Research and Development Achievement

(Year of 1983-2020)

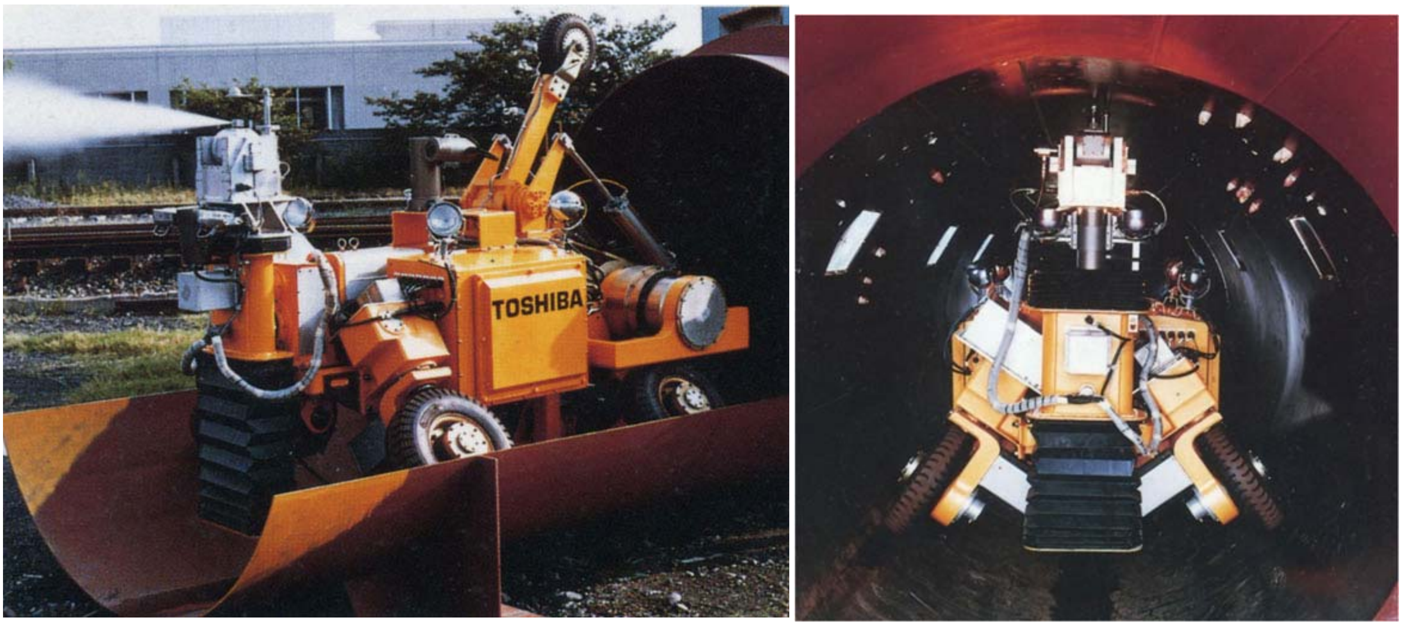
Akita Prefectural University

Ph.D. Nobuhiro SHIMOI

1. Industrial robot (1983–1988)

Automatic VTR head winding machine (1985 Toshiba Institute of Industrial Science).

It can achieve terminal processing in about 140 s. The VTR magnetic head coil is wound automatically. 30 μm polyurethane wire 30 turn VTR head (left panel)

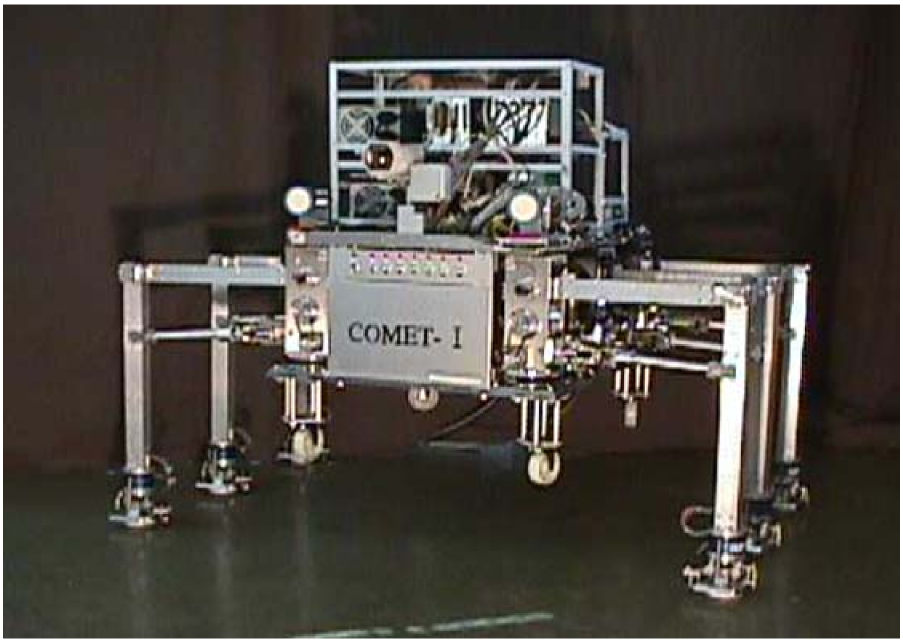


Cleaning robot in the secondary cooling path pipe of a nuclear power plant.

Removal of marine organisms adhering to the inside of the pipe can be accomplished with water jets. Remote control by optical cable was achieved. Toshiba developed the robot around 1985 for nuclear power plant maintenance.

2. Robot development for international contributions (1988–2008)

A humanitarian landmine detection robot (COMET-1) with a metal sensor attached to the foot to ensure safe walking was developed in collaboration with Chiba University (1999). The robot can properly avoid land mines through compliance control. To conduct mine detection experiments using an eight-wheeled prototype, robot RAT-1, we developed end effectors to be attached to the robot's driving wheels. The wheels enabled the robot to step safely and stably in the test area without hitting hidden mines. We created a simulation model for this study to test the movement of a robot having metal sensors attached to the front of its wheels and to test the driving algorithm with effect controls based on IR cameras. We verified the system efficiency in actual walking experiments. We also studied remote sensing technology uses for IR cameras combined with other metal sensors. Tests with trial mines were used to study the detection characteristics of IR cameras and various technologies for collecting and processing image data in real time for optimum mine detection.

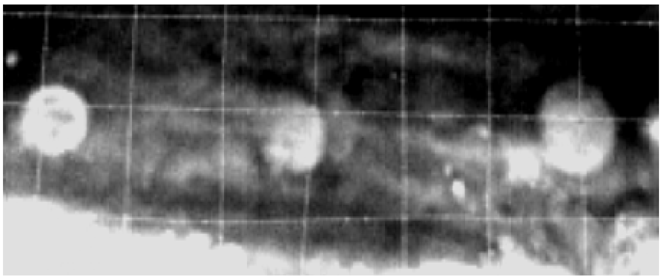


Mine detecting robot COMET-1

Legs of COMET-1

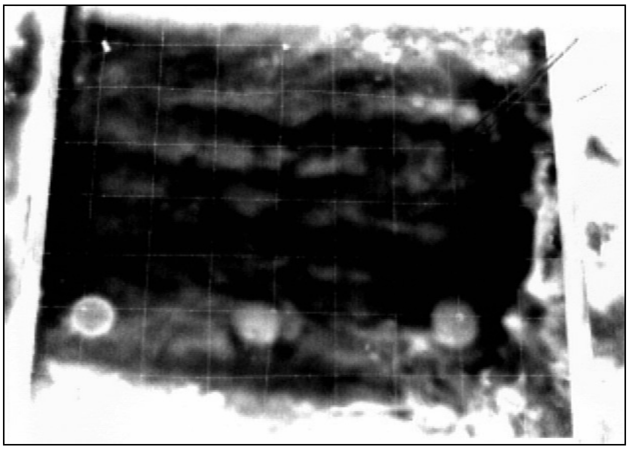
Mine demining

3. Underground buried object exploration experiment using infrared imaging



A simulated land mine (plastic ingot) was buried before the experiment.

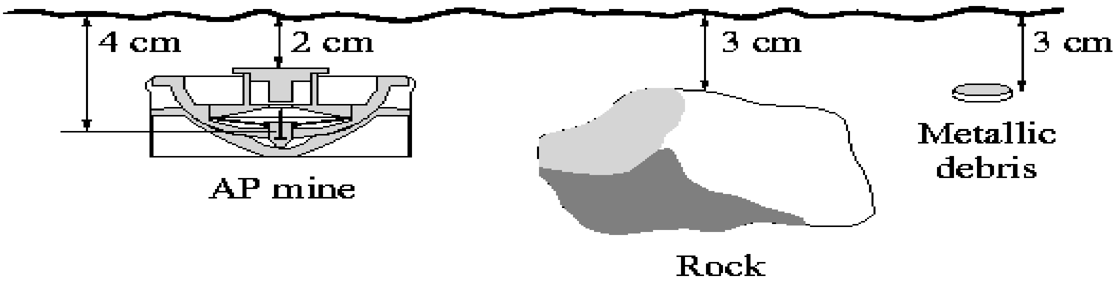
The experiment was conducted 3 min after the ground surface cooled. Using an 8–12 micrometer infrared camera, the simulated land mine was detected after burial.

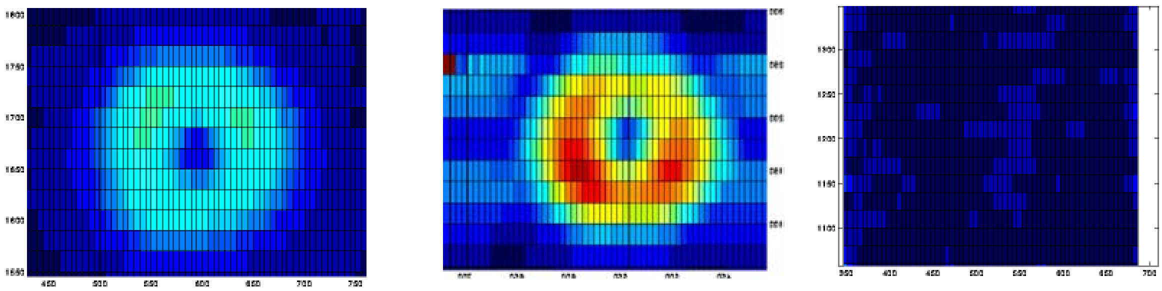


Mine detection using an IR sensor and mine demining.

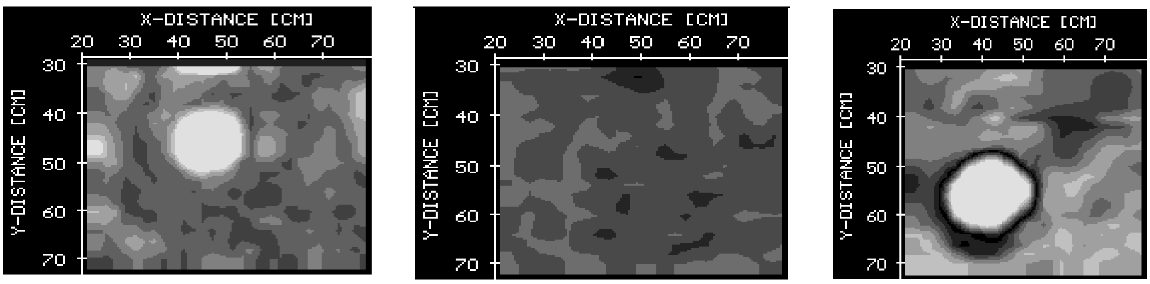
This measurement technology proposes an IR camera system that performs the task of removing mines for humanitarian purposes. Because of the high risks involved, it is necessary to conduct mine detection from the greatest possible distance. By using infrared (IR) cameras, scattered mines can be detected from remote locations. For mines buried in the ground, detection is possible if the peripheral temperature difference is sufficiently large between the ground and the mine device. Tests with trial mines were used to study the detection characteristics of IR cameras for images and various technologies for collecting and processing image data in real time for optimum mine detection.

