PERFORMANCE STUDY ON NATURAL MARKER DETECTION FOR AUGMENTED REALITY SUPPORTED FACILITY MAINTENANCE

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ABSTRACT: *The operation and maintenance phase is the longest and most expensive life-cycle period of building facilities. Operators need to perform activities to provide a comfortable living and working environment and to upkeep equipment to prevent functionality failures. For that purpose they manually browse, sort and select dispersed and unformatted facility information before actually going on the site. Although some software tools have been introduced they still spent 50% of the on-site work on inspection target localization and navigation.*

To improve these manual, time consuming and tedious procedures, the authors previously presented a framework that uses BIM-based Augmented Reality (AR) to support facility maintenance tasks. The proposed workflow contains AR supported activities, namely AR-based indoor navigation and AR-based maintenance instructions. An inherent problem of AR is marker definition and detection. As introduced, indoor natural markers such as exit signs, fire extinguisher location signs, and appliances' labels were identified to be suitable for both navigation and maintenance instructions. However, small markers, changing lighting conditions, low detection frame rates and accuracies might prevent the proposed approach from being practical.

In this paper the performance of natural marker detection will be evaluated under different configurations, varying marker types, marker sizes, camera resolutions, and lighting conditions. The detection performance will be measured using a pre-defined metric incorporating detection accuracy, tracking quality, frame rates, and robustness. The result will be a set of recommendations on what configurations are most suitable and practical within the given framework.

KEYWORDS: *Augmented Reality, Facility Maintenance, Natural Markers, Building Information Modeling, Detection Performance*

1. INTRODUCTION

The longest period in the lifecycle of a building is the operation and maintenance (O&M or FM) phase. In this phase facility managers and operators perform activities to provide a comfortable living and working environment as well as to upkeep equipment to prevent functional failures. Since over 85% of the entire lifecycle costs are spent on facility management (Teicholz 2004), improvements to the maintenance procedure will significantly reduce the overall building lifecycle budget.

Today's maintenance practice is characterized by dispersed and unformatted facility information that operators often need to manually browse, sort and select. Although software systems have recently been introduced, 50% of the on-site maintenance time is spent on localizing inspection targets and navigating to it inside a facility (Lee and Akin, 2011). Moreover, linked maintenance instructions are often multi-page documents, which sometimes are difficult to comprehend, in particular, in case of emergencies.

Although some recent research studies propose to use Building Information Models (BIM) by either integrating or linking work order information to them, not all necessary information needed is currently available in a digitally integrated and standardized model. Moreover, available UWB, WLAN, RFID and GPS indoor navigation approaches are validated, but they rely on costly equipment infrastructure for senders and readers. Existing Augmented Reality (AR) based solution use artificial markers for both navigation and maintenance instruction

Citation: Koch, C., König, M., Neges, M. & Abramovici, M. (2013). Performance study on natural marker detection for augmented reality supported facility maintenance. In: N. Dawood and M. Kassem (Eds.), Proceedings of the 13th International Conference on Construction Applications of Virtual Reality, 30-31 October 2013, London, UK.

support. This kind of markers is tedious to be installed all over a facility and also comes along with esthetical issues.

Previously, the authors have introduced and tested a framework that can digitally support facility maintenance operators in performing their daily on-site maintenance jobs combining Building Information Models and natural markers for AR-based support (Koch et al. 2012). The proposed workflow is comprised of three major activities: (1) Digital Work Order Compilation (collecting relevant information), (2) AR-based Indoor Navigation (positioning and navigation), and (3) AR-based Maintenance Instructions (performing maintenance task).

The main contribution of this paper is to conduct and evaluate the performance of natural marker detection within the given framework. For this purpose, we test different configurations in a controlled environment varying marker types, marker sizes, camera resolutions, and lighting conditions. Based on pre-defined metrics incorporating detection accuracy, distances, frame rates, angles, and robustness the detection performance is measured. Finally, a set of recommendations on most appropriate and practical configurations within the given framework is given.

2. BACKGROUND

2.1 Current practices

In today's maintenance and repair practice facility operators need to gather and access dispersed and unformatted facility information in order to handle work orders (Akcamete et al. 2011). Typically, this information is handed over from the building design and the construction phase and is available in form of 2D drawings, spreadsheets, bar charts, field reports and paper-based guidelines. Collected in so-called Facility Document Repositories, the facility handover data is physically space consuming and might occupy an entire room (East et al. 2013). 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 operators in 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. (East et al. 2013, Akcamete et al. 2011).

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 as well as relevant maintenance instruction manuals. According to Lee and Akin (2011), 50% of the on-site maintenance time is solely spent on localizing and navigating. Furthermore, linked maintenance instructions are often multi-page documents, which sometimes are difficult to comprehend, in particular, in case of emergencies.

