

# RAIS: Towards A Robotic Mapping and Assessment Tool for Indoor Accessibility Using Commodity Hardware

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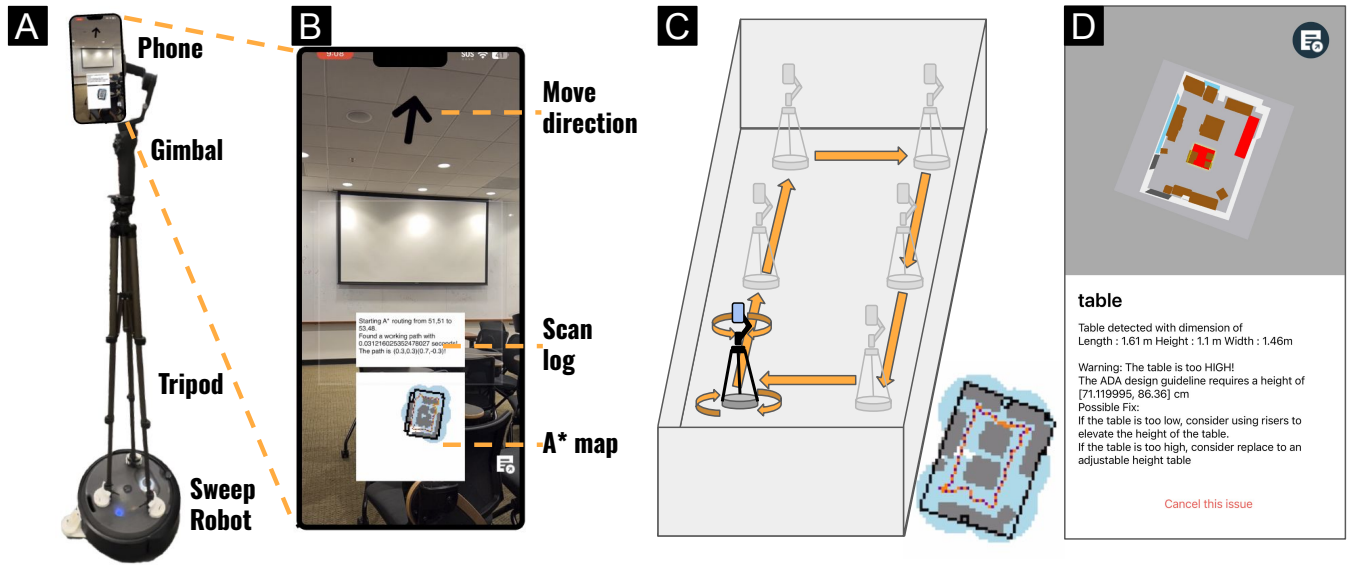


Figure 1: We introduce the *Robotic Accessibility Indoor Scanner* (RAIS), an automated indoor mapping and accessibility assessment system constructed with off-the-shelf components. (A) The RAIS hardware prototype, (B) scanning interface, (C) scanning process with a 2D generated map, (D) and autogenerated 3D parametric model with detected accessibility issues in red.

## ABSTRACT

Mapping, assessing, and creating personalized routes of indoor spaces for people with disabilities remains a grand challenge in accessibility research. Drawing on recent work in robotics as well as emergent work in smartphone-based mapping, we introduce *RAIS* (*Robotic Accessibility Indoor Scanner*), a robotic-based indoor mapping and accessibility assessment system. As a rapid prototype, RAIS is constructed with off-the-shelf components including a vacuum robot, smartphone, and phone gimbal along with a modified version of our previous LiDAR-based accessibility scanner *RASSAR*. In a preliminary evaluation of three indoor spaces, we demonstrate RAIS's ability to autonomously scan spaces, produce detailed 3D reconstructions, and find and highlight accessibility issues.

## CCS CONCEPTS

• Human-centered computing → Accessibility systems and tools.

