Jannicke Baalsrud-Hauge, Anindya Chowdhury, Prabahan Basu, Sundus Fatima, Jakob Baalsrud-Hauge and Artem Schurig

Data-Driven Warehouse Logistics Concepts

1 Didactical Preface

1.1 Overview of Didactical Fundamentals

Table 1 Overview of didactical fundamentals

Effort in lecture hours (given by the teacher and facilitator)	Theory: 60 min (if on-site, 2 classes; if remote, 3x20) Safety introduction 15 min on-site, 15 min remote Lab operation 120 min (2x3x20 min) 3x20 min of debriefing after class
Effort Self-study (flipped classroom)	Preparation 4 h 4 h for report analysis
ECTS	0.5 ECTS
Pre-requisites	Needs to have completed a basic course on introduction to smart logistics, introduction to CPS or similar. However, this is an intro course with a focus on application and experiential learning.
Additional information	To carry out the experiment, passing a safety test is required A facilitator and a technician need to be on-site in the lab The students should submit lab reports afterwards
Adaptability	The usage of the mixed reality environment is flexible. We have a different set of theories if class is on an advanced level

1.2 Keywords

Sensor, actuators, augmented reality, mixed reality, warehouse operations, risks, production logistics

1.3 Learning objectives

- Know the function and specifications of different types of sensors and actuators

- Understand how sensors and actuators can support data-driven logistics
- Understand the opportunities and limitations of the implemented technology in a warehouse operation
- Apply methods to analyze how the technology affects warehouse operations
- Evaluate how the different technologies can support the decision-making process in warehouse operations
- Create an understanding of how the knowledge gained can be transferred to one's own working environment (only for VET and LLL settings)

1.4 Target Group

This MR game environment is designed to support everyone who wants to understand better how different sensors and actuators can be used in a warehouse environment.

It is designed as a sandbox game and can therefore be used both for those with basic knowledge and practical skills as well as those with advanced skills in ICT supported warehouse operations.

2 Use Case

2.1 User Story

Damage to goods and loss of goods are significant issues within warehouse operations [1]. In addition, there is also a risk that the operators may be exposed to various risks like forklift crashes, collapsing pallet racks, spillage of hazardous materials inside the warehouse, etc. [2]. Even though the likelihood of such events is low, the impact is high, and thus avoiding them is given a high priority. The implementation of the Internet of Things technology to continuously track goods [3] and for better visualization [4] can help to reduce both the likelihood as well as the impact of those risks [5]. To implement, use and rely upon this supportive technology, there is a need for qualification and training of warehouse operators [6, 7] as well as of the management involved in the decision-making process of selecting the right technology for its implementation, taking infrastructural boundaries into account [5, 8]. A gamified mixed-reality environment can be more than a testing environment [6, 9,10]; it encourages the ideation process and helps researchers to analyze problems from different perspectives. During the exploration phase, draft solutions are tested with mock-ups or prototypes and the results are transferred into real environments for experimentation. The usage of gamification techniques in production and logistics has some evidence of effectiveness regarding the understanding of complex processes and systems. This challenge brings into focus the fact that gamification tools need to be capable of adapting to the situation: they should enable real-time dynamics and be open to adaptation and personalization to answer to the user's needs better.

The game environment presented is planned to be the experiential learning part of a course on warehouse operations and management in the current setting. The mixed-reality environment is, however, adaptable and can be used in different settings. In Table 2, we have designed the following description of the learning scenario.

Table 2. Learning Scenario Technology-supported decision-making

Course title	Decision-making technology implementation
Possibility of distance learning	Yes, as a part of the shared lab infrastructure or through access to the games and/or simulations and digital twins
Abstract	The module will be used in both strategic and operative decision-making. The main objective is that the participant should get a deeper understanding of how different technologies can support seamless and transparent information flow and material handling in a warehouse, but also on factors that influence the decision-making process because they are not changeable At the operative level, this will be a decision-making process related to daily operations The KPIs used are those from a first and second-level SCOR model.
Goals and objectives of the course in terms of competence and skills	Apply methods for strategic and operative decision-making for technology introduction (S) and usage (O) Apply knowledge & methods on how to analyze risks and opportunities related to technologies in a warehouse in a supply chain Assessment Design layouts of WMS Understand and assess in-stocking and out-stocking technologies Understand how to implement automated material movement in an existing warehouse area Safety issues related to HCI.

