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Research Article

Systematic Augmentation of Artoolkit Markers for Indoor Navigation and Guidance

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Abstract: Augmented Reality (AR) has been deployed in various fields like engineering, medical, gaming, and academic. It has also been utilized for user navigation in large indoor environments. In this study, we present a path generation algorithm that automatically identifies fiducial markers in the building to create a path for user navigation. Path augmentation algorithm adds auditory and textual information to the generated path for user assistance. We implement the algorithms in an android application and its internal mechanism for database creation and guidance system is discussed.

Keywords: Augmented Reality, Indoor Navigation, Fiducial Marker.

1. INTRODUCTION

Augmented Reality (AR) is a technology where real environment is covered with virtual information such that it seems to be a part of it. This virtual layer may comprise of some enhanced features not available in real situations. Augmented reality attempts to improve the real world with some aspects [1]. AR technology is used in diverse fields such as industrial manufacturing, medical visualization, entertainment, consumer design, education, training, finding direction, object identification, location oriented communication, aircraft localization and pilot assistance, military aircraft navigation, and others [2].

Navigation has a vital importance to our daily life activities as we always try to navigate towards our destination via a short and convenient path. Navigation is process to determine the current position and planning to a specific destination via following a path [3]. The indoor systems gained popularity due to the advent of context aware applications and smart mobile devices [4, 5] in different fields such as entertainment, retail, manufacturing, and healthcare [4]. Indoor navigation systems can be categorized into three broad groups; systems using dead reckoning techniques, using wireless mechanisms, and using computer vision mechanisms. Dead reckoning techniques use a variety of sensors like accelerometer, gyroscope, compass, and magnetometer. Examples of wireless method are based on satellite GPS signals [6], Near Field Communication based (NFC) [7], Infrared-based (IR) [8], RFID-based [9], Bluetooth/Wi-Fi based systems [10] Majority of these systems have a common limitation that they require costly installations in the indoor environment like Bluetooth beacons, Wi-Fi access points, RFID/IR sensors [11]. Moreover, these solutions tend to have localization and navigational inaccuracies due to signal strength issues and complex server-client communication models [12]. Computer vision based methods employed for navigation and indoor positioning purposes are considered to be low-cost and easy-to-install alternative to wireless navigational systems [13]. Such techniques are further classified into two types named marker-less and marker-based methods [14]. The former uses features-based approach to identify objects in the video stream; while the latter uses fiducial markers placed in the real environment for detecting and

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identifying with a camera [11]. These markers are printed on plain passive papers without absence of any electro coating over them. The patterns of the markers can be taken from a variety of different toolkits like ARTag [15], ARToolkit [16], AruCo [17] and ARToolkit Plus [18].

To facilitate a user in indoor navigation using marker-based computer vision techniques, this study attempts to achieve the following objectives:

- Proposing an efficient algorithm for automatically generating paths from markers deployed in indoor environment, and subsequently the automatic augmentation of these markers with guidance information.
- Implementation of the proposed algorithms to develop a low-cost, accurate, and easy-to-install system for generating and augmenting indoor paths in a large building for user navigation and localization.
- Developing a companion android application to be used by building administrator to manage floor plans – and by the users to navigate through the indoor environment.
- Evaluate the proposed work in a variety of real paths inside the selected building with help of actual users.

2. RELATED WORK

The GPS is considered a de facto and ideal solution for outdoor navigation and user tracking [6]. Nevertheless, in large multi-floor indoor environments, GPS signals become weak, due to which it cannot accurately track user movement. As such, no unique mechanism exists for user guidance and navigation in indoor environments like museums, shopping malls, exhibitions, and universities. Yet there exists a considerable amount of work proposed by various researchers to address the same problem. Kjærgaard et al. [19] has analyzed the reception of GPS signals for user tracking in large indoor environments like single-roof houses, schools, and high buildings. They have suggested the use of nonstandard building material, minimal signal to noise ratio, and poor satellite signal reception as reasons for incorrect GPS tracking.

As mentioned, we can categorize navigational and positioning techniques into three broad groups, each discussed in the following sections.

2.1. Dead Reckoning Techniques

Dead reckoning techniques are used in some of the research works for user localization. These include the work of Mulloni et al. [20], in which smartphone's accelerometer and compass has been used to calculate user steps and direction towards a destination location. This system faces larger error rates due to inaccurate calculation of step length. Lo et al. [21] have used magnetometer, accelerometer in conjunction with Wi-Fi to guide a user by superimposing directional arrows on a scene picture. This has a limited usefulness, as path could not be modified automatically. Cavallo et al. [22] have employed wearable devices to facilitate a user in navigation, but it is found limited for daily routine use.

