Effects of Interspace and Safety2.0 implementation on safety and well-being in human-robot collaborative environment

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ABSTRACT

In recent years, there has been a growing trend for humans and machines to coexist and collaborate in the same space, not only in manufacturing but across various applications. In such environments, ensuring a certain level of safety is essential, in addition to improving work efficiency and implementing user-friendly features. Amidst these environmental changes, the concept of "collaborative safety," where "humans (humanities), technology (natural sciences), and organizations/environments (social sciences) share information and collaborate to ensure safety," and its technological aspect, "Safety 2.0," have garnered attention.

In the construction field, various digital spatial description formats have been developed as a unique approach to information sharing. However, the lack of interoperability among these description formats has been an issue in achieving effective information integration. Therefore, the need to enhance interoperability between physical spatial information and various digital spatial description information has been proposed.

This paper investigates and reports on how expanding the temporal and spatial information sharing between humans, machines, and the environment in autonomous mobile robot systems that coexist and collaborate with humans can impact the simultaneous achievement of productivity, safety, and well-being.

1 INTRODUCTION

With the development of ICT and robot technology in recent years, not only in the field of factory automation (FA), where industrial robot and automated guided vehicle are used, but also in general society, applications such as autonomous mobile robot (AMR) for transportation and service robot for serving meals are expanding, and opportunities for coexistence and collaboration between humans and machines are increasing dramatically. In addition to significant advances in safety technology and international standards, the fact that it is effective in addressing social issues such as the declining workforce due to the falling birthrate and aging population, and the fact that it can easily respond to diversifying needs due to globalization, are contributing to the expansion of these new applications.

More recently, further expansion and changes in new technologies and applications are expected, such as large-scale data utilization due to the breakthrough of generative AI and the provision of a connected environment for various objects and environments represented by the IoT. These may become new social issues and risks, and proposals for new safety measures have been made [1]. Figure 1 illustrates these new risks. For well-tried technologies and applications, the information on the severity and probability of harm necessary for risk assessment and subsequent risk reduction is abundant, and appropriate risk reduction measures can be selected. However, for new technologies and applications, this information may be insufficient or constantly changing, making it difficult to foresee risks or risks whose existence may not be recognized in the first place. Therefore, it is necessary to expand to new safety approaches to lead to an optimal coexistence and collaborative environment between humans and machines to deal with such risks that are expected to change. Therefore, we have proposed Safety 2.0, which utilizes information on humans, machines, and the environment, as a "state of the art" technology to achieve both safety and productivity in such a changing environment [1][2].

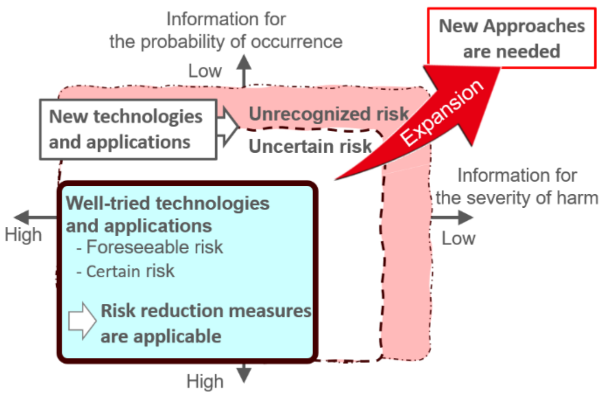


***Figure 1**. Expansion of new risks.*

As shown in Figure 2, the concept of safety has been changing along with the transformation of