4. Landmine detection using a composite sensor (2005–2010)





Detection result by GPR sensor



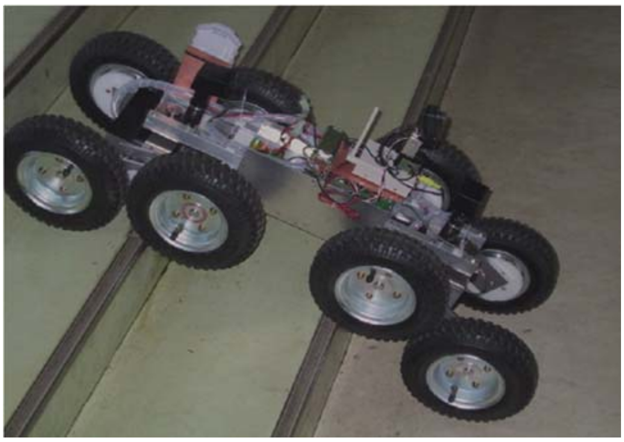
Detection result by metal detector

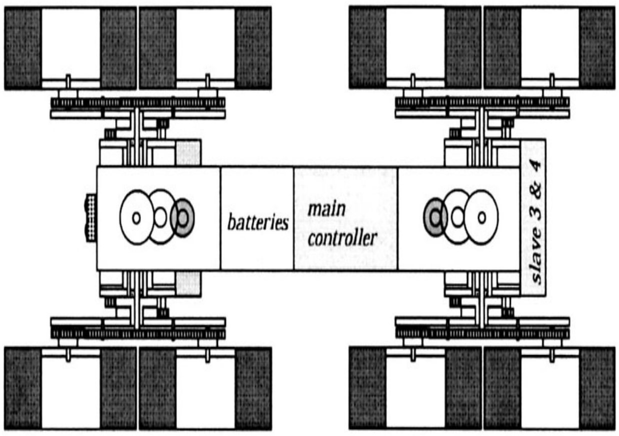
The measurement results of both detectors are judged in a complex manner to ascertain the burial position of the buried land mine.

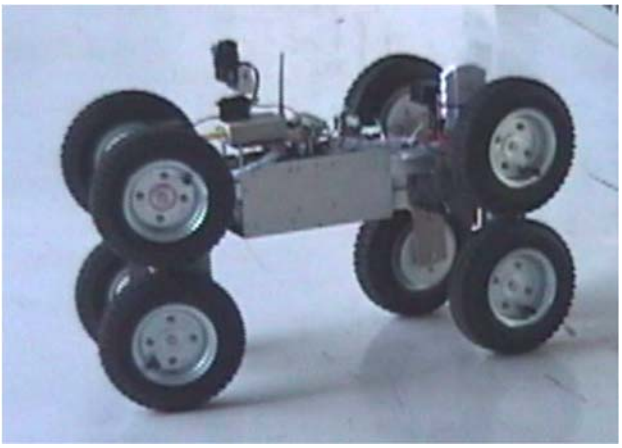
The IR camera system that performs the task of removing mines for humanitarian purposes. Because of the high risks involved, it is necessary to conduct mine detection from the most remote endeavoring. By making use of infrared ray (IR) cameras, scattered mines can be detected from remote locations. In the case of mines buried in the ground, detection is possible if the peripheral temperature difference is large enough between the ground and mine weapon. As one of the world's advanced nations in sensor technology, Japan should promote surveys and studies for detecting mines safely by using its advanced remote sensing technologies.

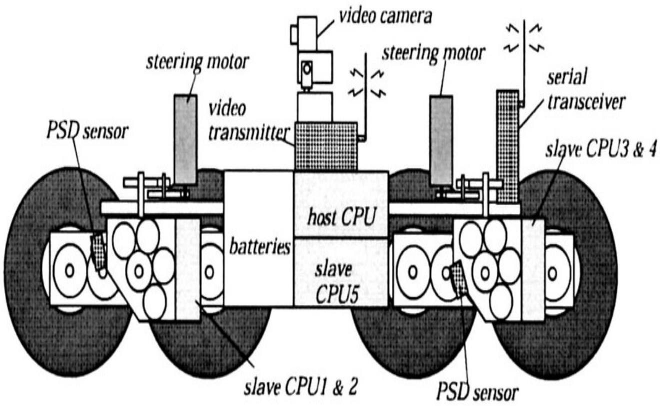
5. Development of the life support robot (2009–2015)

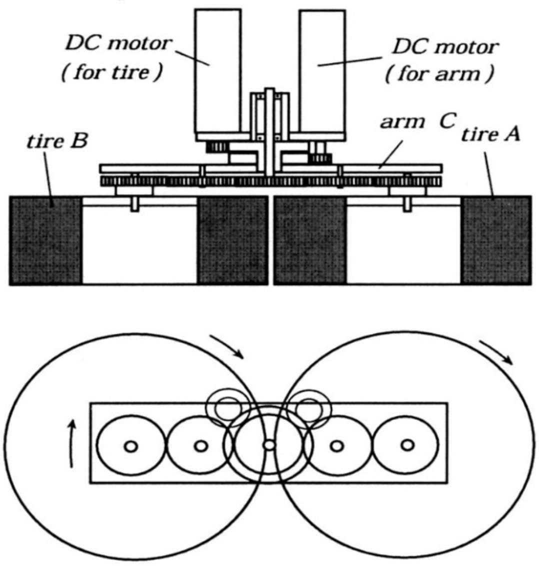
(1) Security and mine detection robot

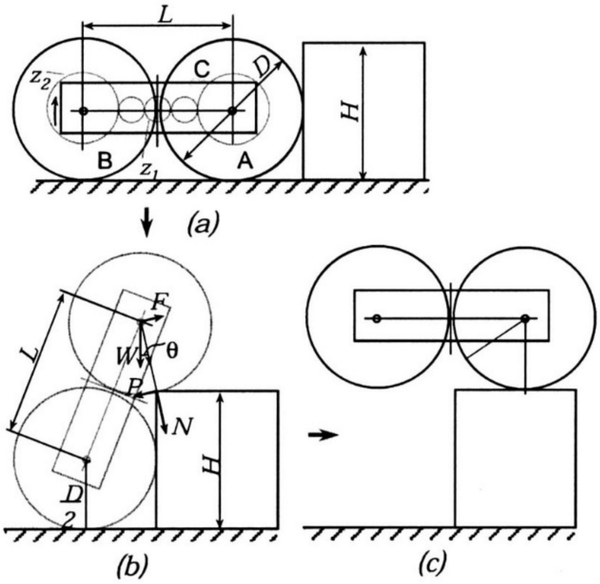








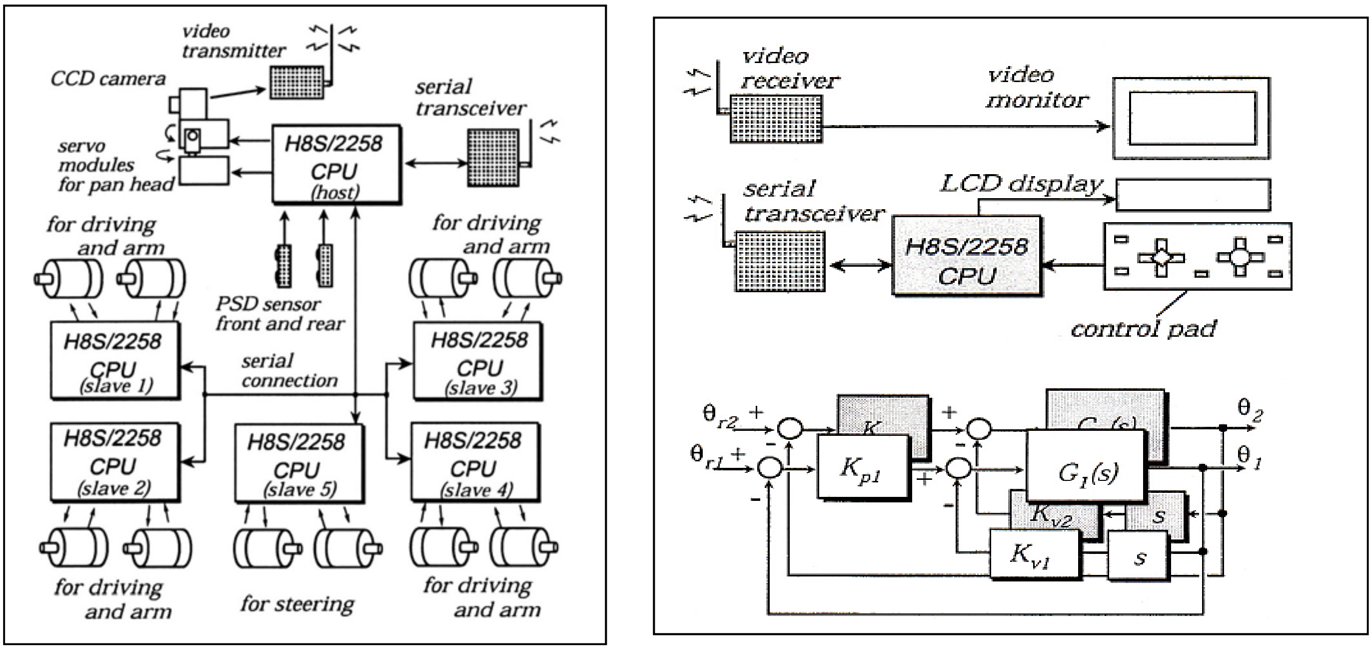




Outline of RAT-1 mechanism and schematic concept of climbing motion over an obstacle.
(Overall dimensions: 300 × 750 × 450 mm, weight about 10 kg)

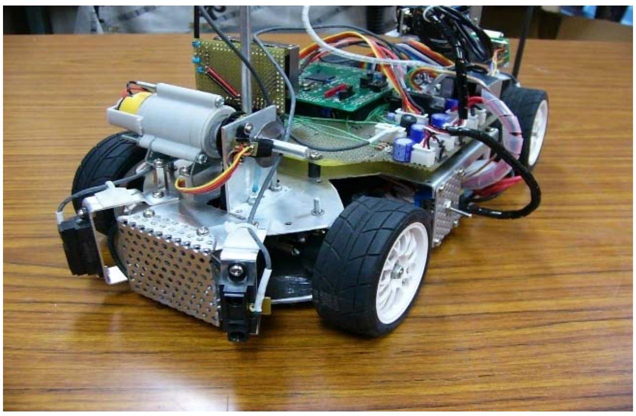
This robot can move up and down steps, such as emergency stairs, autonomously. Normal driving is done by four wheels. The vehicle height can be raised to 750 mm.

To conduct mine detection experiments using the eight-wheeled prototype robot RAT-1, we developed end effectors to be attached to the robot driving wheels. These wheels enable the robot to traverse the area safely and stably without hitting hidden mines. We created a simulation model for this study to assess the movement of a robot having metal sensors attached to the front of its wheels and to evaluate a driving algorithm with effect controls based on IR cameras. We verified the system efficiency in actual walking experiments. We also studied remote sensing technology uses for IR cameras combined with other metal sensors. Tests with trial mines were used to study the detection characteristics of IR cameras and various technologies for collecting and processing image data in real time for optimum mine detection.

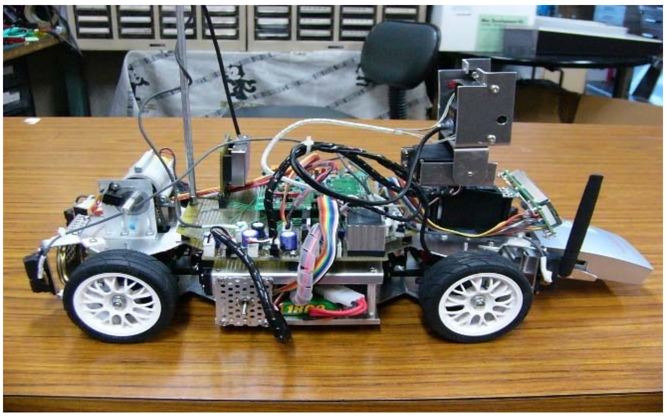


Outline of RAT-1 mechanism and PD control realized using a control.

