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Construction and Application of User-driven Robot Development Methodology

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Abstract: Infrastructure inspection robots and disaster respond robots are required. These robots are designed and manufactured for specific purposes and are not standardized. In order to develop robots that meet the on-site need and can be securely installed in a short period of time, a user-driven robot development methodology has been constructed. This methodology starts from the on-site need and defines system requirements based on the site environment and risk assessment. The design, prototype, and verification are repeated to satisfy the requirements. A survey robot using this methodology was deployed to Fukushima Daiichi Nuclear Power Station, and an inspection robot for transmission lines was also developed. This methodology is similar to a waterfall approach. However, we would like to introduce an agile methodology to minimize development uncertainty and improve it through actual cases in the future.

Keywords: Developing methodologies, Design methodologies, Agile, Field robotics, Maintenance robot, Rescue robot, Decommissioning, Electric power

1. INTRODUCTION

Maintenance robots that can efficiently inspect and repair equipment are required accompanying the aging of infrastructure such as bridges, tunnels, and plants. On the other hand, the need for disaster respond robots (rescue robots) also has been increasing according to the frequent occurrence of disasters such as earthquakes and heavy rain. These robots are different from service robots and are called field robots.

TEPCO has deployed a number of robots to proceed decommissioning work since the accident at the Fukushima Daiichi Nuclear Power Station (NPS) caused by the tsunami attack of Tohoku Pacific Ocean Earthquake in March 2011. These robots were designed and manufactured for a specific purpose in accordance with the progress of work, and the manufacturing number is not large. In each case, it is necessary to proceed with the development within short period and reliably deploy them to the site.

Some of these robots have been developed by manufacturers who are familiar with nuclear power plants. On the other hand, several robots were developed by Tokyo Electric Power Company (TEPCO) alone or jointly affiliated with universities, external research institutions or robot companies. Developing robot in short period based on a needs directly provided by on-site user is expected if a user-driven developing process is applied. Since TEPCO is an electric power company, we have much knowledge about power equipment. However, the equipment used in our facilities are basically designed and manufactured by manufacturers, and we do not have sufficient development know-how. In this paper, we will introduce a user-driven robot development methodology built on the knowledge acquired by TEPCO through the development of decommissioning robots, and start the discussion in the future.

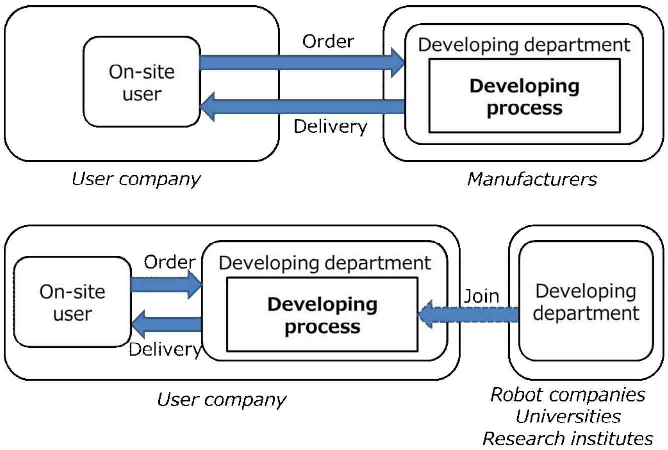

Fig. 1. Difference between Conventional development (upper) and User-driven development (lower)

2. PAST EXAMPLES

The major robots used for the site survey just after the accident were PackBot of iRobot (now Endeavor Robotics) in the United States, Talon of QinetiQ North America and Quince developed by Chiba Institute of Technology, Tohoku University and IRS (International Rescue System). These were developed before the accident and not optimised for the Fukushima Daiichi NPS. In order to convert Quince what was originally developed for firefighting sites to nuclear power plant surveys, the stair climbing performance was improved and the cable winding device was modified while reflecting the site environment.

