DangAR: Prototype of a Collaborative Augmented Reality System for Creating Danger Zones and Real-Time Collision Detection in Industrial Environments

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Figure 1: Exemplary use of the DangAR application in a human-robot collaboration context: a) The user can place a danger zone freely around the robot, b) transform it to the desired location, and c) collaborate with other domain experts in real-time to fine-tune the danger zone spatial configuration.

Abstract

In industrial settings, interacting with machinery poses safety risks. Traditional safety measures, such as physical barriers and warning signs, are often static and inadequate in such settings. We present *DangAR*, an augmented reality system for real-time collision detection and prevention in industrial environments. *DangAR* allows for the definition of hazard zones using an augmented reality application and provides real-time collision prediction and collision detection between workers and machinery. The system leverages cloud anchors for collaborative danger zone marking and employs a headless game engine for collision detection. Alerts are communicated via an event broker to a dashboard and wearable devices, enhancing situational awareness and enabling proactive safety measures. *DangAR* is envisioned for various industrial scenarios, including manufacturing, construction, and logistics.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; *Collaborative interaction*; *User interface design.*

Keywords

augmented reality, human safety, real-time collaboration, danger zones, collision detection

ACM Reference Format:
Vimal Darius Seetohul and Matthias Böhmer. 2024. DangAR: Prototype of a Collaborative Augmented Reality System for Creating Danger Zones and Real-Time Collision Detection in Industrial Environments. In *International Conference on Mobile and Ubiquitous Multimedia (MUM '24), December 01–04, 2024, Stockholm, Sweden.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3701571.3703392

1 Introduction and Related Work

Industrial workplaces, particularly those involving human-machine interaction, present significant safety challenges. Traditional safety measures, such as physical barriers and warning signs, are often static and inadequate in dynamic environments where unexpected hazards can arise. Workers may not always be aware of their surroundings due to complex tasks and limited visibility, increasing the risk of collisions with machinery or other hazards [8, 15].

The use of augmented reality (AR) for safety enhancement in industrial environments is an active area of research. Several studies have explored the potential of AR to improve safety training, hazard recognition, and risk assessment [7, 9–13]. Regarding hazard recognition and collision detection, various techniques have been explored in the context of human-robot collaboration (HRC) [3, 14, 16, 17]. Furthermore, authors have explored the integration of AR with deep learning techniques and heuristics to perform object recognition, hazard detection, and collision prediction for improving collision avoidance systems [1, 2, 4–6, 12].

MUM '24, December 01–04, 2024, Stockholm, Sweden

ACM ISBN 979-8-4007-1283-8/24/12
https://doi.org/10.1145/3701571.3703392

While various collision avoidance systems exist, they often offer limited flexibility for the dynamic nature and collaborative aspects of industrial environments. Many systems rely on static configurations and may not adapt well to temporary setups or evolving workspace layouts. Moreover, the potential of augmented reality for enhancing situational awareness and facilitating collaborative safety planning remains largely underexplored. *DangAR* tackles these limitations through an adaptable solution that leverages augmented reality and real-time collision detection to enhance safety. This is achieved through a combination of safety through prediction (collision prediction) [3, 6], and safety through control (pre-collision detection) [3, 6]. Moreover, *DangAR* encompasses remote monitoring capabilities, which are crucial for timely intervention and proactive safety management.

2 System Overview

The DangAR prototype consists of four components: *DangAR App*, *DangAR Dashboard*, *DangAR Server*, and *DangAR Wearable* (Fig. 2). Three third-party components are used to complete the system: 6 Degrees of Freedom (DoF), inside-out tracking system (*antilatency*[1]), machine, and *Firebase Realtime DB*[2]. The *DangAR Server* and the *Tracking System* are each deployed on a *Raspberry Pi Version 3 Model B+*. The server components are packaged in individual *Docker* containers.

(1) DangAR App: We designed the *DangAR App* to enable the creation of multiple danger zones within a workspace. The app relies on *ARCore*'s cloud anchors[3] to ensure virtual objects placed in the environment are accessible across devices. This multi-user functionality is crucial for collaborative scenarios where teams of safety experts need to mark danger zones in real-time. The use of *ARCore* cloud anchors also ensures that each user sees the same virtual objects in the same physical locations, providing a consistent shared experience. The application's interface features color-coded transformation buttons that align with the gizmo colors for each axis (X, Y, and Z) in 3D space, facilitating manipulation of danger zones (Fig. 1). These zones can be translated, rotated, and scaled in local space, allowing for precise adjustments in their spatial configuration.

