Symbiotic Safety: Safe and Efficient Human-Machine Collaboration by utilizing Rules

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***Abstract*—Collaborative work between workers and autonomous systems in the same area is required to improve operation efficiency. However, there exist collision risks caused by coexistence of workers and autonomous systems. The safety functions of the autonomous systems, such as emergency stops, can reduce the risks and but may decrease the operation efficiency. Therefore, we propose a novel safety concept called *Symbiotic Safety*. The concept improves both safety and operation efficiency by transformation of action plan, e.g., adjustment of action plan or update of safety rule, which reduces frequency of risk occurrence and suppress efficiency loss due to safety functions. In this paper, we explain the symbiotic safety technologies and share results of an evaluation experiment by utilizing our prototype system.**

***Index Terms*—human-machine collaboration, symbiotic safety, collaborative safety, safety-critical systems**

I. Introduction

Automated driving technologies are being evolved and start to be applied to industrial applications such as automotive domain or smart logistics domain and so on. The collaborative work between workers and autonomous systems is required because the combination between flexible and precise operation by workers and high-efficient operation by autonomous systems can improve whole operation efficiency. However, the coexistence between them causes to increase collision risks. The safety design is mandatory. For example, safety design standardized by ISO26262 [1] enables to reduce the collision risks. While the safety function like emergency stops improves safety, there is a concern that operation efficiency decreases. As a safety design concept that balances safety and operation efficiency, collaborative safety called Safety 2.0 was proposed [2].

We propose a novel safety design concept called Symbiotic Safety that evolves Safety 2.0. This concept enables to improve both safety and operation efficiency by transformation of action plan. For example, adjustment of action plan or update of safety rule can reduce frequency of risk occurrence and can suppress of efficiency loss due to safety functions. In this paper, we explain the symbiotic safety concept and results of our evaluation experiment, in which we demonstrate a smart logistics use-case by using our prototype.

II. Symbiotic Safety Concept

The symbiotic safety controls various rules such as operation rules, traffic rules, and safety rules and so on. The rule is the key factor because it influences action plan of humans and autonomous systems. For example, the action plan is transformed by adjustment of action plan or update of rules. In the symbiotic safety, the behavior of the humans and the autonomous systems is monitored by area sensors, which are installed in the field, and is controlled by a symbiotic safety server according to the rules. Fig. 1 shows an example of symbiotic safety technologies.

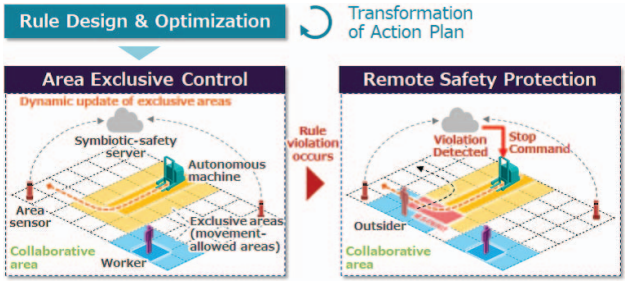

Fig. 1. An Example of Symbiotic Safety Technologies

A. Rule Design & Optimization

The rule may be evaluated quantitively and be designed iteratively to realize high operation efficiency and low safety risks. Therefore, simulation technologies are useful for the rule optimization [3]. For example, the rule design includes layout design such as installation of area sensors for blind spots, installation of dedicated passage for either humans or autonomous systems, minimization of shared passages between humans and autonomous systems. Furthermore, in the rule design, arbitration policy like action prioritization between humans and autonomous systems, safe operation policy like safe distance between humans and autonomous systems in collaborative area are designed. Then, the rules are evaluated and are optimized in terms of safety and operation efficiency.

B. Area Exclusive Control

The symbiotic safety system provides area exclusive control according to the designed rules. Area sensors monitor human behavior and predict the moving direction. The moving direction of autonomous systems is predicted according to the path plan. The area exclusive control assigns area of the moving direction to the object as dedicated area that means the object is allowed to move. As the dedicated area is exclusively assigned,

the human can operate safely in the assigned area. This means that the human can operate safely without reducing operation efficiency by following the area exclusive control rule.