2.2 Current research efforts

2.2.1 Indoor positioning and navigation

In addition to the location of the maintenance item (available in the BIM), it is necessary to know the operator's position inside the facility in order to support real-time indoor navigation. There is a vast amount of ongoing research in this area. As one example from the construction community, Khoury and Kamat (2009a) have evalutated three different wireless indoor position tracking technologies, in particular, Wireless Local Area Networks (WLAN), Ultra-Wide Band (UWB) and Indoor GPS positioning system. Indoor GPS has been identified as being superior, since it could estimate a mobile user's location with relatively low uncertainty of 1 to 2 cm. The main disadvantage of these technologies is the need for extra equipment installation and maintenance (both tags and readers), which involves a considerable cost factor.

Besides the position, the operator's view orientation needs to be determined to provide both location-aware and viewing direction-aware guidance. Here, sensors such as Inertial Measurement Unit (IMU), a combination of accelerometers and gyroscopes, and magnetic orientation sensors (e.g. a magnetic compass) are utilized. Khoury and Kamat (2009b) have used a solid-state magnetic field sensor, installed on the user's head, to track the user's dynamic viewpoint. This information has then been processed to identify building objects in the user's field to retrieve contextual information. Although, the user's position uncertainty is documented, the orientation accuracy has not been presented nor validated.

2.2.2 Performing maintenance task

Once the operator has reached the target, the third work order activity is the component maintenance. At this stage, he/she needs actual maintenance instructions and manuals. Lee and Akin (2011) have proposed to employ Augmented Reality to superimpose equipment-specific data, such as textual maintenance information and geometry, onto a live video stream (Fig. 1). This supports the fieldworker in better comprehending the on-site job. Even hidden parts of the equipment can be visualized in full scale. However, the main disadvantage is that fiduciary (artificial) markers have to be pre-installed on the component of interest, which is tedious and unesthetic, thus preventing this approach from being practically efficient.

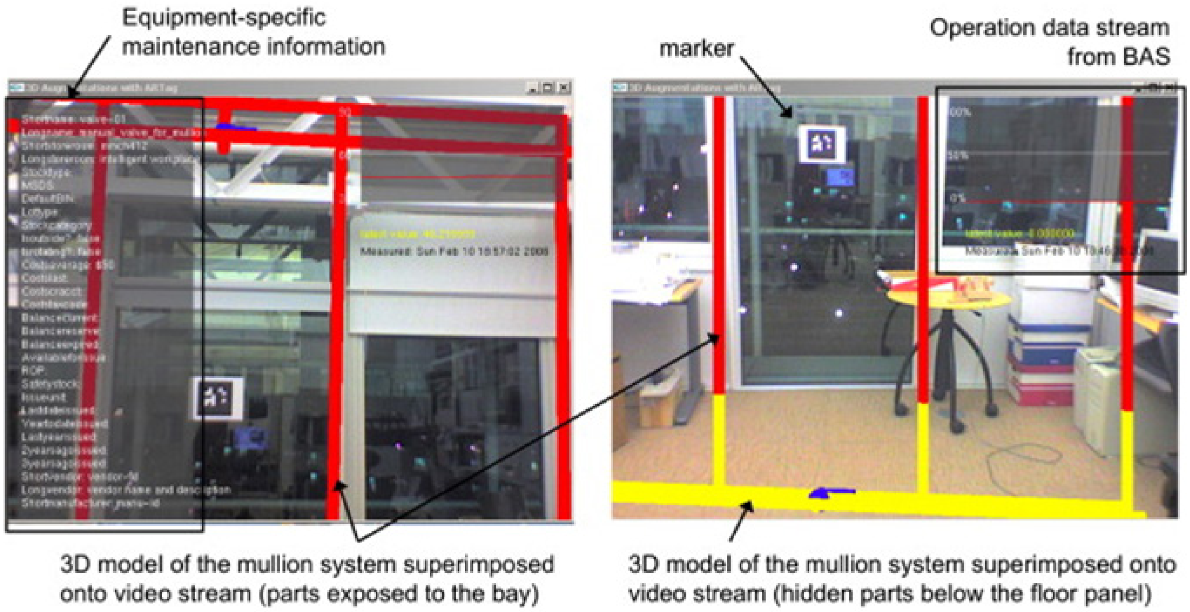


Fig. 1: AR-based computational fieldwork support for equipment operations and maintenance using artificial (ID) markers (Lee and Akins 2011).

