Buried Pipe Detection Technology and In-pipe Traveling Robot Technology

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Summary

The Japan Gas Association researched on pipe-location detection and in-pipe delivery inspection technologies as part of a state-commissioned project between 2008 and 2010 to secure a next-generation solution to safe gas piping. The association has been working mainly with leading Japanese gas companies on these two promising technologies.

With regards to the location detection technology, we succeeded in condensing the size of the substrate mounted with a small, high-performance gyroscope. This has made moving through a 1-inch or 1 1/4-inch diameter pipe possible. As a result, it is also now possible to determine the shape and form of an underground pipe in three dimensions. For in-pipe delivery inspection technology, we improved upon the functions of the active scope camera, which moves autonomously when the fibers attached to the surface of the camera cable respond to vibrations caused by a motor. Shrinking the size of the scope camera so that it can move through a 1-inch and 1 1/4-inch diameter pipe was made possible by the structural improvement of combining the camera cable with the vibration motor.

Keywords

Gyroscope, Camera, Robot, Passage, Location Detection

Introduction

When the time was ripe for improving gas piping safety, the Japan Gas Association was entrusted by the Ministry of Economy, Trade and Industry with a national project from 2008 and 2010. The project, entitled "Search Mission to Improve Next-Generation Gas Pipe Safety," involved searching the world and across industries for technology that promised the safe gas piping for the next generation. We searched worldwide through all the different technologies that addressed the five areas where concern was the greatest among domestic gas providers. Figure 1 shows these areas. After evaluating the prospects of each technology, we selected the most advanced technologies that best fit the providers' needs in terms of location detection and in-pipe delivery inspection.

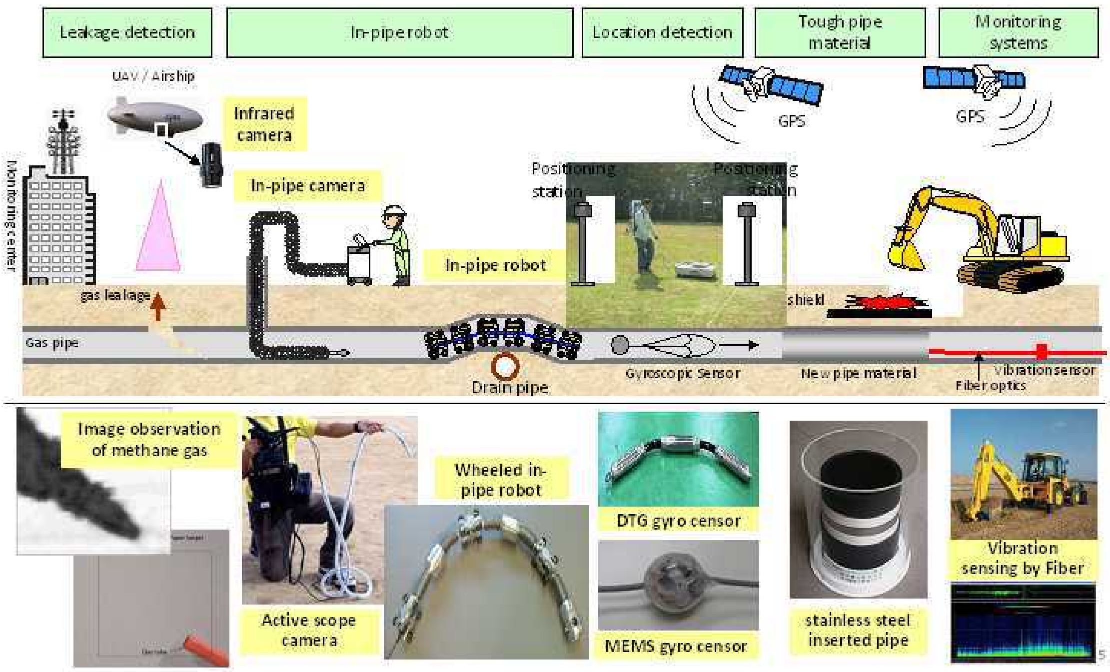


Figure 1 The Five Different Needs of Gas Providers

In location detection, we looked primarily at gyroscopic technology and concluded that submarine location detection and incoming-missile detection technologies were the most advanced. We determined that those gyroscopic technologies were promising ones for the purpose of gas piping, which can take complex shapes and forms.

