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DEVELOPMENT OF A CONSTRUCTION SITE'S PHOTO MANAGEMENT AND SITE INSPECTION APPLICATION USING SMARTPHONE-BASED INDOOR POSITIONING AND LOCALIZATION TECHNOLOGY IN A NON-GPS ENVIRONMENT

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Abstract

On construction sites, providing clear and efficient work instructions to foremen during site inspections, known as "follow-up work," is essential but often burdensome and time-consuming. Follow-up work on construction sites should be carried out daily, where site managers must visit the site, take photos of identified issues, return to the office, print the photos taken on-site, match them with a site map, create detailed instructions, and deliver them to foremen during meetings or breaks. Recently, some sites have been using chat applications like WhatsApp, LINE Works, and Wow Talk, which have sped up the process by allowing real-time sharing of photos and instructions via chat messages. However, the location of the photos is often unclear or inaccurate, which makes it difficult for foremen to understand the instructions accurately. As a result, site managers may need to guide foremen to the location in person, creating inefficiencies. To address this issue, we developed a site photo management app that uses smartphone-based, non-GPS indoor positioning and localization technology. The app allows workers to take photos, automatically tag the location accurately, and generate work instructions directly on their smartphones. These instructions, including both photos and a location map showing the pinpoint where the photo was taken along with the direction of the camera, can be sent to foremen via chat applications, ensuring that the work task is clearly communicated. The system is optimized to work with iPhones, making it accessible to construction site workers at any time. This solution improves the accuracy and efficiency of providing work instructions, reduces the administrative burden on site managers, and enhances communication between site workers and foremen. By streamlining the follow-up work process and ensuring that instructions are clear and precise, the system contributes to improved efficiency on construction sites.

Keywords: construction management, indoor positioning and localization, non-GPS, photo management, site inspection.

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1. Introduction

Construction sites frequently contain areas such as basements, enclosed structures, and underground levels where GPS signals are weak or completely unavailable [1]. This lack of reliable GPS coverage presents a significant obstacle for precise localization, navigation, and the use of digital documentation systems that rely on location data. While various indoor localization technologies have been developed, such as Bluetooth beacons [2], Wi-Fi triangulation [3], ultra-wideband (UWB) [4], simultaneous localization and mapping (SLAM) [5], and AR markers [6]. These approaches often require additional infrastructure, stable network environments, or pre-installed markers. However, such prerequisites are rarely met on dynamic construction sites that are constantly reconfigured, making these technologies impractical for widespread deployment in real-world scenarios.

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Simultaneously, construction sites generate large volumes of photographic data daily for inspection, documentation, and task instruction purposes. However, these images are typically disconnected from precise spatial context, lacking metadata such as exact position, orientation, or camera direction [7]. As a result, the photos often become less useful after specific tasks are completed, and their value diminishes quickly.

To overcome these limitations, we developed a smartphone-based indoor localization and navigation system that relies solely on the built-in camera and motion sensors of standard smartphones [8]. This infrastructure-free approach allows for easy deployment on construction sites without the need for external equipment or environmental modifications. In addition to enabling self-localization, the system automatically attaches detailed spatial metadata to each captured photo, including its position on a floor plan and the orientation of the camera [7]. This transforms ordinary site photos into structured, actionable data that can support follow-up inspections, progress monitoring, and improved on-site communication.

Building upon this localization system, we developed a photo management and site inspection application that streamlines communication between site managers and foremen. Traditionally, follow-up work involves site managers patrolling the construction site, taking photos of issues, and manually annotating them with locations on printed floor plans, followed by in-person explanations. This repetitive and time-consuming process, often called “Chase Work,” has been identified as a major inefficiency in the construction industry. "Chase work" on construction sites refers to the time-consuming process where site managers must repeatedly guide workers in person to ensure instructions are understood and followed. The flow of the site “Chase Work” is shown in Fig. 1.

Our solution directly addresses these issues by integrating smartphone-based localization with an intuitive mobile app [9]. Workers can capture photos that are immediately location-tagged and pinned on a digital site map and can generate annotated instructions for follow-up work that are easily shared through chat applications. By reducing manual work, improving spatial clarity, and eliminating the need for physical site guidance, the system helps to streamline construction workflows and contributes to digital transformation on the job site. Field trials on multiple construction sites have demonstrated improvements in task instruction clarity, communication efficiency, and overall productivity.