## KEYWORDS

Indoor accessibility mapping, LiDAR, computer vision, map generation, indoor accessibility assessment

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## 1 INTRODUCTION

Despite significant recent progress [4, 23, 27, 29, 31, 36], mapping, assessing, and creating personalized routes of indoor spaces for people with disabilities remains a grand challenge in accessibility research [10, 28]. With advances in photogrammetry, camera hardware, and laser scanning, emerging companies such as *Mat-terport* [15], *Metareal* [16], and *EyeSpy360* [13] can create precise and fully immersive 3D reconstructions of indoor spaces for virtual

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tours and other mapping applications. Others have designed pushcarts equipped with scanning sensor suites such as FARO's *Focus Swift* [2] or large wearable "backpack" systems such as the NavVis VLX 3 [19]. While offering high-fidelity scans useful for blueprint generation, construction tracking, and virtual walkthroughs, the focus has not been on understanding and evaluating indoor space accessibility (e.g., narrow hallways, staircases, lack of assistive aids). Moreover, these hardware systems are costly and the scans are time consuming, expensive, and often require professional training. Thus, scaling such systems to identify and track accessibility problems in large indoor buildings such as offices, airports, and train stations is cost prohibitive.

Drawing on recent work in robotics for automated indoor scanning and inspection [14, 25] as well as emergent work in smartphone-based indoor accessibility mapping [30, 31, 36], we introduce *RAIS* (*Robotic Accessibility Indoor Scanner*), a robotic-based indoor mapping and accessibility assessment system (Figure 1). As a rapid prototype, RAIS is made with off-the-shelf components, including a vacuum robot, smartphone, and phone gimbal, and runs an indoor accessibility 3D reconstruction and auditing application called RASSAR [31]. Although preliminary, RAIS is able to independently navigate unknown indoor and detect potential accessibility issues in real time. RAIS generates parametric 3D map reconstructions, which support both *in-situ* and *post-hoc* accessibility audits of scanned spaces.

To evaluate RAIS, we performed a pilot study in three indoor environments: a maker space, a classroom, and an office. We placed RAIS in random positions, started the scanning session, and let RAIS independently conduct the indoor reconstruction and accessibility scan. Our preliminary evaluation shows RAIS is able to complete fully automatic scans, efficiently generate a 3D reconstruction including architectural features (walls, doors, windows) and furniture, and highlight accessibility issues in the space.

In summary, this poster paper contributes a new, low-cost robotic mapping and indoor accessibility assessment prototype made of commodity hardware. Our overarching goal is to develop new automated indoor mapping techniques that prioritize accessibility and support remote visit planning, *in situ* navigation support of accessible routes, and infrastructure maintenance.

## 2 RELATED WORK

To collect indoor accessibility data, current practices predominantly rely on manual efforts, such as home assessments conducted by occupational therapists [17] or the use of accessibility checklists [6, 8, 22, 32, 34]. Research indicates a scarcity of professional assistance [24], suggesting that digitizing indoor accessibility evaluation methods could expand their reach. Recent work, such as RASSAR [31] and *AccessLens* [18], has explored the feasibility of using smartphones to conduct indoor accessibility scans. However, these digital solutions still require manual intervention, making large-scale and long-term data collection challenging.

In contrast, fully automatic indoor mapping and modeling methods have long been implemented [12]. With SLAM (Simultaneous Localization and Mapping) [37], robots can explore unknown spaces and construct maps. As this research field matures, recent work has introduced a variety of robotic platforms [1, 26, 33]

and sensors [21, 38, 39], greatly expanding the potential for application tasks, including accessibility-oriented tasks like guidance robots [4, 5, 11] and assistive robot walkers [7]. We envision such robotic methods being applied to indoor accessibility data collection.

Building on this prior work, our RAIS system aims to combine smartphones' proven capability for indoor accessibility mapping with the maneuverability of indoor vacuum robots to create the first fully automatic indoor accessibility mapping system. By rapidly building and testing a technical prototype, we demonstrate feasibility and describe future work in the Discussion.

## 3 THE RAIS PROTOTYPE

To examine the feasibility of creating a robotic-based indoor mapping plus accessibility scanning system, we rapidly constructed a hardware-software prototype using off-the-shelf components. Below, we enumerate the key design components before describing how the RAIS mapping and scanning process works.

### 3.1 Design & Components

As a rapid prototype, RAIS is built with commodity hardware and software components:

**LiDAR-equipped smartphone:** To scan and reconstruct 3D environments, we use a LiDAR-equipped smartphone (*iPhone 13 Pro Max*). The real-time reconstructed map also guides the robot path control.

**Robot:** To autonomously navigate and map indoor environments, we use a wheeled vacuum robot (*iRobot Create 3*).

**Motorized phone gimbal:** To control the capture angles of the smartphone and ensure maximum coverage, the phone is mounted on a motorized gimbal (*DJI Osmo Mobile 6*) which is controlled to rotate left, right, up, and down during scan.