For pipe inspection work, we searched mainly through robotic engineering and found that rescue robot technology was the most advanced. We concluded that rescue robot technology was also an appropriate one to deal with the complex shape and form of gas piping.

Obviously, none of these technologies can be applied directly to the gas industry; each gas provider would have to develop its own adaptation of those technologies. After the national project came to an end, leading domestic gas companies decided to develop the two technologies for the providers. This report details the results of the technological developments.

Pipe Location Detection Technology
Figure 2 shows the gyroscopic technology, which is a promising element in the national project, "Search Mission to Improve Next-Generation Gas Pipe Safety." A MEMS gyroscope is run through the pipe, then determines the approximate shape of the pipe. Previously, the gyroscope was mounted on to the cable, which pulled it through the pipes. MEMS (MEMS, Micro Electro Mechanical Systems) points out the device which integrated machine element parts, the sensor, the actuator, and the electronic circuit on one silicon substrate, the glass substrate, the organic material, etc.

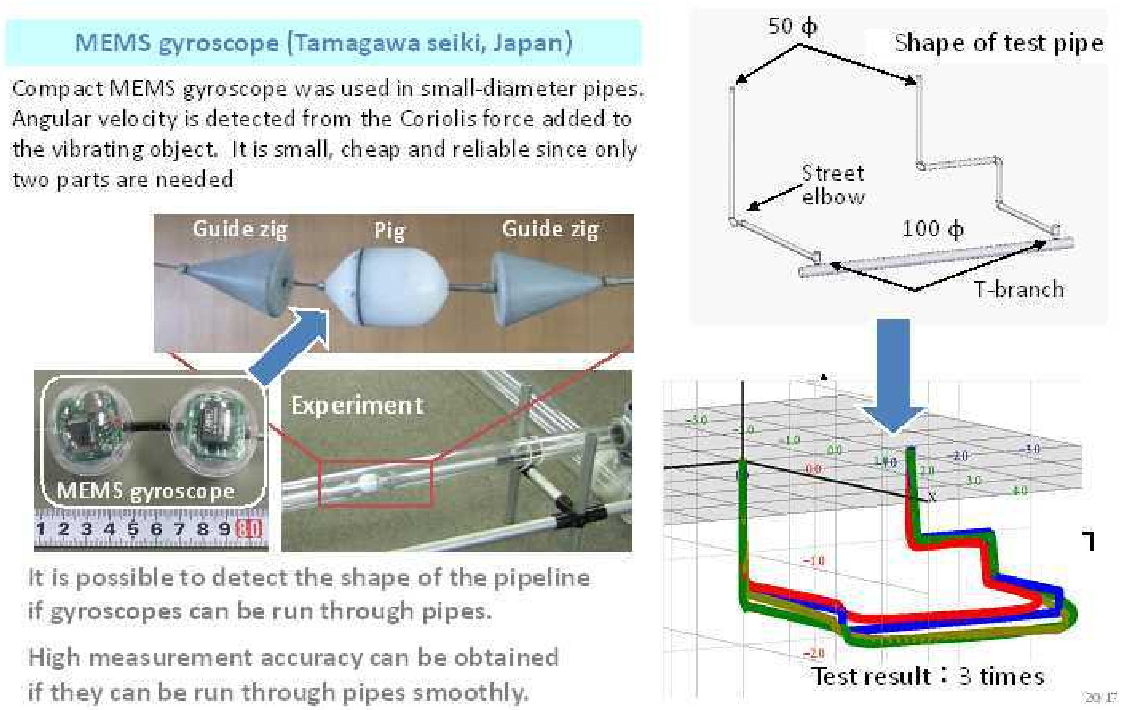


Figure 2 Extraction of the Promising Gyroscopic Technology

In order to bring this technology into practical use as a gyro-locator that can measure gas pipes, we worked on improving the device's precision. We pinpointed the issues that needed to be addressed for the application and precision of the gyro-locator, and from there, developed a super-compact sensor.