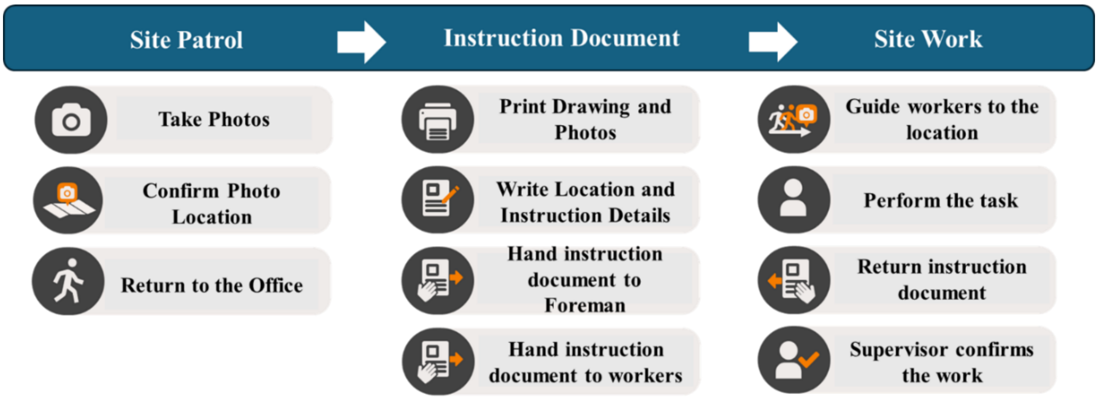

Fig. 1. Flow of chase work on construction sites.

2. System Configuration

2.1. System Overview

The core innovation of the site photo management application lies in its ability to estimate a user’s movement and orientation in real time by analysing the movement of feature points in images captured by a smartphone camera [10],[11]. This is further enhanced by combining data from built-in sensors such as the gyroscope and accelerometer [12]. Unlike traditional positioning systems that require high-performance computers to process spatial data, this application is optimized for smartphones. Through algorithmic improvements, the system achieves high accuracy in self-localization and movement estimation, while also reducing power consumption, making it suitable for continuous use in the field.

When a photo is taken using this application, the exact shooting location is automatically pinned on a digital floor plan. Additionally, the system embeds precise latitude and longitude metadata into the image. This significantly improves the usability of the photo by providing spatial context and enabling seamless tracking and communication of site conditions. The system consists of four integrated components as shown in Fig. 2.

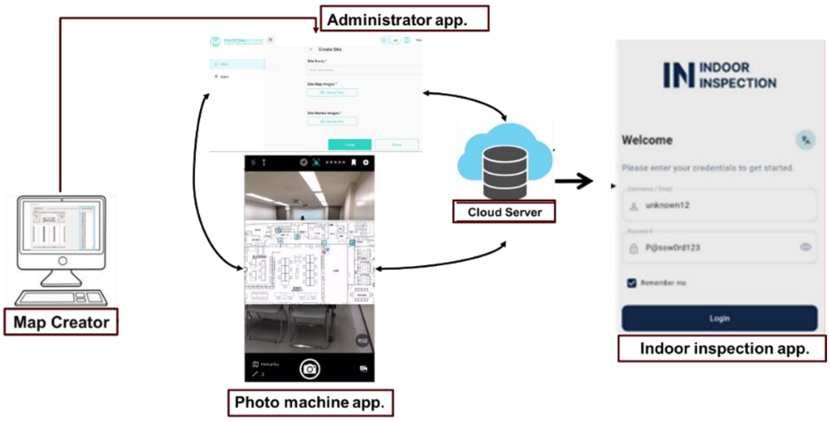

Fig 2. System configuration of our onsite photo management and site inspection applications

Map Creator: This tool is used to generate the necessary base data for the site, including floor plan diagrams, marker data, and the precise coordinates of those markers. These markers are used as reference points for localization.

Administrator App: This application is used by site managers or supervisors to define and register new construction sites using the map data created in Map Creator. It acts as the control interface for managing site settings and configurations.

Photo Machine App: Installed on smartphones used in the field, this app allows users (e.g., site workers or managers) to capture photos. These images, along with detailed spatial metadata, are automatically uploaded to a cloud server. The app references the site maps created earlier, enabling accurate photo localization in real-time.

