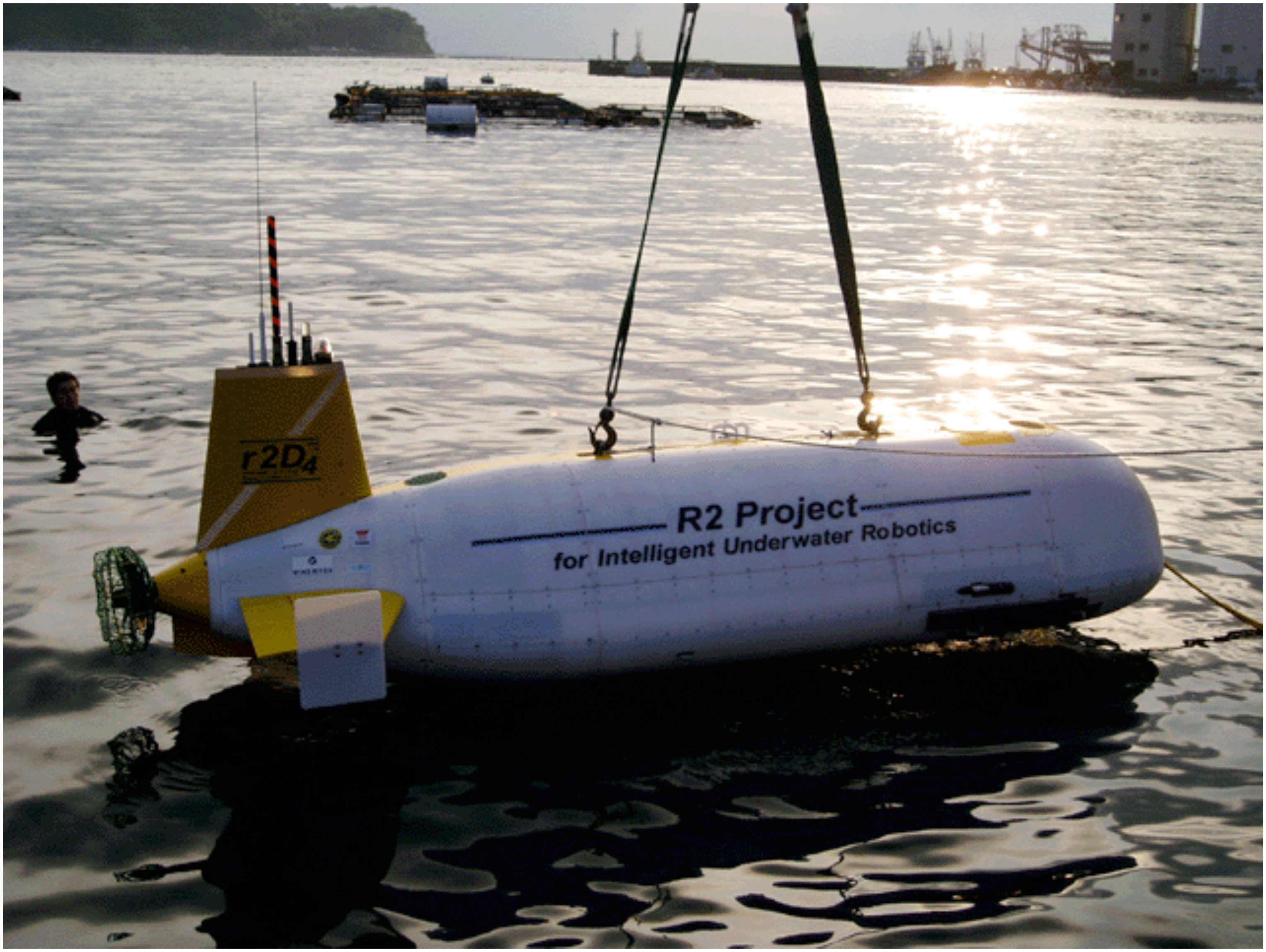
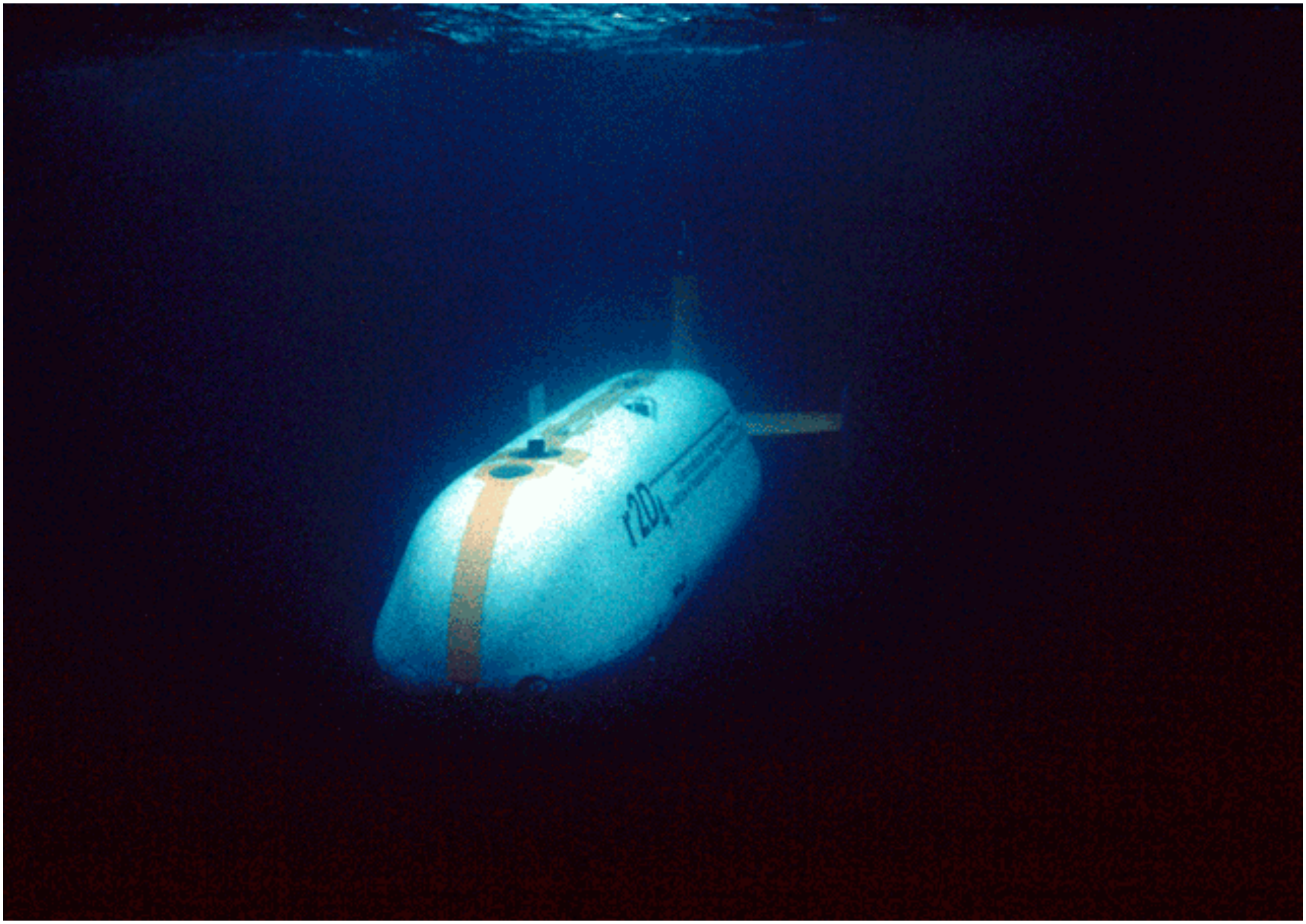
Intelligent Autonomous Underwater Vehicle r2D4 for Deep-Sea Operation