**Tripod:** We elevate the gimbal and phone with a tripod to improve capture of indoor objects.

**Software:** The 3D reconstruction and real-time accessibility barrier scanning is conducted by our previously published system called RASSAR [30, 31], a custom iPhone application that identifies, localizes, and visualizes indoor accessibility and safety issues such as inaccessible table height or unsafe loose rugs using LiDAR and a custom-trained computer vision model. In addition, we wrote custom iPhone software to help route the RAIS robot and control the gimbal, which we describe below.

### 3.2 Scanning Process

To enable RAIS to explore and scan unknown indoor spaces, we implemented SLAM and a routing strategy. We use *Apple's ARKit* and *Roomplan API* [3] to create real-time 3D reconstruction of indoor spaces and locate the 3D coordinates of the robot. For the exploration and navigation algorithm, we implemented two methods: (1) a strategy to guide the robot into unknown spaces, (2) and an A\* pathfinding algorithm to avoid obstacles.

For the former, we use the classic wall-following algorithm [35]. First, the robot is placed in a position away from the wall where the phone performs an initial scan to recreate a partial map. RAIS picks the nearest wall to follow at a constant distance of 1.2 meters. When a new wall is detected within 1.2 meters, RAIS chooses this

**Algorithm 1** RAIS Wall Following Strategy

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1: while not back at initial position do
2:   if further than 2.5m from already scanned positions then
3:     Rotate robot and gimbal to perform scan at current position
4:   end if
5:   if not following any wall then
6:     Find nearest wall and start following it
7:   end if
8:   Move along the following wall
9:   if new wall detected within 1.2m then
10:    Follow the new wall
11:   else if left-side wall ends then
12:    Turn left, move forward until a new wall to follow is found.
    Follow this new wall.
13:   end if
14: end while
15: end algorithm

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new wall to follow. This strategy continues until the robot returns to its initial position and closes its moving trajectory loop (*i.e.*, the scanning process is declared complete). See Algorithm 1.

Since objects such as furniture and clutter may obstruct the robot's path, we employ the well-established A\* pathfinding algorithm to avoid obstacles [9]. As the RoomPlan API provides the real-time 3D reconstruction of the scanned space, we rasterize this information to create a grid map. The current location and the moving goal are projected onto the grid map to conduct A\*. The resulting path is then executed by the robot. An example of such routing process is shown in Figure 2.

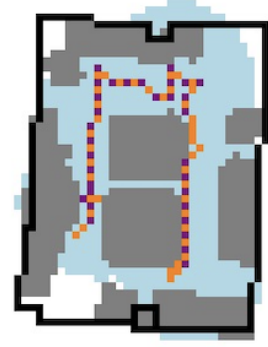
### 3.3 Scanning Result

After the scan, the layout of the room as well as the indoor objects (*e.g.*, tables, chairs) are represented as a 3D parametric model. This model includes architectural features like walls, doors, windows, and also furniture like tables and chairs. An example of the room reconstruction is shown in Figure 1D. This visualization interface is reused from RASSAR [31] but the model could be downloaded and viewed by other CAD programs in the future. By further applying accessibility rubrics, potential accessibility issues can be detected in the scanned space either during the scan or in *post-hoc* analysis.

For this initial prototype, we adopt four accessibility rubrics from ADA design guidelines [20]. (1) *door width*: if doors are wide enough—more than 32" (81.3 cm)—for wheelchair to pass; (2) *table or counter height*: if tables and counters have proper height—between 28–34" (71.1–86.4 cm); (3) *cabinet height*: if cabinets are placed low enough—below 27" (68.6 cm)—to reach; (4) *Routing Space*: if indoor paths/corridors are wide enough for wheelchair to pass—more than 36" (91.4 cm). Issues 1, 2 and 3 can be automatically detected in real-time during the scan process, while Issue 4 is currently filtered from scan results manually and will be automated in the future.