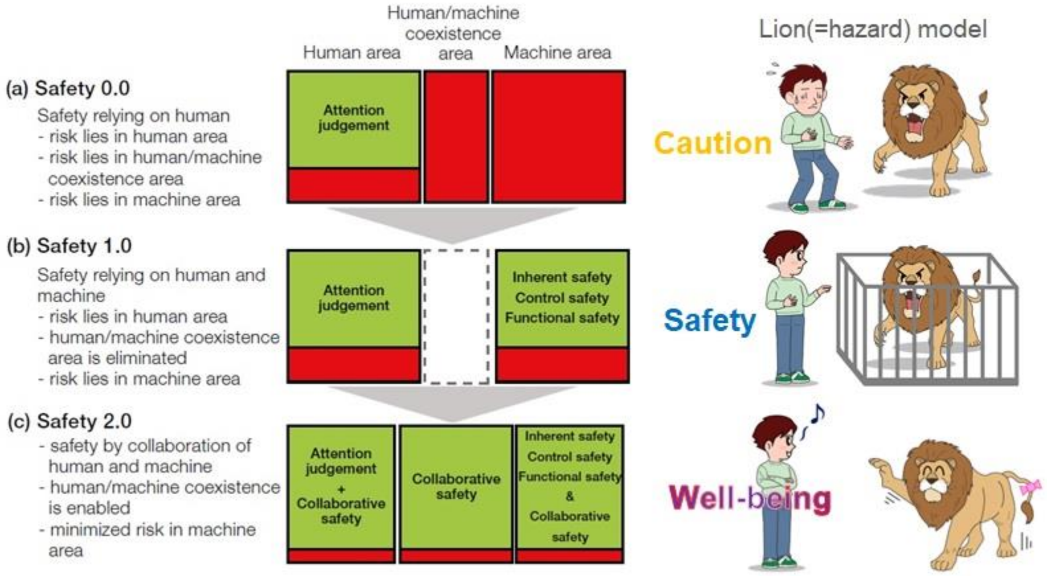


Figure 2. *Safety concept classification and "Lion model".*

manufacturing sites. In the past, there was an era of "Safety 0.0," in which safety was ensured by human attention and experience. Comparing dangerous machines to lions, people used their caution and experience to keep them at a safe distance from the lions. Later, the concept of "Safety 1.0," which is based on the principle of "isolation" by fencing off machines (sources of danger) and "stopping" machines when people approach them, emerged in the manufacturing field and has spread widely throughout the world. Then, "Safety 2.0" was proposed as a new technical measure to improve safety and productivity in various applications where coexistence and collaboration between humans and machines are required [3][4]. Figure 3 outlines conceptual idea of Positive Safety by human's physical and psychological attributes [6], and Safety2.0 is one of the technical measures to realize this concept.

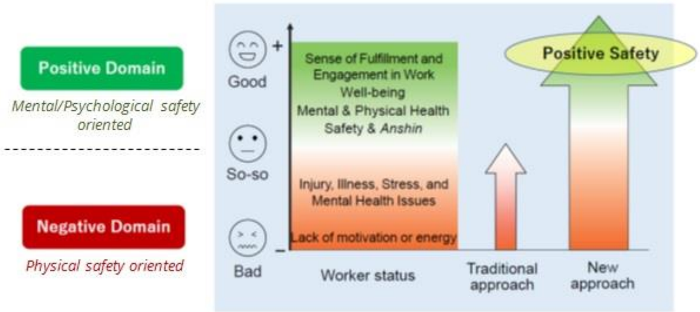


Figure 3. *Conceptual Image of Positive Safety.*

2 OVERVIEW OF SAFETY2.0

As shown in Figure 4, Safety 2.0 is a technological measure to realize safety, ANSHIN (peace of mind), and well-being by sharing information between people, machines, and the environment, and by optimizing the actions, control, and coordination of each. In other words, information from people controls machines, and information from machines prompts people to take action. The environment of people and machines is then adjusted to optimal conditions using ICT and other technologies. Information on people is used, for example, to control and adjust the movement and speed of machines using qualification information on safety, static information on roles and competence, and dynamic information on position, vitals, and behaviour safely and efficiently. In addition, machine information, for example, conveys machine status and movement information to people so that they can work and act more safely and efficiently.