1. Issues that Arose during Development and Study Results
Issues that came up during development and study results are as follows.
1) Improvements in the gyroscopic sensor
In order to improve the gyroscopic sensor's response to external stimulus, we extended the range of the sensor's rotation speed to protect against over-range from 300 degrees/sec to 900 degrees/sec.

And, to reduce an unfavorable effect of the coupler passing through the pipe, the substrate was constructed as a stable, flat-shaped board, compact in size measuring 14 mm x 30 mm. The new and improved sensor is shown in figure 3.

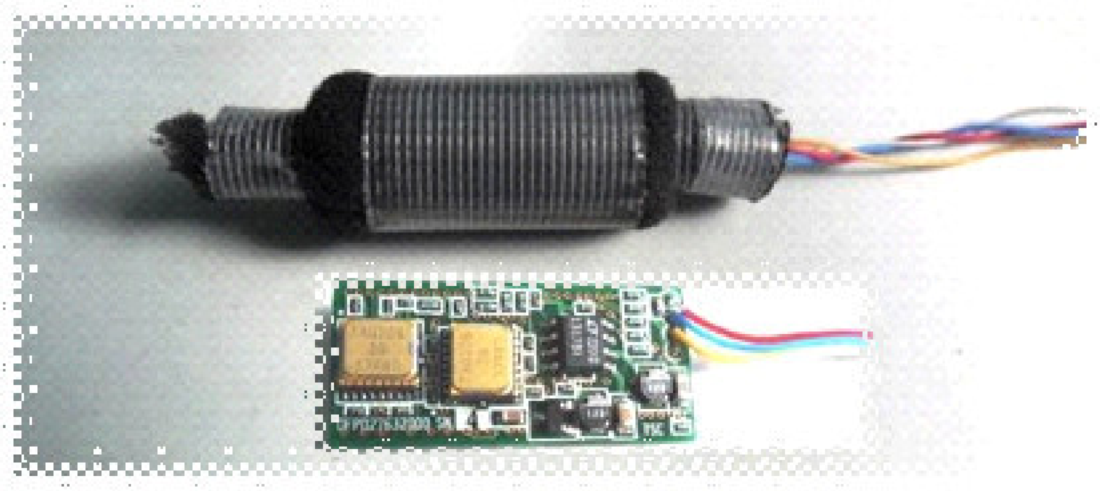


Figure 3 The Newly Developed Sensor

2) Developing the Insertion and Collection Technology
Pulling the sensor through the pipe causes a big shock to the sensor itself. The impact could not be addressed by changes in the case or the wire/cable, which meant that the sensor was not able to work to its full potential. Seeing that pulling the sensor alone through the pipe made for imprecise measurements, we decided to use a delivery device gas providers use for other types of inspection tool. The device used is shown in figure 4. The device is made out of coiled metal wire. By inserting the sensor inside the coil, the sensor is protected from impact.

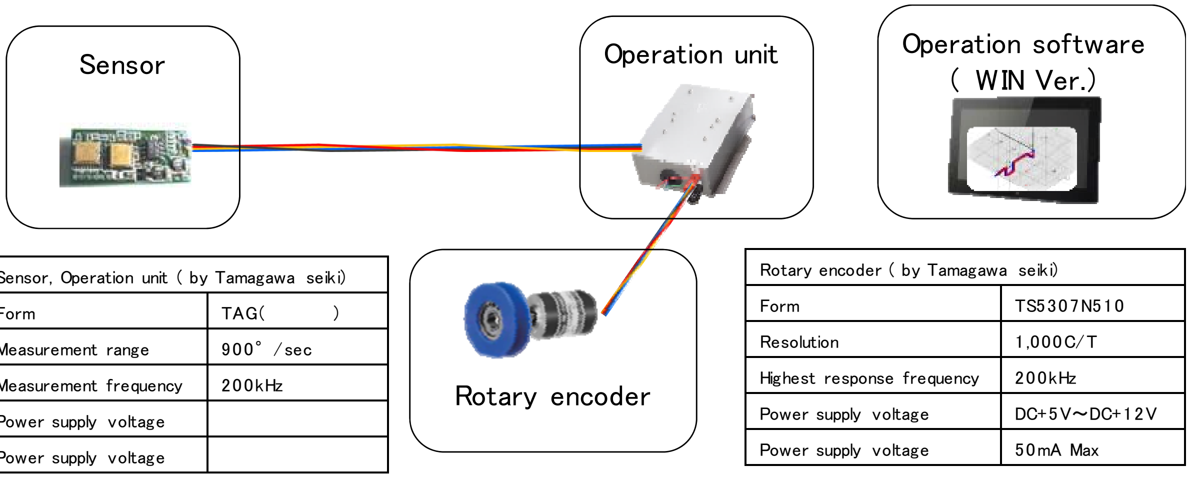
Figure 4 The Delivery Device : Coiled Metal Wire