(2) DangAR Server: Within the *DangAR Server*, danger zones created by the *DangAR App* are persisted in a *Firebase Realtime Database* and a *CouchDB*[4] database through the *Workspace Manager*. Once the danger zones are persisted, the *DangAR* system can operate independently of the *DangAR App*. The *Collision Detection* service, powered by a headless (*Panda3D*[5]) game engine, checks for discrete collision between tracked objects and defined danger zones. The coordinates of the tracking system, the *DangAR App*, and the *Panda3D* game engine are aligned to each other using a physical marker in the real world. Linear interpolation is used for the collision prediction (pre-collision detection). The tracking data is based on data incoming from the third-party tracking system, which monitors the *DangAR Wearables*. If a collision is predicted or detected, an alert is published to the *MQTT Broker*. The third-party machine can also be programmed to stop in the event of a collision, if the machine has a programmable interface or can be controlled by a relay.

(3) DangAR Dashboard: The workplace is visualized on the web-based *DangAR Dashboard*, which uses *Three.js*[6] as a foundation. Tracked objects can be followed in real-time and collision and collision prediction events are highlighted, if the tracked objects collide with danger zones.

(4) DangAR Wearable: The *DangAR Wearable* consists of an *ESP32* controller and a vibration motor. The wearable is connected to the *MQTT Broker* of the *DangAR Server* to subscribe to collision and collision prediction events. If a worker equipped with the wearable (for instance attached to the lower arm) enters a danger zone and a collision is predicted or detected, the wearable vibrates to signal the danger. Moreover, safety experts can remotely monitor the workspace in 3D through the *DangAR Dashboard*.

3 Envisioned Scenarios

DangAR is envisioned for industrial workplaces, for instance in manufacturing, construction, and logistics, where safety and efficient spatial planning are critical. It enables the marking of dangerous zones around machinery and other hazardous areas, including robots, trolleys, and workstations. The system allows for real-time danger zone definition for temporary setups, which is essential in dynamic environments. It also supports collaborative safety planning with multiple stakeholders, including workers, safety officers, and managers, who can contribute to a safer work environment with their respective expertise. *DangAR* could facilitate the training and onboarding of new employees by providing a visual representation of the danger zones within the workplace layout via the Augmented Reality *DangAR App*. This is particularly helpful for those unfamiliar with the workplace. The system's ability to adapt to dynamic and reconfigurable spaces ensures that safety protocols remain current even when the workplace layout changes. Additionally, the *DangAR Dashboard* enables safety officers to monitor the workplace in real-time and respond promptly to potential safety threats.

4 Conclusion and Future Work

DangAR is an augmented reality system for creating danger zones and real-time collision detection and prevention in industrial environments. It addresses the limitations of traditional safety measures by providing dynamic hazard definition, collision alerts, and collaborative safety planning. The system leverages cloud anchors and a headless game engine for collision detection and visualization. Future work will focus on improving the collision prediction algorithm, adapting *DangAR* to more complex scenarios and layouts, enabling dynamic danger zones, for instance, when the hazardous machine moves close to the user, evaluating the system in a user study, and ultimately improving situational awareness.

[1] https://antilatency.com/
[2] https://firebase.google.com/docs/database
[3] https://developers.google.com/ar/develop/cloud-anchors
[4] https://couchdb.apache.org/
[5] https://www.panda3d.org/
[6] https://threejs.org/

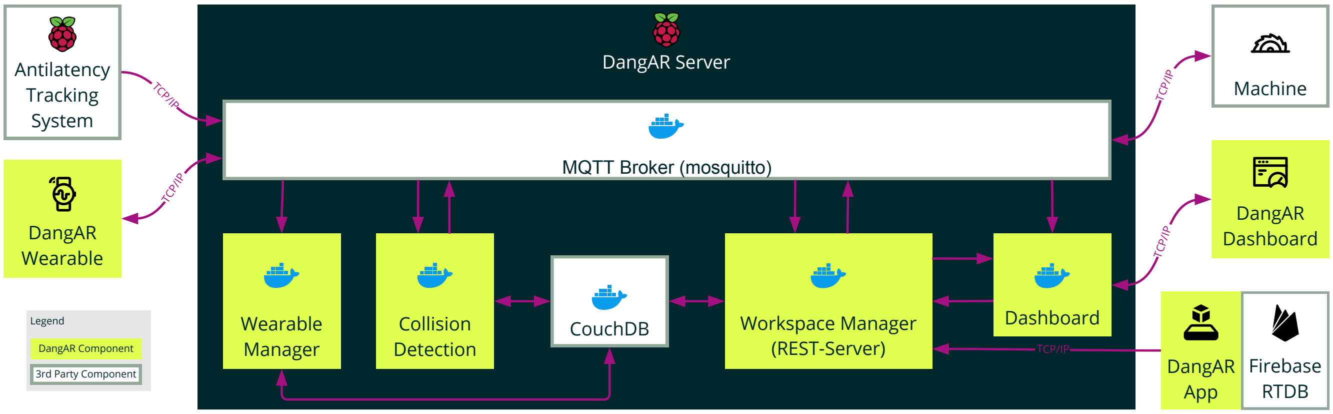

Figure 2: *DangAR* Architecture.

Acknowledgments

This work has been partly funded by the European Regional Development Fund under grant EFRE-20500002 and the German Federal Ministry of Education and Research under grant 02P19K012.