Aiming to expand this Safety 2.0, we have proposed various human interfaces. [7][8][9][10]. These new human interfaces are used not only in factories and other manufacturing fields, but also in civil engineering and construction, logistics, agriculture, and many other applications, and are essential devices for realizing safety, ANSHIN, and well-being.

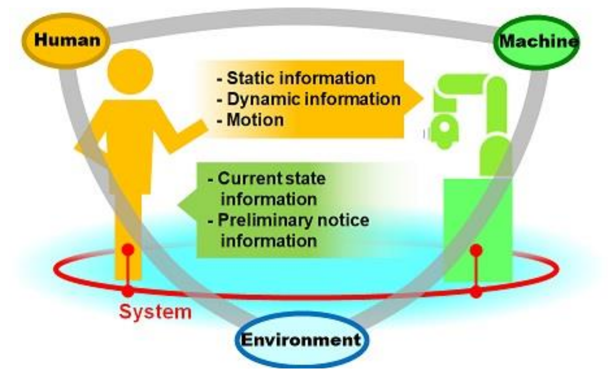


Figure 4. *Technical Aspect of Collaborative Safety "Safety2.0".*

3 COMMON GROUND AND INTERSPACE

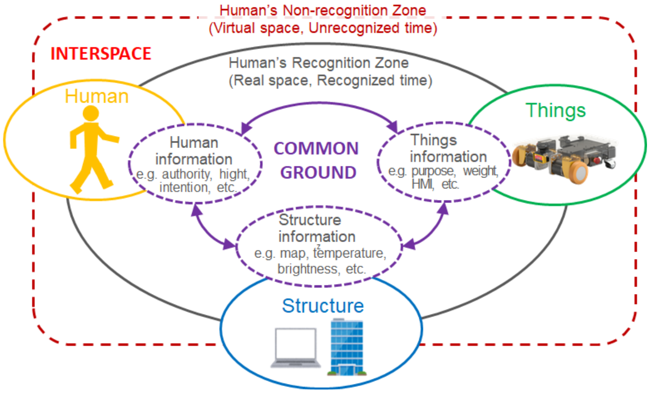


Figure 5. *Common Ground and Interspace.*

The use of such data, the extension of connectivity, and the development of new human interfaces are being considered in various industries, and the concepts of Common Ground and Interspace have emerged from these discussions.

In the field of architecture and design, Common Ground is an attempt to create a mutually readable common format for information between various buildings and the various people and machines that operate within them. Furthermore, based on this Common Ground, the concept of Interspace, which uses the entire space as an interface, has been proposed for the purpose of utilizing information from different spaces and time axes that cannot be recognized by the people and machines in those spaces and time axes, in addition to the information available to people, objects, and structures [11].

This concept of Common Ground and Interspace is shown in Figure 5. Information on people, objects, and structures is connected in a common format that people can recognize through Common Ground. These information are also provided by spatial information of different places and units that are not recognizable to people through Interspace and different time frames. For example, a mobile robot that does not have map information of a destination structure can construct an optimal route to the destination by itself by obtaining map information of the destination, hierarchical information, and congestion information from the sensors that the structure has. Furthermore, the real-time updating of information on structures and people, and the ability to identify people and things can be used to improve productivity and safety by sharing optimal map information and risk information. Therefore, these concepts are highly compatible with Safety 2.0, which is based on the concept of balancing safety and productivity through information sharing between people, machines, and the environment. Therefore, in an experimental facility where the concept of Interspace, in which the entire space is an interface, and information readability through Common Ground are introduced, the concept of Safety 2.0, which enables both safety and productivity through information sharing between humans, machines, and the environment, was introduced to AMRs, a market that is expected to expand greatly. We introduced the concept of Safety 2.0, which enables the combination of safety and productivity by sharing information between humans, machines, and the environment, to an AMR, which is expected to expand into a large market.