The corresponding game uses an open narrative, where the players get a set of tasks related to typically operational processes in a warehouse, like in- and out-stocking, ordering, picking, and placing, etc. In the current gameplay, the players are first asked to become familiar with the logistics operations and then to evaluate how different IoT technologies can support the operational process in terms of process quality, and efficiency, as well as cost and time reduction versus the implementation and operational costs of the technologies. The narrative then broadens to differences in the goals for individual players—i.e. it can also be used for assessing privacy and ethical issues. It is possible to solely focus on technical implementation, be more specifically related to how to select what types of sensors depending on what we are interested in (humidity, tilt of forklift, temperature, real-time tracking, etc.) and depending on what types of goods we have or to focus more on the flow of materials.

More information can be found in the articles referenced under additional material.

2.2 Tasks

The goal of this unit is that you will experience how different types of sensors and actuators can support your warehouse operations. You will also be able to test how the usage of augmented reality (AR) can support the same operations, but an important takeaway is also to identify the limitations of both sensor and actuator usage as well as AR support.

Before you start your lab exercise:

- Read the introductory article
- Open the video of the forklift operation and start by reflecting on what information you would like to receive. Base your analysis on what you have learned in your previous lessons on warehouse operations and cyberphysical systems
- Read the fact sheet about the different sensors. It is especially important here that you reflect on the details and analyze the warehouse environment you will play in the mixed-reality environment
- Analyze the problem description (we currently have 10 different descriptions of problems)
- Based upon the problem description, design your experimental setup related to
    - Improving overall operational processes
    - Safety issues
    - Efficiency
    - Data-driven warehouse management
- Design the protocol for your experiments and select the choices of sensors and actuators in terms of expected impact they will have on warehouse operations
- Carry out the experiments in the sequence and complete the debriefing (with all your classmates) before you carry out the next experiment.

- Use the replay function in the unity model to analyze the results in terms of the planned and expected results
- Identify any deviations and look for possible reasons.

Self-test

- We have a self-test on safety and risks which you need to pass
- We offer a test on sensors and actuator knowledge, which you may take before you start the experiments
- Define what the functionalities of each component are
  - e.g., sensors read data related to different operations, the devices collect data from sensors and forward them to the central entity and/or process them to control actuators

Exercises

- Analyze the video material
- Remote/physical lab exercise
- Deliver lab report

2.3 Learning Resources

- Introduction to warehouse operations (lecture)
- A set of articles
- Fact sheets
- A set of illustrative videos

3 Introduction to a mixed-reality environment for warehousing operations

Due to changes in the working requirements for people working within production and logistics operations, there is a need for training and educational offers that prepare current and future employees for these requirements. During this lab exercise, you will have the opportunity to try out how different technologies (in this case, sensors, actuators, and augmented reality) can support operations and provide a safer working environment. This introduction describes the mixed-reality environment you will use. It is complemented by a video that gives a more practical overview of the environment. The environment you will use is described in more detail in [5, 6, 8].

3.1 Overview of game flow

The part of the MRLift mixed-reality sandbox game, which is the focus of this lab, is illustrated in Fig. 1.