Survey Runner of Topy Industries and FRIGO-MA of Mitsubishi Electric TOKKI Systems were developed for exclusive use at the Fukushima Daiichi NPS. Because Quince could not pass the landing to the basement floor in the reactor building due to its external dimensions, the two models were required to be able to climb down to the basement floor. While the basic specifications were defined by TEPCO, and each development was conducted by both manufacturers to satisfy them. In these developments, the detailed performance required beyond the specifications was not clearly specified, and their perfections were improved based on the experience of the person in charge.

High-Access Survey Robot jointly developed by Honda R & D, AIST and TEPCO was the first case for the decommissioning robot development in which the clear design method was introduced. Since there was no access to the high places inside the reactor buildings, and it was thought that valve operations would be required to establish pipe boundaries in the future, the development of an operation arm attached on a high-access platform was started. Although the robot was roughly completed in about one year, its total weight of about 1 ton in order to ensure stability when extending from a high place. This is because the robot was modified from a commercially available high-access platform without outriggers. At the time of completion, the opinions provided from the on-site user were as follows.

a) High-access survey device was required before valve operation.
b) The robot was too heavy and cannot be rescued if it is stuck on site.
c) The risk of falling was concerned.

Based on the opinion in a), the robot was converted from a valve operation to a survey. Moreover, AIST introduced the concept of system safety in order to solve the concerns in b) and c). (Ogure 2018)

Table 1. Introducing progress to Fukushima Daiichi NPS

Name	Progress	Methodology in user side
PackBot	Just apply the original military robot to Fukushima NPS	Unknown
Quince	Originally developed for firefighting sites	Unknown
	Converted to use at Fukushima NPS	No specific methodology
Survey Runner, FRIGO-MA	Originally developed for Fukushima NPS	No specific methodology
High-Access Survey Robot	Originally developed for Fukushima NPS	System safety

The essence of system safety is to clarify how to use it in the field first, enumerate potential risks, include counter measures what can be reflected in the design, and have the user accept any residual risks that cannot be reflected (See references for details). The involvement of the on-site users from the clarification of how to use on-site to the acceptance of residual risk enabled the development to obtain a sense of security and satisfaction. This robot conducted survey missions for high places through three times from 2014 to 2015. Although some troubles occurred during the missions, they were calmly dealt with due to events within the range assumed in advance, and the surveys were completed successfully.

3. CONSTRUCTION of DEVELOPMENT METHODOLOGY

The concept of system safety in High-Access Survey robot was considered to bring the following values.

a) Applicable to the development of individualized (multi-product, small-quantity) robots such as decommissioning robots.
b) Development can be carried out with common understanding for the safety and reliability required on site.
c) Clarify the usage situation first to reduce rework and develop a robot that can be reliably used in the field in a short time.

Since these values are universal to other robot developments, TEPCO has independently constructed a development methodology based on system safety considerations for High-Access Survey Robot. The reasons for introducing a specific methodology are following three points.

(1) Ensuring robot quality

If each person proceed a robot development project using his or her own development methodology that is deemed necessary, the quality will highly vary from project to project. In case a methodology is standardized, a certain level of quality will be ensured without being personal. In addition, the methodology leads to reliable process control, ensuring safety and reliability.

(2) Smooth development

Without a methodology, there is a high possibility that necessary design items will be missed and unnecessary rework will be performed later, or conversely, more than necessary requirements will be included with thought. All of these directly lead to wasted time and cost.

In addition, it might be possible to share a common language with development partners outside, such as a purpose, terms, schedule and goal. It could foster a sense of unity in the team.

(3) Focus on technology

Without a methodology, each person would always have to be aware of project management, such as the adequacy of what they were doing at the time and what to do next, which would have development overhead. If there is a methodology, development process can be carried out in accordance with the methodology, and each person can concentrate on technology itself.

Fig. 2 shows the development flow proposed by us. The differences from system safety in High-Access Survey Robot are that it includes design requirements for basic performance as well as safety, and that the concept has been simplified so that it can be easily penetrated by members.