In other industries, such as the mechanical engineering, Augmented Reality is used to support maintenance and repair tasks, for example on vehicle equipment such as engines (e.g. Henderson and Feiner 2011). Using a see-through Head Worn/Mounted Display (HWD/ HMD), the mechanic's natural view is augmented with text, labels, arrows, and even animated sequences designed to facilitate task comprehension, localization, and execution. However, the major disadvantages of HMDs are the low display resolution and the separate uncomfortable head-mounted device.

2.2.3 Previously proposed framework

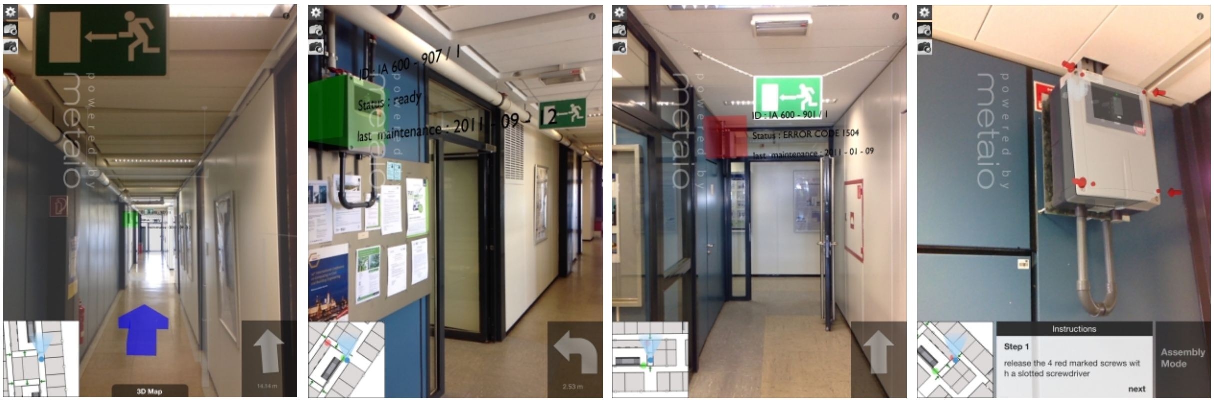
The authors previously presented a BIM-based Augmented Reality framework for facility maintenance using natural markers (Koch et al. 2012). The proposed framework comprises three major activities: digital work order compilation (collecting relevant BIM and FM information), AR-based indoor navigation (positioning and routing), and AR-based maintenance instructions (performing maintenance task). Within the latter two activities so-called natural markers, for example, exit signs, are employed as AR markers. AR markers are very distinctive images with known visual patterns and dimensions that are used as reference objects to superimpose virtual 3D content onto the camera's live view. In contrast to artificial markers, which are practically inefficient and unesthetic to install inside a building, natural markers have the advantage to be already available on-site. Koch et al. (2012) emphasized the potential of exit signs as they are very distinctive due to their color and shape, the have an appropriate size (not too small), and they are clearly visible since the have to be in case of emergencies. Moreover, Koch et al. (2012) implemented the framework on an iPad® 2 using the Augmented Reality framework metaio™ Mobile SDK 3.1 (Metaio 2013) and conducted several experiments in a controlled environment to highlight the potential of the proposed framework.

Promising experimental results of our previous work regarding an AR-supported indoor navigation to a defective smoke detector as well as AR-based smoke detector maintenance instructions are depicted in Fig. 2. A 3D model and 3D navigation arrows (Fig. 2a), 2D navigation arrows (Fig. 2a-c), 3D positions of intact and defective smoke detectors (Fig. 2b, c), animated 3D maintenance instructions (Fig. 2d), and the 2D user position on a map (Fig. 2a-d) are superimposed on the camera life view.

However, in order to validate the complete framework it is necessary to test the performance of the most essential framework part – the natural marker detection. While the previous work of the authors (Koch et al. 2012) introduced the overall framework and highlighted its potential, this paper presents the first specific experimental results on the actual performance of indoor natural marker detection.

2.3 AR markers for optical tracking

In AR applications, optical marker tracking is essential to determine the position and viewing direction of the camera. Based on the nature of the tracking algorithms, several types of markers can be distinguished.



(a) (b) (c) (d)

Fig. 2: Augmented life view: (a) superimposed 3D model, 3D navigation arrow and intact smoke detector position (green box), (b) showing left turn instruction and intact smoke detector (green color), (c) superimposed target smoke detector position (red box) and error code, (d) textual instructions (bottom) and superimposed 3D animated instructions (red arrows) (Koch et al. 2012).