Intelligent Autonomous Underwater Vehicle r2D4

July 23, 2003

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1. Introduction

Since 1984, Underwater Technology Research Center (Head: Professor Tamaki Ura), Institute of Industrial Science, the University of Tokyo has developed several Autonomous Underwater Vehicles(AUV, see #1) of various types and purposes (refer to http://underwater.iis.u-tokyo.ac.jp) and successfully achieved a few meaningful undersea missions. Some of representative examples are the full autonomous survey of Teisi knoll by the AUV "R-One" (see #2) in 2000, construction and field operation of Tantan, which was developed by the environments monitoring of lake Biwa in the middle of Honshu, Japan and experiment of humpback whale chase by AUV. As these examples explain, we are still challenging to broaden the practical applications of autonomous underwater vehicles. By these efforts, as the intelligent machine exploring the underwater region, AUV is becoming more and more a practical mean to survey and exploit the mysteries of undersea realm.

Based on the successes in development and field operations of AUVs in IIS, the university of Tokyo, we established a next generation AUV project named "r2D4" (see #3). This project is supported by Japan Society for the Promotion of Science(JSPS), as a scientific research awarded project grants-in-aid for "Development of Intelligent Autonomous Underwater Vehicle for Deep-Sea Operation" (see #4).

Purposes of this projects are summarized as follows; - After developing a highly-intelligent and highly-reliable AUV, it is deployed in the undersea region with the mission of surveying undersea hydrothermal vents. - During this survey mission, not only survey data containing the records of surrounding physical states near the vent spout, but the sequential data from vehicle operation are also recorded and fed back in order to improve the system architecture of r2D4 by getting rid of the expected problems for deep-sea operation. Repititions of this feedback procedure shall make r2D4 converge to the optimized system architecture for deep-sea hydrothermal vent exploration and result in the newly proposed undersea region survey system supported by the Autonomous Underwater Vehicle r2D4.

Costruction of hardware system as well as primary software system are completed in July, 2003 (Hardware Construction: Mitsui Engineering and Shipbuilding(MES), Co., Ltd.). The first field operation was conducted at the nothern part of Suruga bay, dated 7th July. During 15th - 17th July, the second field operation was held at the offing of Sado island, located in sea of Japan. This field work was done by the joint cooperation with underwater device department of MES. During this underwater operation, r2D4 tracked the pre-designated way points keeping the trajectory deviation sufficiently small. Due to the successfully achieved trajectory tracking control, r2D4 succeeded in taking the high-quality images of undersea geography by the side scanning sonar operation. In addition, measurement of CTDO was also carried out during this operation.

Though the main purpose of development is the survey of undersea hydrothermal vent, deployment of r2D4 is expected to enable several undersea missions such as seeking for lost articles in undersea, surveillance of undersea volcanoes, swimming animals watching, cooperative survey with undersea station and etc., because it has realized the handy system architecture with small size. And in december 2003, r2D4 is planned to be deployed in the Okinawa trough in order to survey the underwater hydrothermal vent near that region.

2. Introduction to r2D4

In the development of r2D4, key technologies acquired throught the development of R-One, the predecessor of r2D4, is directly applied. Owing to this technical inheritance, r2D4 is completed only within two(2) years with excellent vehicle performances, which is extremely short period compared to other AUV development projects in the world.

1) Characteristics of r2D4

- Compact size and light weight (length overall: 4.4(m), weight: 1,600(kg))
  Due to its compactness, r2D4 does not require the large size support vessel. And since its operation can be completed fully autonomously, neither does it require operational experts.
- Self-Completeness
  Laborious supports such as transponder installation are not neccessary
  Accurate positioning by the combined instrumentation of optical gyroscope and doppler sonar
  High reliability and safety
- By the simultaneous manipulation of the data from multiple sensors(sensor fusion)
  r2D4 has superior recongnition ability on the complicated underwater environments transition
- Flexible and dynamically adaptive path planning ability for the observation.
  If the vehicle finds out a suspicious place or an object in underwaer space, it can re-generate the target path dynamically in order to make this observation.