(2) Nursing and medical assistance robot



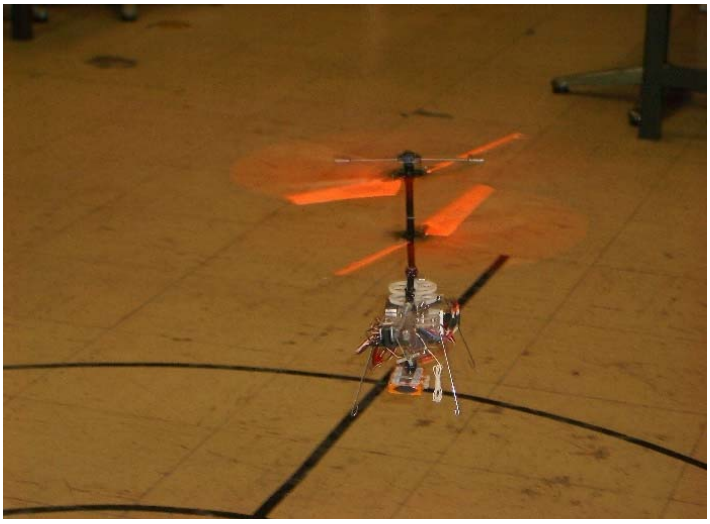
Observe daily changes of elderly people using wireless LAN



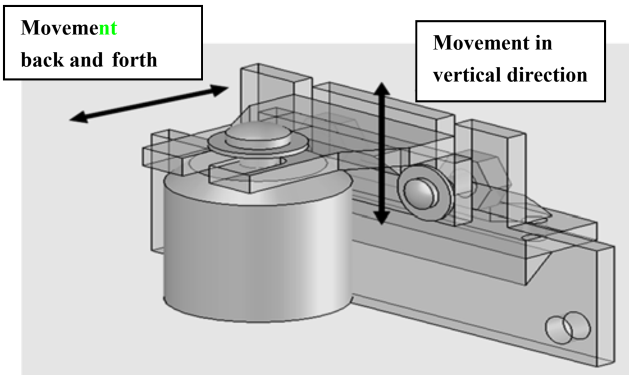
Remotely observe or diagnose treatment status

Equipped with sensors according to the purpose and carrying out program driving. (Battery can be charged by the user.)

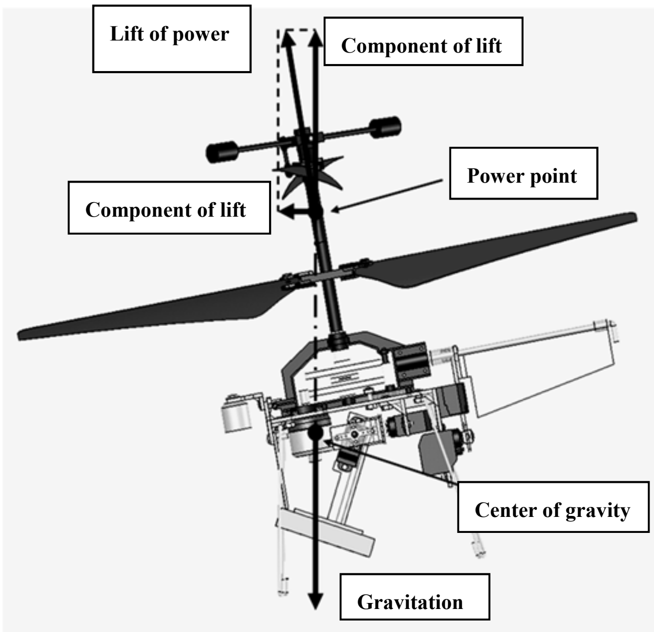
(3) Disaster relief support robots (2008-2014)



Autonomous flight state (center of gravity variable device) PID control
Small helicopter for disaster reconnaissance indoors, tunnels, etc.



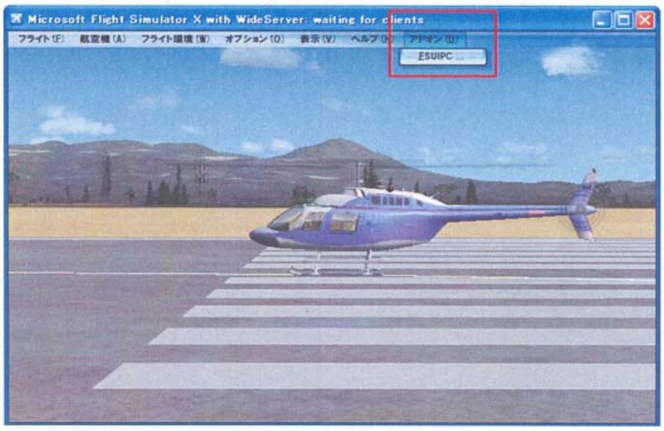
Center of gravity front adjustment device



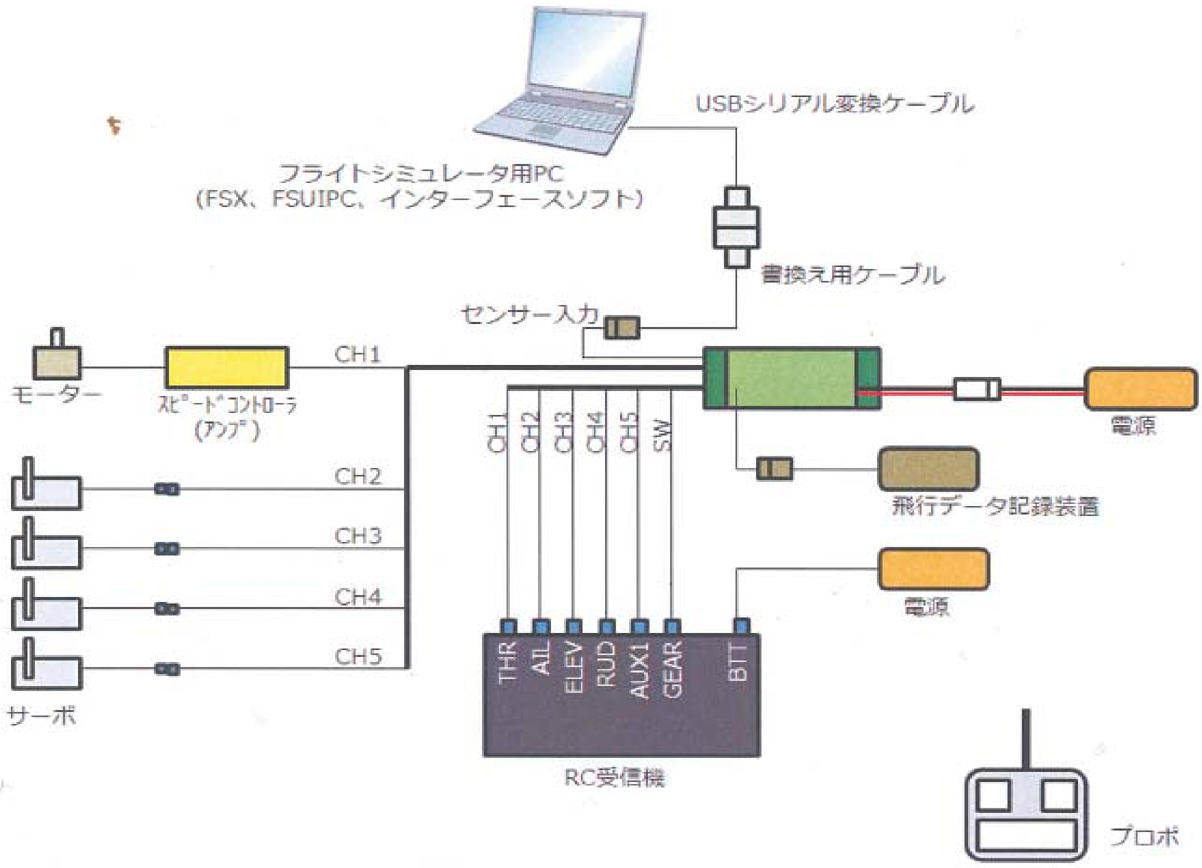
Center of gravity active adjustment device

This research examines a disaster prevention rescue system used for a small rescue flying robot. Immediate assessment of damage information and continuous collection of information for constructing a revival plan are important for damage mitigation after natural disasters such as huge earthquakes. This research examines a proposed rescue system for detecting moving objects in spaces of underground roads in disaster areas. The aims of this study are to improve the performance of rescue systems and to detect injured people and provide for their safe extraction from remote sensing areas.

(4) Autonomous flying robots for tunnel disaster relief

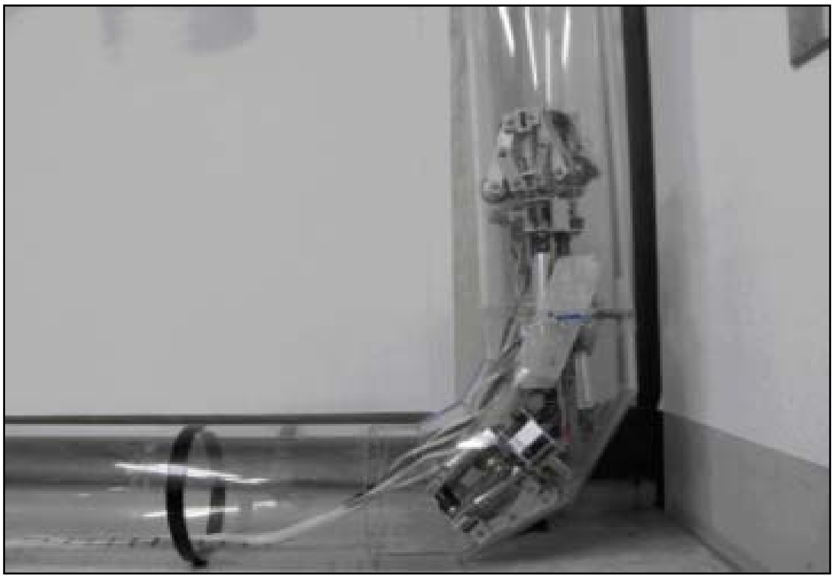


The flying robots can search for victims during autonomous flight in underground routes and tunnels.



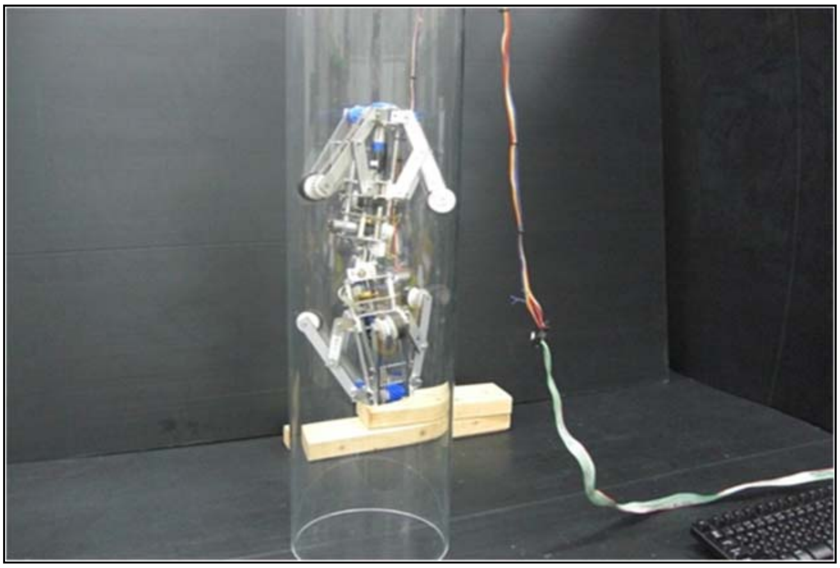
Flight simulation development

(5) Autonomously controlled pipe inspection robot



Bent piping (90°)

Bent piping (30°)