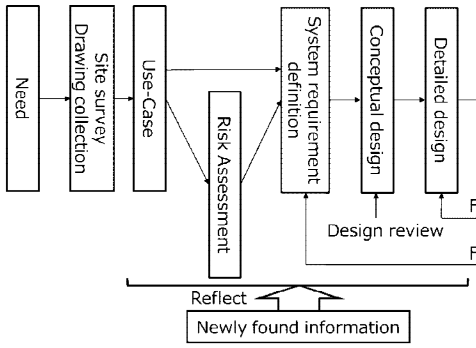

Fig. 2. Development flow of proposed methodology

The first step in the development is a need provided by the on-site user, to what and where a robot do. From the user company's point of view, we basically do not develop seed-first robots. Standing on this need, site surveys and drawing collections are conducted next. The aim is to clarify the constraints by ensuring the environment where the robot is used.

Create a use case based on this information. Use cases are clarified by 5W1H procedures, why, when, where, who, what and how to do.

・Why: What is the purpose of the work? (Same as the first need)

・When: Describe how long you want to use the robot. From when is the deadline of the development period, and by how long is related to the life of the robot. The life of the robot indicates the required durability.

・Where: This is environmental requirements. Clarify the temperature, humidity, wind speed, radiation dose and whether in the air or in the water.

・Who: Clarify the roles of developers, producers, operators and maintainers.

・What and How to do: Describe the specific work flow. Starting from the storage status in the warehouse, it will clarify the following process such as transportation, setting, start-up inspection, actual work, clearing, and withdrawal.

Once the use case has been described, expand it into a system requirements definition. Basically, it is a required specification that satisfies the use case, which is the reverse of the use case. The major categories of the system requirement definition are generally dimensions, weight, communication, control, mobility, sensors, safety and standards for robots. If it is necessary to define the system requirements despite the use case is not fixed, the consideration of the use case might be insufficient. In such cases, the process have to go back to the use case and expand it. For example, even if there is no description regarding the robot weight in the use case, there is no possibility that the robot weight restriction does not defined in the system requirement definition. In that case, it is required to consider again, for example, whether there is no weight limitation when transporting the robot or on the load resistance at the place of use.

Next, a risk assessment is conducted using the FTA (Fault Tree Analysis) concept based on use cases. Major risks include that the robot cannot perform a predetermined task, a personal injury occurs. Next, major risk factors are subdivided into three levels, large, medium and small. The risk assessment should be performed in a brainstorming manner, as it is necessary to avoid possible risks. Once the risks are identified, devise countermeasures for each risk. Some of countermeasures that can be reflected in the design of the robot are added to the system requirements definition, and remained countermeasures that are not reasonable to reflect in the design are written down as residual risks.

The system requirements definition items are classified into those that must be satisfied (Must) or those that can be implemented if possible (Wants). Even if a requirement is judged as Must, in case the expected value for the robot is mitigates, it might not be Must. It is very difficult to classify the requirements properly.

We can proceed with the conceptual design of the robot that satisfies the system requirements definition. The use image of the robot should have been roughly drawn at the use case, but the conceptual design should be conducted without any assumptions. This is because it may be impossible to realize a robot that satisfies all Must requirements in the system requirement definition. In such case, it is necessary to find out another solution without hesitation. When the conceptual design is completed, a design review is conducted with the person who provided the need, and make a consensus of the results of the previous investigation, the validity of the concept design and the acceptability of residual risk. If there is any pointed out information or newly found information on the site, it is necessary to reflect it in past documents and remake the concept design.

After the design review, the development process can move to detailed design, prototyping and testing. Basically, these works could be divided into three elements: machine, electric, and software. However, there are many items that cannot be verified without integration, so keep in mind that integration can be done early even if incomplete. The test items are basically to confirm whether the system requirement definition is satisfied. If there is a problem with the test results, the detailed design will be reviewed and the prototyping and the testing will be repeated. After verification of each item of the system requirement definition, a mock testing based on the use case is conducted. If the mock testing can be cleared a predetermined number of times, it is determined that the robot can be deployed in site.