- **ID Markers** are rectangular 2D markers used for simple AR applications. Since they have a fixed structure and distinctive black border they can be easily and very robustly detected and tracked (Fig. 3a). Using the inside pattern a few hundred markers with different encoded information can be configured.
- **Barcodes and Quick Response codes** are optical machine-readable 2D representations of data items. While barcodes are well-known (Fig. 4b), Quick Response (QR) code markers are similar to ID markers as they consist of black square modules arranged in a square grid on a white background (Fig. 3c). Based on that, they can be read by read by imaging devices and interpreted to extract information from the patterns.
- **Picture Markers** are somehow in between ID markers and Markerless. Similar to ID markers the have a strong and distinctive rectangular border. In contrast, however, they can contain any arbitrary image (containing enough visual content) inside the boundary (Fig. 3d). Due to their distinctive border they can be detected faster than borderless markers.
- **Markerless** is the (maybe misleading) term for 2D borderless markers that do not have an explicit rectangular boundary, but need to have moderately textured content. Based on distinctive visual features (e.g. point descriptors) and advanced algorithms they can be robustly detected and tracked (Fig 3e).
- **Markerless 3D** tracking is the most advance optical tracking method that facilitates the detection and tracking of any real world object. However, the 3D object needs to have enough visual features and needs to be scanned from several perspectives in order to determine its distinctive visual features (Fig 3f).

Fig. 3: Different types of AR markers for optical tracking (Metaio 2013): (a) ID marker, (b) barcode marker, (c) QR code marker, (d) picture marker, (e) markerless (borderless) marker, and (f) markerless 3D tracking.

Regarding the proposed framework that suggests using natural markers, such as exit signs, the most appropriate marker type is the picture marker. This is due to the fact that, for example, exit signs as well as fire distinguisher signs have a rectangular shape, a strong boundary and a distinctive inner visual content.

2.4 Problem statement and objectives

As previously proposed by the authors, indoor natural markers such as exit signs, fire extinguisher location signs, and appliances' labels have to potential to support AR-based navigation and maintenance instructions (Koch et al. 2012). However, small markers, changing lighting conditions, low detection frame rates and inaccuracies might prevent the proposed framework from being practical. Moreover, there is no study on the actual performance of indoor natural marker detection available. For these reasons, the objectives of this paper are to design, conduct and evaluate experiments to determine the detection performance of indoor natural markers and to give recommendations on what configurations are most practical within the given framework.

3. PERFORMANCE STUDY METHODOLOGY

3.1 Experimental setup

In order to conduct the performance test we set up a controlled environment in one of our laboratory (Fig. 4a). As depicted in Fig. 4 two different scenarios were designed. While in scenario I a straight walk towards the marker was performed (about 1500 frames per setting), in scenario II a curved path with viewing direction towards the marker was investigated (about 4000 frames per setting). Moreover, we varied the type of the marker (exit sign, fire extinguisher sign, text sign), the size of the marker image template (width of 50, 100, and 300 pixels), and the camera resolution (192x144, 480x360, and 640x480 pixels) (Fig. 4b). The three markers have a natural size of 400x200, 210x210, and 300x160 mm, respectively. In addition, for the exit sign marker we conducted test under artificial lighting condition by switching on the ceiling light in the lab. According to our previous study we implemented the AR test application on an iPad® 2 based on the Augmented Reality framework metaio™ Mobile SDK 4.1.2 using the Picture Marker Tracking functionality (Metaio 2013). To achieve representative results we ran the same test three times for each setting. Moreover, two people of different height and different walking behavior and speed conducted the tests.

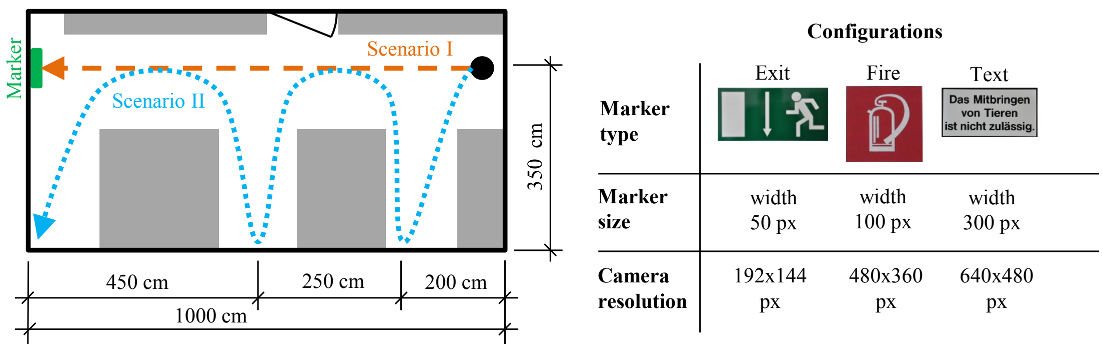


Fig. 4: Experimental setup: (a) controlled environment in the lab, (b) experiment configurations.

3.2 Performance metrics

While running the test, the AR test application recorded performance data, such as the tracking quality, the frame rate, the distance to the marker as well as the horizontal angle to the marker. Based on these values we calculated the following performance metrics.

