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The Logistics Lab: From a one-week block lab to an asynchronous hybrid course

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Abstract

The article describes, driven by the Corona pandemic, how the "Logistics Lab" laboratory course was/is being transformed from a conventional face-to-face block course into an online and now hybrid format. The pandemic acted as a catalyst for change, as concepts had to be recapped and realigned within a short period of time. The chair's aim consists in finding an advantageous balance between further development on the one hand and the retention of established content and teaching concepts on the other.

Der Beitrag zeigt, wie das Praktikum „Logistics Lab“ vor dem Hintergrund der Corona-Pandemie von einer konventionellen Präsenzveranstaltung erst in ein Online- und anschließend in ein Hybridformat überführt wurde bzw. wird. Die Pandemie übernahm dabei die Funktion eines Entwicklungsbeschleunigers, da bestehende Konzepte binnen kurzer Frist hinterfragt und neu ausgerichtet werden mussten. Dabei besteht der Anspruch des Lehrstuhls, eine vorteilhafte Kombination zwischen einer Weiterentwicklung einerseits und der Beibehaltung etablierter Inhalte und Lehrkonzepte andererseits zu erreichen.

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1. Introduction

Lab courses are a core element of engineering education. They allow students to apply and recap theoretical knowledge in a practice-oriented context and thus acquire job-related, practical competences (cf. [1]).

The design of lab courses is complex and challenging. An existing concept will usually be applied over multiple semesters. However, against the background of the Corona pandemic and managing regularly changing requirements, a high degree of flexibility and speed of adaptation was and is necessary. The aim of the chair is to achieve a suitable balance between refining the lab course on the one hand and the retention of tried and tested concepts on the other.

This paper describes how the course "Logistics Lab" has been and still is being transformed from a conventional face-to-face lab course into an online and subsequent, hybrid format. For this purpose, in this paper the lab course is first described regarding its focus and its content (see Sections 2 and 3). Subsequently, the individual development stages are shown (see Section 4). A special focus is given to two aspects: the analysis of the students' results from the online-based lab course format documented in the submitted reports (see Section 5) and the extension of the course's content by a novel data transmission technology (see Section 6). Section 7 summarizes the contribution, with special focus on the findings of the transformation process.

2. Classification of the lab course

The "Logistics Lab" is an application-oriented course offered by the Chair of Material Handling and Logistics Engineering on a semester basis. Its objectives are to give students of all semesters and different disciplines without domain-specific prior knowledge an understanding of using actuators, sensors, and their programming by applying simple models.

The lab course is designed to support students in acquiring skills in the areas that are typical for engineering courses (cf. [2]), in detail:

- to grasp the necessary basics by researching literature,
- to conduct simulation studies and interpret their results,
- to design, conduct, and evaluate experiments to derive appropriate conclusions,
- to evaluate the significance of experiments by error analysis and considering uncertainties, and
- to evaluate the design of equipment and processes.

In accordance with the chair's research topics, the focus of this lab is on tasks concerning the control and dimensioning of transport systems for intralogistics applications. The contents of the "Logistics Lab" are based on the current research focus of the chair—especially the control of automated guided vehicles (AGVs, see Figure 1) with special focus on task-to-vehicle assignment, route selection, and position detection.

Figure 1: Example of an AGV in intralogistics [3].

In total, there are 15 Lego Mindstorms robots and 15 Turtlebot platforms available for the lab course (see Figure 2). Both systems are designed for lessons at schools and universities and allow the development of driving robots on a small scale. They provide a low threshold into first robotics applications, but also complex projects.

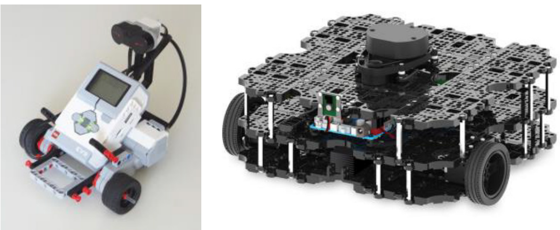

Figure 2: AGV transport vehicle models—Lego Mindstorms (left) and Turtlebot (right) [4], [5].

