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Combining visual natural markers and IMU for improved AR based indoor navigation

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ABSTRACT

The operation and maintenance phase is the longest and most expensive life-cycle period of buildings and facilities. Operators need to carry out activities to maintain equipment to prevent functionality failures. Although some software tools have already been introduced, research studies have concluded that (1) facility handover data is still predominantly dispersed, unformatted and paper-based and (2) hence operators still spend 50% of their on-site work on target localization and navigation. To improve these procedures, the authors previously presented a natural marker-based Augmented Reality (AR) framework that digitally supports facility maintenance operators when navigating indoors. Although previous results showed the practical potential, this framework fails if no visual marker is available, if identical markers are at multiple locations, and if markers are light emitting signs. To overcome these shortcomings, this paper presents an improved method that combines an Inertial Measurement Unit (IMU) based step counter and visual live video feed for AR based indoor navigation support. In addition, the AR based marker detection procedure is improved by learning camera exposure times in case of light emitting markers. A case study and experimental results in a controlled environment reveal the improvements and advantages of the enhanced framework.

1. Introduction

Within the lifecycle of buildings and facilities, their operation and maintenance periods cover the largest parts, both in terms of time span and costs. For the purpose of providing a comfortable living and working environment, and maintaining equipment to prevent functional failures, facility managers and operators carry out maintenance activities. Since over 85% of the entire lifecycle costs are spent on facility management [34], improvements to maintenance procedures will significantly reduce the overall building lifecycle budget. Consequently, this fact reveals the need and potential for advancements in designing and performing facility maintenance procedures.

The current state of practice is characterized by dispersed and unformatted facility information [2]. Akcamete et al. [2] have reported that operators often have to go through several documents to find information necessary to support their daily tasks and decisions. This constitutes to lost time during operations for searching for and accessing data when needed [2]. Although software systems have recently been introduced, 50% of the on-site maintenance time is solely spent on localizing inspection targets and navigating to them inside a facility [21]. Moreover, linked maintenance instructions are often multi-page documents, which sometimes are difficult to comprehend, in particular in case of emergencies [2].

Although some recent research studies propose to use Building Information Models by either integrating or linking work order information to them, not all necessary information is currently available in a digitally integrated and standardized model [2]. Moreover, available indoor navigation approaches using UWB, WLAN, RFID and GPS have been compared and validated [14], but they rely on costly equipment infrastructure for senders and readers. Moreover, these solutions only provide the operator's position, not the orientation that is needed to present augmented virtual content. Existing Augmented Reality (AR) based solutions

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use artificial markers for both navigation and maintenance instruction support [21]. However, these kinds of markers require high installation efforts all over the facility and also come along with significant aesthetical issues. Other, more advanced AR based methods use 3D point maps and Simultaneous localization and mapping (SLAM) procedures (e.g. [4,5]). These approaches, however, require an unreasonably huge amount of pre-collected 3D data and additional IT infrastructure. Also they are prone to fail in cases of scene changes due to temporary objects [4].

Previously, the authors have introduced and tested an AR based framework that can digitally support facility maintenance operators in performing their daily on-site maintenance jobs combining Building Information Models and natural markers (e.g. exit signs) [18]. Within this framework AR based indoor navigation plays a significant role. For this purpose, the authors have conducted a performance study on natural marker detection and tracking [17]. The results of this study indicate the practical applicability and potential. However, in the cases where no pre-defined natural markers are available in the camera live view, the distance between two markers is larger than approximately 10 m and the same marker is available at multiple locations, the framework fails to determine the position and orientation of the operator's device. Unfortunately, in such a situation augmentation is completely lost.

In this paper we propose an enhanced method that combines an Inertial Measurement Unit (IMU)-based step counter and visual live video feed to improve the previously introduced natural marker-based augmented reality framework for indoor navigation. In addition to natural marker detection and tracking, IMU data is used to estimate the position and orientation of the mobile device where sole AR based concepts fail. In addition, the AR based marker detection procedure is improved by learning camera exposure times in case of light emitting markers. The proposed method has been implemented and tested in a controlled indoor environment on-campus. The results indicate the feasibility and the potential of the improved method.