Attia et al. [23] have used a map matching algorithm in which a pedestrian dead reckoning system is aided with phone accelerometer and gyroscope for user navigation. A physical building map is manually submitted to the system, which increases burden on the user side. The system provides inaccurate results due to large difference between actual and calculated position.

2.2. Wireless Techniques

Several researchers have used wireless techniques to help users navigate in indoor environments. Their work heavily relies on installation of networking infrastructures like access points, beacons, and other sensors. Kasprzak et al. [24] have used a combination of Bluetooth, Wi-Fi, and RFID sensors for indoor guidance of sightless users with the help of audio instructions.

An NFC-based indoor navigation system has been developed by Ozdenizci et al. [7], have stored map information on a server. Location information can be retrieved with touching the NFC tag with a smartphone. User has to manually search and touch next NFC tag on the path, which is the main limitation of the solution. Mehta et al. [8] have used infrared and magnetic sensors to detect unique location-based codes attached to the ceiling for user navigation. Building map is downloaded to a handheld IR device via Bluetooth as soon the user enters the building. Voice commands are used to retrieve location information from the system. The solution relies on large IR sensors infrastructure deployed within a building. It hinders in the mobility of the user, as the user has to carry bulky IR devices on the way.

2.3. Vision-based Techniques

Vision-based navigation and positioning techniques use marker-based or marker-less approach. Plain markers are fixed on floor, ceiling, or walls of indoor environment. The markers are then captured using a video stream from camera device. Marker-less techniques gather features from a video stream like corners, walls, and objects and computes path based on those features. Huey et al. [25] have used a camera connected to a laptop for detecting ARToolkit markers in indoor environment. A predefined 2-dimensional map is fed into the system, which is augmented with directional arrows using a route planner algorithm. The paths are not automatically generated as the map and its node matrix has to be manually updated from the floor plan of the building. Audio information is played when a marker is detected using the camera. Carrying a laptop by the user for guidance is not usually practical.

Kim et al. [26] have used ARToolkit markers which overlays video steam with location information. Video is captured using a head mounted camera, which is attached with a tablet. It transmits image sequence to a remote server for identification of markers and finally calculates user's position. The markers are not interconnected, due to which shortest path cannot be determined. The system heavily relies on Wi-Fi network and it takes a considerable time in image recognition. Kalkusch et al. [27] uses a laptop hung on the back of the user aided by a camera and an inertial tracker on user's head. AR Toolkit markers are tracked by the camera and location information is displayed on a wrist-mounted touchscreen. The system provides accurate results in normal light condition but is bulkier because carrying of laptop. The system also lacks capability of map generation, as it requires manual editing of map coordinates.

Zeb et al. [28], developed a desktop application using ARToolkit library to detect markers with the help of a webcam attached to a laptop. Markers are deployed inside a building and their connectivity is manually carried out using hardcoded entries in the application's database along with auditory information about each marker. A blind user can then navigate through the building by detecting the markers with a webcam, and getting audio information using headphones. The solution well addresses the situation but needs the user to carry a laptop device. Moreover, hardcoding the path manually into the application makes it harder to extend/update the current path setup. Al-Khalifa et al. [29] have developed a system named Ebsar, which uses Google Glass connected to a smartphone to assist a visually impaired person in indoor navigation and positioning. The building is prepared with the help of a sighted person, called a map builder, who moves around the indoors of the building and explores different paths. The map builder marks every room, office, etc. with QR codes generated by Ebsar installed on a smartphone. Distance and direction between the QR codes is determined with the help of smartphone's accelerometer and compass sensors. All the information gathered is used to create a floor plan graph with each node representing a checkpoint in the building like a room, office, or stairs; and edges for number of steps and direction between the checkpoints. The map is then uploaded to some central web server, which is available to any user with Ebsar installed on smartphone. At the first entrance to the building, the Google glass worn by a visually impaired user detects the QR code, and the application automatically downloads the corresponding map file of the building to the user's phone. The user can then use voice commands for both input and output of information about the current location. The system is evaluated for performance and accuracy with several sighted and blind users yielding acceptable results. Although, it heavily relies on the smartphone's accelerometer that can cause certain margin of error in calculating the steps; and the user should constantly have to wear a Google glass connected via Wi-Fi to the phone.