Indoor Inspection App: This component is used to review and annotate the photos captured by the Photo Machine App. Users can add inspection comments, highlight defects, or require follow-up actions directly on the photo, and share the annotated images with relevant personnel using integrated messaging tools.

The user scenario of the onsite photo management and site inspection application is shown in Fig. 3.

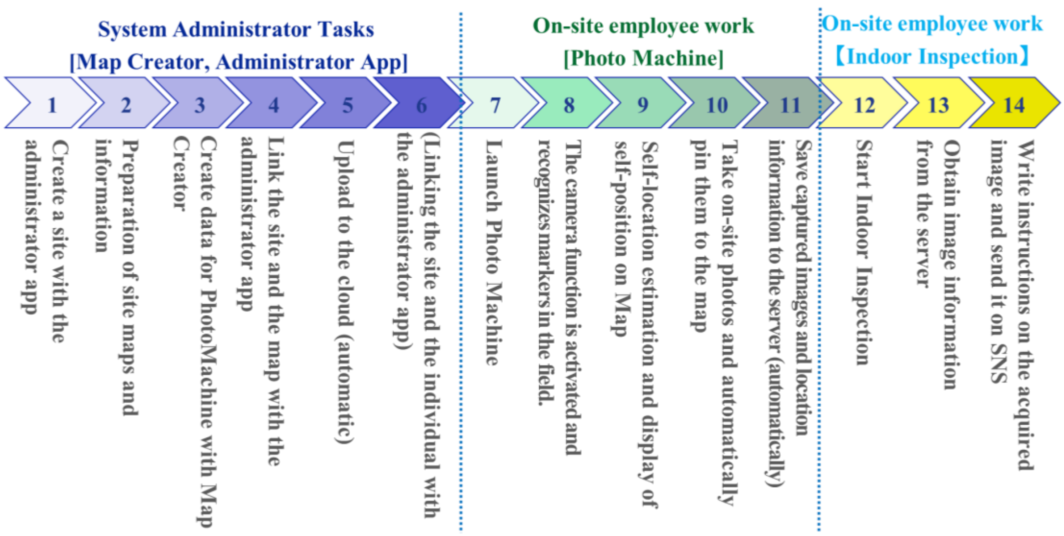

Fig. 3. The user scenario of the onsite photo management and site inspection application

2.2. Map Creator

The Map Creator is a desktop application designed to convert conventional 2D construction drawings into interactive, georeferenced digital maps. Users define the physical scale of the map and specify reference markers by assigning latitude and longitude to a known point within the 2D layout. Based on these inputs, the application calculates the relative positions of other markers and automatically determines their geographic coordinates, taking into account the map's scale and orientation [13]. This innovative method eliminates the need for on-site surveys using costly lidar systems or specialized cameras. An example of the Map Creator interface is shown in Fig. 4.

The main functionalities of the Map Creator include:

I. Bitmap Map Import and Scaling: Users can import floor plans in bitmap format and scale them by registering known distances and setting base coordinates. Key features such as corridors and entryways can be annotated to aid navigation.

II. Orientation and Geolocation Assignment: By setting a north reference and assigning geographical coordinates to known markers, the application calculates the latitude and longitude of all map features [14]. This allows photos taken later to be precisely geotagged.

III. Visual Verification with Google Earth: To ensure accuracy, the system exports calculated coordinates to Google Earth. This visual verification process provides a straightforward way for users to confirm the alignment and scale of the generated map [15].

IV. Export and Compatibility: The output includes the bitmap map, spatial metadata, and marker positions in a format directly loadable by the mobile application, ensuring smooth data integration.