4 AUTONOMOUS MOBILE ROBOT FOR SAFETY 2.0 COMPLIANCE

With the aim of addressing societal challenges such as the declining workforce and improving working conditions, the introduction of AMRs is being advanced for various applications. AMRs are equipped with a range of cutting-edge safety technologies, including high-precision sensing technologies, high-speed and large-capacity computing technologies, and miniaturized driving technologies. Utilizing the installed sensors, AMRs are capable of autonomously creating maps of their operating areas and determining optimal driving routes by estimating their self-positions. This capability promises to facilitate changeovers and maintenance, as well as improve workspace efficiency through the liberation of spaces previously dedicated to rails or fixed routes. Notably, the realization of safety technologies enabled by these technological advancements is a key point of interest. The international standard ISO 3691-4 [12], which specifies risk reduction measures required for industrial trucks, has been revised, clarifying the necessary safety functions such as maintaining safe distances, reduced speed, and stop functions. Consequently, AMRs equipped with these safety features are now widely employed globally.

Figure 6 shows the Safety Wheel Drive Kit (SWDK), an AMR utilized in this experiment. The SWDK is an experimental AMR that integrates the driving system and safety system required for AMRs through the Safety Wheel Drive (SWD), and is equipped with a safety laser scanner, emergency stop switches, a PC for navigation control, a battery, and other components. The key device of this AMR, the SWD, has safety functions such as Safe Torque Off (STO) that immediately cuts off power supply to the motor based on safety input information, Safe Brake Control that outputs brake control signals for stop control after power cutoff by STO, Safety Limited Speed that limits the motor speed within a configured value, and Safety Direction that

Figure 6. *Safety Wheel Drive Kit (SWDK)*

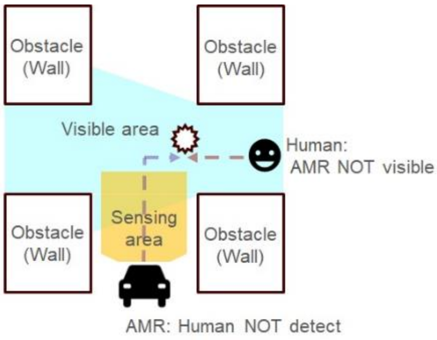


Figure 7. *Risks due to movement of human and AMR.*

controls the motor to prevent rotation towards sensor detection area. Therefore, the SWDK, constructed with the SWD having these safety functions, can be considered a device capable of easily implementing the risk reduction measures for AMRs specified in ISO 3691-4.
However, when using AMRs in a shared environment with humans, risk reduction measures are not prescribed in the standard for situations involving human movement or human suddenly appearing in the AMR's travel direction. In such cases, management approach to exclude these situations or risk reduction through speed and force limitations tailored to the application are required. Figure 7 shows an example of risk in a shared space between humans and AMR. The AMR's sensors detect surrounding structures to maintain its continuous operation but do not initiate stopping actions in response to them. However, if a human or object is detected at a distance that could pose a collision or contact risk, the AMR is set to stop safely. In a shared environment with humans and machines, people move around, and structures have various shapes. Therefore, if a person approaches from outside the AMR's detection area, they may be detected in close proximity at corners or intersections, or the AMR may detect a moving person in close proximity after turning a corner, increasing the risk of collision or contact. To mitigate this risk, in addition to imposing movement restrictions and providing education for human, it is not uncommon to expand the AMR's sensor detection area or limit its speed. However, such movement restrictions on human or expanding the AMR's sensor detection area can lead to decreased workability and productivity.
To address these challenges, we have introduced the Safety 2.0 concept, which aims to realize safety, ANSHIN, and well-being by sharing information among humans, machines, and the environment. By implementing the SWDK in the Common Ground Living Labo (CGLL), which utilizes a Common Ground for shared recognition of information about humans, objects, and structures, and employs an Interspace where the entire space serves as an interface, we have established a Safety 2.0 system leveraging the CGLL's Interspace and Common Ground functions.

