for each type of approximation.

Table 2 shows the results per subject (A to E). Containment in the cylindrical area occurred in every trial, whereas almost no case was observed in the cuboid approximation. However, this does not suggest that a cylindrical model is not necessary. As shown in Table 1, the processing speed of the shadow and blind areas for the cuboid approximation took slightly longer than that of the cylinder. Although the difference is less than 0.5 [msec], it increases as the number of objects increases because the processing speed of these areas depends on the number of objects. Therefore, an appropriate model selection is a good option for improving real-time processing performance in the case that the number of objects is expected to be large in a particular application.

<table>
<thead>
<tr>
<th>Situation/Subject</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within a cylinder</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Within a cuboid</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The size of an object is currently measured and registered into the system by hand, which is a burdensome task. The type of model approximation is also predefined; however, sometimes static approximation is not adequate. For example, a bottle lying on its side on a table can be modeled as a cuboid, while a cylindrical approximation is suitable when it is standing upright on a table. Thus, dynamic measurement and model selection allows more precise detection of overlapping. A depth sensor, e.g., Microsoft Kinect, would be a solution for this challenge [7]. A depth sensor provides the shape of an object as a cloud of points, and so it could remove the model approximation process; however, it may sacrifice the simplicity of shadow and blind area estimation. Therefore, a hybrid approach is worth considering as an alternative, in which a depth sensor is employed to identify an appropriate model, as well as to obtain the size of the model.

7 Future Work

The estimation of shadow and blind areas plays an important role in the usefulness of NGD. Therefore, we will carry out an in-depth evaluation on the correctness of the estimation by comparing the area of an actual shadow or a blind area with an estimated area. The comparative study in Section 4.3 was conducted under controlled conditions. To see whether the effectiveness can be scaled up to a real-world application, we are planning to conduct another comparative user study under a particular scenario, e.g., a chemistry experiment, that contains objects with various shapes, sizes, and layouts on a table. Furthermore, automatic model selection and size measurement based on depth information is under investigation.

8 Conclusion

We proposed a novel view management technique for tabletop projection type AR, in which we investigated the importance of considering the shape, the size, and the material of tabletop objects for placing a label in a meaningful manner. The issue we dealt with was overlap of a label with other objects, labels, and linkage lines. Also, projection on the critical projection area, i.e., the shadow and blind areas, was another issue to further improve the legibility of projected information.

To address the issue of overlapping labels, we proposed the Nonoverlapped Gradient Descent (NGD) method, which was designed as an extension of the GD method of Azuma et al. [1]. The difference between GD and NGD is that NGD varies the length of the linkage line between an object and the label. Although Azuma et al. suggested a short distance between a label and its target object for better legibility of information, we prioritized the overlap issue over the distance-derived issue in projection type AR due the three-dimensional nature of the display environment. The result of a preliminary user study showed that NGD was superior to GD in the time and the correctness of associating a label with its corresponding object.

Regarding the issue of the critical projection area, we proposed a method to estimate the area by model approximation of either a cylinder or a cuboid based on preregistered information for each object. We showed that cuboid approximation utilized the desktop real estate efficiently.

We consider that the proposed method would open a door for applying a tabletop projector-based AR to a critical domain in which the speed and the correctness of associating labels with a target object is important, such as in a chemistry experiment [16].
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References