3. Content of the lab course

Having the aim to provide low-threshold participation in the course, a major challenge is the design of tasks that comply with a wide range of students’ prior and specific knowledge. Methods from the field of "gamification" are used to encourage the students and support the learning objectives’ achievement (cf. [6], [7]). This allows teaching technology and practical elements playfully and provides a low risk of injury or damage.

Basically, there are three subtasks within the scope of the lab course. These are based on the planning, launch, and control of a transport system (cf. Figure 3).

Subtask (1) is about creating a theoretical operational plan for all vehicles to execute given transport orders in minimal time (Makespan). This is a typical problem in intralogistics and usually clearly defined in mathematical models. Unfortunately, for solving these models, there is no dominant and generally applicable procedure or algorithm (cf. [8]). In the field of research as well as in teaching, there is always the challenge of managing the ambivalence between solution quality and effort.

In subtask (2), a Turtlebot or Mindstorms robot vehicle needs to be programmed so that a series of specified experiments can be carried out to characterize the driving behaviour. For this purpose, the students must design and run experiments and evaluate the results.

Subtask (3) combines the insights of the two previous subtasks: the results of the operational planning from a theoretical perspective and the results gained from the vehicles’ experiments. Both need to be combined to critically reflect the transferability of planning and control approaches into practice.

The lab course allows and requires the independent and practical application of existing prior knowledge. To increase motivation, the "Logistics Lab" encourages mutual exchange and competition for the "best" solution (e.g., operational plans with short execution times).

The tasks are designed to be solved collaboratively through group work. The students are only faced with given goals, but no specific solutions or methods are given. Each group has to find its solution through prior knowledge, creativity, and "engineering expertise". In an initial lesson, basic aspects of the lab course are presented. This includes the scientific field, the industrial application of AGVs and a basic introduction to methods required to tackle the lab. Supplementary literature references give clues for independent research. During the semester, teachers remain passive. Questions will be answered as needed in consultations and/or OPAL forums (learning platform OPAL, see https://bildungsportal.sachsen.de/opal/).

Transparent, practical evaluation criteria are provided as benchmarks to assess the quality of the students’ solutions. These serve primarily to reflect the groups' own performance but also the competition between the groups and thus to encourage improvements. Students gave feedback that the mutual comparison in the informal competition for the best solution is seen as an enrichment.

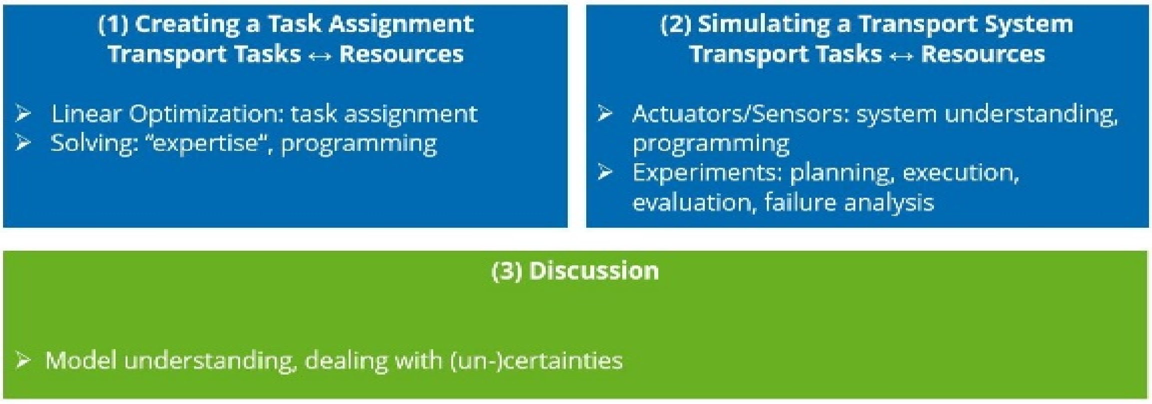

Figure 3: Overview of subtasks (1) to (3) and their contents.