5 OVERVIEW OF CGLL

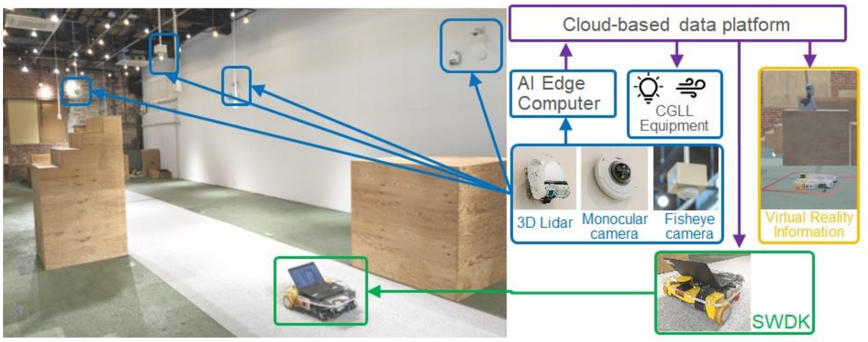


Figure 8. *Experimental space of CGLL*

Figure 8 shows an overview of the experimental space in the CGLL. The CGLL is a shared experimental facility where various participants construct and mutually share data and experimental results, advance demonstrations, and accumulate technologies and operational know-how for the development of next-generation data platforms. The lab consists of an experimental space, an office space, and a corridor space. Each space is equipped with sensors such as 3D LiDARs, monocular cameras, and fisheye cameras necessary for obtaining information about human, spaces, lighting, and air conditioning. This information is connected directly or through AI edge computers to a cloud-based data platform. The edge computers perform AI-based human identification, behavior estimation, and clothing recognition. This information is processed and managed on the data platform and utilized for controlling lighting, air conditioning, robots operating within the lab, and virtual space data and avatars. The lab possesses sensor arrays for collecting information about human's locations and behaviors, as well as a platform and processing engine for aggregating and rendering this information readable to enable optimal environmental control. It facilitates optimal control of equipment used within the lab and information delivery to human through information terminals and virtual spaces. Indeed, this facility is ideal for demonstrating the Safety 2.0 concept, which realizes safety, ANSHIN, and well-being by sharing information among humans, machines, and the environment.

6 SAFETY2.0 PROOF OF CONCEPY AT CGLL

Figures 9 and 10 show an overview of the proof of concept conducted in the CGLL. An area of 10.35 m in length and 4.46 m in width was prepared in the experimental space where sensors were installed, and this area was used

