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Automated Accident Response Robot for Rapid Leak-Sealing on Damaged Pipes

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1. Introduction

With advancements in technology, significant improvements have been made in areas such as safety and accident prevention. However, catastrophic incidents continue to occur persistently. The scope and types of these incidents vary widely, ranging from natural disasters to nuclear facility accidents. Particularly in the case of nuclear-related accidents, the subsequent consequences such as radioactive material leakage and contamination can be severe. Therefore, more rigorous prevention of the accident and the maintenance of related facilities are inevitable. Looking at relatively recent events, such as the Fukushima nuclear power plant accident, it becomes evident that beyond prevention, there is a crucial need for practical accident response measures that can be applied during emergencies. The importance of systems capable of responding to various accident scenarios and devices, including robots, suitable for diverse applications, has come to the forefront. Various efforts have been made to realize this goal.

In this study, we consider scenarios within nuclear accidents where issues like pipe damages can result in the leakage of radioactive materials. We introduce an automated device or robot capable of early intervention at the accident site, aiming to respond effectively to such situations.

2. Problem Statement

The types of pipe damage vary, including corrosion, weld defects, cracks, and others. Fig. 1 illustrates examples of pipe damage [1,2].

Fig. 1. Various types of pipe damage.

In situations where complete rupture has not occurred yet, but in relatively early stages of leakage, most pipe damages tend to appear in the form of cracks along the length of the pipe. In the scenario considered for this study, we assume the occurrence of leakage from the pipe, specifically focusing on this type of damage. Detailed scenario settings are given in Table I and Fig. 2.

Table I: Test Environment

Size of crack	under 150mm
Position of crack	100mm or more distant from the pipe edge/connection
Diameter of pipe	~ 7 inch
Pressure of leakage	~ 5 bar

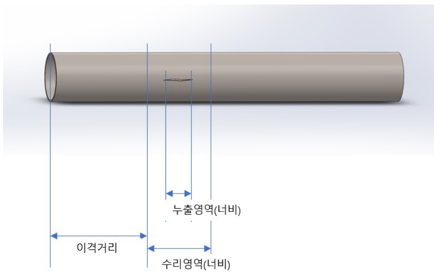

Fig. 2. Parameters of damaged pipes.

While there are various methods for repairing pipes, such as welding, paste application, and taping, we have decided to go with the taping method considering the need for rapid response and low complexity in the early stages. In the following section, we will introduce an automated pipe taping device designed for utilization by unmanned robots.

3. Development of a Rapid Leak-Sealing Robot

The phase of robot development introduced in this section is under the concept verification. Thus, it is not the final one and the study and development changes are still undergoing.

The robot needed in this accident scenario is an automated taping robot which do the following tasks autonomously once it is delivered and located close to a damaged pipe with the help of another mobile robot.

- Continuous and automated taping on the pipe (main feature)
- Centering and settling on the pipes
- Attaching/detaching the tape
- Slide along the pipe while taping

Main feature of this robot is under concept verification and the modeling for the taping mechanism is illustrated in Fig. 3.

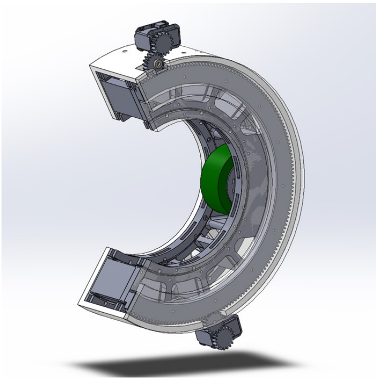

Fig. 3. The mechanism for taping feature.

As we can see from the figure, overall structure of the main feature is based on circular rack and pinion mechanism. The taping feature requires more than one actuator since the inner rack is not a loop and it travels from one end of the housing to the other. The actuators need synchronized actuation to avoid jamming or stuck inside the housing, and the structure needs to be rigid enough to endure the operation when the half of the inner rack is traveling outside the housing.

The concept of the taping mechanism is proven by conducting tests on a mockup pipe. Fig. 4 shows the test environment.

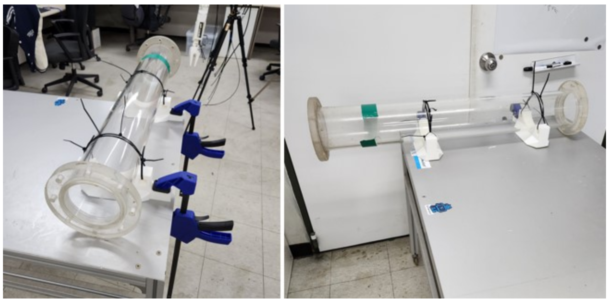

Fig. 4. Three kinds of SK5 hinges used in tests.

A transparent acrylic pipe which has 5inch diameter is used to visualize the taping performance easily. The pipe is located and fixed on the test table and one end of the pipe is simulated to be exposed to the external space to allow for the attachment of the taping robot. The test for verifying taping operation is depicted in Fig. 5.

General duct tapes were used for the early tests, and we can replace it with other types of stronger or special purpose tapes when it meets the size requirement. During tests, twenty rotations of taping around pipe is done and the result was solid enough to seal the leakage from the pipes immediately.

More tests need to be conducted in more realistic test environment that has actual crack damages on the pipe and visualizing material to be leaked out from the pipes. We will also prepare for the pipes with pressurized state so that the strength of the leakage could be realized.

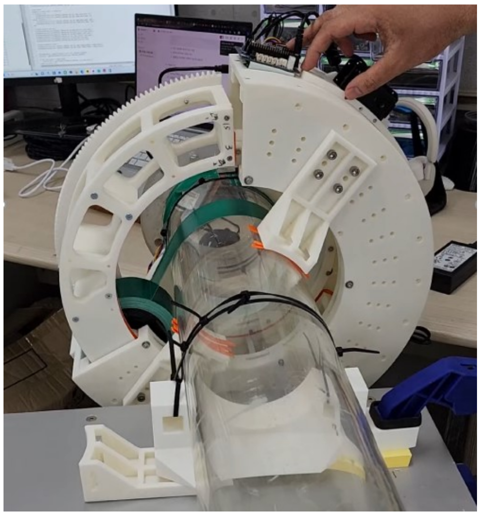

Fig. 5. Taping tests on the mockup pipe.

3. Conclusions

A rapid leak-sealing robot for damaged pipe is introduced. The main feature of the robot is verified in a test environment and it showed satisfying rapid leak-sealing operation. Additional features need to be developed and verified in more realistic test environment.

ACKNOWLEGEMENT

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