A final report serves as the basis for examination. It should document the procedure and results in a comprehensible form. Due to the high degree of freedom in processing the tasks, the applied approaches have to be discussed self-critically. Potential for improvement identified during the semester should be focused on in the report and thus contribute to the student's process of gaining knowledge.

In a joint final lecture, the solutions and achieved results are discussed. The chair will provide an insight into current developments in industrial applications and research to demonstrate the transferability of the approaches developed by the students and outline development possibilities.

4. Developments in the Corona pandemic

In its history, the "Logistics Lab" was affected by two major developments. On the one hand, the event developed from an elective (for general qualification) to a regular course as part of a module. This led to an increase in participants from about 10 to 60 per semester. In addition, the Corona pandemic, and in particular the demand to avoid face-to-face teaching, forced established concepts to be questioned. In the following, the three stages of development of the "Logistics Lab" are shown.

Initial: The on-site lab course

Initially, the lab course was held as a block course with fixed laboratory working hours. The task was the development of a logistics system with robotic vehicles made from numerous individual Lego parts (cf. Figure 4) to perform transport and storage tasks (e.g., storage of items on a shelf). The focus was thus on the realization of basic functions, with relatively low requirements in terms of system control.

The format was characterized by an intensive exchange between all participants, which was highly appreciated by the students. At the same time, the supervision effort was relatively high for a few participants.

It was found that the students generally spent too much time setting up the system and managing faults. It was therefore concluded that the use of less complex systems with a focus on individual intralogistics components seems more appropriate to meet the set of teaching objectives.

Figure 4: Experiment/model setup of the on-site course: robotic vehicles and intralogistics components.

Revision 1: online and asynchronous

Due to an expected increase in the number of participants and the Corona restrictions, a redesign of the lab course was necessary while maintaining the intended learning objectives.

Basically, the course was adapted so that students were able to complete tasks in group work without the need to be on-site. Experiments were rethought to be carried out using a single robotic vehicle, and necessary parts were handed out at the beginning of the semester (see Figure 5). Instead of complex Lego setups in the chair's own laboratory, the focus shifted to planning the use of the vehicles—which also enhanced the content of the practical course: operational planning is not trivial, requires system-thinking, and thus a high degree of creativity as well as the ability to implement own ideas in terms of programming.

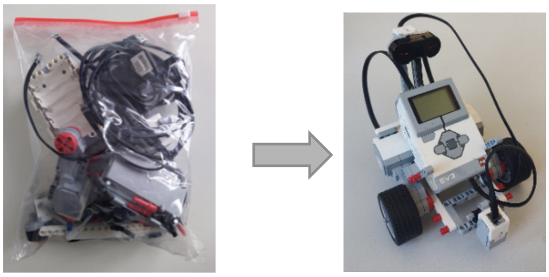

Figure 5: Hand out to perform experiments: components (left) and assembled robot vehicle (right).

To provide flexibility, after an initial lesson, fixed dates during the semester were avoided, which allowed individual time management. The groups were thus able to work independently and asynchronously. The learning platform OPAL and especially the associated forum for the course played a central role in terms of supervising the students, answering and documenting questions, and exchanging intermediate results. Contrary to expectations, the offer of the chair to use the facilities of the university for processing as needed has not been used so far.

The application of the revised concept was accompanied by a considerable increase in efficiency in supervision, especially because presence at fixed times on-site in the laboratory was no longer necessary. To the benefit of both sides, it was now possible for students to work independently. Furthermore, distance learning students were also able to participate in the lab course. The effects of these measures, i.e. an overview and a classification of the results achieved in the practical course, are given in Section 5.