3) Software Development
In the early stages of development, we used a correction formula that favors angles (angular velocity) to produce mild changes in measurements (i.e., non-excavation method of construction). But after analyzing data, we learned that we wanted to use a formula that favored straightness (acceleration), so we switched to a formula that calculates attitude angles from the inertial navigation system, which was the initial specification. After this adjustment, we were able to obtain stable sensor-output test results.

4) Studying Other Correction Techniques
We installed a camera in front side of the delivery device outlined in 2). By distinguishing between a straight path and a coupler within the pipe, we studied the feasibility of correcting the margin of error in the gyroscope's measurements. By looking at the images inside the pipe, we found that it is possible to distinguish a straight path in the pipe from fittings, and the different types of fittings used. Whether this information can be used in correcting the margin of error in the measurements is a topic for the future.

2. Test Assessment of Simulation Piping

The test assessment of the above-mentioned gyro-locator was conducted as a test on simulation pipes. The gyro-locator is shown in figure 5. The delivery device mounted with a gyroscopic sensor picks up information as it moves along the interior of the pipe. That information is quantified through an arithmetic logic unit and length-measuring machine. The information gleaned from this is passed through a software that can provide a pipe path analysis.



Sensor, Operation unit (by Tamagawa seiki)	
Form	TAG(　　　)
Measurement range	900° /sec
Measurement frequency	200kHz
Power supply voltage	
Power supply voltage	

Rotary encoder (by Tamagawa seiki)	
Form	TS5307N510
Resolution	1,000C/T
Highest response frequency	200kHz
Power supply voltage	DC+5V～DC+12V
Power supply voltage	50mA Max

Figure 5 The Structure of the Gyro-Locator

Figure 6 shows results from a test done on simulation pipes that were actually installed. The piping that was laid down was 4 meters long, 1 1/4-inch in diameter, and with numerous curves. After inserting a gyroscope through this pipe three times as part of the test, the gyroscope was able to measure the shape and form of the piping with a margin of error of 10 cm. Similar results were achieved for pipes that were 1 inch in diameter, as well as for four other types of piping with different shapes.