- **Detection rate:** The detection rate is calculated for every single configuration using the formula below. It is assumed that the number of frames with successful detection is equal to the number of frames with detected distances larger than zero.

detection rate = number of frames with successful detection / number all frames

- **Quality:** The current tracking quality is provided by the metaio SDK. It is a value between 0.5 and 1.0, with 0.5 as minimum quality to detect at all, and 1.0 with (assumed) perfect tracking.

quality = [0.5, 1.0]

- **Frame rate:** The current frame rate is determined by means of the metaio SDK and is calculated as number of processed frames per second.

- **Robustness:** It is assumed that the person walks smoothly and continuously along the designed path at almost the same speed without any jumps in speed and position. Under this assumption the tracking robustness is determined as the relative deviation of the provided consecutive distance and angle values. Thus, it can somehow be understood as detection precision.

4. EXPERIMENTAL RESULTS

4.1 Scenario I: Straight walk

4.1.1 Detection rate

Table 1 depicts the marker detection rates for the diverse settings in scenario I. It is clearly visible that the markers *exit sign* and *fire sign* outperform the marker *text sign*. This is most likely due to the very narrow border of the text sign marker. For this reason we excluded the text sign marker as well as the camera resolution of 192x144 from all subsequent test settings. Moreover, under natural lighting conditions the configuration settings 50-480x360, 50-640x480, 300_480x360, and 300-640x480 performed best. Note the detection rate improvement under artificial lighting condition for the marker exit sign.

Table 1: Detection rate [%] for scenario I (straight walk) depending on marker type, marker size and camera resolution. Note the values for artificial lighting in case of the exit sign marker.

Marker size (width) [px]	**50**	**50**	**50**	**100**	**100**	**100**	**300**	**300**	**300**
Exit sign / Art. light	67.0/63.4	98.9/96.8	98.8/98.8	63.4/61.6	89.3/97.5	88.6/98.6	42.5/59.8	95.6/96.8	93.6/98.3
Fire ext. sign	42.3	95.4	98.4	47.3	96.9	96.9	44.1	97.0	97.0
Text sign	26.8	53.7	54.6	27.7	58.6	67.4	36.7	58.2	70.4
Camera resolution [px]	**192x144**	**480x360**	**640x480**	**192x144**	**480x360**	**640x480**	**192x144**	**480x360**	**640x480**

4.1.2 Tracking quality

Fig. 5 (top) highlights the achieved tracking qualities for the marker *exit sign* and the marker *fire sign*, respectively, plotted with regard to the marker distance depending on the marker size and the camera resolution (e.g 50/630 means: marker size 50px and camera resolution). In case of the exit sign marker the settings 50/480 and 300/640 outperform the other settings. However, in case of the fire sign marker the settings 50/480, 100/640 and 100/480 are best. These findings are both valid for the tracking quality and the achieved maximum marker distance.

4.1.3 Tracking frame rate

In analogy to the quality, Fig. 5 (bottom) highlights the achieved tracking frame rates (only for successful detection) for the marker *exit sign* and the marker *fire sign*, respectively, plotted with regard to the marker distance depending on the marker size and the camera resolution. In general it was found that the camera resolution has a much larger impact on the achieved frame rate than the marker size. Moreover, the frame rate increases while the marker distance decreases. However, all tested settings achieved a suitable average frame rate of 25 to 30 fps.