This development methodology is considered to be classified as a waterfall approach, because the design requirements are first thoroughly identified before proceeding with the design. On the other hand, since feasibility is the most important as a user, it is flexible in that new information found at each stage of development is reflected to the previous stage of the flow to pursue feasible functions.

4. PRACTICE

Apart from robot development with external partners as described in Chapter 2, a small survey robot had been developed by TEPCO itself. A smartphone was installed on the remote-controlled robot as a survey tool, and prototypes were developed repeatedly to meet the needs of on-site surveys.

A specific on-site need for this robot was the survey for the apparatus hatch in No.3 reactor building in Fukushima Daiichi NPS (Sakaue 2017). Since the access route was very narrow and could not be handled by other existing survey robots, we decided to develop a smartphone robot specifically for this mission, and applied the robot development methodology described in the previous chapter. The survey mission using this robot was successfully completed in November 2015. In the middle of the mission, a falling incident actually occurred as expected in the risk assessment, but the posture of the robot could be recovered using the prepared measures.

In addition to the rescue robots used in nuclear power stations, this methodology was applied to the development of a robot that inspects transmission lines (Sakaue 2019). This robot was jointly developed with external companies, but our methodology was introduced after their understanding. This robot inspects equipment of transmission lines while traveling on an overhead ground wire installed at the top of the transmission line. When it arrives at the steel tower, it crosses the top of the tower and proceeds to the next span. Requirements for crossing towers had to be realized as a technical hurdle, and its design had to meet the constraints in operation at actual power transmission facilities. At the time of system requirements definition, it was anticipated that there would be feasibility. However, there were items that could not fully meet the requirements despite repeated detailed design, prototyping and testing, and finally the robot was not completed as expected at first. When a technical feasibility is deemed hard to achieve, it is a difficult to make a decision to mitigate requirements at an appropriate timing.

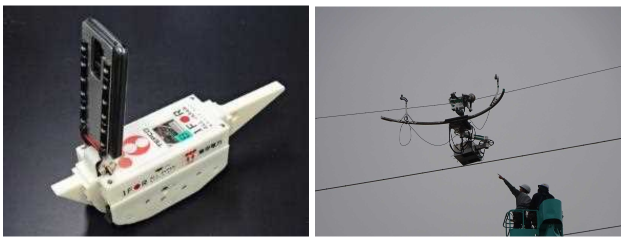

Fig. 3. Smartphone robot (Left) and Transmission lines inspection robot (Right)

5. FUTURE SUBJECT

This is like a waterfall method, because it first defines the usage conditions of the robot, then defines the system requirements, and proceeds with development to satisfy those requirements. In the case of manufacturer-led development, if the initial usage conditions are different from those required by the user, it is relatively likely that the trajectory correction will be required at the end of the development. On the other hand, if it is possible to proceed user-driven development based on need, the terms of use are clear from the beginning, and the possibility of rework can be reduced by applying this methodology.

However, user companies lack the technical knowledge of robotics, and the perception of what robots can do is different depending on person. This insufficient knowledge tends to cause excessive expectations for robots, misleading development schedules and development costs. In order to minimize such uncertainties, it is considered effective to apply an agile development methodology.

In the agile methodology, the minimum viable product (MVP) is developed in a short period of time, while presenting the result to the user, obtaining feedback, moving to the next step and improving the degree of perfection. The following values can be expected by applying the agile methodology to robot developments.

- Development risk is reduced because it is possible to obtain products with reasonable functions in a short period of time and with low development costs.
- At the early stage, the on-site user can grasp a concept image of what the robot can do. It can correct the development goal easily.

At the same time, the following issues are also conceivable.

- Since hardware construction is required for robot development, it is not suitable for repeating development and rework in a very short time like software.
- By presenting an incomplete state to the on-site user, a negative impression is given for the final perfection.

Two ways are mentioned to introduce the agile development concept in the user-driven development methodology proposed in this paper. The first is to minimize the first need itself, and the second is to implement a conceptual design from the minimum items in the system requirements definition. In future robot development, we would like to improve this methodology proposed in this paper while introducing the agile concept into it.

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