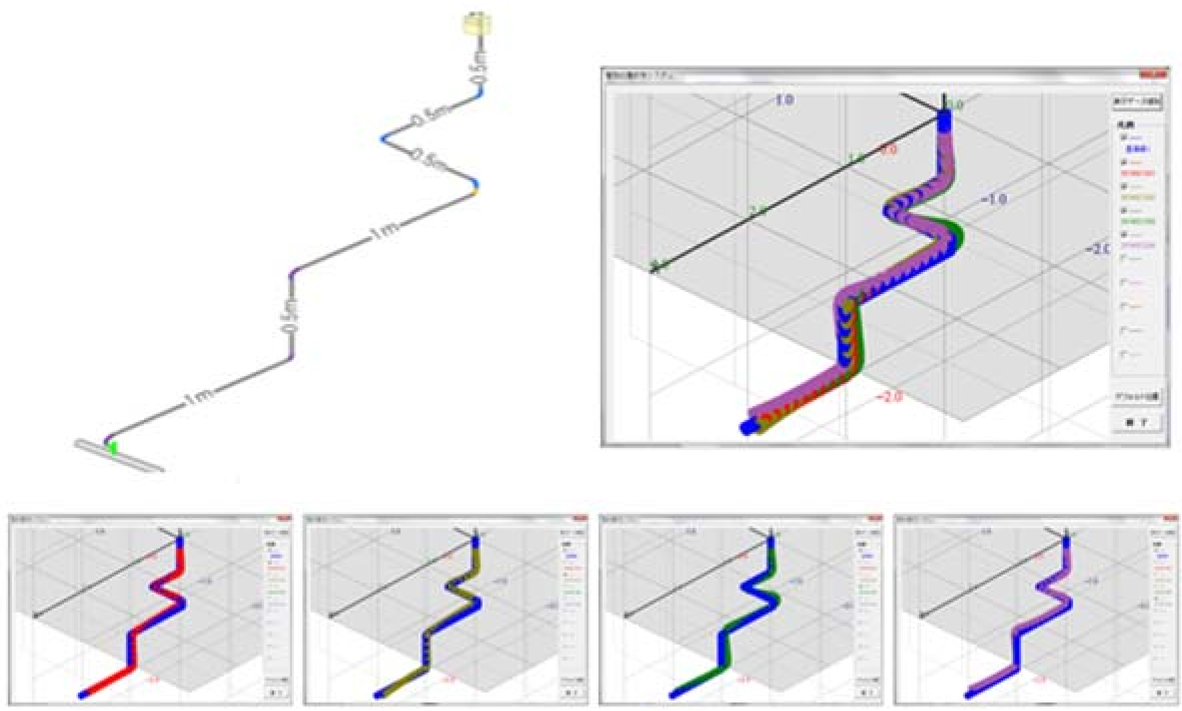


Figure 6 Test Results from Installed Simulation Pipes

Development of an In-Pipe Traveling Technology

Figure 7 shows the active scope camera for small-diameter transport device, which is a promising element in the national project, "Search Mission to Improve Next-Generation Gas Pipe Safety. The active scope camera, as seen in Figure 7, is based on a technology in which fibers attached to the surface of a camera cable respond to a vibrating motor and autonomously move the camera along through the repeated motion of bending and sliding forward. We decided to improve upon this technology for use on gas pipes. We specifically worked on improving its mobility through narrow pipes with various twists and turns by adding certain functions, such as retreating and pulling-out, mounting a gyroscope, as well as on assessing its practical use.

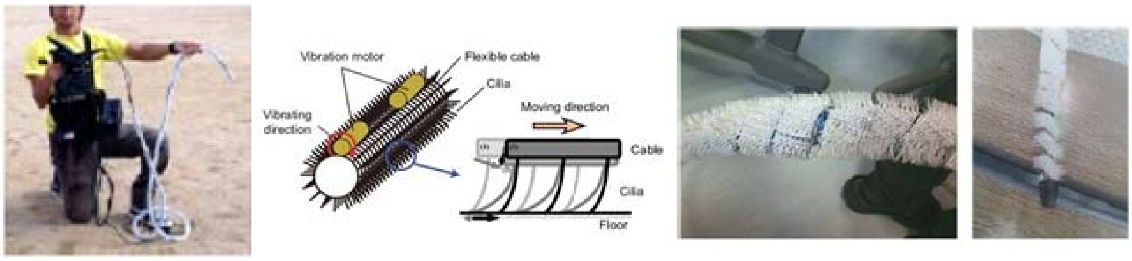


Figure 7 Active Scope Camera

１． Development Issues and Study Results

１) Adapting to narrow apertures and improvements that increase the camera's mobility.

The former active scope camera was a search robot developed for narrow roads. Therefore it needed to be decreased in size to adapt to gas pipes. Our study specifically honed in on improving the camera's ability to move through a pipe diameter of 1 to 1 1/4 inch, through elbows and street elbows, bends and service tees, through 90-degree turns in fittings, and differences in levels between fittings.

① Improving Cable Storage Methods

Any type of undulation within the cable-storage tube can hamper the cable's movement through the level differences at the elbow. As show in figure 8, we decided to wind a monocoil around the tube (left image) in a helix fashion, and apply a blade (right figure). This reduces the chances for the scope camera to get stuck at the elbow joints and creates a smoother passage.