Lo et al. [21] proposed an indoor navigation system using smartphone, a newer version of Bluetooth, known as Bluetooth Low Energy (BLE), and visual 2D markers. The building is split into multiple logical regions where each region is installed with a BLE beacon device. The visual markers, ArUco [30], are pasted on the floors of the building, which are then detected by a user with a phone camera pointed towards the floor. Location information decoded from the marker is used by the smartphone application along with the beacon's data to localize the user in the environment. Although the markers are not inter-related, they provide information about the current position only. The system provides an efficient and accurate positioning but requires beacons infrastructure to be deployed in the overall building, while no path calculation algorithm is proposed. Shah Sani et al. [31] presented a guided indoor navigation system for blind users. The proposed system uses a smart phone camera for detection of ARToolKit markers in indoor building. The recognition of the markers guides the visually impaired people to their desired destination.

3. DATABASE CREATION & GRAPH GENERATION

3.1. Building Preparation

The indoor of the building is prepared for the path generation process by printing markers on plain paper. These markers are fixed on the ceiling besides each key-point like offices, laboratories, stairs, restrooms, etc. These key points will serve as destinations to which a user will be guided from any source location in the building with help of the proposed system.

3.2. Path Generation

The database for the navigation and guidance system is generated simultaneously with the path generation and path augmentation procedures. We start with an empty data structure, named Node that represents a single marker in the floor graph, having the attributes given in Table 1. When the system detects the first marker, say m1, it fills up the Node data structure as shown in Table 2.

Reason for all other fields initialized to null is that these are related to the connectivity of this maker with adjacent marker, which we have not yet been detected. Soon when the system detects another marker m2 along the path, the node for m1 is updated with m2's identifier. Similarly, a

Table 1. Marker attributes

Attribute Name	Description
marker_id	Each marker has a unique numerical identifier that represents the pattern displayed on the marker
target_marker_id	Id of the marker adjacently connected to this marker along the path
target_marker_direction	Direction in which the target marker is connected with this marker, i.e. left, right, straight, back, slightly left, slightly right, highly left, or highly right
Weight	Distance between this marker and the target marker, measured in feet
edge_detail	Type of the path between this marker and the target marker, i.e. stairs up, stairs down, or straight path

Table 2. Detection of first marker in path and its data storage

marker_id	target_marker_id	target_marker_direction	Weight	edge_detail
1	Null	Null	Null	Null

Table 3. Detection of subsequent marker in path and data updation in the table

marker_id	target_marker_id	target_marker_direction	Weight	edge_detail
1	2	Null	Null	Null
2	1	Null	Null	Null

node for m2 is also created, as given in Table 3. We still leave the last three attributes null, as they will be populated in path augmentation phase. Interconnection between the markers on a sample path is depicted in Fig. 1.

3.3. Path Augmentation

After path generation phase, we scan and detect all the markers deployed in the entire building, a composite floor graph is generated using the procedure mentioned in previous section. We perform a second scan of the same paths, and detect each marker with phone camera for augmentation purposes. Two main tasks are performed here:

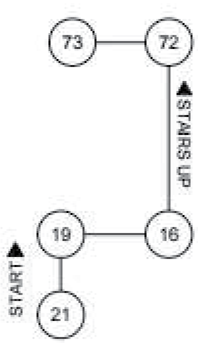
1. We update the remaining three attributes, i.e. target marker direction, weight, and edge detail for each of the entry in Node list using the following mechanism:
   - ✓ When a marker is detected, the system displays its target marker id. We would fill-in its direction with respect to the current marker, distance between them, and nature of path between them.
   - ✓ We move to the next marker in the path and repeat the same process for it. The tabular representation given in Fig. 1 would become (with assumed weight attributes) as shown in Table 4.
2. We assign information about the key point

Table 4. Path augmentation with textual information

marker_id	target_marker_id	target_marker_direction	Weight	edge_detail
21	19	Straight	8	No Stairs
19	21	Back	8	No Stairs
16	19	Left	10	No Stairs
19	16	Right	10	No Stairs
72	16	Back	14	Stairs Down
16	72	Straight	14	Stairs Up
73	72	Left	6	No Stairs
72	73	Right	6	No Stairs