## 4 PRELIMINARY EVALUATION

To evaluate the RAIS's performance, we performed test scans in three indoor environments: a makerspace, a classroom, and an office



**Figure 2: Example of RAIS's A\* routing. Grid cells are 20cm × 20cm. Black indicates wall, gray for furniture, blue for scanned space, orange for path, and purple for stopped positions.**

(Table 1). For each space, we deployed RAIS at a random location and started an automatic scan. The RAIS robot then maneuvered within the space, generated a 3D reconstruction and 2D map, and conducted an accessibility scan. The entire scanning process was timed and recorded. For comparison, we also conducted a manual inspection to determine ground truth. The space details, scan time, as well as accessibility issue detection stats are shown in Table 1. We also show corresponding pictures of the indoor spaces, the generated maps, and RAIS' scan route in Figure 3.

Overall, we found that RAIS could successfully complete indoor scans in all three indoor spaces. The scans took approximately 8.5 minutes. RAIS detected 75% of accessibility issues, including inaccessible table and counter heights in the makerspace and office as well as narrow corridors in the classroom and office; however, RAIS missed identifying an inaccessible cabinet in the makerspace. While preliminary, these results demonstrate feasibility.

## 5 DISCUSSION AND FUTURE WORK

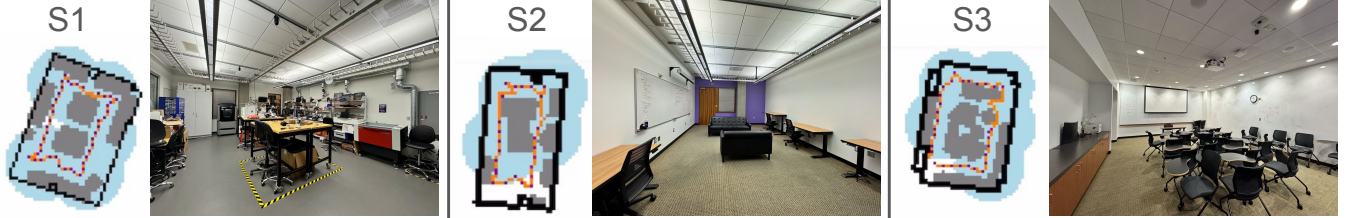
RAIS addresses the challenge of indoor accessibility mapping data collection. The data collected, as parametric 3D reconstructions, could promote accessible infrastructure and provide information and directions for people with disabilities. We built RAIS to explore the feasibility of automatically creating, updating, and maintaining indoor maps focused on accessibility. The preliminary evaluation demonstrated RAIS' potential and is a promising step towards addressing the grand challenge of indoor accessibility maps.

RAIS, being fully automated and capable of exploring unknown indoor spaces, is ideal for deployment in constantly changing environments that require regular accessibility maintenance, such as malls and public transportation stations. By conducting regular scans, RAIS can provide continuously updated indoor accessibility maps at a low cost. These scan results can also assist building managers in improving other aspects of the space, such as cleanliness and safety.

As a proof-of-concept prototype, RAIS demonstrates scanning capabilities but leaves several research questions unanswered. For

**Table 1: The RAIS test spaces and results. Accessibility issues are indicated by their index in Section 3.3.**

Space	Space Size (Sqm)	Scan Time (Min)	Time Per Sqm (Sec/Sqm)	Issues in Space	Issues Detected
S1: Makerspace	40	10	15	i2, i2, i2, i3	i2, i2
S2: Office	32	6.5	9.75	i2, i2, i4	i2, i2, i4
S3: Classroom	48	9	11.25	i4	i4

**Figure 3: We conducted a preliminary evaluation of RAIS in three indoor spaces: a makerspace (S1), an office (S2), and a classroom (S3). We show images of each space as well as the autogenerated 2D map created by RAIS and RAIS's scanning route.**

instance, can RAIS's scanning devices integrate with other widely applied indoor robots, like floor scrubbers? Can RAIS robustly and efficiently scan larger indoor spaces such as malls and train stations? Additionally, how can the scan results be inspected, tracked, archived, and shared to enhance understanding of indoor accessibility while supporting space maintenance? We plan to conduct future implementations and studies to address these questions.

## 6 CONCLUSION

In this paper, we present RAIS, a step towards the first fully automated indoor accessibility mapping system. RAIS can scan and reconstruct unknown indoor environments, create 3D parametric reconstructions and 2D maps, and identify potential accessibility issues using LiDAR and computer vision. Our preliminary evaluation in three indoor spaces demonstrates RAIS's potential. We believe that RAIS represents the future of indoor accessibility auditing, where fully automated systems can conduct regular scans of indoor spaces without manual control, maintaining a constantly updated accessibility map that can benefit indoor navigation and facility maintenance.

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