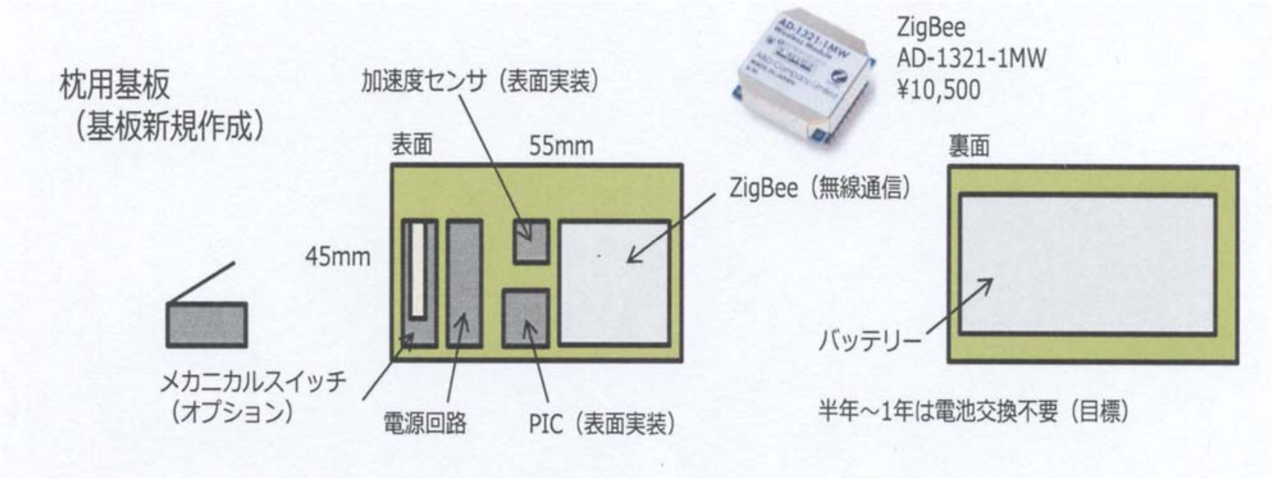
Vertical piping

Inspection for gas leaks in gas pipes and corrosion inside pipes

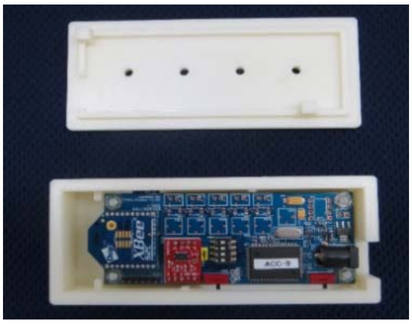
6. Health Monitoring Research and Development (2010–2019)

(ICT system for elderly people living alone using pillow sensors)

(1) Vibration piezoelectric sensor development



New monitoring system

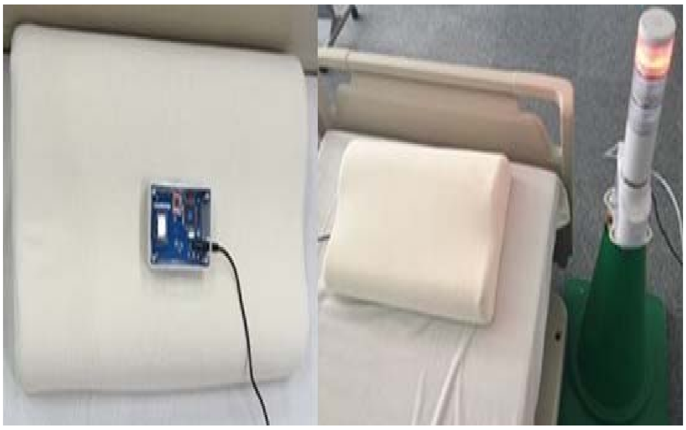


Mechanism

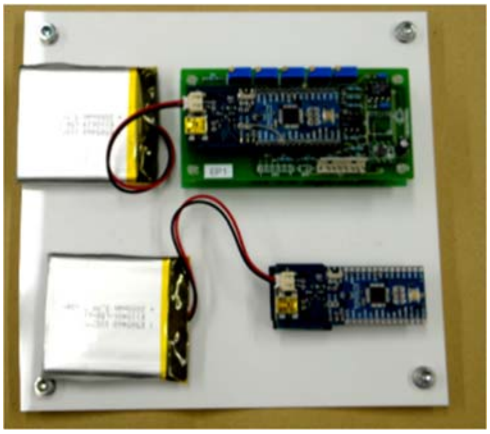
Because all communications among sensors and simple network robots in home networks use the ZigBee standard, it is highly reliable and can contribute to improvement of the performance of these communication devices. The final information is sent via LAN cable to the management server. Then the commands are judged.

(2) ICT System development

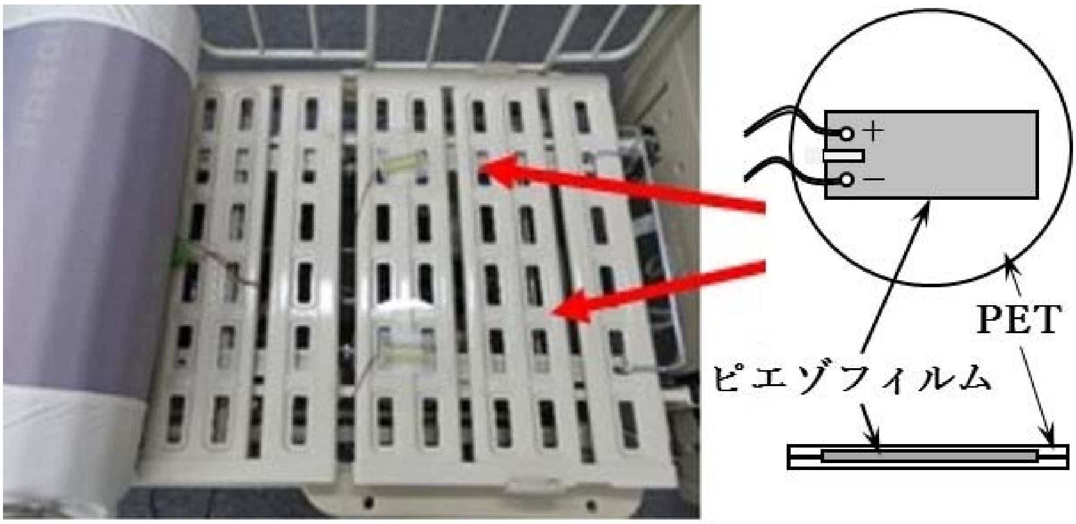
This announcement presents a multiple sensor system that is able to predict behavior patterns which occur when a patient leaves a bed. We originally developed a vibration bolt sensor using a piezoelectric cable and a pillow sensor using an accelerometer. Existing sensors such as clip sensors and mat sensors require restraint of patients. Moreover, these sensors present privacy problems. The features of our sensors are that they require no power supply or patient restraint. We evaluated our system using a basic experiment to predict seven behavior patterns. We obtained a result of predicted behavior patterns related to bed-leaving using only two sensors installed on a bed. Especially, our system can correctly detect behavior patterns of lateral sitting, which is a position that a patient uses when trying to leave from the bed, and terminal sitting, which is a position used immediately before bed-leaving. They were discerned from other behavior patterns.



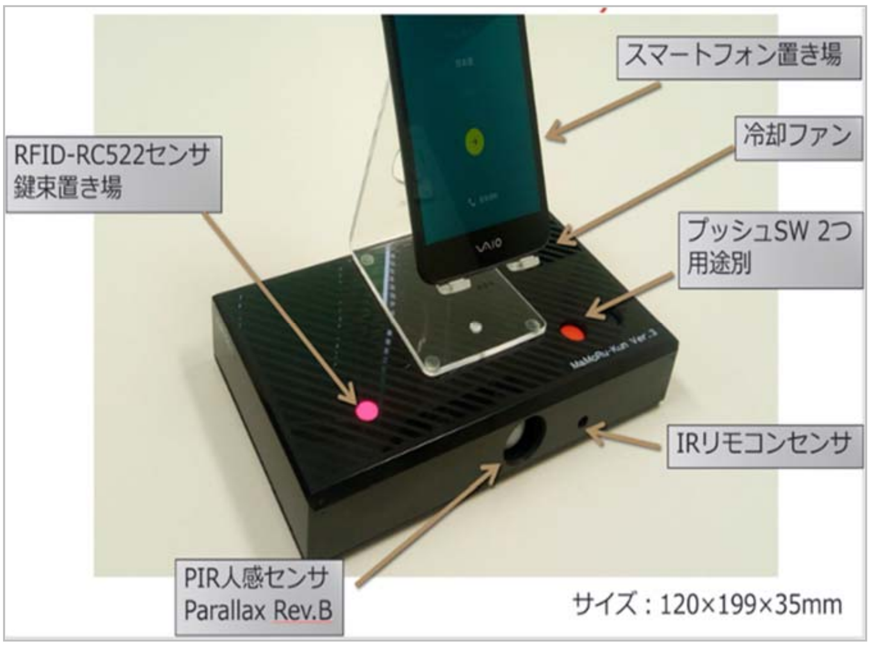
Pillow sensor



Radio systems



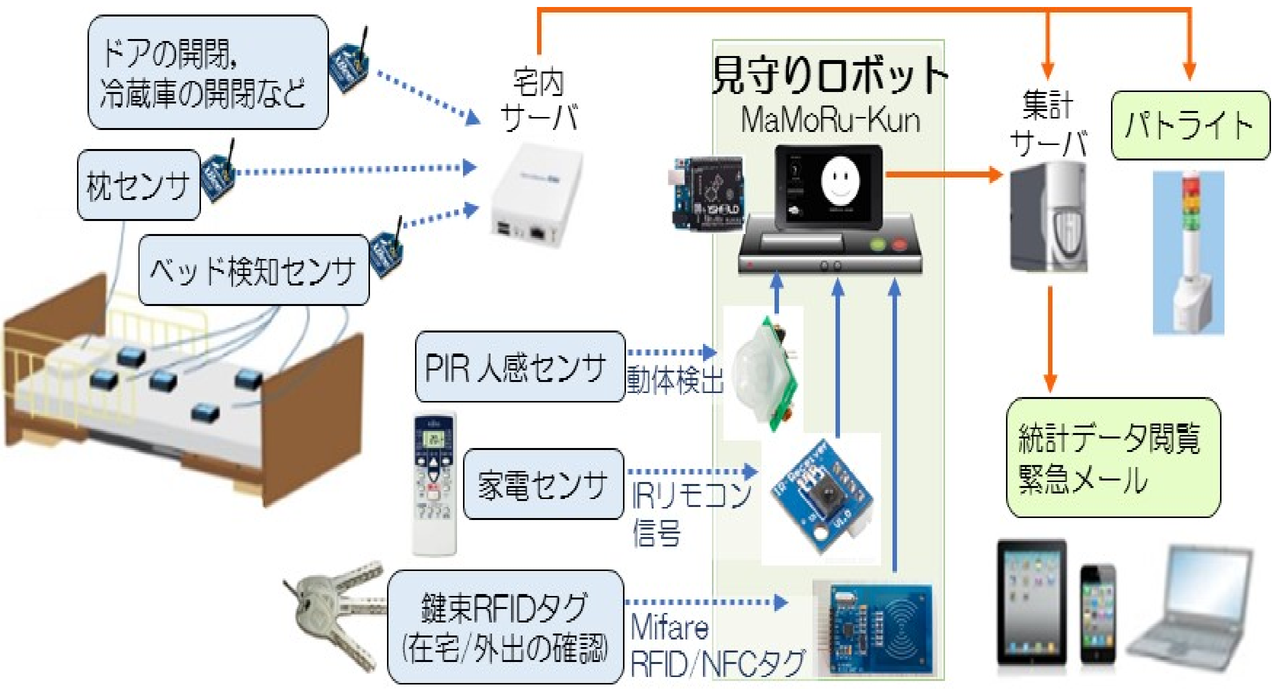
Bed monitoring system for high-level quality of life by using AI System.



Monitoring robot (Mamoru-kun) and insertion assignment of bed frame vibration sensors.

7. Health monitoring system for elderly people (2010–2019)

This announcement presents a multiple sensor system to predict behavior patterns that patients use when leaving their bed. We originally developed a vibration bolt sensor using a piezoelectric cable and a pillow sensor using an accelerometer. Existing sensors such as clip sensors and mat sensors require restraint of patients. Moreover, these sensors present privacy problems. The features of our sensors are that they require no power supply or patient restraint. After we evaluated our system using a basic experiment to predict seven behavior patterns, we obtained results of predicted behavior patterns related to bed-leaving using only two sensors installed on a bed. Especially, our system can correctly detect behavior patterns of lateral sitting: a position that a patient uses when trying to leave a bed, and terminal sitting, which is the position immediately before bed-leaving. They were discerned from other behavior patterns.