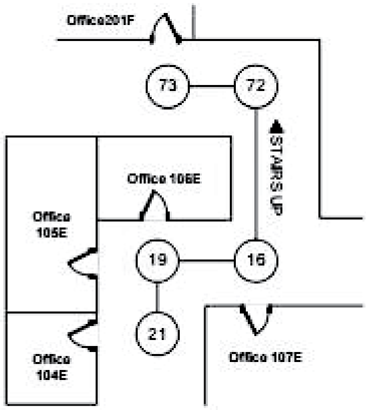
Table 5. Key points information with respect to a marker

Attribute Name	Description
marker_id	Numerical identifier of the marker
Direction	The direction of the key point with respect to this maker
point_name	Name of the key point associated with this marker



marker_id	*target_marker_id*	*target_marker_direction, weight, edge_detail*
21	19	Null
19	21	Null
16	19	Null
19	16	Null
72	16	Null
16	72	Null
73	72	Null
72	73	Null

Fig. 1. Actual path given on the left, while its corresponding tabular structure given next



marker_id	*direction*	*point_name*
21	Left	Office 104E
19	Left	Office 105E
19	Straight	Office 106E
16	Back	Office 107E
73	Straight	Office 201F

Fig. 2. Block diagram of key-points and its corresponding Node_info table

associated with each marker to its corresponding node. These details are stored in a data structure named Node info having the attributes given in Table 5. Fig. 2 shows the sample path along with key points and their direction to respective markers on the path.

3.4. Floor Graph

The floor graph created during path generation phase, and then augmenting it with key-point location information, the overall data structure for the indoor paths of the building becomes as given in Fig. 3.

As depicted, each marker is surrounded by four neighboring information nodes. A Null value represents a wall or that there is no key-point location on that side of the marker.

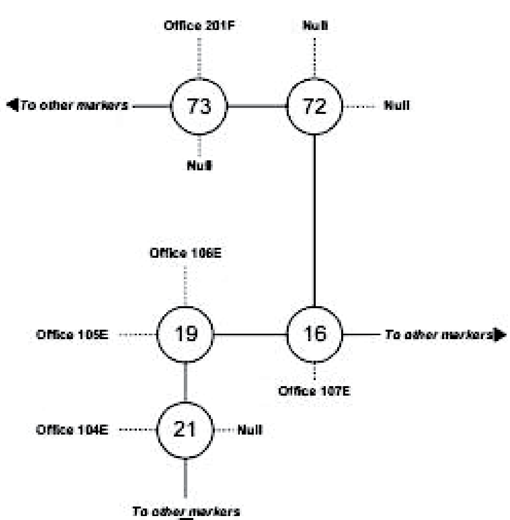


Fig. 3. Final floor graph of the indoor paths of the building after augmentation

3.5. User Guidance

In guidance mode, the user selects a destination from a given list and moves forward to detect a source marker in proximity. The guidance module works as:

- ✓ The system first calculates all distinct paths, which connect the source to destination locations. If multiple paths are found, Dijkstra's shortest path algorithm [32] is employed to find out the shortest path based on distance between each pair of markers in Node data structure.
- ✓ We use the target marker id field of a marker to get next marker and target marker direction for determining path direction, while we keep track of covered distance using the weight field.
- ✓ For each marker, we look for the required destination key-point in its Node info data structure. If it is found, we stop the location search process, save the path, and look for alternate path, if it exists.
- ✓ Shortest path can be calculated by summing up the weight field of all markers in the identified paths, and thus selecting the one with the lowest value. Let the user wants to navigate to a destination, say Office 201F, and moves forward to detect a source marker in proximity,

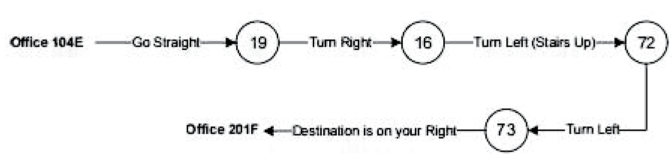


Fig. 4. Guidance from Office 104E to Office 201F.

say marker with id = 21. For the source marker, we have target marker id=19, connected to it in straight direction and no stairs in between. Same procedure is repeated for target marker id=16, which is connected to id=19 in right direction and having no stairs in between. Fig. 4 illustrates the guidance mechanism in detail.

4. CONCLUSION

In this study, we have discussed how a database is created in our proposed path generation algorithm for assisting user navigation in large indoor environments. This database is augmented with location aware information about various key-points that come along the identified paths. The consolidated information about the discovered paths is stored using a bidirectional graph. This graph helps the system efficiently find the shortest route to a destination location from any current location in the building.

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