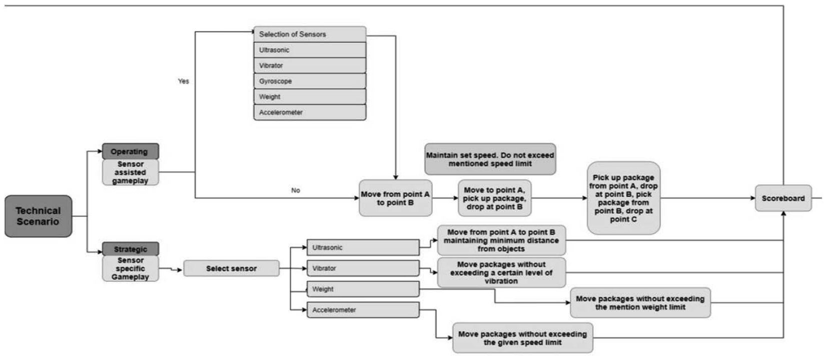

Figure 1 Gameflow Diagram MRLift Sandbox game.

In a lab (remote or physically on-site) or a test bed, gamification approaches can be applied to both the virtual and the physical environment. A part of the purpose of the lab is that you as a student can experiment with different settings. In some cases, you will do that by changing the sensor, while we also foresee that you will deal with the manipulation of data from the physical environment in the virtual (unity model) to support the planning process. The intention is to foster a deeper understanding of how the accuracy of a sensor may be affected. For this purpose, in the virtual part (i.e. the DT), we only map the relevant processes, with the data either imported directly from the physical demo area or reused from a database.

Table 3 shows the design of one of the scenarios realized in line with [9]

		First Feedback on # bumps	Discussion on sensor selection	Move the pallet	Second Feedback on # bumps
Gaming	Action	See performance evaluation	Plan Select	...	See performance evaluation
Gaming	Tools	Performance meter	Multiplayer List of components	...	Performance meter
Gaming	Goals	Collect information	Carry out task	...	Collect information
Learning	Actions	Assess	Compare Discuss	Compare	Assess
Learning	Tools	Tips	Group discussion	Simulation Demonstration	Tips
Learning	Goals	Evaluate the performance	Learn about different sensor applications	Show differences with and without sensors	Evaluate the performance
Intrinsic Instructional	Actions	Quantitatively assess feedback	Present material	Repetition	Quantitatively assess feedback
Intrinsic Instructional	Tools	Performance measure	Limited set of choices	Simulator Checklist	Performance measure
Intrinsic Instructional	Goals	Provide feedback	Elicit performance	Elicit performance	Provide feedback

We have integrated different kinds of mechanics into the decision-making process of a simulation. This includes information on time spent on movement, on how the vehicle has moved, the quality of the service delivered, the selection of different sensors or actuators, etc. The mechanics implemented depend on the specific aim of our investigation, so you may use it in different ways, depending on the problem in question. For a focus on the operating processes, other KPIs (like mistakes, bumps, etc.) would have been of more interest than mechanics. To realize the current prototype, we created the digital twin of a warehouse in which IoT technologies are used.

Figure 2 shows the physical test bed and illustrates one main cause of damage—the in-stocking process. To reduce component size, the demonstrator is not full-scale. Since the purpose of this digital twin is to support learning by using experimental learning methods, we only need sufficiently detailed processes rather than exact physical mapping. However, this also places boundaries on the usability of the twin for different learning goals.

Figure 2 The physical test bed from which we import the real-time sensor data

The digital twin scenario teaches whether and how IoT technologies can improve and enhance warehouse operations. The pedagogical method used is problem-based learning (PBL). This approach calls on the learner to face a real-world problem, analyze it, and present a possible solution. It has been demonstrated to positively affect the learning outcomes of engineering students. The students need to use the digital twin, either with data from the database or from the demonstrator, to assess which technology is best for which problem and to explore the limitations of the technology. As an example, we use an RC-forklift with environmental sensors, e.g., temperature and humidity, and tilt sensors to detect the tilt of the forklift.