References

[1] Haosen Chen, Lei Hou, Shaoze Wu, Guomin Zhang, Yang Zou, Sungkon Moon, and Muhammed Bhuiyan. 2024. Augmented reality, deep learning and vision-language query system for construction worker safety. *Automation in Construction* 157 (2024), 105158.

[2] Jen-Hao Chen and Kai-Tai Song. 2018. Collision-free motion planning for human-robot collaborative safety under cartesian constraint. In *2018 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, IEEE, Brisbane, Australia, 4348–4354.

[3] Sami Haddadin, Alessandro De Luca, and Alin Albu-Schäffer. 2017. Robot collisions: A survey on detection, isolation, and identification. *IEEE Transactions on Robotics* 33, 6 (2017), 1292–1312.

[4] Akira Kanazawa, Jun Kinugawa, and Kazuhiro Kosuge. 2019. Adaptive motion planning for a collaborative robot based on prediction uncertainty to enhance human safety and work efficiency. *IEEE Transactions on Robotics* 35, 4 (2019), 817–832.

[5] Dana Kulić and Elizabeth Croft. 2007. Pre-Collision Safety Strategies for Human-Robot Interaction. *Autonomous Robots* 22, 2 (Jan. 2007), 149–164. https://doi.org/10.1007/s10514-006-9009-4

[6] Przemyslaw A. Lasota, Gregory F. Rossano, and Julie A. Shah. 2014. Toward Safe Close-Proximity Human-Robot Interaction with Standard Industrial Robots. In *2014 IEEE International Conference on Automation Science and Engineering (CASE)*. IEEE, New Taipei, Taiwan, 339–344. https://doi.org/10.1109/CoASE.2014.6899348

[7] Quang Tuan Le, AKEEM Pedro, Chung Rok Lim, Hee Taek Park, Chan Sik Park, and Hong Ki Kim. 2015. A framework for using mobile based virtual reality and augmented reality for experiential construction safety education. *International Journal of Engineering Education* 31, 3 (2015), 713–725.

[8] Timo Malm, Juhani Viitaniemi, Jyrki Latokartano, Salla Lind, Outi Venho-Ahonen, and Jari Schabel. 2010. Safety of interactive robotics—learning from accidents. *International Journal of Social Robotics* 2 (2010), 221–227.

[9] George Michalos, Panagiotis Karagiannis, Sotiris Makris, Önder Tokçalar, and George Chryssolouris. 2016. Augmented reality (AR) applications for supporting human-robot interactive cooperation. *Procedia CIRP* 41 (2016), 370–375.

[10] Ricardo Eiris Pereira, Masoud Gheisari, and Behzad Esmaeili. 2018. Using panoramic augmented reality to develop a virtual safety training environment. In *Construction Research Congress 2018*. ASCE, New Orleans, Louisiana, 29–39.

[11] Jorge Ramos-Hurtado, Felipe Muñoz-La Rivera, Javier Mora-Serrano, Arnaud Deraemaeker, and Ignacio Valero. 2022. Proposal for the deployment of an augmented reality tool for construction safety inspection. *Buildings* 12, 4 (2022), 500.

[12] Dušan Tatić and Bojan Tešić. 2017. The application of augmented reality technologies for the improvement of occupational safety in an industrial environment. *Computers in Industry* 85 (2017), 1–10.

[13] Georgios Tsamis, Georgios Chantziaras, Dimitrios Giakoumis, Ioannis Kostavelis, Andreas Kargakos, Athanasios Tsakiris, and Dimitrios Tzovaras. 2021. Intuitive and safe interaction in multi-user human robot collaboration environments through augmented reality displays. In *2021 30th IEEE international conference on robot & human interactive communication (RO-MAN)*. IEEE, IEEE, Vancouver, Canada, 520–526.

[14] Marcello Valori, Adriano Scibilia, Irene Fassi, José Saenz, Roland Behrens, Sebastian Herbster, Catherine Bidard, Eric Lucet, Alice Magisson, Leendert Schaake, Jule Bessler, Gerdienke B. Prange-Lasonder, Morten Kühnrich, Aske B. Lassen, and Kurt Nielsen. 2021. Validating Safety in Human–Robot Collaboration: Standards and New Perspectives. *Robotics* 10, 2 (June 2021), 65. https://doi.org/10.3390/robotics10020065

[15] Milos Vasic and Aude Billard. 2013. Safety issues in human-robot interactions. In *2013 ieee international conference on robotics and automation*. IEEE, IEEE, Karlsruhe, Germany, 197–204.

[16] Lihui Wang, Robert Gao, József Váncza, Jörg Krüger, Xi Vincent Wang, Sotiris Makris, and George Chryssolouris. 2019. Symbiotic human-robot collaborative assembly. *CIRP annals* 68, 2 (2019), 701–726.

[17] Angeliki Zacharaki, Ioannis Kostavelis, Antonios Gasteratos, and Ioannis Dokas. 2020. Safety bounds in human robot interaction: A survey. *Safety science* 127 (2020), 104667.