Presented as late breaking results contribution
21st IFAC World Congress (Virtual)
Berlin, Germany, July 12-17, 2020

Development of ROV for Underground Power Transmission Equipment Inspection in Submerged Manhole

Toru Nagakita*. Tomoki. Sakaue*

*Tokyo Electric Power Company Holdings, Incorporated, 4-1 Egasakicho, Tsurumi-ku, Yokohama, Japan (Tel: +81-90-6722-1444; e-mail: nagakita.toru@ tepco.co.jp).

Abstract: When inspecting underground power transmission equipment inside a submerged manhole, it is necessary to pump up groundwater inside the manhole before the inspection. Since pumping up groundwater requires large costs, it is expected to reduce costs by applying a Remotely Operated Vehicle (ROV) which does not require pumping up groundwater. This ROV requires high mobility, wide visibility, and sufficient operating time, to inspect underwater objectives and above-water objectives inside the manhole. However, commercially available ROVs could not meet these requirements. Therefore, we developed an ROV that can satisfy the requirements. As a result of the verification test using a prototype, good results were obtained for the mobility, but issues such as insufficient resolution of the camera and the voltage drop were also confirmed. In the future, we aim to solve the issues by changing the camera specifications and compensating the voltage, in order to complete the ROV.

Keywords: Field robotics, Telerobotics, Robotics technology, ROV, Underground power transmission, Manhole, Inspection, Camera

1. INTRODUCTION

Underground transmission lines connect substations mainly in urban areas. Since the length between substations is too long to be laid with one cable, so plural cables are connected each other inside manholes installed every few hundred meters. Regarding inspection objectives inside manholes, workers enter the manhole and conduct visual inspections periodically. In many cases groundwater is flowing into the manhole and it is necessary to pump up groundwater before the inspection. Normally, groundwater is dumped into a nearby drain using a temporary pump. However, if there is no drainage nearby, it is necessary to transport and dispose the groundwater far away using a tank lorry which requires a lot of cost. As a countermeasure, there is an inspection method using an underwater camera fixed to the tip of a rod. However, the underwater camera can only be used for manholes with small and simple structure due to the limited reach of the underwater camera. If the range of underwater inspection can be expanded, inspection costs can be reduced. For this reason, we decided to develop an ROV that can inspect submerged objectives in many types of manholes.

2. REQUIRED SPECIFICATIONS

The inspection objectives inside the manhole are laid in a small space. In order to approach these inspection objectives, the ROV may need to enter the manhole through the ground opening and pass through the ladder frame inside the manhole. And the groundwater inside the manhole is not always full. Therefore, the ROV is required to have high mobility to be able to move freely in a narrow space and wide visibility to inspect underwater and above-water objectives. Usually, inspections can be performed within one hour. Figure 1 shows an example of a manhole structure.

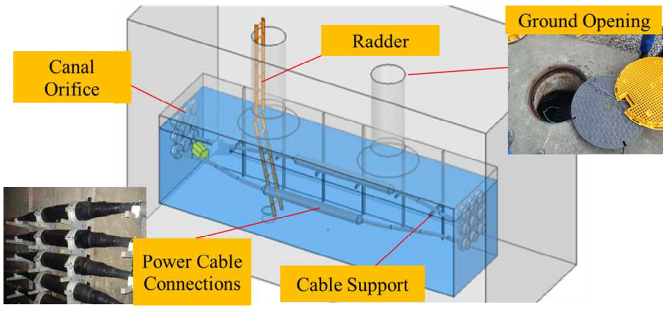

Fig. 1. Manhole Structure

Table 1. Main required specifications of ROV

Item	Description
Dimension	・Can be inserted into the manhole through the Φ750 mm ground opening. ・ Can pass through the ladder frame (300mm x 300mm)
Mobility	Forward, Reverse, Ascent, Descent, Right turn, Left turn
Visibility	・Can grasp the crack of inspection objectives ・Can inspect underwater and above-water objectives
Maximum Depth	20m
Operating Time	1 hour or more

Presented as late breaking results contribution
21st IFAC World Congress (Virtual)
Berlin, Germany, July 12-17, 2020

3. EVALUTION FOR APPLYING COMMERCIALLY AVAILABLE ROV

Initially, our development was started based on commercially available ROVs (OpenROV and VideoRay) of which specifications are close to the requirements specifications. But the following issues were confirmed after our early examination.