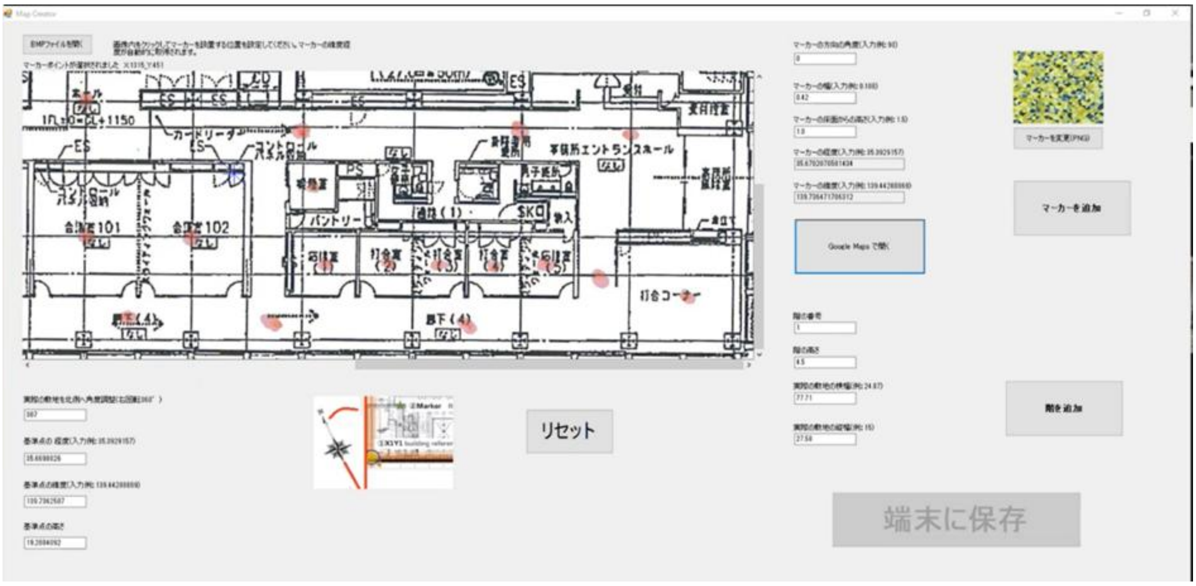

Fig.4. Operation screen of the Map creator system

2.3. Administrator application for the site's photo management

The Administrator Application serves as a backend management tool that enables the creation of site environments and the organization of photographic data captured in the field. It utilizes map files (i.e., site floor plans) generated by the Map Creator to define and structure individual construction sites within the system. These site environments act as the digital backbone for managing photos taken by the Photo Machine mobile application.

To support future scalability and enable the management of multiple construction sites, the system has been developed as a web-based platform. This design allows site administrators to access and control project data from any internet-enabled device, facilitating remote monitoring, centralized data handling, and cross-site coordination.

The process of creating a new site instance is conducted via a form-based interface, as shown in Fig. 5. This interface allows users to upload a floor plan, specify metadata such as project name, location, and map reference, and initialize the photo management structure. Once the site is created, the system automatically links incoming photos to their respective spatial coordinates based on the geo-referenced map data. This centralized approach to photo and site management improves the traceability of site conditions, supports compliance documentation, and enhances communication among stakeholders by providing an integrated, map-based interface for visual recordkeeping.

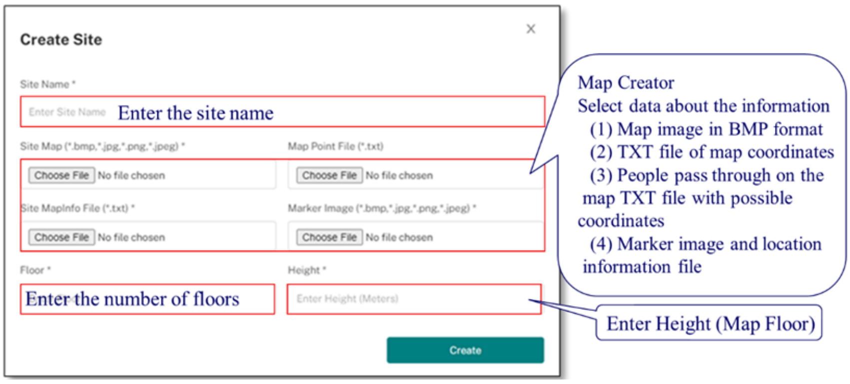

Fig.5. Operational screen of the administrator application

3. On-Site Photo Management Application

3.1 *Photo Machine application*

The Photo Machine application is a mobile tool designed to capture and manage photographs taken during site patrols, automatically associating each image with the estimated indoor location of the device at the time of capture. This is achieved through a seamless integration with the Map Creator-generated digital floor plans, which are displayed within the application interface. As users move through the site, their current position is estimated and updated in real time on the displayed map.

When a user captures a photo using the application, a pin is placed on the map at the estimated location of the device at the time of capture. Each photo is enriched with detailed metadata, including the timestamp, EXIF data, latitude and longitude, 2D map coordinates, as well as information on the device's orientation, heading, and posture. This rich set of metadata ensures that the images carry all essential spatial and contextual information required by the overall system.