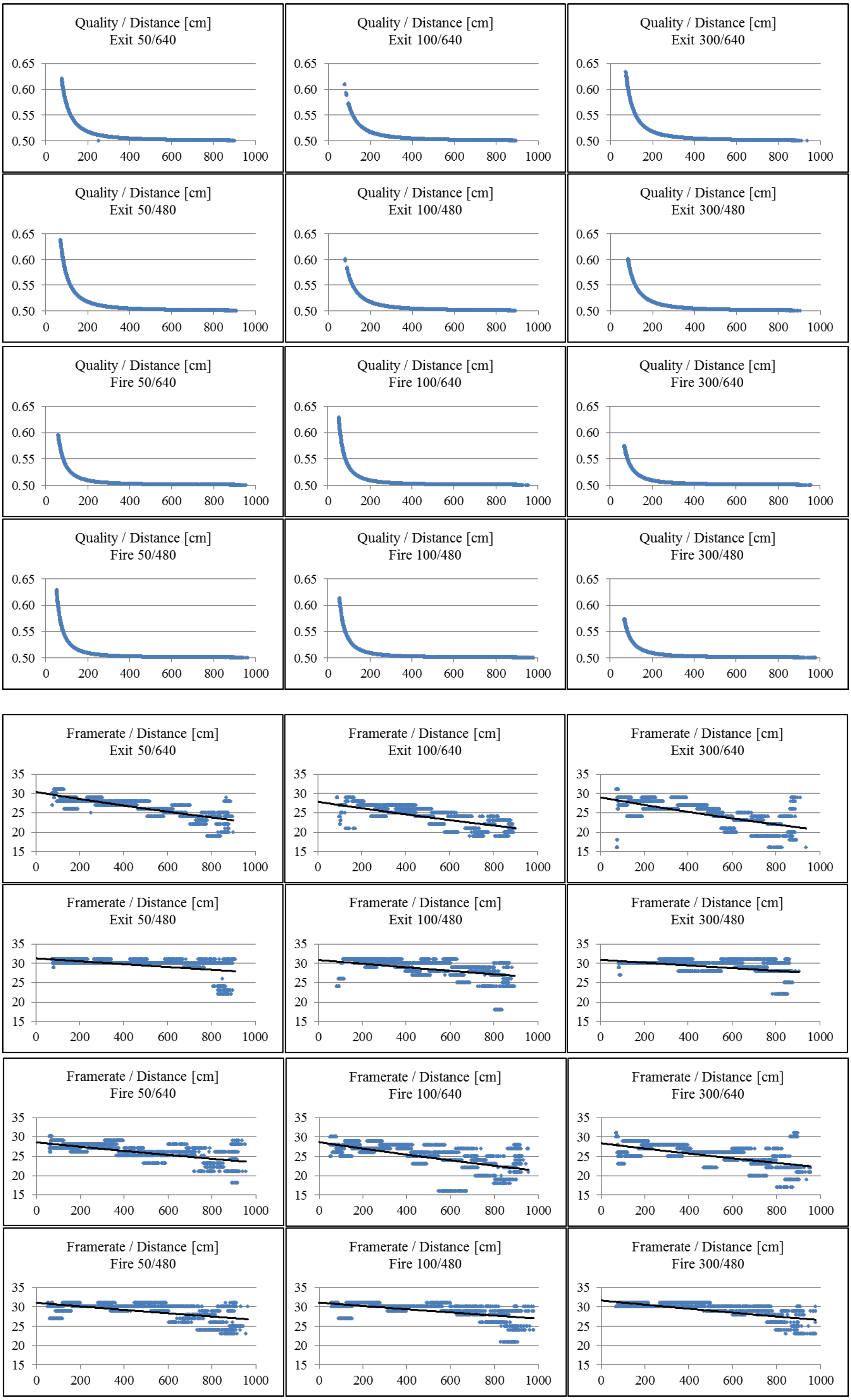


Fig. 5: Tracking quality (top) and tracking frame rate (bottom) for scenario I depending on marker distance.

4.1.4 Tracking robustness

In Fig. 6, the robustness of the marker tracking is depicted, both in terms of distance deviation and horizontal angle deviation plotted with regard to the marker distance. It is clearly visible that the exit sign marker outperforms the fire sign marker as the value corridors are much narrower. Moreover, the maximum distance errors and the angle errors for exit sign marker are much smaller than the corresponding ones for the fire sign marker. However, the maximum errors are justifiable as they are about 50 cm in distance and 20 degrees for the angle.

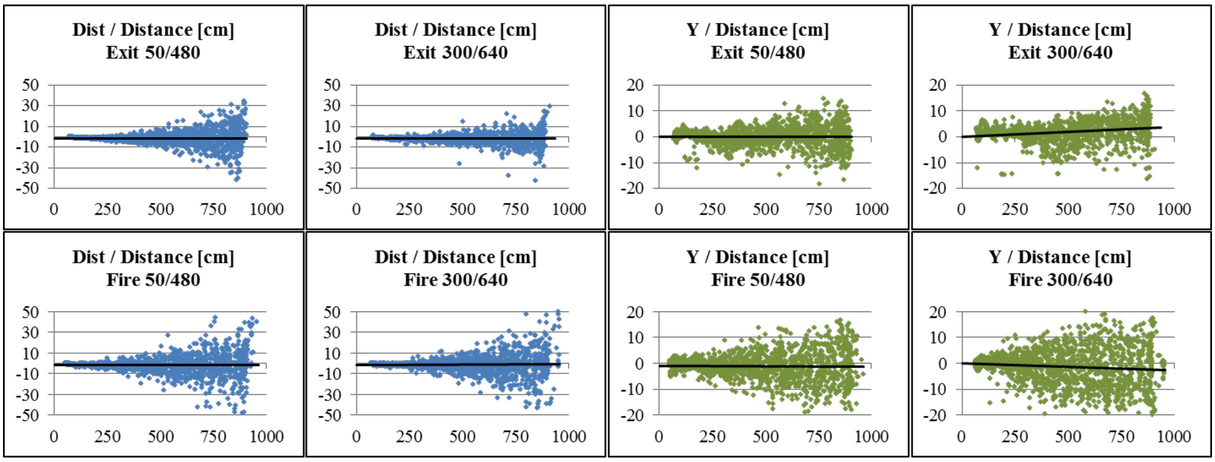


Fig. 6: Tracking robustness for scenario I depending on marker type, marker size and camera resolution.