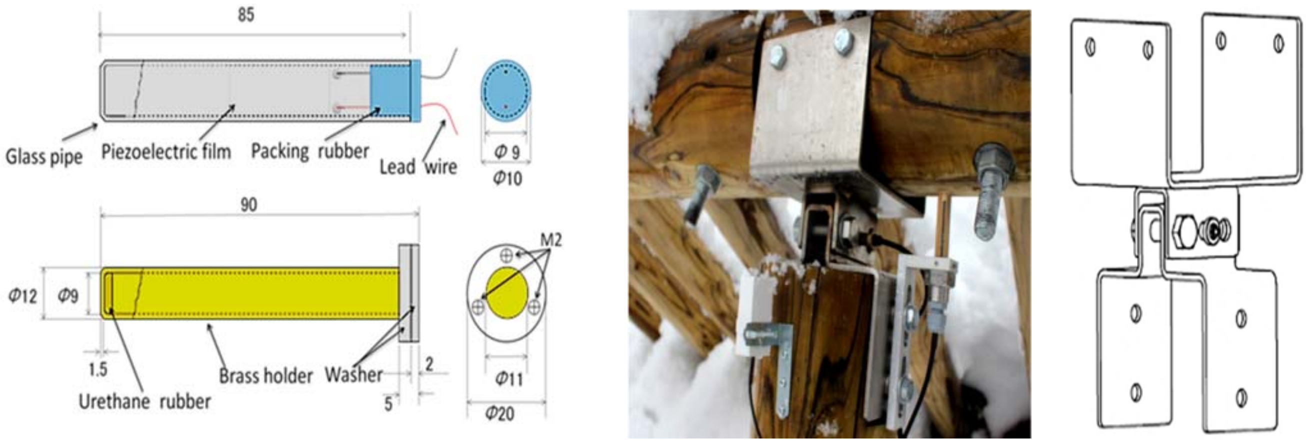
Health monitoring system

Existing sensors such as clip sensors and mat sensors require restraint of patients. Moreover, these sensors present privacy problems. The features of our sensors are that they require no power supply or patient restraint. We evaluated our system using a basic experiment to predict seven behavior patterns. We obtained a result of predicted behavior patterns related to bed-leaving using only two sensors installed on a bed. Especially, our system can correctly detect behavior patterns of lateral sitting, which is a position that occurs when a patient tries to leave from the bed, and terminal sitting, which is the position immediately before bed-leaving. They were discerned from other behavior patterns.

8. Early detection system for avalanches and debris flows (2009–2017)

(1) Health monitoring sensor and measurement system

Under certain conditions, when weather and snow cover steep slopes, an avalanche occurs. It can reach protective fences. If a collapse of these fences causes an avalanche to occur and arrives at a roadway, then traffic would be hindered. Predicting the occurrence of avalanches is important, but it has not been implemented. To avoid and resolve difficulties caused by avalanche and debris flow hazards, we measured the snow pressure using the magnitude of the voltage to assess danger during a snowfall period at an avalanche protective fence. We developed a piezoelectric limit sensor and a piezoelectric vibration sensor for detecting avalanches by converting the avalanche load and vibration, as well as the pressure and shock received by the device as electrical signals. This measurement system is fixed with a dedicated mounting bracket so that pressure and vibration measurements related to snowfall at the time of avalanche occurrence can be measured at the main structural part of the avalanche defensive fence. In addition, this measurement fence is designed to withstand pressure imposed by 3–5 [t/m^2] snowfall using wood supports.

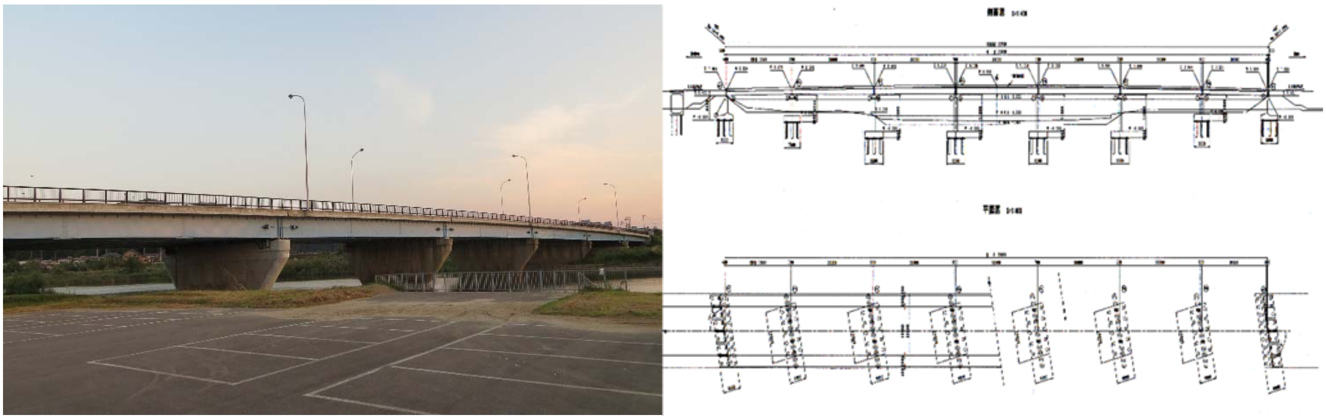


Piezoelectric limit sensor and sensor bracket

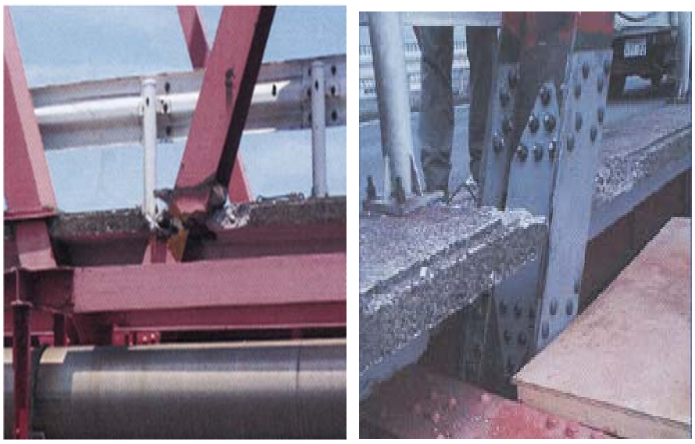
Measurement fence and measurement sensor unit.

(2) Combined sensor system development (2012–2015)

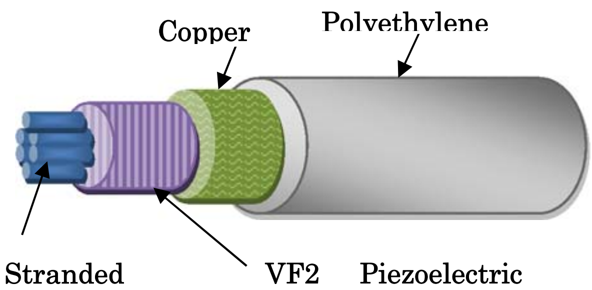
Reinforced concrete bridges of structure occasionally became unstable because of deterioration and because of effects of strong earthquake disasters. Operational restrictions imposed according to strong earthquakes are practical methods to secure safe road operations. This paper presents a prototype of a piezoelectric cable vibration sensor for a monitoring system that can easily evaluate the integrity of a reinforced concrete bridge structure quantitatively and easily using displacement measurement analyzing. We performed measurements at a reinforced concrete bridge using an accelerometer and a piezoelectric cable vibration sensor to sense natural vibrations during loading and car run testing. However, the system presents some difficulties in terms of accuracy and reliability in application to evaluate the soundness of bridge piers in a practical environment. As described in this paper, we present the outline of our system study executed on upgrading of function and principal specifications of the developed system for monitoring the stability of reinforced concrete bridges. Bridge pier joints occasionally become unstable because of deterioration and after strong earthquakes. This paper represents an outline of smart sensor studies executed to upgrade functions and principal specifications of the developed sensor for monitoring bridge pier joint stability. We have proposed this system as a prototype of a monitoring system that can easily evaluate bridge pier joint integrity quantitatively and easily using vibration analysis.



Experiment point of bridge (Aska Oohashi)



Old broken bridge of maintenance model

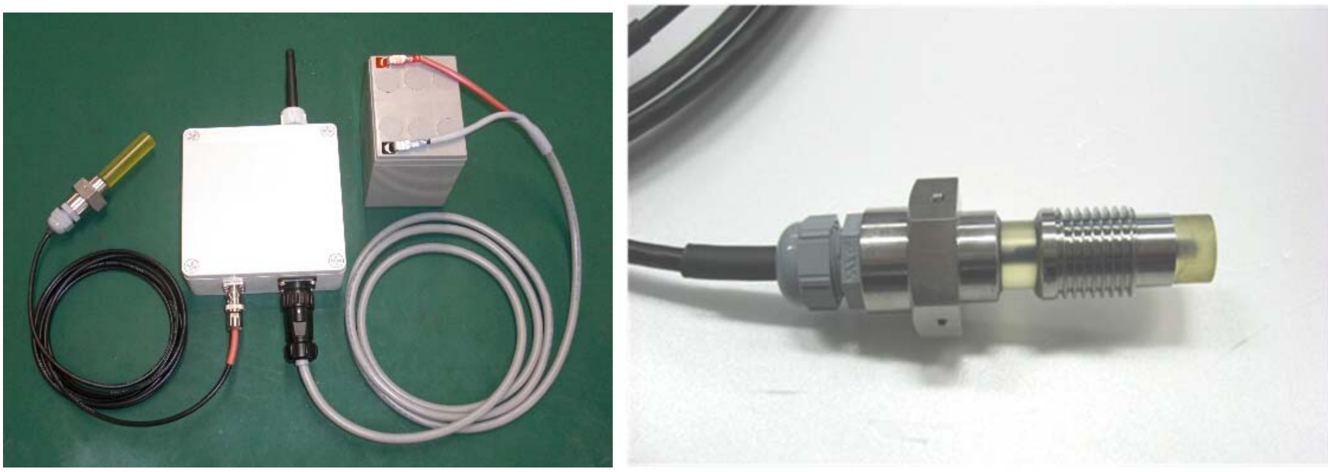


Piezo cable sensor

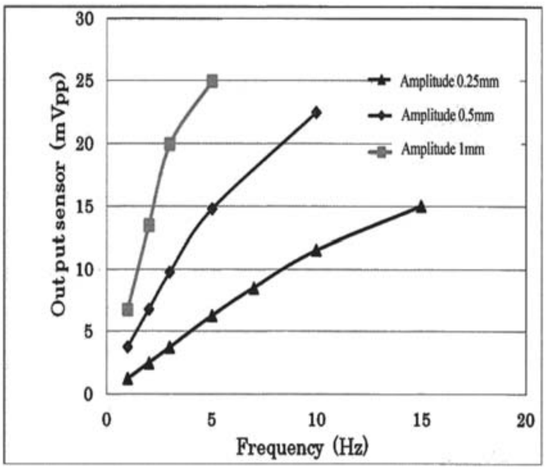
Piezo electric vibration sensor

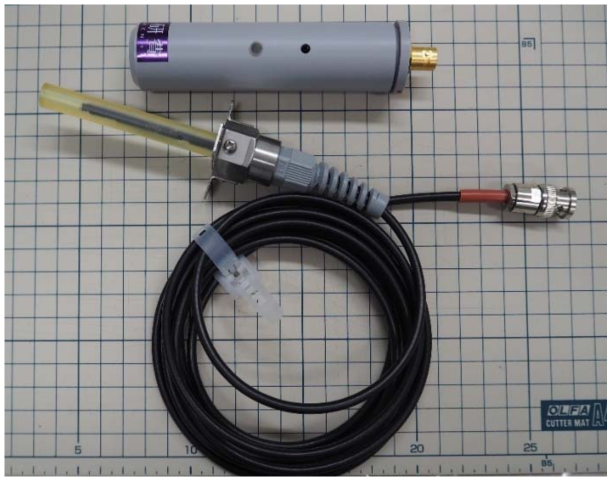
(3) Simple Sensor Developed to Foretell Bridge Danger

Bridge pier joints occasionally become unstable because of deterioration and because of strong earthquakes. This research investigated a smart sensor through a study executed on upgrading of functions and principal specifications of the developed sensor for monitoring bridge pier joint stability. We have proposed this system as a prototype of monitoring systems that readily evaluate bridge pier joint integrity quantitatively and easily by vibration analysis.



Simplicity displacement measurement sensor.