3.2 Introduction to the physical lab environment

These sensors are connected with Arduino. Xbee modules send these processed bytes wirelessly to a computer terminal. The user can monitor Xbee frame packets using XCTU software. We use Unity to model 3D data from the data sensed, which requires an interface that shows the data in real-time. It is also possible to do this the other way around—i.e. instead of collecting data from the real-world sensors, we can manipulate the data (perhaps collected from moving objects and sensor data in the first step) and spin them back in the real world, in order to validate the module. However, this has some restrictions—that we need to have the same equipment, so we have not tried it out for the planning process. In addition, in our case, we have objects which pose a certain risk of accidents and injuries—in this case, the import of manipulated data in a real-world need to undergo a safety assessment process before being tested. The idea of the physical scenario is to develop a working replica of the scenario that will be created in the games. To develop that in the physical world, we use a model forklift and add sensors and motors to it. The forklift is then operated, and the data collected by the sensors is transferred back. The sensors used, the reason for the selection of the sensors, and how the sensors can assist the use of the forklift will be discussed in detail by you and your classmates during the debriefing sessions. This is just the basic idea of how the sensors will be implemented on the forklift; more sensors might be added later to enhance its performance.

The objective of extending the digital game with physical components is to increase the players opportunities to experiment with different components (like sensors, actuators, or tracking technologies). The player may then investigate what impact small differences might have on the overall results in a more practical way, and still have the opportunity to visualize, manipulate, and replay the game (in the digital part). To develop that in the physical world, we use a model forklift and add sensors and motors to it. The forklift is operated, and the data collected by the sensors is transferred back. The basic concepts of the physical model are discussed here. The sensors used for this purpose are:

1. Ultrasonic sensors,
2. Vibration sensors,
3. Touch sensors.

Different sensors have different purposes and are installed in the forklift to assist its performance. The sensors are described below.

3.2.1 Ultrasonic sensors

Ultrasonic sensors (also known as transceivers when they both send and receive, but more generally called transducers) work on a principle similar to radar or sonar, which evaluate the attributes of a target by interpreting the echoes from radio or sound waves respectively. Ultrasonic sensors generate high-frequency sound waves and evaluate the echo, which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object.

Figure 3 Example of an ultrasonic sensor

This type of sensor will be used on all four sides of the forklift to determine the distance of the forklift to any surrounding object. The more area the ultrasonic sensors cover, the more accurate the measurement will be. The main purpose of installing the sensor is to alert the forklift driver to nearby surrounding objects.

3.2.2 Vibration Sensors

A vibration sensor's internal structure is like a metal ball that is fixed in a special spring as a pole; around it is the other pole. When the vibration gets to a certain extent, the two poles are connected so as to judge the shock that occurs. A vibration sensor emits a digital signal and is used for vibration detection. This sensor has two contact pins. When an external force is acted upon either by movement or vibration, the sensor's two contact pins are closed, and contact is made between the two pins. When the force is removed, the sensor's terminals return to open contacts.

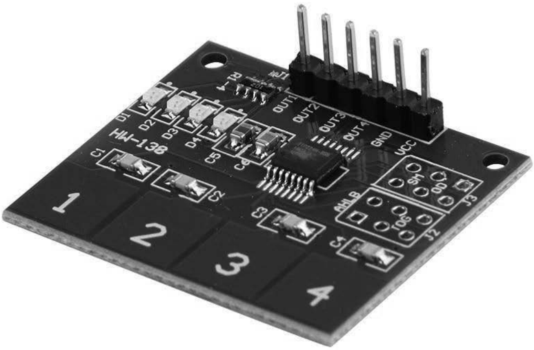

Figure 4: Example of a vibration sensor

The vibration sensor can be installed on the forks of the forklift to measure any kind of vibration. If the vibration limit given is exceeded, an alert system can be installed to alert the driver of the forklift to certain vibrations or irregularities. The vibration sensors can be installed on the forks of the forklift, where most of the vibrations will occur due to the lifting of materials. If the materials create vibrations that exceed the limit, the sensor can create an alert. A vibration sensor can also be installed at the rear end of the forklift for extra safety measures.