4.1.5 Lighting condition

Fig. 7 highlights the result that both tracking quality and robustness benefit from artificial ceiling lighting. This is concluded because the tracking quality increases in average from below 0.65 to above 0.65, and robustness corridor for both the distance and angle deviation is much narrower in case of artificial lighting. In addition note the detection rate improvement depicted in Table 1.

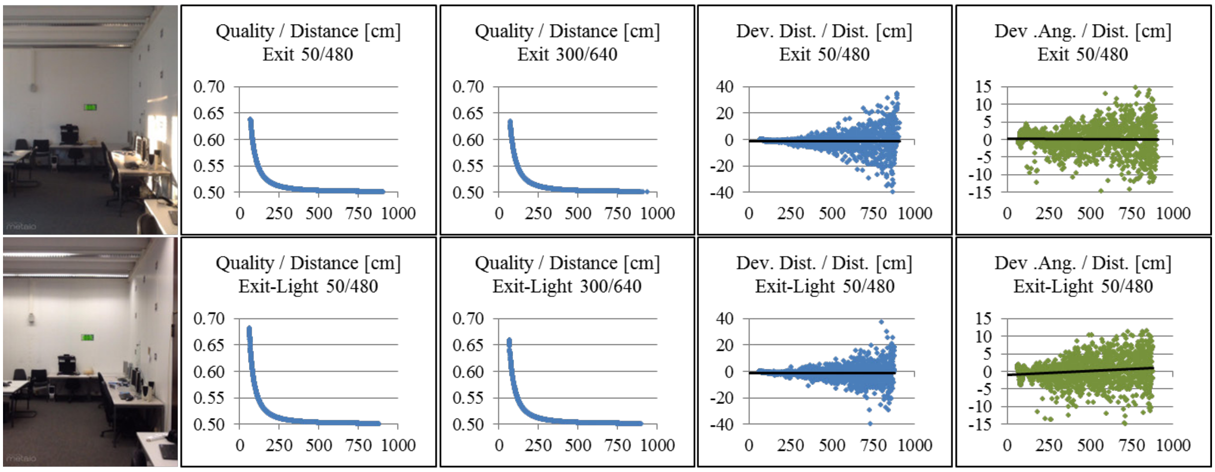


Fig. 7: Influence of lighting condition on tracking quality and robustness for scenario I and exit sign marker.

4.2 Scenario II: Curved walk

4.2.1 Detection rate

In analogy to scenario I, Table 2 summarizes the detection rates for scenario II. Note that the settings 50-480x360, 50-640x480, 300-480x360 and 300-640x480 outperform the other settings.

Table 2: Detection rate [%] for scenario II (curved walk) depending on marker type, marker size and camera resolution.

Marker size (width) [px]	**50**	**50**	**50**	**100**	**100**	**100**	**300**	**300**	**300**
Exit sign	64.14	92.43	95.36	66.99	77.41	77.96	61.39	94.83	93.58
Fire ext. sign	21.65	86.95	89.59	23.70	85.27	89.93	33.04	85.63	90.59
Camera resolution [px]	**192x144**	**480x360**	**640x480**	**192x144**	**480x360**	**640x480**	**192x144**	**480x360**	**640x480**

4.2.2 Tracking quality

Fig. 8 depicts the achieved tracking quality plotted with regard to the detected horizontal angle. Here, the exit sign marker outperforms the fire sign marker. Moreover, the settings 50-480x360 and 300-480x360 seem to be best.