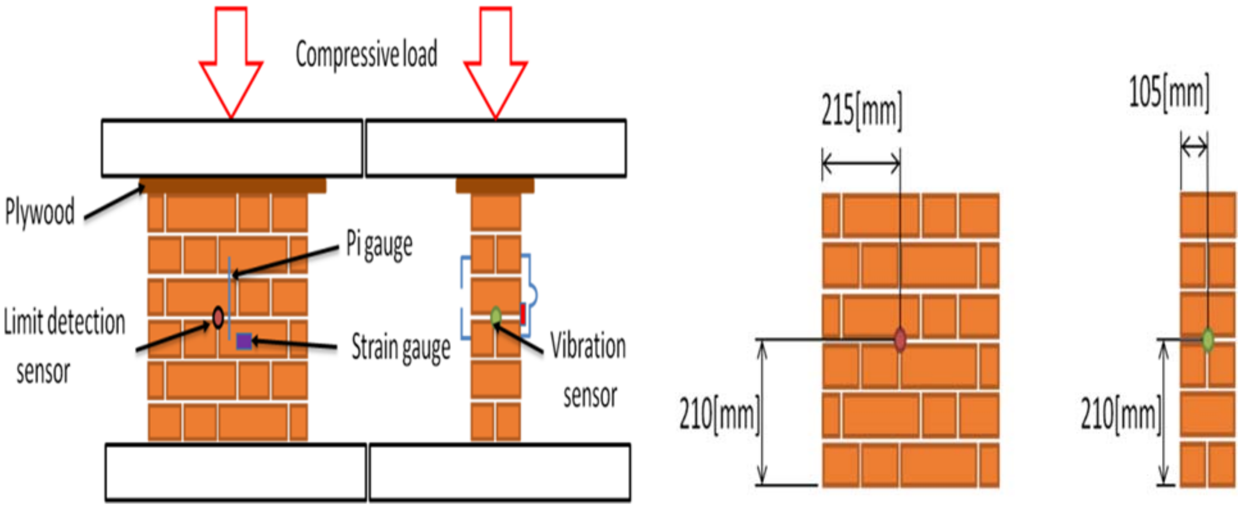
Relation frequency and output voltage of sensor by amplitude.

Experiment point of bridge

(4) Static Loading Test Measurements for Failure Prediction

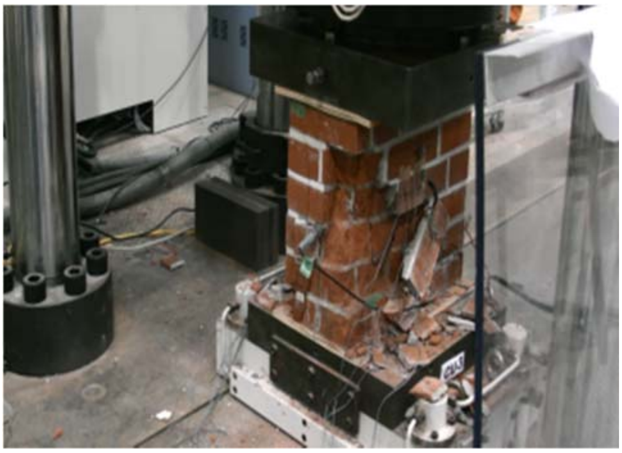
Reinforced masonry structures occasionally became unstable because of deterioration and because of the effects of strong earthquakes. This research examined a novel piezoelectric vibration sensor prototype for use in a monitoring system. It easily evaluates the integrity of reinforced masonry structures quantitatively and easily based on displacement measurements. Vast numbers of unreinforced masonry (URM) structures around the world have not been designed for seismic loads. The structural walls of these buildings were designed primarily to resist gravity loads.

A brick wall collapsed during an earthquake. These photographs of collapsed brick walls in Sichuan Province, China, were taken immediately after a M7.9 earthquake occurred at 14:28, May 12, 2008.



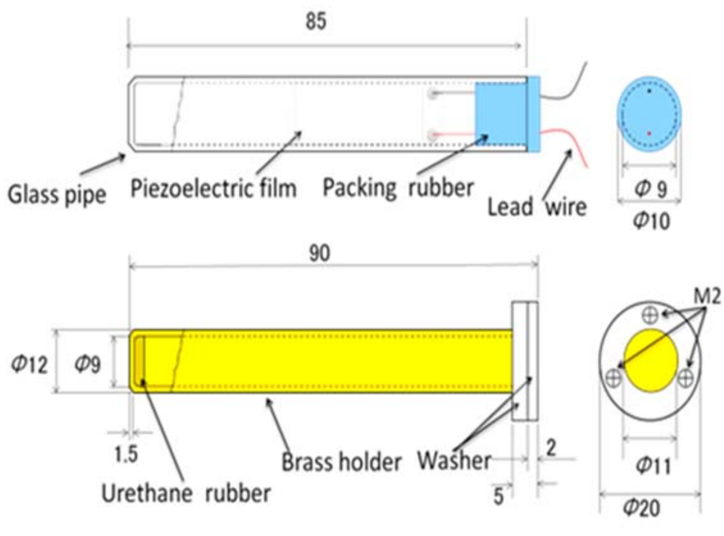
Sensor unit location. Using a compression testing machine, we conducted compression measurements using a Pi-shaped displacement transducer (Pi gauge), taking distortion measurements while using a distortion gauge, load-compressive loads were measured and were mutually compared until specimens failed.

(1) (2)



(3) (4)

Masonry specimens after compression testing. We measured and compared compressive stress and average strain effects on an English brick pattern specimen and a Flemish brick pattern specimen.

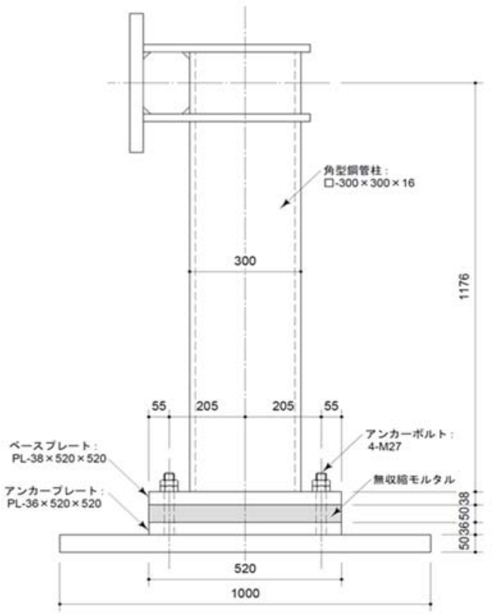


Piezoelectric limit sensor by first modelu. .

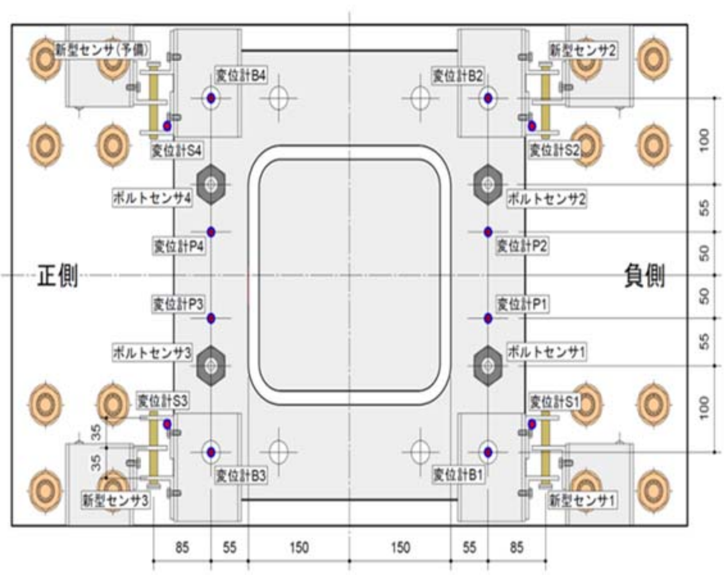
9. Monitoring sensors and integrity-monitoring technology for structures

(1) Comparison of Displacement Measurements in an Exposed Type Column Base Using Piezoelectric Vibration Sensors and Piezoelectric Limit Sensors (2017–2018)

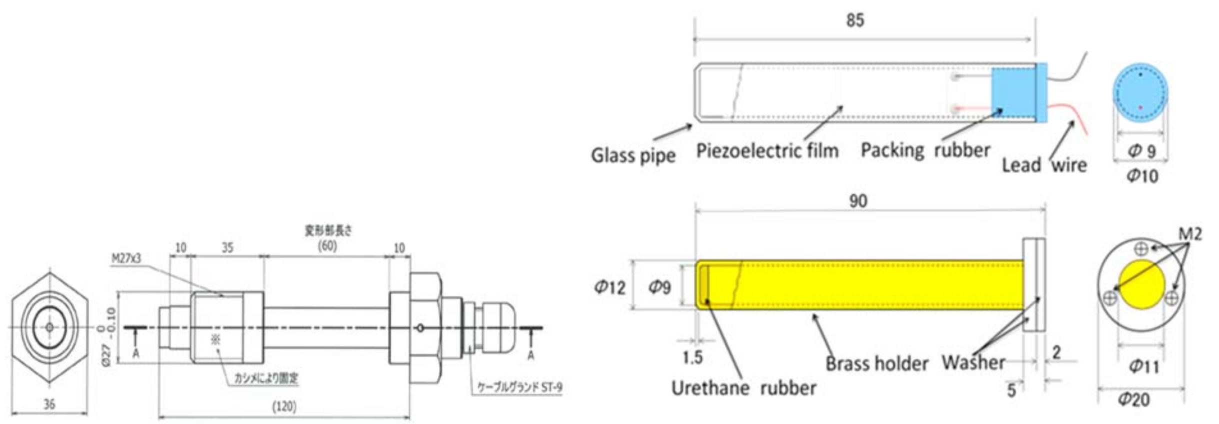
The Hyogoken Nanbu earthquake (Kobe earthquake), which occurred on January 17, 1995, caused extensive and severe damage to numerous buildings in Kobe city area. After the earthquake, numerous steel structures were constructed using exposed-type column-base joints. However, the capacity of these joints to absorb energy during earthquakes is small. For that reason, during the design of steel structures that use exposed-type column-base joints, higher earthquake-resistance characteristics must be provided specifically for those joints of the first floor. Moreover, structural health monitoring is recommended. This research examined the use of piezoelectric limit sensors to evaluate the resistance and displacement characteristics of exposed-type column-bases using simple measurements.



Test specimen layout

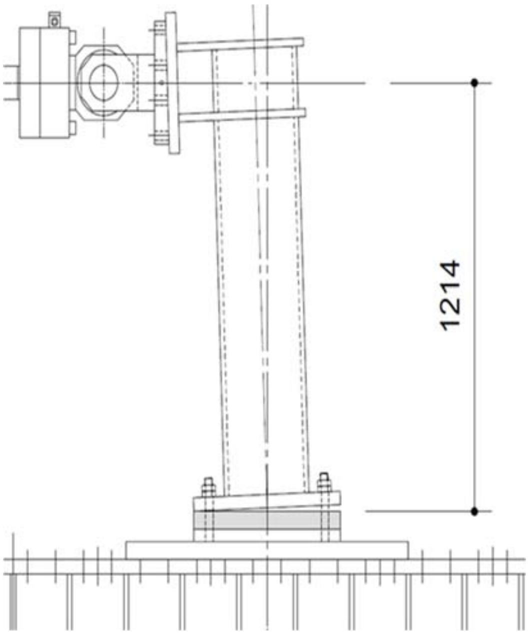


Sensors and measurement unit setup

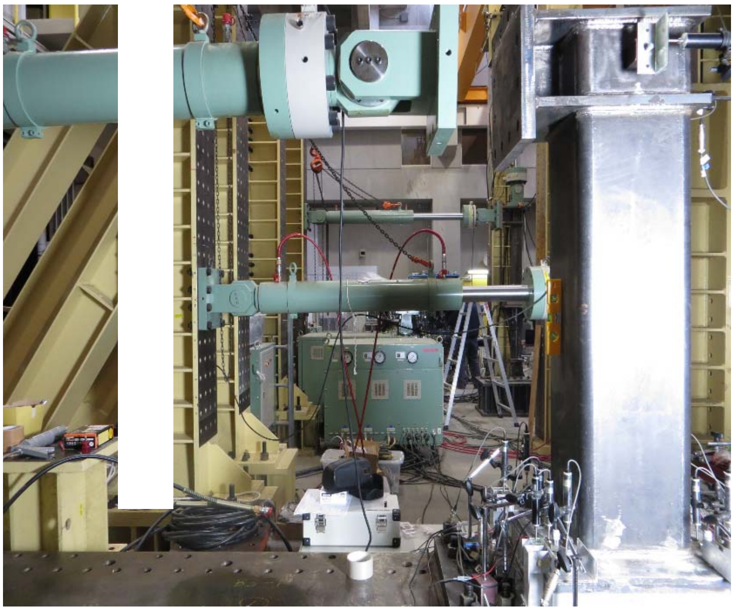


(1) Piezoelectric cable vibration sensor (2) Piezoelectric limit sensor

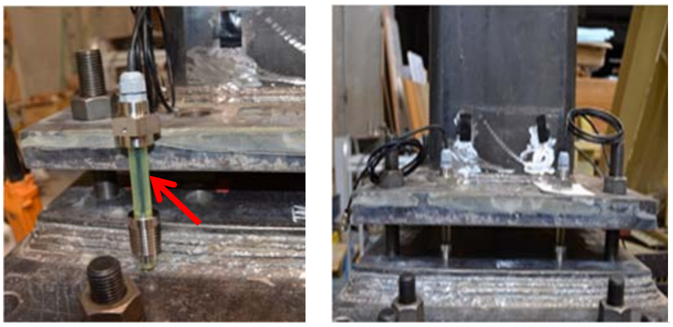
Characteristics of piezoelectric sensors.