- Since one camera is installed only in front, it is not possible to inspect above-water objectives.
- Since there is no camera behind, the tether behind cannot be seen. Therefore, there is a risk that the tether may get caught in the obstacle and the ROV cannot be collected.
- Since the motors of OpenROV are exposed underwater, the lubricant applied to the bearings will melt and float on the water surface. Lubricating oil floating on the water surface may be confused with oil leaking from the Oil Filled cable.

To solve these issues, it is necessary to mount multiple cameras on the ROV. However, commercially available ROVs do not have enough space to add cameras. For this reason, we judged that we could not solve the issues by remodeling commercially available ROVs. Therefore, we decided to develop a new ROV.

4. PROTOTYPE PRODUCTION

The prototype system consists of a main body, tether, PC, controller, and stabilized power supply. Figure 2 shows the system configuration diagram of the prototype. Figure 3 shows all the components of the prototype system.

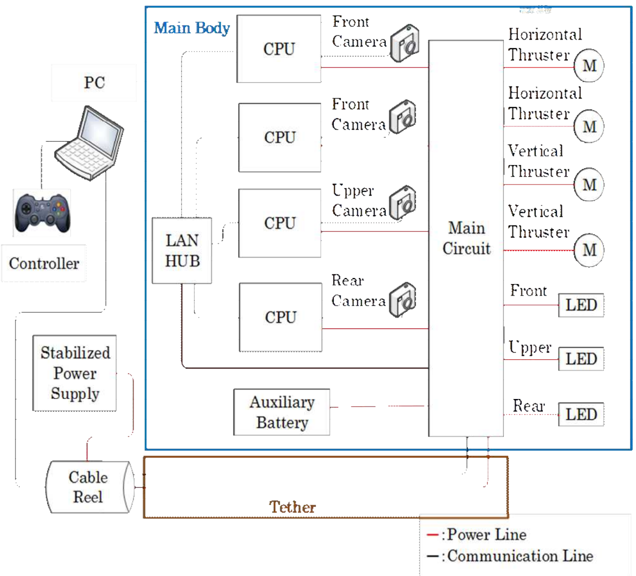

Fig. 2. System Configuration Diagram of Prototype

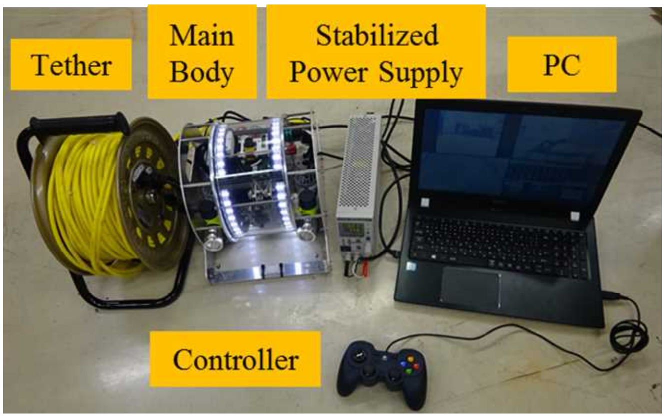

Fig. 3. Components of Prototype System

4.1 Main body and tether

The main body uses a watertight body composed of a transparent acrylic cylinder and two aluminum plates. Cameras and electronics are housed inside this watertight body. The cylindrical structure is excellent in pressure resistance and reduces the dead space in the internal area where the tilt mechanism is mounted. The aluminum plate secures the strength and reduced the risk of breakage. The tether has a built-in power line and communication line.

A highly flexible neutral buoyancy tether can reduce the drag that the ROV receives from the tether when moving. Figure 4 shows the appearance of the main body.