2) General Missions of r2D4

Observation by AUV is realized by tracing the successive way poionts arranged previously. One of the most common observation activities by AUV is the construction of 3-dimensional seabed topology or wide-range surveillance of undersea region using side scanning or interferometry sonar. Provided an abnormality is detected during the observation, r2D4 re-plans its cruising trajectory and makes the detailed observation in order to clarify the causes of recognized abnormality.

3) Comparion with "R-One", the predecessor of r2D4
Since it is designed compact and small, r2D4 does not require a support vessel which has several functional capabilities. Despite its compactness, r2D4 has much redundancy in its payload to install various equipments for observation. R2D4 is designed to be capable of submerging up to 4,000(m) of depth, aiming at the observation of undersea hydrothermal vent near Marina trough in midwest Pacific.

In the following table, we summaraize key items of r2D4 compared with those of R-One

Items	r2D4	R-One
length overall(m)	4.4	8.27
breadth (m)	1.08	1.15
height (m)	0.81	1.15
weight (kg) (w/o payload)	1,506	4,550
weight (kg) (w payload)	1,630	4,740
max depth (m)	4,000	400
cruising range (km)	60	100
energy source	Li-ion secondary battery	CCDE
max speed (knot)	3	3
Main CPU	PowerPC 233MHz	MC68040x2
OS	VxWorks	VxWorks
navigation system	INS(FOG)+DVL	INS(RLG)+DVL

4) Observation and Instrument Devices

Not only the device units of generl purpose, r2D4 is able to be equipped with special devices for detailed observation and instrument near hydrothermal vent region, as shown.

* Side Scanning Sonar	* Interferometry Sonar (accuracy order of 1(m))
* Video Camera x 2	* Oxidization-Reduction Voltage Meter
* 3-Axes Magnetometer	* Manganese Ion Desitometer
* pH Sensor	* Turbidimeter
* Thermal Flow Meter	* Oxygen Densitometer

3. Outline of the Experiments on Suruga-Bay and Sado-Offing

Feedback from the experimental results in actual sea area is extremely important for the improvement of vehicle's performance. Therefore, we are planning a few field experiments of r2D4 since its primary software system as well as the hardware has been completed. During July in this year, we have made two (2) field experiments and obtained the data from as well as images of side scanning sonar. Analysis of the obtained data is the procedure of fundamental importance to improve the performance of AUV.

operation ID	place	date	max depth	purpose
#1	northern part of Suruga-bay	10:26 - 11:01, 7th July, 2003	194(m)	observation of the upper part of continetal shelf, 30(m) altitude
#2	northern part of Suruga-bay	11:13 - 12:07, 7th July, 2003	444(m)	observation of the upper part of continetal shelf, 30(m) altitude
#3	Ryotsu, Sado-island in sea of Japan	12:10 - 14:06, 15th July, 2003	280(m)	observation of the middle part Ryotsu-bay, 70(m) altitude
#4	Ryotsu, Sado-island in sea of Japan	11:59 - 16:43, 18th July, 2003	550(m)	observation of a dislocation Ryotsu-bay, 50(m) altitude
#5	Ryotsu, Sado-island in sea of Japan	10:37 - 14:36, 19th July, 2003	418(m)	observation of a dislocation Ryotsu-bay, 30(m) altitude

4. R2D4 - Expectations

Operation of r2D4 will enable the observation of undersea hydrothermal vent over a wide range. This kind of observation is expected to gather the fundamental data for the investigation of undersea carbondioxide discharge and hydrothermal spout, which will help us to understand the global circulation mechanism of them better. In addition, completion of r2D4 has brought about the installation of new oceanographic observation platform. Small and compact system architecture of r2D4 will enable the better achievement of various underwater missions, such as searching for the underwater lost articles, surveillance of underwater volcanoes, observation of sea animals, instrumentation of seawater quality as well as the observation of undersea hydrothermal vents.

5. Future Activities

At present, r2D4 is planned to carry out the following undersea observation activities.