3.2.3 Touch Sensors

Touch sensors work like a switch. When they are subjected to touch, pressure, or force they are activated and act as a closed switch. When the pressure or contact is removed, they act as an open switch. A capacitive touch sensor contains two parallel conductors with an insulator between them. These conductor plates act as a capacitor with a capacitance value C0. When these conductor plates come into contact with something, they act as a conductive object. Due to this, there is an uncertain increase in the capacitance. A capacitance measuring circuit continuously measures the capacitance C0 of the sensor. When this circuit detects a change in capacitance, it generates a signal. The resistive touch sensors calculate the pressure applied on the surface to sense the touch. These sensors contain two conductive films coated with indium tin oxide, which is a good conductor of electricity and separated by a very small distance. Across the surface of the films, a constant voltage is applied. When pressure is applied to the top film, it touches the bottom film. This generates a voltage drop which is detected by a controller circuit and a signal is generated, thereby detecting the touch.

Figure 5: Touch Sensor

In this scenario, the sensors can be used to activate certain switches or can be installed on the forks to automatically control the fork's movement after the materials to be lifted come into contact with the touchpads of the sensors. The touch sensor can also be placed under the seat of the forklift, which will signal if a driver is present on the seat. If not, the forklift will not start.

Other sensors can also be incorporated into the model. Infrared sensors can be installed along with ultrasonic sensors. Although they will serve the same purpose, the output of the sensors will be different and will give the user a different perspective on the model. The infrared sensors can also be installed on the sides or on the four corners of the forklift to maximize its coverage area. Weight sensors can be installed under the forklift and a weight limit can be set to avoid carriage of excess weight on the forklift.

Figure 6 the integration of the different sensors in the physical devices

In the above image, dots of three different colors are visible. The different colors signify different sensors. The blue dots signify the ultrasound sensors, the red dots signify the touch sensors, and the green dot signifies the vibration sensor. The dots denote where the sensors will be positioned. The sensors will be programmed using an Arduino, and if the Arduino is used to set up the model, a portable battery will also be installed along with it. A motor is also planned to be installed to be able to run the forklift without human interference. That will require more sensors and accuracy in measurement. Human supervision will always be necessary.

3.3 Currently available sensors and actuators (March 2022)

For each of the sensors and actuators, you will find a fact sheet in the course learning management system. You will also find information on how to use them as well as how to replace the sensors with others if you are in the physical lab environment. If you are in the remote lab, please set up your experiment in advance so that the technician can change it for you.

List of sensors used/can be used for the Forklift

1. Ultrasonic sensors (used)(HC-SR04)
2. RFID sensor (used)(RC-522)

3. Camera (used)
4. Time of flight sensors (used)(VL53IOX)
5. Gyroscope (used)(GY-521)
6. Proximity sensors
7. Pressure sensors
8. Vibration sensors
9. Accelerometer sensors.
10. Touch sensors

Actuator used

1. L298 H-Bridge

4 Evaluation

The usage of this DT is different from the previous examples in which the twins are used for planning and operation. Our evaluation also reflects this difference. The accuracy of the DT is of relevance but not on a level similar to applications used for monitoring and control. Furthermore, since the mixed-reality environment is used for learning, we have to consider different constraints, like the capacity of the human brain to just follow a few variables. The evaluation of one of the first prototypes is described in [6]. This was evaluated by master's students, while the first results of the new mixed-reality environment at the design stage and first prototypical implementations are described in [12, 13] and have so far only been tested by research assistants and researchers. However, the potential users of the sandbox game are an inhomogeneous group both in terms of their experience of warehouse management and operations and of their technical skills. It is therefore imperative that the game can be adapted to suit different learning needs. In the first testing with prototype 2, as shown in Fig.7, we identified the need for an introduction to the topic that is adapted to the player's knowledge, i.e. if a player has no experience in logistics operations, he/she will get a different introduction, support, and feedback while playing than one with more experience. The same would be the case in terms of the technologies used, i.e., the current mock-up related only to sensor selection. A player with little knowledge of sensor technologies, he/she might only choose between the three types of sensors described in the previous section. In contrast, a more advanced player would get the chance to select different types of sensors in the same category to emphasize their deeper understanding. The mock-up testing also revealed the need for better-customized feedback (in our case via tablets) to keep track of what is