Captured images and their associated metadata are then uploaded to a cloud server, where they can be centrally stored, accessed, and managed. This cloud-based architecture facilitates data integrity, enables real-time sharing among project stakeholders, and supports long-term archival of visual site records. The workflow of the Photo Machine application is illustrated in Fig. 6, while Fig. 7 shows an example of the application interface during real-time use on site.

3.2 Indoor Inspection Application

The Indoor Inspection application was developed to support on-site inspection and follow-up tasks commonly carried out during routine patrols in construction environments. This application works in integration with the Photo Machine application, extending its functionality by enabling users to annotate site photographs taken during patrols.

With the Indoor Inspection app, users can draw text, arrows, circles, and other graphical elements directly onto the photos captured via the Photo Machine app. These annotations allow users to clearly specify instructions or highlight issues directly on the image, facilitating precise communication of on-site observations.

Additionally, the application enables users to share annotated photos along with the corresponding floor plan showing the photo's capture location via commonly used business chat platforms such as Line Works, Wow Talk, WhatsApp, etc. This integration with real-time messaging tools enhances team collaboration and ensures that annotated site information is delivered promptly to relevant personnel.

The operational workflow of the Indoor Inspection app with the operation screen is illustrated in Fig. 8. By employing this tool during site patrols, users can significantly reduce the time required to prepare instruction documents and improve the accuracy and clarity of communication, ultimately contributing to enhanced productivity and operational efficiency on construction sites.

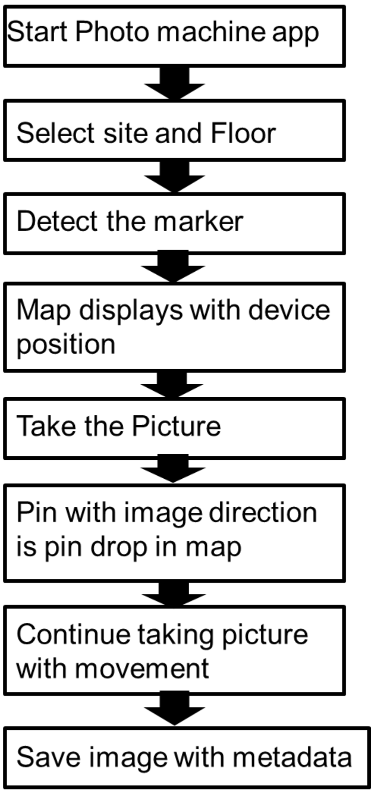

Fig. 6. Flow of the Photo machine app

Fig 7. Operational screen of Photo machine app.