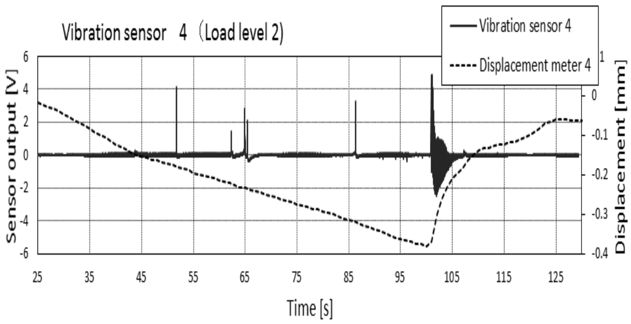
Load test devices



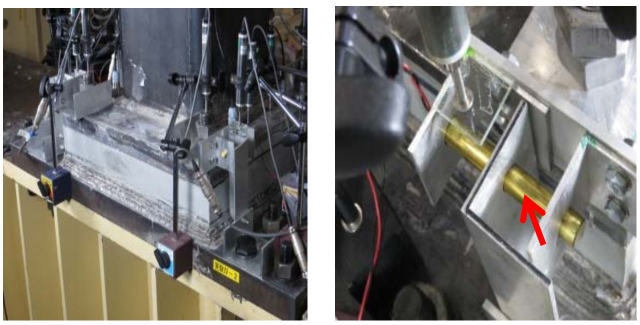
Positive loading direction



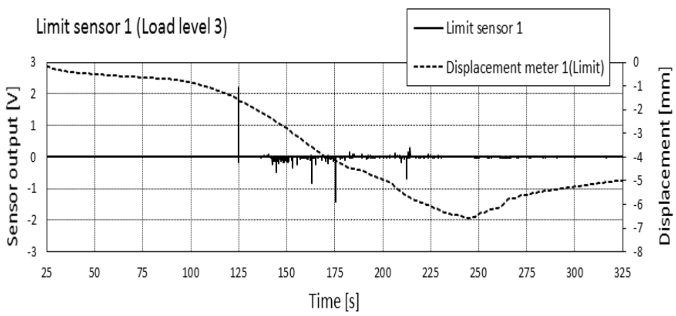
Setup of piezoelectric cable vibration sensor



Vibration sensor output



Setup of piezoelectric film sensors

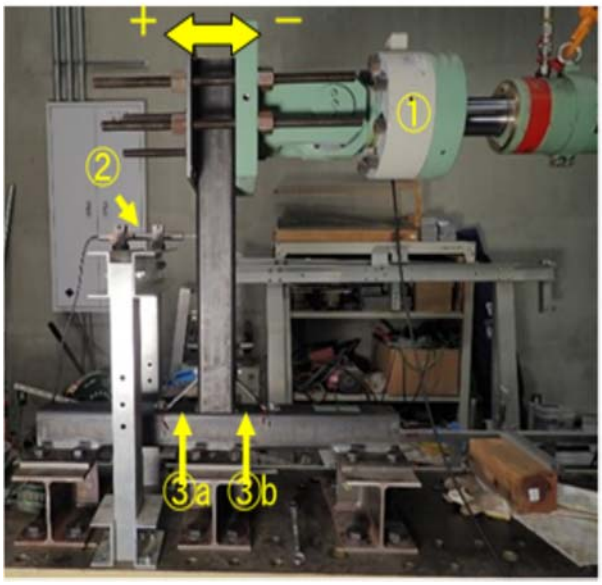


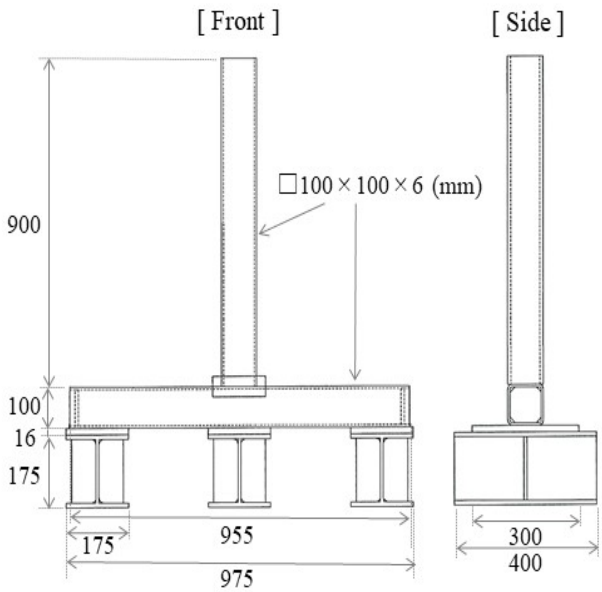
Piezoelectric limit sensor L_1 output voltage

Relation between displacement measurement and transformation by compressive stress.

(2) Weld joint development for steel column bases using piezoelectric joint sensors (2020–)

Japan's social capital stock was accumulated and concentrated particularly during its era of high economic growth. However, the future deterioration of that stock of infrastructure represents a mounting concern. Over the next 20 years, facilities 50 years old or older will become increasingly common. Therefore, an urgent need exists to maintain and renew such aging infrastructure. Unfortunately many steel structures were constructed using frame-welded joints of fillet welded construction and a welded base. These weld joints will not only be old: they will have little capacity to absorb energy during great earthquakes. Therefore, for designing steel structures incorporating welded joints, strong earthquake-resistance characteristics must be specially investigated and provided for those joints of steel welded bases. Moreover, structural monitoring will be necessary. This report describes, using simple measurements and simulations, our piezoelectric joint sensors for evaluating resistance and displacement characteristics of fillet-welded construction.



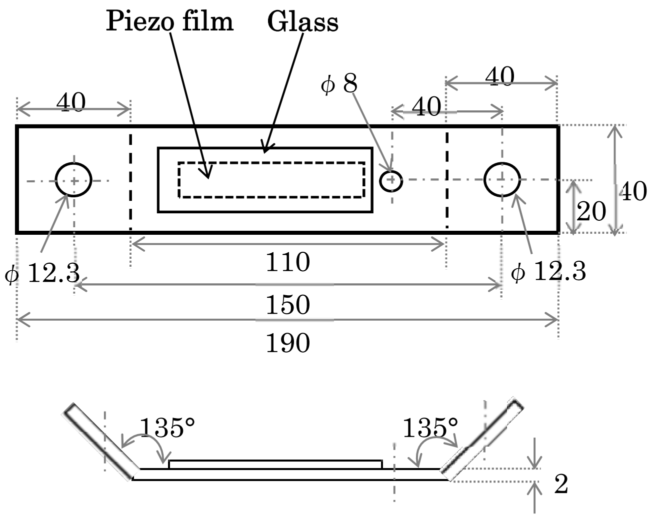


(1)　　　　　　　　　　(2)

Load and displacement experiments

(1) Load test devices. Presents the measurement apparatus of (1) the loading device, (2) the displacement meter, and (3) the piezoelectric joint sensor.

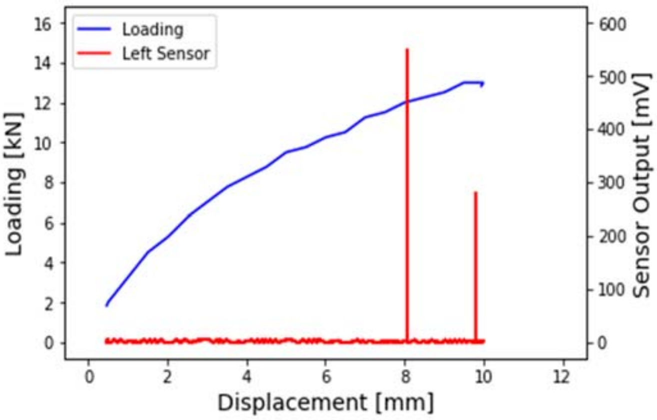
(2) Test specimen layout. Presents the test specimen shape and dimensions. This test piece is intended for exposed column bases of a low-rise steel frames.



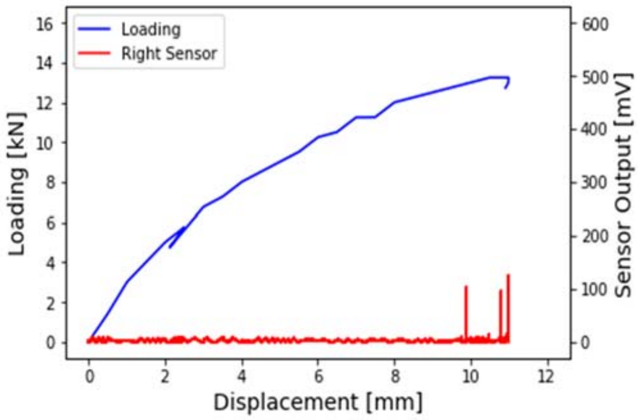
Sensor appearance

Measurement of sensor output (after using the sensor)

Characteristics of the piezoelectric limit sensor



(a) Experiment of strain

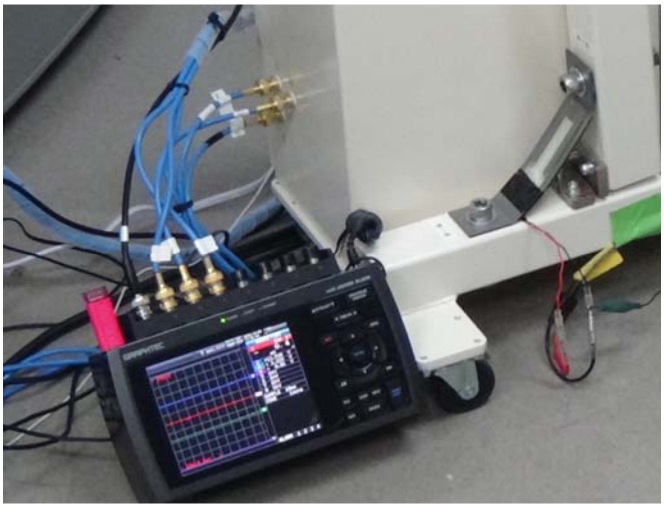


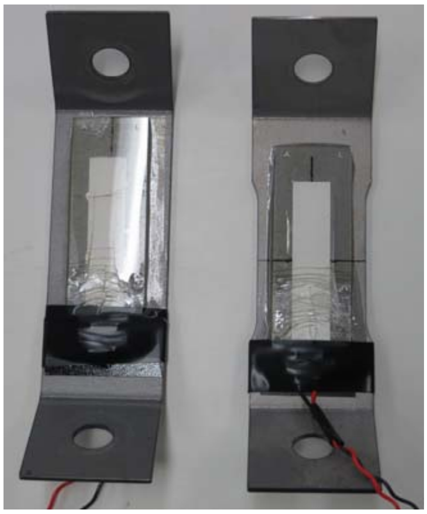
(b) Experiment of compression

Relation between displacement and piezoelectric joint sensor output by mounting test. The displacement by the negative direction force and the output result of side strain and compression when piezoelectric joint sensor. (Sensor base bode:2mm).