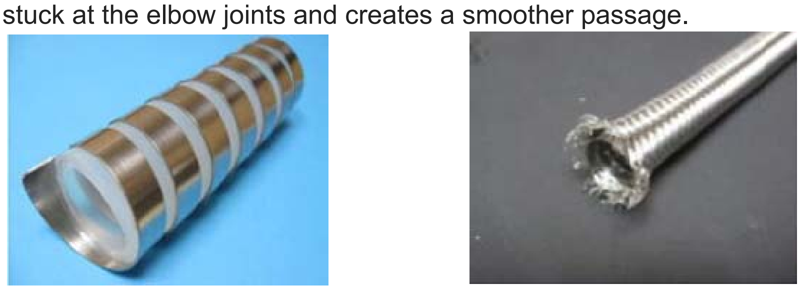


Figure 8 Monocoil and Blade

② Installing a tip rotating mechanism

We installed a new rotation mechanism to the tip; specifically, a tire. We chose a tire with screw-like grooves so that it won't lose momentum when it passes through different levels within the pipe. Figure 9 shows the tire chosen as the new tip rotation mechanism. This has improved the cable's mobility through street elbows and bend fittings with significant level differences.

Figure 9 Tire Use for New Rotation Mechanism

２) Discussion of backward movement and retracting functions

The former active scope camera was designed only for forward movement, so in adapting the camera for gas pipe use, we had to figure out how to add backward movement and retracting functions. We couldn't install an actuator small enough for the compact scope camera, so we considered the option of retracting the cable through external force.

Easy-to-Retract Design

In order to easily extract the camera, we designed the cable so that it would not get stuck at the curves within the pipe. The exterior of the active scope camera and the fixed body part can be seen in figure 10. Tapering the metal in the back end of the fixed body part helps reduce friction when it passes through curves in the pipe. By using a design that uses tapered fixed body parts and takes full advantage of the fiber location, we were able to develop a forced-retraction method that can navigate through five curved pipes. And, with the addition of a wire (which will be dealt with later), we can expect a significant improvement in the cable's retractability.

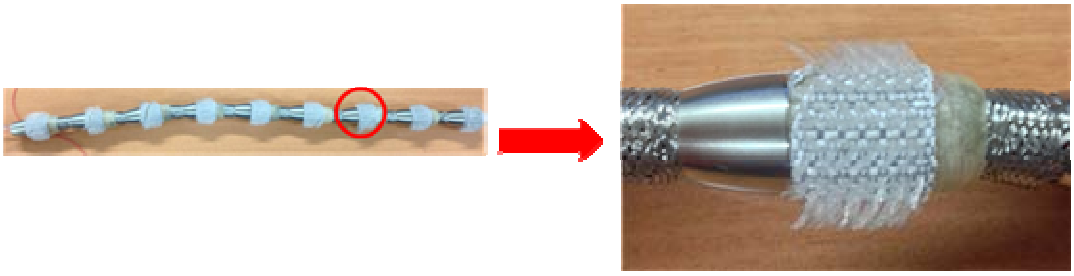


Figure 10 Shape and Appearance of the Active Scope Camera

② Retraction Method Using a Wire

We installed a wire fixed to the tip inside the camera so that tube was flexed and gradually retracted through the curves by pulling the wire. This method retracts the active scope camera gradually, and can go through eight curves in short pipe.

3) Mounting a Gyroscope

We examined the different shapes of the active scope camera if a gyroscope were to be mounted. We also tested the camera's ability to move through the pipe fitted with a box simulated as a gyroscope. We found that the camera traveled without a hitch for 32A piping through pipe flexions that included continuous fittings, such as elbows and street elbows.

2. Test Assessment through Simulated Pipes

Finally, we created a prototype of the active scope camera and ran it through four different pipe simulations. These simulated pipes are typical shapes of piping from the meter to the main pipe used in gas providers. In the test, we studied about the amount of time it took for the camera to reach the flexed part of the pipe. We ran the test three times per pipe. With each pipe, we tested how many flexions the camera can be retracted through. The pipes we used for the test were 25A and 32A. Figure 11 shows the active scope camera we developed. It is 7 meters long, and the fixed body part is 12mm in diameter without including the fibers. The fiber length is 5mm. The tube diameter is 10mm. Figure 12-15 shows the assessment test result of the four different pipes.