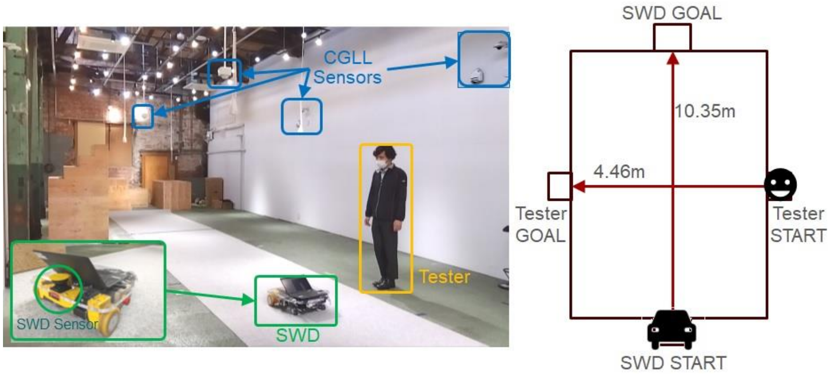


Figure 9. *Test environment without obstacles.*

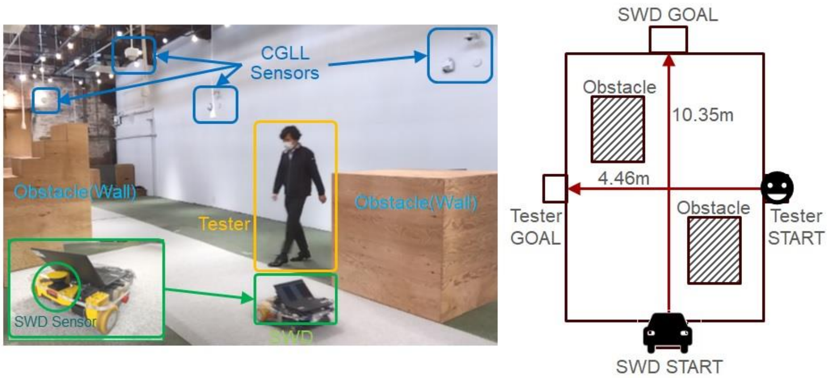


Figure10. *Test environment without obstacles.*

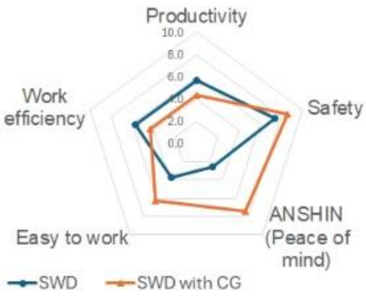
as a space where humans and SWDKs could coexist. In this experiment, two patterns of space conditions were prepared: a flat space without obstacles as shown in Figure 9, and a structured space with obstacles installed as virtual walls as shown in Figure 10. Both the human (tester) and the SWDK had the task of reaching the goal point from their respective start points. The testers were seven people of different ages and genders who had knowledge of the SWDK, but did not have information on the intention of the experiment or the specifications of the CGLL. The SWDK has two modes of operation: one in which it uses its own safety laser scanner alone and one in which it combines the safety laser scanner with the CGLL functions. These two operational modes represent the presence or absence of the Safety 2.0 concept using the Common Ground. Measurements of "productivity" and "safety" were taken, and evaluations through interviews were conducted regarding "ANSHIN", "easy to work", and "work efficiency". The differences between the two modes were then verified. "Productivity" was measured by the time taken for the tester and the SWDK to reach the goal from their respective start points. "Safety" was assessed by counting hazardous events, such as close encounters or collisions, and dangerous human actions that could lead to increased risk during the tasks of the tester and the SWDK. Table 1 presents representative examples of interview questions asked to the testers, from which the evaluation criteria were derived. Figure 11 shows the measurement results. Each measurement and evaluation content is scored with 5 points as the average. For "productivity" and "work efficiency", the condition without using the CGLL yielded better results. This is likely because the CGLL detects tester and their behaviors at an earlier stage, causing the SWDK's low-speed control and avoidance control to be executed earlier. On the other hand, the condition using the CGLL performed better in terms of "safety", "ANSHIN", and "easy to work". Notably, significant improvements were observed in "safety" and "ANSHIN". These results suggest that early-stage low-speed control and avoidance control adapted to human behavior and state are effective in enhancing "safety", "easy to work", and particularly "ANSHIN".

Table 1. *Examples of Hearing Contents.*

Q. Is there any difference between with and without the CGLL sensor? What kind of difference do you notice?
Q. Are there any differences in the points you paid attention to with and without the CGLL sensor? What kind of difference do you notice?
Q. Is there a difference in how you felt with and without the CGLL sensor? What kind of difference do you notice?
Q. How do you feel about AMR and your own productivity with and without the CGLL sensor? Why is that?
Q. Is it easier to work with or without the CGLL sensor? What is the reason for this?