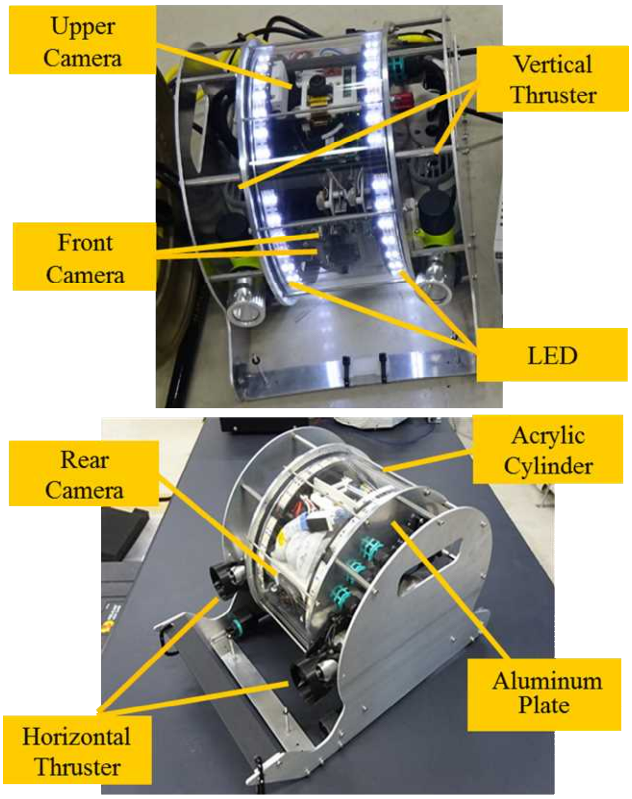

Fig. 4. Appearance of Main Body

4.2 Cameras

A total of four cameras are mounted inside the main body, two in front, one in upper part, and one in rear. The front camera is used to operate the ROV and inspect underwater inspection objectives. The upper camera is used to inspect above-water inspection objectives. The rear camera is used to check the tether.

The reasons for mounting two cameras in front are as follows. Low resolution images are sufficient for operation, but high resolution images are required for inspection. Due to the limited communication capacity of the cable, it is not possible to send three camera images including high resolution video at the same time. If the resolution of one camera is switched between the operation and the inspection, a time lag occurs, which makes the operation difficult. Therefor a low-resolution video camera for operation and a high-resolution still image camera for inspection are mounted in the front, and these are used while switching according to the purpose.

The front camera employs a tilt mechanism, so that the field of view can be changed up and down without moving the ROV when inspecting in narrow places. Furthermore, manual focus and auto focus can be changed each other, so that the inspection objective can be clearly photographed without being affected by floating objects.

With the upper camera, it is possible to inspect above-water inspection objectives such as a ceiling wall. By floating only the upper camera part of the main body above the water surface, it is possible to clearly shoot images of above-water inspection objectives, without being affected by the refraction on the water surface.

The rear camera has a large field of view so that the situation of the rear tether can be checked. This makes it possible for the tether to be steered without getting tangled with obstacles.

Regarding lighting, tape LEDs are arranged along the circumference of the acrylic cylinder. It is possible to light only necessary portions of the three (front, upper, rear) at an arbitrary brightness.

4.3 Thrusters

The main body is equipped with four thrusters, two for horizontal movement and two for vertical movement. By operating these thrusters, the ROV can move forward, backward, ascend, descend, turn right, and turn left. Figure 5 shows the horizontal thrusters operation and the ROV movement.

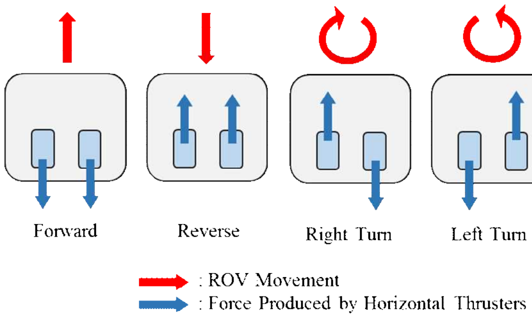

Fig. 5. Horizontal Thrusters Operation and ROV Movement.

4.4 Power supply

An external power supply system is used to enable continuous use for one hour or more required for inspection. In order to operate the main circuit stably, the voltage of the main circuit needs to be 14.4V or more. In consideration of the voltage drop in the power line, power is supplied to the main circuit from the stabilized 16.0V DC power supply through the tether. The main body is equipped with an auxiliary battery to ensure stable operation of the system. When a large load fluctuation occurs and the voltage of the main circuit becomes insufficient, power is also supplied from the auxiliary battery to compensate the voltage of the main circuit.

5. VERIFICATION TEST

We conducted a verification test of the prototype at the actual underground transmission line manhole, evaluated the mobility, visibility and operating time of the prototype.

Table 2. Test conditions

Facility	Commercially used manhole in urban area
Manhole Size	L:8.2m W:1.9m H:5.8m
Water Depth	5.0m
Water Temperature	22.6 °C

Fig. 6. Verification test

5-1 Mobility

The ROV was able to pass through narrow spaces, such as gaps between obstacles, and get closer to the inspection objectives without the tether being entangled with obstacles. It was possible to shot still images of the inspection objectives while maintaining a stable hovering state. The ROV was able to move horizontally and downward smoothly, but it was difficult to move upward. It was considered that when the ROV moving upward, the voltage of the main circuit decreased and the output of the thruster became insufficient. The voltage drop of the main circuit was larger than expected, therefore the main circuit voltage could not be sufficiently compensated with the auxiliary battery.