Revision 2: hybrid with final event in the laboratory

Despite the advantages mentioned above, the online concept shown in the paragraphs before revealed two crucial disadvantages: first, it rather remained unclear that the subdivision into subtasks (cf. Figure 3) not only served for structuring but intentionally targeted the understanding of interacting entities in intralogistics systems. The learning outcome and the teachable content were limited to the individual sub-aspects. On the other hand, the general concept of the course offered a platform for collaborative work and thus an opportunity to exchange interdisciplinary. However, the spatial and temporal separation prevented the generation of possible novel value.

To overcome the disadvantages mentioned above, the online concept was combined with elements of classroom teaching again. A hybrid initial lesson, in presence and parallel online, serves to convey the basics and organizational topics, to get to know each other, to find groups, and to hand out course material. These points were previously characterized by considerable efforts, primarily due to the anonymity of the communication channels used (e.g., web conferences). With a closing lecture in hybrid, on the one hand, a new learning experience is created, and on the other hand, the achievements obtained are appreciated. The solutions developed by the groups will interact in a jointly experiment, be analyzed, and discussed regarding their functionality. The focus will be on the live evaluation of the data. The experiment will be online video streamed.

In detail, a transport system with several vehicles will be set up, and transport orders will be executed in a test environment. For this purpose, the students integrate their robot vehicles and developed software components into a joint system and complete experiments, such as the processing of an operational plan. The goal is to test the control approaches developed during the semester and to comprehensively evaluate the system's performance.

A wireless network is being set up for recording and processing the required data. This is to enable the exact logging of the processing of transport orders, even when several vehicles are used. For this purpose, the laboratory will not be equipped with "conventional" radio technology but with a solution based on light waves, so-called Visual Light Communication (VLC, see Section 6). So, in addition to the pure functionality, state-of-the-art technologies and techniques are used, and a high degree of actuality is conveyed.

Comparison and critical evaluation of the developed teaching concept

In the following, the three development stages of the “Logistics Lab” Initial (I), Revision 1 (R1) and Revision 2 (R2) are summarized and compared.

Format:

- I) Block lab course on-site
- R1) Online and asynchronous
- R2) Hybrid

Number of participants:

- I) Up to twelve students
- R1) Up to sixty students
- R2) Up to sixty students

Role of teachers:

- I) Active supervision of the entire lab course.
- R1) Primarily passive accompaniment, e.g. through consultations.
- R2) Primarily passive accompaniment, e.g. through consultations, and active accompaniment when conducting the joint experiments.

Equipment used:

- I) Logistics system with various components

- R1) Single robot vehicle
- R2) Single robot vehicles are combined across groups using a communication network to form a joint system.

Location of experiment execution/processing:

- I) In the laboratory
- R1) Outside the university
- R2) By arrangement in the laboratory, preferably outside the university, with joint completion in the laboratory.

Examination:

- I) Report
- R1) Report
- R2) Report

The three teaching concepts have in common that students are faced with goals to achieve without providing specific ways of solving them. The objective is to complete the tasks independently within the groups. The focus is on generating solutions that meet the specified requirements in terms of functionality. The quality of the solutions achieved (e.g., duration of the processing of all transport requests) is of secondary importance.

5. Analysis Revision 1

The asynchronous online format of the lab course in Revision 1 requires a high degree of self-reliance from the students. In addition to the organization of the group work, methods for processing the tasks have to be chosen and implemented. In the following, selected analyses of the submitted results/reports are presented to discuss the quality of the results and methodological deficits.

The analysis covers three semester periods and in total 35 groups, each with approximately three students. Of these, 29 groups submitted a report at the end of the semester.

Subtask 1 of the "Logistics Lab" is challenging: An algorithm to solve the optimization problem of task-to-vehicle assignment (resource planning) must be developed, implemented, and tested independently. Apart from two groups, all groups were able to present valid (in the sense of meeting all given restrictions) results.