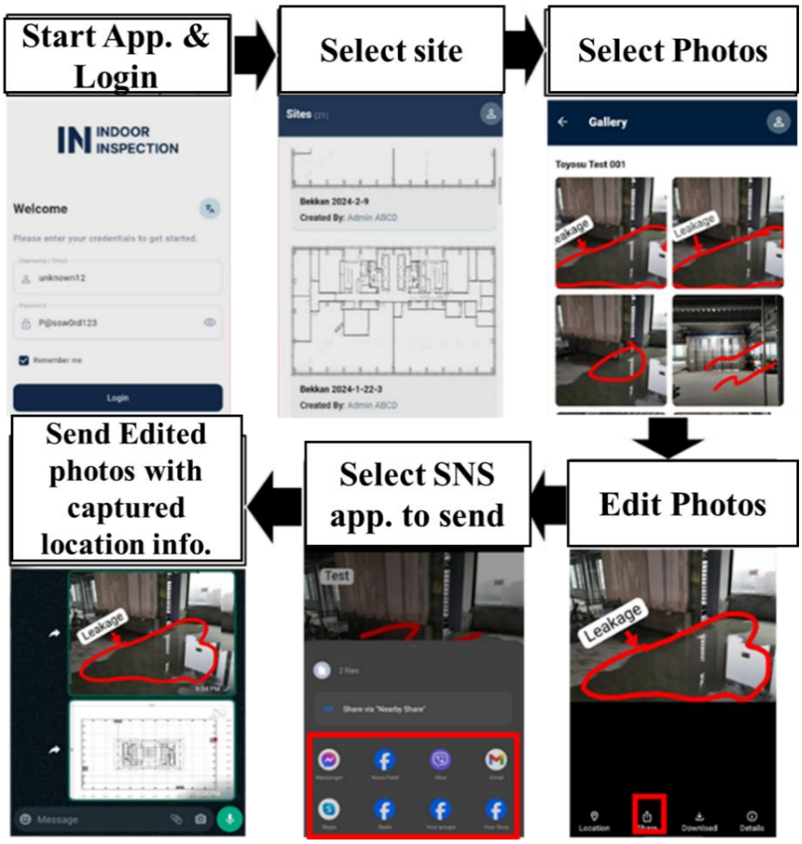

Fig.8. Indoor inspection app. flow diagram with operation screen

4. Experimentation and Evaluation

To validate the proposed system and assess its effectiveness in practical applications, we developed and tested two core applications: the Photo Machine app, which enables indoor photo capture linked to self-localized positioning in non-GPS environments, and the Indoor Inspection app, which facilitates follow-up instruction management and communication. Field trials were conducted between September 2024 and March 2025 on three active construction sites in Japan.

4.1 Application Testing in Non-GPS Indoor Environments

The Photo Machine application was systematically tested in GPS-denied indoor environments, such as underground basements, enclosed steel-framed buildings, and partially constructed floors with obstructed sky visibility conditions that are common on active construction sites. These environments were intentionally selected to assess the system's performance where satellite-based positioning methods are ineffective or highly inaccurate.

The key objective was to evaluate whether the application could accurately determine and record the user's indoor location and camera orientation using only smartphone-integrated sensors and visual data, without relying on external infrastructure or GPS signals.

Furthermore, each captured image was automatically tagged with high-precision metadata, including timestamp, 3D coordinates, and camera orientation (yaw, pitch, roll). This enabled accurate spatial referencing and seamless integration with digital construction tools such as Building Information Modeling (BIM) platforms and digital twin systems. Such a level of precision was previously unattainable with traditional methods, which often required manual annotation or external reference markers.

We compared our photo management system with the GPS based The image showing the comparison of GPS localization and our photo management application is shown in Fig. 9. Blue arrows represent the photo locations estimated by our system showing the localization error of les than 1cm whereas, Pink arrows represent the locations estimated using GPS with localization error of more than 5 cm.

As shown in the figure, the pink arrows are often outside the building layout, while the blue arrows stay correctly inside the map. This clearly shows that our system provides much more accurate positioning than GPS in indoor environments. This visual evidence confirms that the system successfully localizes and visualizes each image capture point in real time without external infrastructure. Pins generated by the system perfectly align with the expected positions on the site layout, reinforcing the system's precision.