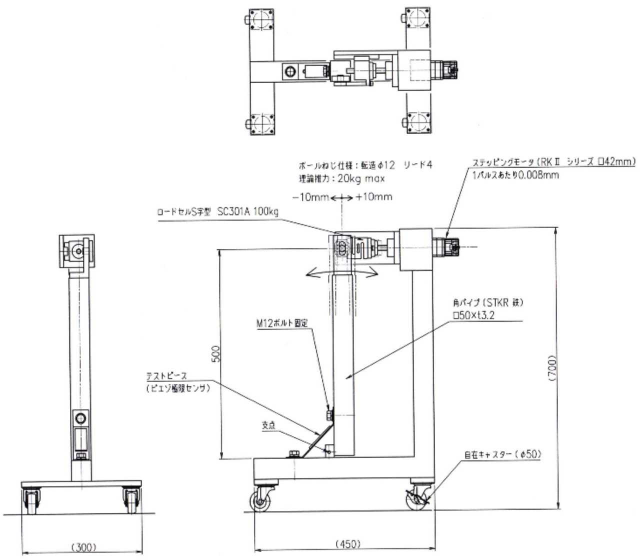
(3) Sally, a Robot for Measuring Piezoelectric Joint Sensor Characteristics

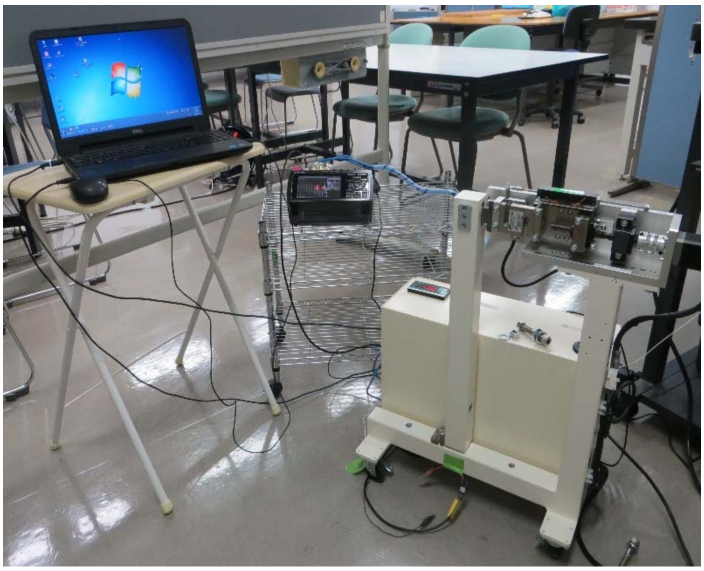
Steel structures are regarded as earthquake-resistant structures. However, many steel structures are constructed using frame-welded joints of fillet-welded construction and welded column bases. These weld joints can have low capacity for absorbing energy during earthquakes. Therefore, during the design process of steel structures that use welded joints, strong earthquake-resistance characteristics must be considered especially for welded column bases. Moreover, measurements using piezoelectric sensors are recommended for evaluation of the long-term performance of these structures. As explained in reports of this research, we will describe results obtained from evaluation of the resistance load and displacement characteristics of a piezoelectric joint sensor using a sensor measurement robot (SALLY). The introduction of the sensor measurement robot has reduced the working hours necessary for measurement experiments of sensor characteristics to about 1/19, which is expected to boost the cycle of sensor improvements in the future considerably.





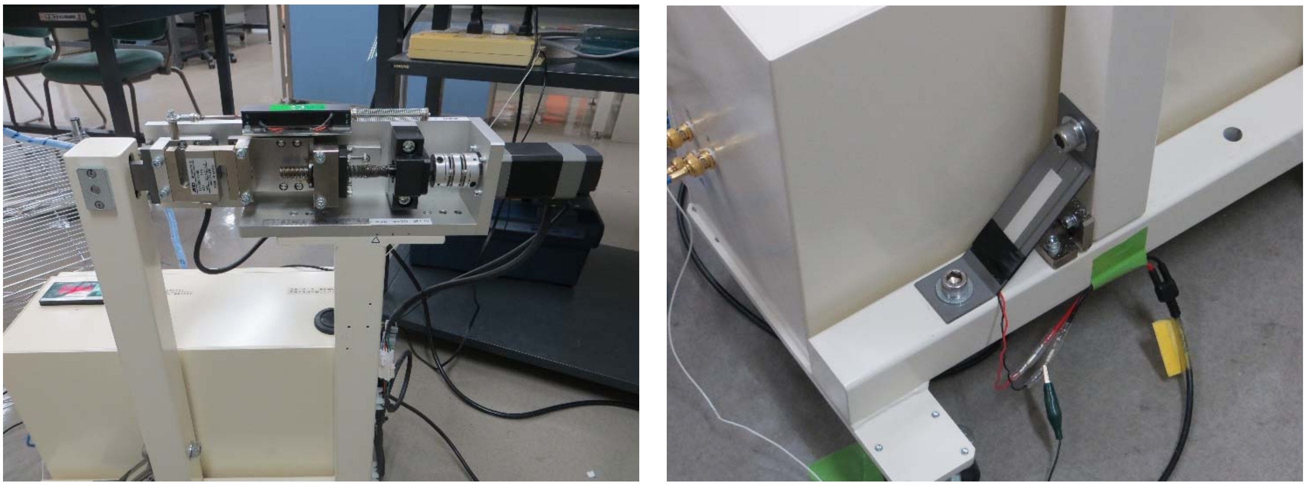
Setting of piezoelectric joint sensor on the steel specimen and SALLY after using sensors.



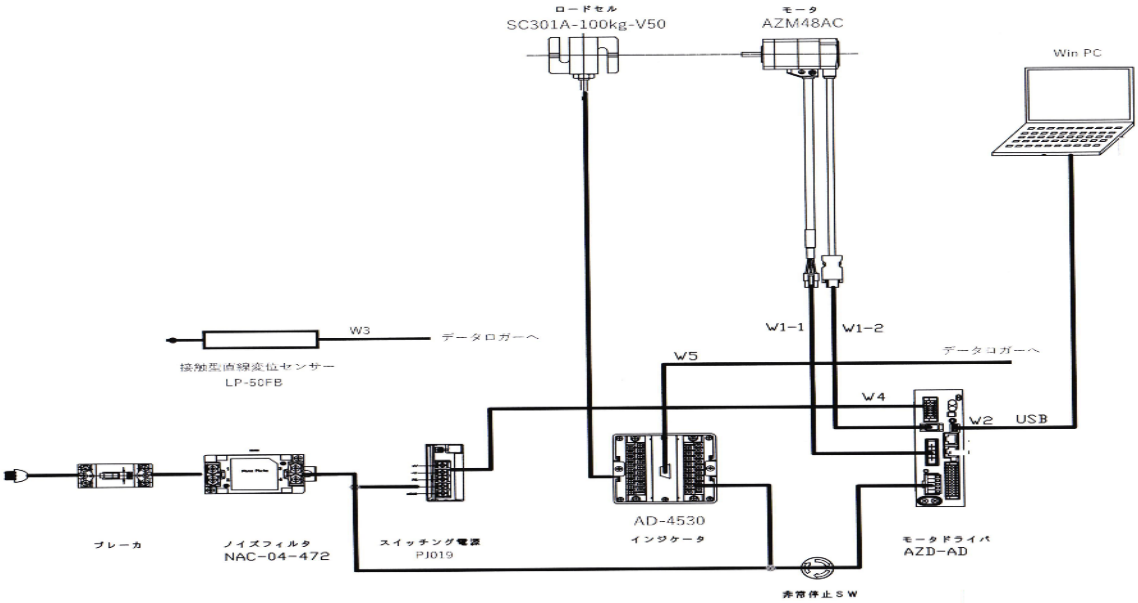


(1) (2)

Setting of piezoelectric joint sensor on the steel specimen and SALLY.



Robot mechanism and automatic control system for sensor measurement.



SALLY is compact: 300 × 450 × 700 mm. The configuration consists of a drive pulse motor, columns, horizontal columns, load cells, displacement meters, sensor mounts, control PC, and logger measuring instruments.

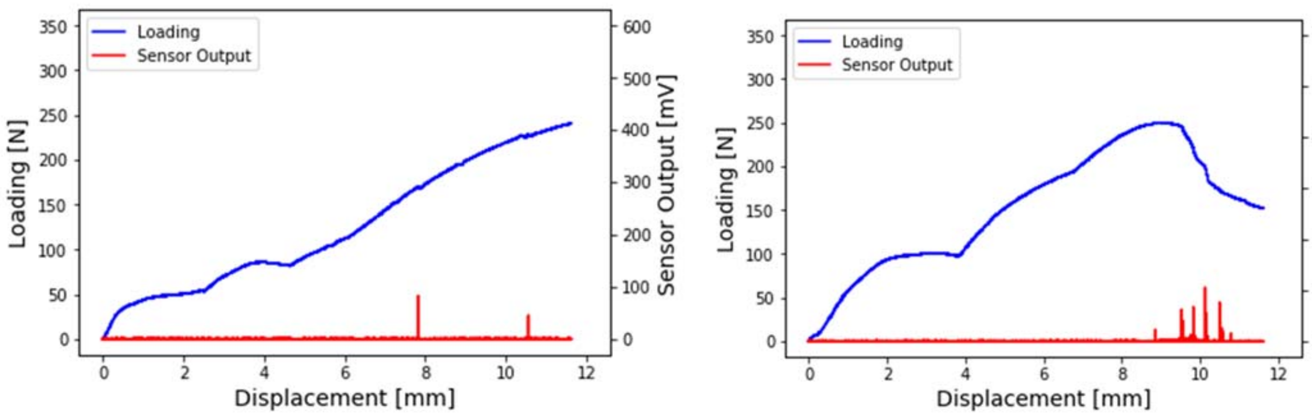
(1) Robot mechanism design for sensor measurement. The robot is 700 cm long, 45 cm wide × 30 cm deep.

(2) The sensor measurement robot name is SALLY: a robot that measures the relation between sensor output because of impossibility and displacement. Equipment description: (1) Drive stepping motor, (2) Support, (3) Horizontal pillar, (4) Load cell, (5) Displacement meter, (6) Sensor mount, (7) Control PC, and (8) Logger.

Table 1. Sensor output in tensile test and compression test for changes in base plate thickness (Average of three times each)

Base plate (mm)	Tension test (mm)	Compression test (mm)	Sensor output (mV)	Sensor output (mV)
1.0	2.7–3.2	10.7– 11.0	80–480	80–480
1.2	5.1–6.5	10.2– 10.7	50– 100	
1.6	6.4–7.3	10.2– 10.5	80–35	50–100
2.0	7.8–9.3	9.4– 9.9	167– 60	80–35
2.3	7.0–9. 6	9.0– 10.3	150– 90	167–60

The SALLY measurement results were 7.8–10 mm for the tensile test and 8.3–9.8 mm for the compression test. For the mounting test, we were able to obtain results of 8–10 mm for the tensile test and 9.8–10.8 mm for the compression test. Based on these findings, although the measured values are slightly different, the SALLY measuring robot performance is good. This method is regarded as being an effective measure for assessing the characteristics of numerous sensors. Regarding work efficiency in the characteristic test, if 30 items are to be tested for the mounting test, then the mounting time is limited to the measurement of one test piece per day by three workers including the mounting, detachment, and measurement time. Therefore, 15 days × 3 people (45 days in total) are necessary. Furthermore, because the test body price is 150,000 yen per body, a cost of 2.25 million yen is incurred. However, for SALLY, the measurement time for one item is about 20 min. Therefore, two measuring workers can test 24 items each day. For 30 items, the total number of days would be 1.5 days × 2 people, therefore requiring 4 days. Therefore, results demonstrate clearly that the human cost was reduced to 1/19 by the use of robot measurements. Although depreciation costs for robots must also be considered, equipment costs for cranes and the purchase price for hydraulic jacks are included in the mounting tests. They are ignored herein for ease of comparison.



The displacement by the positive direction force and the output result of side strain and compression when piezoelectric joint sensor (Sensor base bode:2.0mm).

Relation between displacement and piezoelectric joint sensor output by SALLY.