2. Background

2.1. Current practices

In today's maintenance and repair practice, facility operators usually gather and access dispersed and unformatted facility information in order to handle work orders [1,2]. Typically, this information is available in form of 2D drawings, spreadsheets, bar charts, field reports and paper-based guidelines that are created during the building design and construction phases. Consequently, operators often have to collect, sort and browse through several documents to find relevant information to support their daily tasks and decisions, which results in lost time during maintenance procedures [2]. In addition, the facility handover data is then stored in so-called Facility Document Repositories, which are physically space-consuming, so that they may even occupy an entire room [7].

Recently, Computer-Aided Facility Management (CAFM) Systems for space management and Computerized Maintenance Management Systems (CMMS) for work order management have been introduced to digitally support FM operators in organizing and integrating preventive maintenance schedules and intervals, shop and installation drawings, cost control and documentation, device specifications and manuals, warranty information, replacement parts providers, as-is performance data, etc. [1].

Building Information Modeling (BIM) is an up-to-date method involving the generation and management of a digital representation of the physical and functional characteristics of a facility during its entire lifecycle [7]. Although an increasing amount of maintenance-related information has been incorporated into BIM so far, not all data necessary to perform work orders is currently part of BIM solutions (e.g. manufacturer's maintenance instructions).

Even if supported by BIM standards, such as the Industry Foundation Classes (IFC), the actual FM data still needs to be manually rekeyed into the building model multiple times based on the handover documents [7]. To automate this process, East et al. [7] have proposed an open-standard IFC-based Facility Management handover model view definition that is based on the Construction-Operations Building information exchange (COBie) format [8]. The advantage is that when the FM handover occurs, the relevant information captured during the design and construction phase can be directly transferred into tools supporting the long-term management and maintenance of the facility. COBie data can be stored in the common ISO STEP format, in the ifcXML format or as a spreadsheet (SpreadsheetML). The use of COBie has been successfully documented in several case studies [7].

However, in order to prepare an actual on-site maintenance job, operators need to identify the location of the maintenance item inside the building, the route towards it, and the relevant maintenance instruction manuals. According to Lee and Akin [21], 50% of the on-site maintenance time is solely spent on localizing and navigating. For this reason, the focus of this paper is placed on the development of a new indoor navigation solution.

2.2. Current research efforts in indoor location and navigation solutions

2.2.1. Estimating the operator's position

In addition to the location of the actual maintenance item, it is necessary to know the operator's position inside the facility in order to support real-time indoor navigation. In recent years, a vast amount of ongoing research has been conducted in this area. Fuchs et al. [10] have presented an overview of existing indoor tracking systems for mission-critical scenarios, including Indoor GPS, Wireless Local Area Networks (WLAN), Ultra-Wide Band (UWB) as well as Inertial Measurement Unit (IMU) based systems. They have evaluated these technologies in terms of precision, deployability, complexity and cost, and have come to the conclusion that a combination of multiple localization methods is required to implement a solution that is deployable, less complex and cheap. As one example from the construction community, Khoury and Kamat [14] have evaluated three different wireless indoor position tracking technologies, in particular, WLAN, UWB and Indoor GPS positioning system. In their study, Indoor GPS has been identified as being superior, since it could estimate a mobile user's location with relatively low uncertainty of 1–2 cm. Li and Becerik-Gerber [22] have presented a performance-based evaluation of RFID-based indoor location sensing solutions for the built environment. They have concluded that no single solution meets all the criteria for successful implementation, and that the adaptability of the evaluated solutions within the built environments is uncertain, so that further research is needed.

Motamedi et al. [27] have investigated the use of RFID technology for indoor localization of RFID-equipped, fixed and moving assets during the operation phase of facilities. Apart from the asset location, the operator's position can also be estimated using surrounding fixed tags and a handheld RFID reader [27]. However, the main disadvantage of signal-based technologies, such as Indoor GPS, WLAN, RFID and UWB, is the need for extra equipment installation and maintenance (both tags and readers), which still involves a considerable cost factor. Razavi and Moselhi [31] as well as Montaser and Moselhi [26] have presented a low-cost location sensing solution for indoor facilities using passive Radio Frequency Identification (RFID) that have a mean error of 1–2 m for location identification.