However, humans may violate the rules. For example, outsiders like the track driver don't know the specific rule of the delivery destination. Therefore, the symbiotic safety server provides the remote safety protection function.

C. Remote Safety Protection

The symbiotic safety server makes the autonomous systems stop immediately via wireless communication if the human violates the rule. For example, the server detects the rule violation if the human position after several second will enter to dedicated area for the autonomous system. The real-time performance of the remote safety protection is influenced from wireless communication quality. Therefore, if the remote safety protection cannot guarantee the performance requirement due to low quality of the wireless communication, a fail-safe function is necessary. While the fail-safe like degradation may decrease the operation efficiency, it can reduce safety risk when the rule violation occurs during lossy wireless communication.

III. Demonstration and Lesson to Learn

We developed a prototype of the symbiotic safety system mentioned in Section II. Fig. 2 shows an overview of the symbiotic safety architecture.

The autonomous vehicle moves by following a path based on own localization. The symbiotic safety system integrates the recognition results from area sensors and predicts the human position after several second. Then, the system judges whether the rule violation will occur or not. If the violation will occur, the system sends the emergency stop command as the remote safety protection. The wireless performance monitor evaluates wireless communication performance by utilizing heartbeat. If the evaluated performance cannot satisfy the requirement, the monitor sends the degradation command. The vehicle arbitrates various commands and selects a command with the lowest target speed. The vehicle has own emergency brake system as the safety function during degradation.

We conducted an evaluation experiment based on use-case of the temporal storage area in the logistics warehouse (see Fig. 3). In the experiment, there are workers unloading cargo from the track and autonomous forklifts carrying the cargo. Several camera and LiDAR device are installed as area sensors and are connected to the symbiotic safety system by wired network. The automated forklift can communicate with the symbiotic safety system via wireless network. In this experiment, we established the dummy storage area at a parking lot and used small size mobility instead of the forklift and WiFi 6 (IEEE 802.11ax) as wireless network.

The results of the evaluation experiment showed that the area sensor can recognize humans and autonomous mobility, and the symbiotic safety system assigns dedicated area to them exclusively. Furthermore, we confirmed that the system can stop the mobility by remote safety protection when an outsider will enter the dedicated area of the mobility. Thus, we consider that the symbiotic safety concept is feasible.

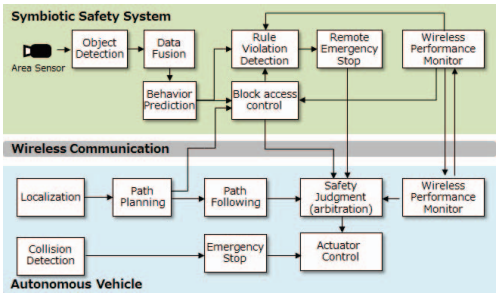

Fig. 2. An overview of symbiotic safety system architecture

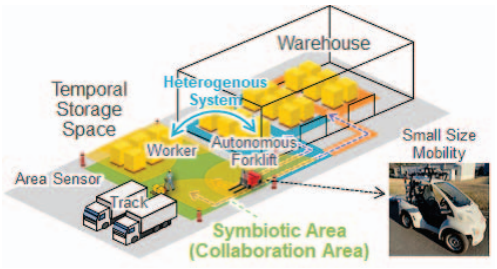

Fig. 3. Evaluation Experiment

Through the experiment, we learned that customization and improvement of the following points according to application property further increase the operation efficiency and cost-effectiveness.

- area exclusive control algorithm (prioritization, grid size optimization)
- security with minimum overhead for remote safety protection
- reliable wireless communication for large sensor data between area sensor and symbiotic safety server
- layout design algorithm of area sensors for wide area
- usage of cost-effective sensor for human position recognition
- open interface design of area exclusive control and remote safety protection between vehicle and symbiotic safety server

IV. Conclusion

We proposed symbiotic safety concept to improve both safety and operation efficiency. We developed the prototype and evaluated symbiotic safety functions by utilizing the use-case of logistics warehouse. Through experiment results, we confirmed that our proposed concept is feasible.

References

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