Pattern A shows the camera passed through all flexions without any problems for both 25A and 32A. The camera was able to retract through up to four curves for both 25A and 32A. With pattern B, the camera passed through 25A, but we found that it got stuck inside curve 2, the street elbow, which was the narrowest of all the pipes. That accounted for the reason the camera took time moving past curve 3. For the first and second time through pattern C, the tip of the tube was too hard and got stuck descending past curve 4. After solving this problem, the camera passed through all curves in the third try. When retracting, the camera was able to retract through four curves. The camera passed through curve 6 or 7 for pattern D piping.

Figure 11 The Active Scope Camera We Developed

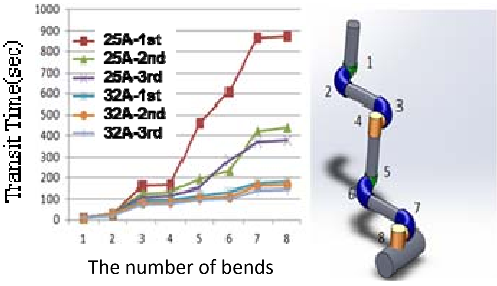


Figure 12 Pattern A Test Results

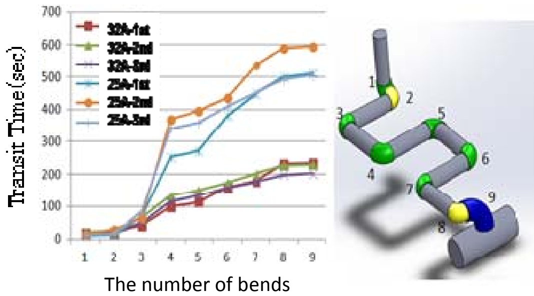


Figure 13 Pattern B Test Results

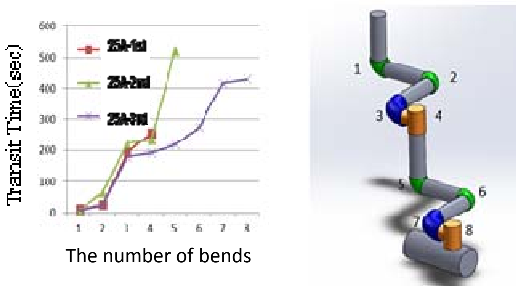


Figure 14 Pattern C Test Results

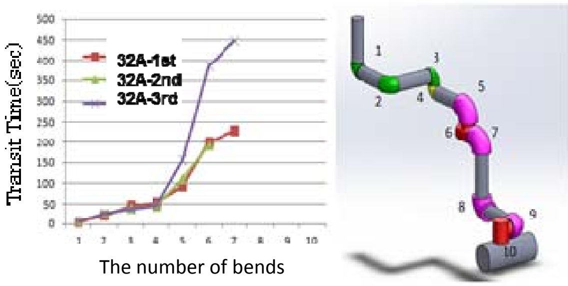


Figure 15 Pattern D Test Results

Conclusion and Plans for the Future

With regards to pipe detection technology, we succeeded in super-miniaturizing the platform that would be outfitted with the high-performance compact gyroscope. The ability to pass through small pipes measuring 25A to 32A in diameter has made the three-dimensional measurement of the pipes with a 10-cm margin of error possible. As a result, it became easier to check the three-dimensional form of piping laid underground. The topic of discussion for the future is to find ways to pass through pipes with fittings or inverted siphons that have bigger gradations, reduce the amount of shock when passing through fittings, and better run through deep underground piping.

We took the active scope camera, which moves autonomously when the fibers attached to the surface of the camera cable respond to the motor's vibrations, and made revisions on it to develop the pipe-run technology. By revamping the cable storage method, and fashioning the fixed body parts in a way that prevented it from getting stuck in the pipe, we created a method that not only accommodates small diameters, but also allows for easy passage. This has made passage through small pipes, such as 25A and 32A, possible. Our future issue is to improve the retraction method.

In conclusion, by developing a pipe-run technology that combined these two separate technologies, we no longer have to dig out deeply buried pipes to detect their location and shape. The technology also allows for an extensive survey of the interior of the pipe. This, in turn, contributes to safer gas pipe maintenance.