7 CONCLUSION

In this experiment, we utilized the CGLL experimental facility, which incorporates an expanded human-machine interface via Interspace and information readability techniques through Common Ground. By enabling the sharing of information among humans, machines, and the environment, we were able to confirm the validity of the Safety 2.0 concept, which aims to reconcile productivity and safety through the realization of safety, ANSHIN, and well-being. While coexistence spaces for humans and machines have significantly improved safety and ANSHIN, thereby contributing to the well-being of workers, productivity has been on a declining trend. This is presumed to be due to the fact that the evaluation of the CGLL effects was limited to a narrow space and tasks different from actual production sites, and the Safety 2.0 functions were also restricted to CGLL. On the other hand, it was confirmed that the implementation of Safety 2.0 through CGLL had a positive effect on improving safety and ANSHIN. In the future, we intend to demonstrate that the sharing of information among humans, machines, and the environment, which is the concept of Safety 2.0, can effectively achieve a balance between productivity and safety by conducting measurements in a wider space and tasks closer to actual working environments, as well as incorporating display devices and voice information for conveying information from machines to humans.



Item	With CGLL	Without CGLL
Productivity	5.7	4.3
Work efficiency	5.7	4.3
Safety	7.4	8.6
ANSHIN (Peace of mind)	2.5	7.5
Easy to work	3.8	6.3

Figure11. *Measurement results.*

8 REFERENCES

1. IEC White paper ”Safety in the future”, International Electrotechnical Commission, 2020.
2. Mukaidono M., Takaoka H., Ogihara H., Ariyama M., Fujita T. *Japan's Approach for the Realization of the Future Safety Concept by Implementing Collaborative Safety Technologies*, 9th International Conference on Safety of Industrial Automated Systems (SIAS), France, 2018, pp.77-87.
3. Yamada Y., *Safety2.0 Technology in Support of Collaborative Safety*, 10th International Conference on Safety of Industrial Automated Systems (SIAS), Japan, 2021, pp.106-111
4. Dohi M., Okada K., Maeda I., Fujitani S., Fujita T., *Proposal of Collaboration Safety in a Coexistence Environment of Human and Robots*, 2018 IEEE International Conference on Robotics and Automation (ICRA), pp. 1924-1930, Australia.
5. Shimizu T., Fujitani S., Maeda I., Okada K., Dohi M., Fujita T., *New Collaborative Safety Concept in Various Coexistence Areas for Human and Machinery*, 9th International Conference on Safety of Industrial Automated Systems (SIAS), France, 2018, pp.88-94
6. Mukaidono M., Takaoka H., Ogihara H., Ariyama M., Fujita T., *Japan's Approach for the Realization of the Future Safety Concept by Implementing Collaborative Safety Technologies*, 11th International Conference on Safety of Industrial Automated Systems (SIAS), Finland, 2024,.
7. Shimizu T., Fujitani S., Inada K., Dohi M., Fukui T., Fujita T., *Development of New Emergency Stop Methods Essential for Well-being Improvement in Collaborative Safety/Safety2.0 Systems and Application Examples*, 10th International Conference on Safety of Industrial Automated Systems (SIAS), Japan, 2021, pp.82-87.
8. Fukui H., Shimizu T., Maeda I., Nobuhiro M., Okada K., Dohi M., Fujitani S., Fujita T., *Development of devices applied to collaborative robot production system based on Collaborative Safety / Safety2.0*, International Symposium on Robotics (ISR), Online-event, 2020, pp.155-160.
9. Oishi M., Nakano Y., Asa N., Tanaka H., Yasukawa K., Miyamoto T., Pursuing safety, ANSHIN, and well-being in robot teaching using tablet computers, Human Interface Symposium, Japan, 2023, pp.196-201
10. Kojima H., Ueda S., Hirano H., Nakai T., Inada K., Shimizu T., Fujita T., Kawata T., *Achieving Worker Well-Being through the Introduction of Collaborative Safety and Safety2.0 in the Construction Field*, 10th International Conference of Safety of Industrial Automated Systems (SIAS), Japan, 2021, pp.52-57.
11. Toyoda K., *Deployment of the idea of Common Ground as a basis of the digitization of the built environment*, SEISAN KENKYU, Vol. 74, No.1, 2022, pp. 139-142.
12. ISO 3691-4: 2023, *Industrial trucks — Safety requirements and verification, Part 4: Driverless industrial trucks and their systems*