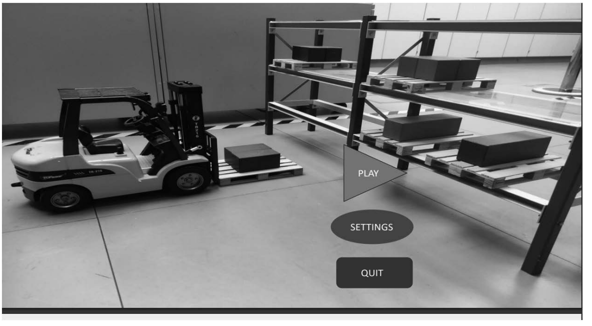

Figure 7 Prototype

relevant and what is not. Based on our experiences with the mock-up, we also introduced (as an integral part of the game) a tutorial. The tutorial's sole objective is to teach players about the game's basic topology and controls. This will broaden the players' general understanding and understanding of warehouses. We also think that, in some cases, it would be suitable to let the player acquire prior knowledge by exploring sensor technology and the interfaces by free roaming in the sandbox mode.

As regards the use of Augmented Reality (AR) with a tablet, we identified in which processes it had the most supportive effect. AR interaction and controls with tablets engage players significantly in terms of interactivity in the learning process while playing games. The realization of this is shown in Fig.8

References

[1] B. Sai Subrahmanya Tejesh, S. Neeraja (2018). Warehouse inventory management system using IoT and open-source framework, Alexandria Engineering Journal, vol. 57 (4), pp. 3817–3823

[2] V. (2017). Four Common Warehouse Accidents and Steps to Prevent Them. MSDSonline. https://www.msdsonline.com/2016/09/21/four-common-warehouse-accidents-and-steps-to-prevent-them/

[3] Zafarzadeh, M. et al. (2021). A Systematic Review on Technologies for Data-Driven Production Logistics: Their Role from a Holistic and Value Creation Perspective. Logistics 2021, 5, 24. https://doi.org/10.3390/logistics5020024

[4] Wang, W. et al. (2020). Application of Augmented Reality (AR) Technologies in inhouse Logistics; E3S Web Conf. 145 02018 (2020); DOI: 10.1051/e3sconf/202014502018

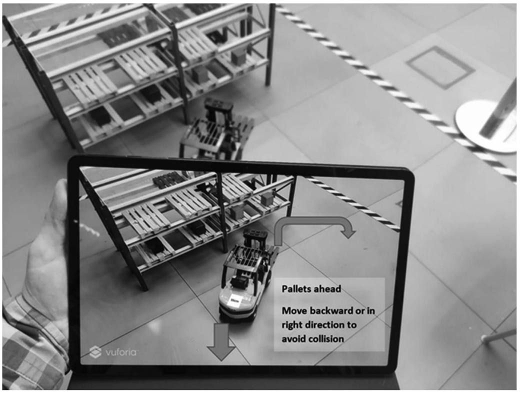

Figure 8 AR supported interaction and feedback GUI

[5] Baalsrud Hauge, J. et al (2020). Employing digital twins within production logistics, ICE conference proceedings. 978-1-7281-3401-7/18/$31.00 ©2020 IEEE 2020 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)

[6] Oliveri, M., et al. (2019). Designing an IoT-focused, Multiplayer Serious Game for Industry 4.0 Innovation. IEEE ICE/ITMC https://doi.org/10.1109/ICE.2019.8792680

[7] Leal, L.F. et al. (2020). Starting up a Learning Factory focused on Industry 4.0, Procedia Manufacturing, vol. 45, 2020, pp. 436–441, ISSN 2351-9789

[8] Baalsrud Hauge et al. (2021). Design of a Mixed Reality Game for Exploring how IoT Technologies Can Support the Decision Making Process, In International Conference on Remote Engineering and Virtual Instrumentation 2021

[9] Carvalho, M. B., Bellotti, F., Berta, R., De Gloria, A., Sedano, C. I., Baalsrud Hauge, J., Hu, J., & Rauterberg, M. (2015). An activity theory-based model for serious games analysis and conceptual design. Computers & Education, 87, 166–181.