5-2 Visibility

The ROV shot the inspection objectives such as the power cable connection and the cable support by the front camera. High-resolution still images made it possible to clearly understand the condition of the inspection objectives. In shooting still images, it took time to aim at the inspection objectives. Since it takes too much time to shoot all the inspection objectives with still images, only main inspection objective could be shot. Therefore, for other inspection objectives, it was necessary to conduct inspections using the video. However, the resolution of the video shot by the front camera was sufficient for the ROV operation, but not enough for the inspection. Figure 7 shows the sample PC monitor screen of the prototype.

When the thruster power was increased, the illuminance of the LEDs decreased and it became difficult to see the inspection objectives. This was considered to be due to the voltage drop of the main circuit under high load.

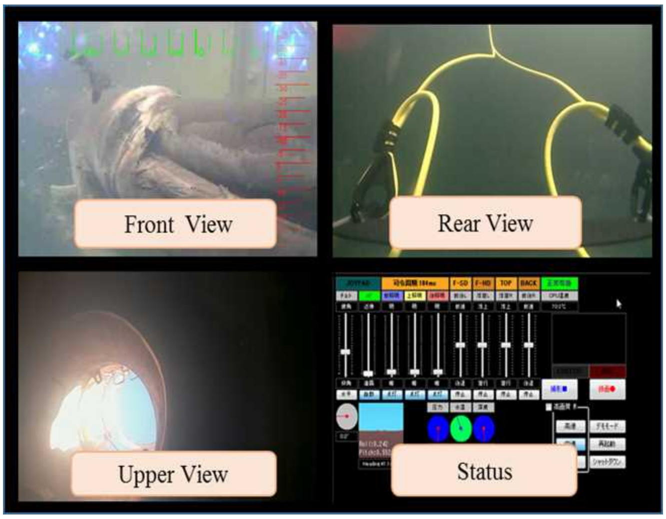

Fig. 7. PC Monitor Screen

5-3 Operating time

It was confirmed that the ROV can be operated for more than one hour inside the manhole. The temperature of the CPU inside the main unit was stable in the range of 45 °C to 60 °C, which was far below the operating limit temperature of 85 °C. Figure 8 shows the time transition of the CPU temperature during the verification test.

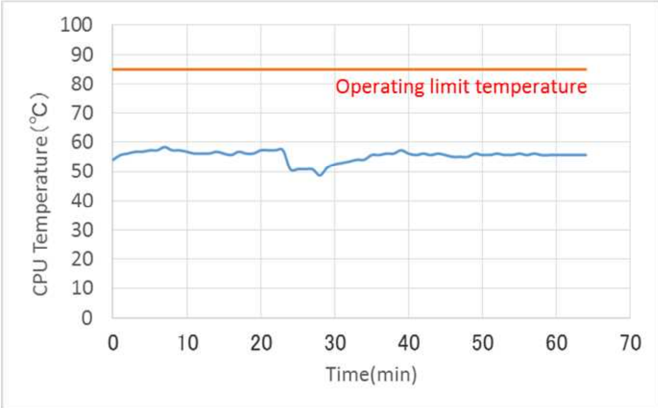

Fig. 8. Time Transition of CPU Temperature

6. FUTURE SUBJECT

In the verification test, it was confirmed that the video resolution of the front camera was necessary to be improved in order to perform an efficient inspection. Although the front camera need to be changed, the camera installation space can hardly be increased. For this reason, a solution is needed to install the high resolution camera in the same space as the current camera. It was confirmed that when a large load was fed to the thrusters, the voltage drop occurred more than expected of the main circuit, and mobility and visibility were reduced. We plan to solve these issues, and improve the completeness of the ROV, and apply the ROV on site early.

REFERENCES

R.Capocci, G.Dooly, E.Omerdic, J.Coleman, T.Newe and D.Toal (2017), Inspection-Class Remotely Operated Vehicles, *Journal of Marine Science and Engineering*, Volume 5,Issue 1,13

T.Nagakita, and T.Sakaue (2020), Development of submarine for underground power transmission manhole inspection, IEEJ National Convention2020,Tokyo.(in japanese)

S.Okada, R.Kobayashi, K.Otani, and K.Ohno (2017), Development of a Swim-type ROV for Narrow Space Inspection, *Journal of Nuclear Science and Technology*, Volume 54, Issue 04, pages 414 - 423.