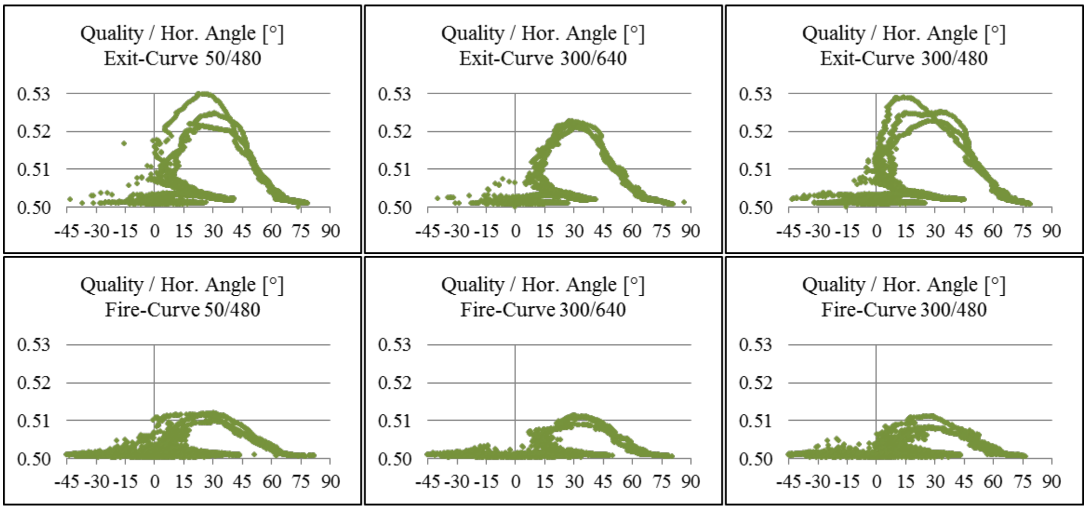


Fig. 8: Tracking quality for scenario II depending on marker type, marker size and camera resolution.

4.2.3 Tracking robustness

Fig. 9 highlights the tracking robustness in terms of the detected horizontal angle plotted with regard to the frame number. Again, the exit sign marker outperforms the fire sign marker as it achieves a less amount of negative, thus wrong angle estimations. However, note the achieved detected angle is almost 85 degrees.

5. CONCLUSION

The longest phase in a facility's lifecycle is its operation and maintenance period, during which facility operators perform activities to provide a comfortable living and working environment as well as to upkeep equipment to prevent functional failures. In current practice operators need to manually process dispersed and unformatted facility information, which takes 50% of the on-site maintenance time for localizing and navigating.

Based on a previously presented framework that suggest to support on-site facility maintenance activities using BIM based Augmented Reality, this paper has highlighted the results of a performance study of natural marker detection. The performance has been evaluated under different configurations, varying marker types, marker sizes, camera resolutions, and lighting conditions. Several metrics, namely detection rate, tracking quality, frame rates, and robustness have been defined to actually measure the detection performance.

To conclude, the presented performance study reveals the high potential of natural markers for AR-based FM support as the detection rate can achieve more than 95%, the marker distance can be about 10 meters, the marker can be detected up to an angle of 85 degrees, and the maximum distance deviations and angle deviations are less than 50 cm and 20°, respectively.

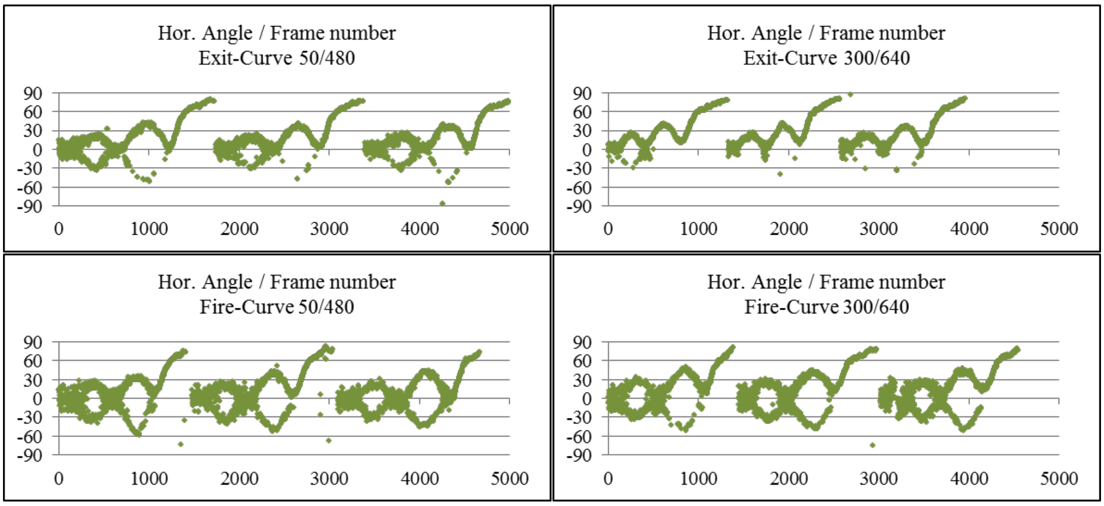


Fig. 9: Tracking robustness for scenario II depending on marker type, marker size and camera resolution.

Based on the presented results, it is finally recommended

- to use natural markers that have a strong, distinctive border with high contrast to the background,
- to have artificial lighting switched on
- to use settings, such as 50-480x360 or 300x640, depending on the desired tracking quality and frame rate

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