[10] Baalsrud Hauge J.B., Zafarzadeh M., Jeong Y., Li Y., Khilji W.A., Wiktorsson M. (2020). Digital and Physical Testbed for Production Logistics Operations. In: Lalic B., Majstorovic V., Marjanovic U., von Cieminski G., Romero D. (eds.) Advances in Production Management Systems. The Path to Digital Transformation and Innovation of Production Management Systems. APMS 2020. IFIP Advances in Information and Communication Technology, vol. 591. Springer, Cham. https://doi.org/10.1007/978-3-030-57993-7_71

[11] Baalsrud Hauge, J. et al (2020). Employing digital twins within production logistics, ICE conference proceedings. 978-1-7281-3401-7/18/$31.00 ©2020 IEEE 2020 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)

[12] Baalsrud Hauge J.B., Chowdhury A., Basu P., Fatima S., Schurig A. (2021). Designing a Mixed-Reality Sandbox Game on Implementation in Inbound Logistics. In: Fletcher B., Ma M., Göbel S., Baalsrud Hauge J., Marsh T. (eds.) Serious Games. JCSG 2021. Lecture Notes in Computer Science, vol. 12945. Springer, Cham. https://doi.org/10.1007/978-3-030-88272-3_4

[13] Fatima S., Baalsrud Hauge J., Basu P., Baalsrud Hauge J., Chowdhury A., Schurig A. (2021). Investigating Impact of Augmented Reality on Game Design to Facilitate Learning Experiences in Logistics Operations Using Immersive AR Interfaces. In: Baalsrud Hauge J., C. S. Cardoso J., Roque L., Gonzalez-Calero P.A. (eds.) Entertainment Computing – ICEC 2021. ICEC 2021. Lecture Notes in Computer Science, vol. 13056. Springer, Cham. https://doi.org/10.1007/978-3-030-89394-1_34

Authors

Prof. Dr.-Ing Jannicke Baalsrud Hauge
Bremer Institut fuer Produktion und Logistik (BIBA)
KTH Royal Institute of Technology
Hochschulring 20
28359 Bremen, Germany
Kvarnbergagatan 12
15181 Södertälje, Sweden
https://www.kth.se/profile/jmbh;https://www.biba.uni-bremen.de/institut/mitarbeiterinnen/homepage.html?nick=baa
baa@biba.uni-bremen.de; jmbh@kth.seX

Anindya Chowdhury
Bremer Institut fuer Produktion und Logistik (BIBA)
Hochschulring 20
28359 Bremen, Germany
https://www.biba.uni-bremen.de/institut/mitarbeiterinnen/homepage.html?nick=cho
cho@biba.uni-bremen.de

Prabahan Basu
Bremer Institut fuer Produktion und Logistik (BIBA)
Hochschulring 20
28359 Bremen, Germany

Fatima Sundus;
Bremer Institut fuer Produktion und Logistik (BIBA)
Hochschulring 20
28359 Bremen, Germany
https://www.biba.uni-bremen.de/institut/mitarbeiterinnen/homepage.html?nick=fat
fat@biba.uni-bremen.de

Jakob Baalsrud Hauge
Bremer Institut fuer Produktion und Logistik (BIBA)
Hochschulring 20
28359 Bremen, Germany

Artem Schurig
Bremer Institut fuer Produktion und Logistik (BIBA)
Hochschulring 20
28359 Bremen, Germany
https://www.biba.uni-bremen.de/institut/mitarbeiterinnen/homepage.html?nick=sch
sch@biba.uni-bremen.de