Students are asked to independently design and discuss multiple approaches, if necessary, using "engineering expertise". Figure 6 uses a boxplot to show how many (different) approaches were investigated by each group.

Most of the groups describe one or two approaches. Usually, there is a basic approach and an optimized version. Groups that only present one solution method typically do an intensive analysis in advance. In some cases, three or more approaches are presented to increase the quality of the solution.

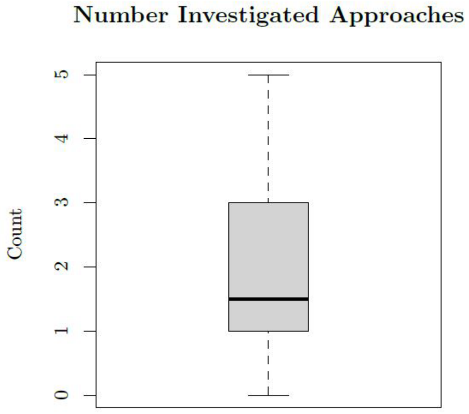

Figure 6: Number of described approaches for solution generation.

An adequate solution is characterized by vehicles traveling as little as possible in an unloaded state ("empty runs"). This basic principle was recognized by the majority of the groups. So, students intuitively came up with heuristic solution strategies, which are typically used in practice.

In parallel, some groups use meta-strategies (e.g., simulated annealing), which are common for solving optimization problems and tend to provide a better solution quality in terms of efficient operational plans—but at the price of higher computational efforts.

Rarely, exact solution strategies (to provide optimal solutions) were applied. Students obviously recognized that these approaches are unsuitable, as the given problem size results in high computation times.

The analysis of the discussions in the reports regarding the approaches used reveals that, compared to a predefined solution path, students delved into the topics. This can be seen in the solution quality: Figure 7 shows the achieved objective function values of the groups in relation to the provided reference solutions. The so-called Makespan was evaluated, i.e. the time span in which all transport tasks were completed and vehicles returned to their specified parking positions. Results for scenarios with one, three, and five transport vehicles are shown.

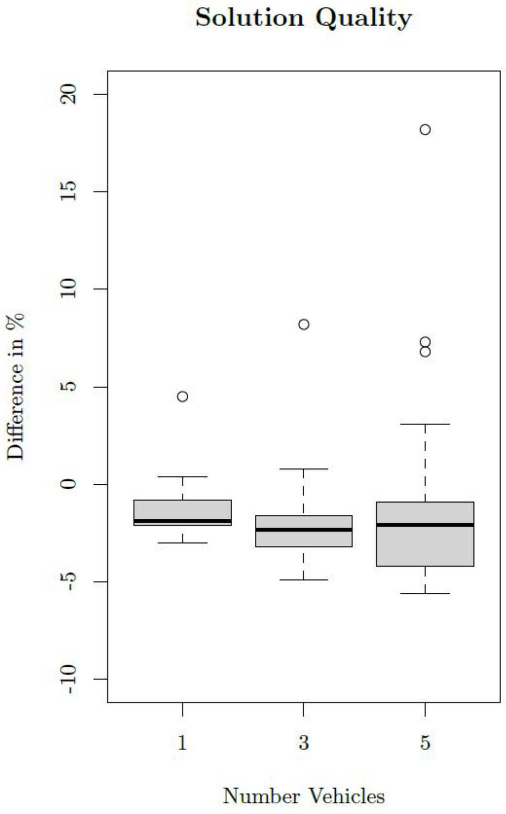

Figure 7: Achieved solution quality measured in percentage deviation from the (provided) reference solution depending on the number of robot vehicles to be considered. Negative values outperform the reference value.

The majority of groups outperformed the reference solutions, that is, the generated operational plans can be processed more quickly. On average, an improvement of 1.5 %, in some cases even up to 6 %, was achieved compared to the reference values. The range of deviation from the specified reference value increases with the problem size (increasing number of vehicles).