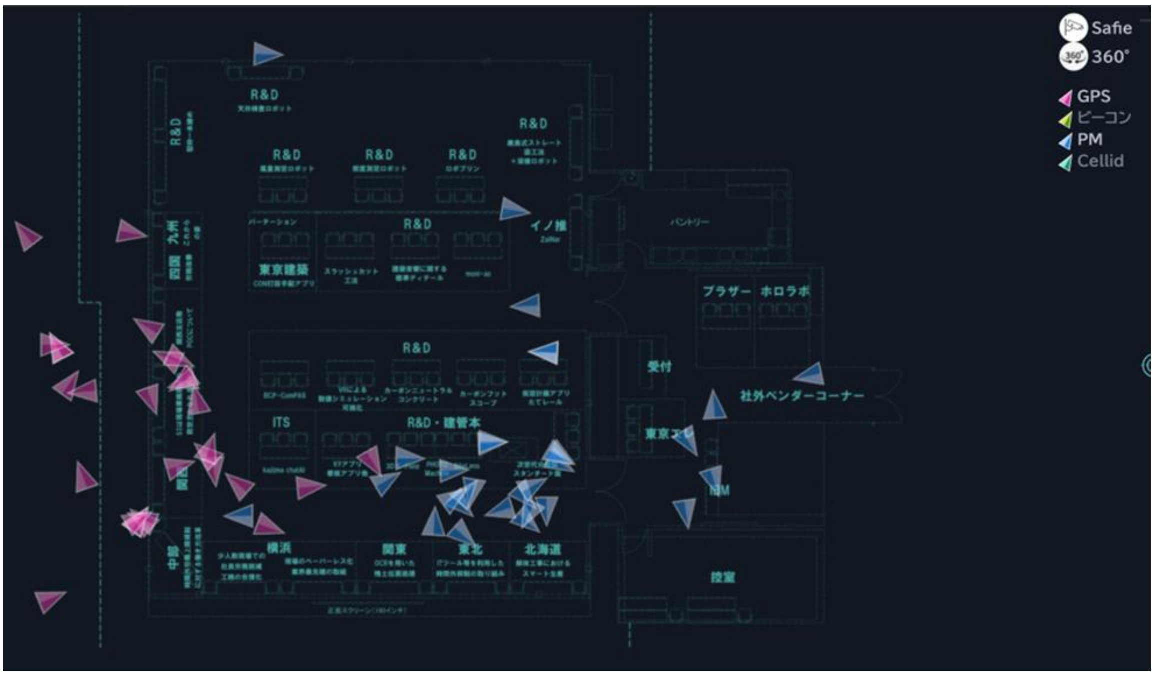

Fig. 9. Image comparing accuracy with GPS and our proposed system.

4.2 Evaluation of the Indoor Inspection Application for Chase Work Reduction

The Indoor Inspection application was developed to improve communication and task management efficiency on construction sites by enabling users to annotate photos captured with the Photo Machine app and deliver follow-up instructions directly to workers via an integrated chat interface. This approach aimed to replace conventional “chase work” methods, which often rely on in-person meetings, handwritten notes, or delayed verbal communication, resulting in inefficiencies and potential misunderstandings.

Time Efficiency: Testing on site demonstrated that the use of the Indoor Inspection app resulted in a 92% reduction in instruction delivery time compared to traditional methods. This substantial improvement is attributed to the system’s capability to transmit annotated visual instructions instantly, minimizing the need for on-site coordination and physical documentation.

Instruction Accuracy: The integration of annotated photos with information for follow-up work significantly improved clarity in task execution. According to user feedback, 91% of foremen and workers were able to carry out instructions without requiring further clarification, and unwanted tasks like printing, documentation, navigation, and so on, indicating a high level of accuracy and effectiveness in communication.

User Feedback and Usability: Site managers reported that the application was intuitive and seamlessly integrated into existing workflows. They observed a marked reduction in the frequency of site revisits and face-to-face explanations, allowing more efficient allocation of supervisory resources and contributing to overall project efficiency. The Indoor Inspection application demonstrated strong potential to enhance on-site communication, reduce delays, and increase the accuracy of task execution. By digitizing and streamlining the follow-up instruction process, the system effectively addressed common inefficiencies in traditional construction site management practices.

5. Conclusion

This research aimed to address the challenge of indoor localization in non-GPS environments, which is a significant issue in many construction sites. To achieve this, we developed the *Photo Machine* application, a tool that allows users to capture photos that are accurately linked to their real-time location and camera orientation using smartphone sensors. This application leverages advanced localization techniques to provide precise location information in environments where GPS signals are unavailable, such as underground or steel-framed structures.

In addition to the *Photo Machine*, we developed the *Indoor Inspection* application, which facilitates efficient follow-up work management by enabling the annotation of photos and direct communication of instructions to workers via a chat interface. This application is specifically designed to address the inefficiencies of traditional "chase work," which typically involves manual coordination, repeated site visits, and delayed task execution due to unclear or incomplete instructions. By digitalizing the workflow, the *Indoor Inspection* application offers real-time communication, significantly reducing time and minimizing errors during task execution.

Together, these applications form a cohesive system that not only enhances communication and task management but also contributes to significant productivity gains on construction sites. The ability to quickly and accurately document inspection points and provide clear, annotated instructions has proven to reduce follow-up time by **92%** compared to traditional methods. Moreover, the system’s intuitive interface and high level of user satisfaction, as reported by field personnel, highlight its potential to be easily integrated into existing workflows with minimal disruption.

Ultimately, this research demonstrates the potential of combining self-localized positioning technology with photo management and communication systems to streamline operations and improve productivity on construction sites. By reducing the time spent on follow-up tasks and enhancing the accuracy of instructions, the system has the potential to revolutionize construction site management, making it more efficient and less reliant on manual processes. This approach can serve as a foundation for future advancements in construction technology, particularly in environments where GPS and traditional methods fail to provide adequate solutions.

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