2003

July : Sado-offing observation (completed, with the support vessel of Tansei-Maru belonging to the Ocean Research Institute, the University of Japan)
December : The 4-th Yonaguni-kaizan and Hatoma-kaizan observation (with the support vessel of Yokosuka, JAMSTEC)

2004

Observation of undersea hydrothermal vent near Mariana basin (with the support vessel of Hakuho-maru belonging to Ocean Research Institute, the University of Tokyo)

2005

Not decided yet

2006

Observation of undersea hydrothermal vent near Mariana basin (with the support vessel of Hakuho-maru belonging to Ocean Research Institute, the University of Tokyo)
Observation of Mid Ridge in Indian Ocean (with the support vessel of Hakuho-maru belonging to Ocean Research Institute, the University of Tokyo)

Observation in Kumanonada-offing is also planned in conjunction with the SMAPS(Super-detailed Mapping of Seafloor) project. In addition, observation of whale (Humpback, Sperm, etc.)by r2D4 is under consideration too.

6. If you have any questionnaire about r2D4 please contact

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URL : http://underwater.iis.u-tokyo.ac.jp/Welcome-e.html/

Linked Data

1. Photos of r2D4
2. General Arrangement of r2D4
3. Navigation Trajectory during Sado-offing Observation
4. Side Scanning Sonar Images of Sado-Offing-1
5. Side Scanning Sonar Images of Sado-Offing-2
6. Schematics of the Undersea Intelligence Engineering and its Missions

#1) Autonomous Underwater Vehicle(AUV):

Unmanned, untethered submersible which moves according to the guidance by its own control system without the energy replenishment during the mission At present, majority of the unmanned submersible is ROV(Remotely Operating Vehicle) which is remotely operated one by human operators through the cable connection with the support vessel. But the utilization of AUV is expected to be more and more popular, because the treatment of cable system becomes extremely troublesome as the depth of operation becomes deeper.

#2) AUV R-One

R-One was developed by the joint cooperation between IIS, the University of Tokyo and Mitsui Engineering & Shipbuilding Co., Ltd. Actual sea operation of R-One began in 1996 and in 1998, R-One achieved the continuous operation during 12 hrs 37 mins. In 2000, R-One took the very fine side scanning sonar images of Teisi knoll in Ito-offing by the fully-autonomous vehicle operation.

#3) R-Two Project

In the terminology of "R-Two(or R-One)", "R" represents the Ridge System coming from Mid-Ocean Ridge. The first project of this is R-One, and R-Two is the successive project launched secondarily. In addition, "D4" means the maximum submergible depth of the vehicle, which is 4,000(m).

#4) "Development of Intelligent Autonomous Underwater Vehicle for Ridge System Survey in Deep Sea"

Research group for this awarded project is consists of the researchers from both engineering and scientific fields. Researchers from engineering fields are working for the underwater technology research center, institute of industrial science, the university of Tokyo. Other researchers from scientific fields consist of experts in underwater hydrothermal vents in Japan.

name	institute	major research items
Tamaki Ura	IIS, the University of Tokyo	Underwater Vehicle Project Manager, Research and Design of AUV
Akira Asada	IIS, the University of Tokyo	Underwater Acoustics Sonar System for AUV
Teruo Fujii	IIS, the University of Tokyo	Underwater Acoustics Intelligent Control
Yoshiaki Nose	IIS, the University of Tokyo	Mechanical System of AUV
Kensaku Tamaki	Ocean Research Institute, the University of Tokyo	Earth Tectonics Observation of Undersea Bottom Structure
Toshitaka Gamo	Graduate School of Science, Hokkaido University	Oceanographic Geochemistry Instrument for Chemical Measurement in Hydrothermal Vent
Hiromi Fujimoto	Graduate School of Science, Tohoku University	Undersea Physics Analysis of Undersea Magnetization Structure
Kouichi Nakamura	Institute for Marine Resources and Environment, National Institute of Advanced Industrial Science and Technology (AIST)	Ocean Geology Instrument for Chemical Measurement in Hydrothermal Vent

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