The evaluation also shows that solution methods that provide good results for a specific scenario (e.g., one vehicle) are not necessarily advantageous for other scenarios. Most of the students recognized that operational planning is a challenging task lacking a superior solution method, both in theory and in practice.

In summary, students' solution approaches reflect previous research activities regarding the control of automated guided vehicles in terms of diversity and the solution quality achieved (cf. [8], [9]).

For generating the operational plans, no prerequisites are given, i.e., whether and which programming environments to be used. So, students have to apply skills they already have from former courses. From the reports, it becomes clear that initial solutions mostly base on basic considerations and/or created manually. Afterward, software support was used. Even though Java and C# are primarily taught in basic mechanical engineering courses, Python is the dominant programming language applied in this course (67 %, see Figure 8). Software tools such as Matlab and Excel are also used.

Overall, the groups managed to generate operational plans automatically using a self-created program and test them for validity using a provided script.

The solutions or operational plans generated in subtask 1 must be critically discussed in the remaining subtasks regarding their applicability and transferability for controlling real systems, considering experiments with a robot vehicle.

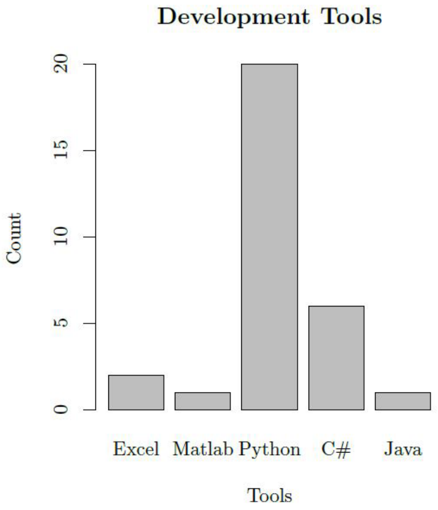

Figure 8: Overview of the frequency of programming languages used for generating operational plans (n = 30).

So far, all participating groups have succeeded in programming the robot vehicles. There were differences in the experimental design and the statistical evaluation of the performed experiments. In particular, the determined number of repetitions of the experiments in most of the cases happened unsystematically, i.e., less according to aspects of statistically valid experimental design than according to pragmatic aspects (cf. Table 1). Most groups determined 10 experiments, or "as a precaution", a particularly high number (> 20). To sum up, there is a methodological deficit.

In subtask 3, all groups succeeded in assessing the transferability of the solutions or the underlying processes to practical applications. For this purpose, the given assumptions were critically discussed. The fact that stochastic travel times are particularly problematic for sequence planning (assuming static values) was usually unrecognized. Looking back and critically questioning the concept of the "Logistics Lab", one reason can be the separation of tasks and, as a result, a lack of perception of an automated guided vehicle system as a dynamic system.

Table 1: Experimental design of protocols—observed frequency of the number of experiment repetitions performed.

Experiment repetitions	Observed frequency in the reports
1	2
3	2
4	1
5	4
7	1
8	1
10	12
20	4
23	1
30	1

For the evaluation, a protocol, or report on the work performed and algorithms implemented, has to be prepared by the students. Again, students are faced with the greatest possible flexibility, with the aim of teaching them to appropriately determine form and scope for summarizing their results.

29 groups submitted a text-based report, often showing more than 30 pages. Two groups submitted presentation slides. Suitable forms of representation, such as pseudocodes and/or UML diagrams, are regularly used to describe the algorithms. Overall, however, descriptions are often too detailed. It is a challenge for the majority of the groups structuring their ideas and present them in a comprehensible form. This deficit should be counteracted in the future by supplementary materials, e.g. based on a "best practice" for a similar task, for self-study.

Regarding the way of organization, the course is characterized by a high degree of autonomy among the groups. Questions concerning the content and organization are answered primarily via the OPAL forum. The majority of the participating groups contributed by sharing interim results, which also allowed them to assess their work. Additionally, available online consultations by the chair are, on the whole, neglected.

As a result, the tasks given to the students are suitable for achieving the learning objectives set. Remarkably, the deficiencies of the work are primarily in interdisciplinary competencies, such as experimental design and documentation. To tackle this, supplementary materials are provided, and shortcomings of past semesters are discussed. In addition, students are asked to present an interim report in a joint lesson in the middle of the semester to allow for constructive advice.

6. Visual Light Communication

As mentioned in the previous chapters, VLC technology (VLC: Visual Light Communication) will be used in the "Logistics Lab" to establish a data network. VLC is a technology based on modulated visible light that takes on the role of a transmission medium for communication. The signal is emitted by a light source (e.g., LED) and received by a photodetector (cf. [10] and Figure 9).

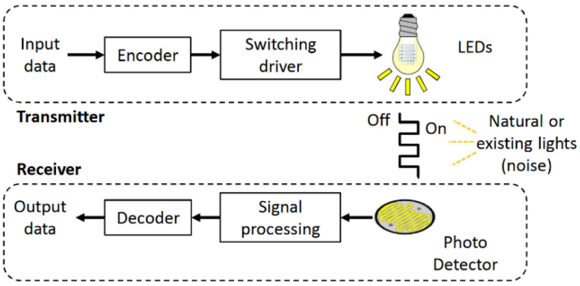

Figure 9: VLC working principle [8].

VLC promises numerous advantages (cf. [11], [12]), including minimal latency and interference for transmission of high data rates with low-energy consumption, especially when existing radio-based networks are already highly utilized or their operation is prohibited. Since light, unlike radio waves, cannot pass through walls, the technology promises high data security. In addition to its role as a communication network, VLC can also be used to localize objects.

These properties promise applications in production and logistics, which students are taught accordingly.

In particular, application possibilities for communication in AGVs are currently being investigated (cf. [13]-[15] and Figure 10). Potentially, the technology can also be used for localizing AGVs (cf. [16]).

In practice, the use of VLC leads to several challenges. For example, there must be a line of sight between the transmitter and receiver. Artificial light sources or solar radiation may also cause interference. This means that there are uncertainties about VLC that need to be investigated.

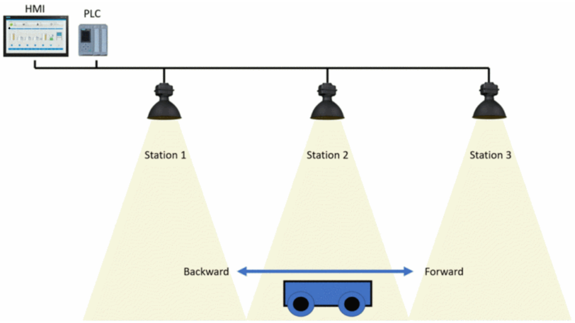

Figure 10: Application of the VLC technology for communication with an AGV (from [15]).

The VLC technology is introduced and critically discussed within the "Logistics Lab". At this point, the course shows a high degree of practical relevance. This is especially true as it is implicitly communicated that logistical systems and their material flows can only be efficiently controlled and realized if associated data and information flows are available and handled appropriately, too.

7. Summary

The "Logistics Lab" course is characterized by constant development. The focus was and still is on digitization, on the one hand to meet the requirements of an increase in the number of students and the associated supervision and organizational effort, and on the other hand, to enhance the teaching content and concepts.

The lab course will be offered as a hybrid course, which allows students to develop solutions independently in small groups and then test them in large group and joint experiments. In this context, a data network with VLC technology will be set up. This allows vehicles to be tracked, system performance to be analyzed, and finally optimized—e.g., by adapting transport plans.

To motivate the students, the gamification approach and its idea of playful competition through disclosure and discussion of key performance indicators are used. This has proven to be successful, following positive student responses and increased solution quality.

Acknowledgement

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