BATHYMETRIC SURVEY SYSTEM, BELUGA, WITH REAL-TIME PROCESSING CAPACITY–COMBINED USE OF GPS AND NARROW MULTIBEAM SOUNDER

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ABSTRACT

Offshore civil engineering work in many cases requires accurate information about the seafloor topography or underwater structures. The conventional single beam sounder, however, cannot offset ship motions, in particular heaving, due to characteristics resulting from the wide directional angle of the beam. To solve such problems, the Beluga System was developed for bathymetric survey by combining the GPS and a narrow multibeam (NMB) sounder.

The new system can compensate for the motions of a survey ship with motion sensors and carry out the bathymetric survey with a NMB sounder. This enables accurate measurement of seafloor topography and is applicable to a survey line with a width two to seven times greater than water depth.

The main feature of the system is the realtime display function of graphic images on a personal computer with optionally decided mesh while measuring topographical data. This is achieved by presetting the latency obtained from patch tests (the latency is the difference between the time required for measurement and time required for data acquisition), the mount angle of the sonar head, and the sound velocity in seawater.

This feature permitted the system to be developed into a parallel-run system for measuring and dredging on a cutter suction dredger and a Seafloor Data Transmission System, an information collection system on deep seafloor, using a wireless LAN and cellular phones. Thus, the Beluga System is expected to be used in various ways.

Keywords : Bathymetric survey, GPS, narrow multibeam sounder, mesh coordinates.

INTRODUCTION

Japan has based much of its societal development on marine engineering works such as construction of port facilities, bridges, underwater tunnels, and energy-related facilities.

During the marine engineering works, the bathymetric survey has been a principal technology necessary for construction, and is important in work achievement measurement as an evaluation technique. Originally, water depth had been measured by casting a lead from a survey ship. However, in the 20th century, survey using the single beam sounder became main stream. At present, various types of acoustic measuring devices have been developed by employing advanced beams. Particularly, the narrow multibeam (NMB) sonar developed in the later half of the 20th century has the superior characteristics in sounding a broader width of the seafloor area including right below the running survey ship because NMB emits beams in sectorial directions. Advancement of acoustic measuring devices is now changing the function from the general idea that "sounds" water depth to the new concept that "visualizes accurately" the seafloor.

Focusing on this advantage, Toa Corporation has developed the Beluga System, a high density sounding system combining use of NMB sonar and GPS, in 1994. The system was mainly been operated for estimating underwater attainment of marine construction work. This has been developed into a parallel-run system for measuring and dredging work, which was provided on a cutter suction dredger, and a Seafloor Data Transmission System, which is used to collect information about the seafloor using a wireless LAN, or cellular phones and broadcast via Internet, and these new applications are in use at present in Japan.

In this report, the Beluga System will be described together with the new systems.

BELUGA SYSTEM

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Characteristics of the Beluga System

In general sounding under the single beam method, a beam with a beam width of 6 degrees is emitted from the survey ship, which runs along the designed measurement line to gather data of the water depth.

The NMB employed by the Beluga System emits fine beams in sectorial directions (i.e. lateral directions to the ship moving forward). This allows plane measurement along the course of the ship. E.g. In case of the Seabat 8125, 240 beams with a beam width of 0.5 degrees can be emitted, the total width of which is about 120 degrees. The data are obtainable from a range about 3.5 times wider than the water depth in a single navigation as shown in Figure 1.

Figure 2 shows how NMB accurately measures the seafloor and represents the result on a screen. (* Figure 2 shows collapsed caissons of a breakwater caused by the typhoon in September 2004. The site is located in Hakodate Port, Hokkaido)

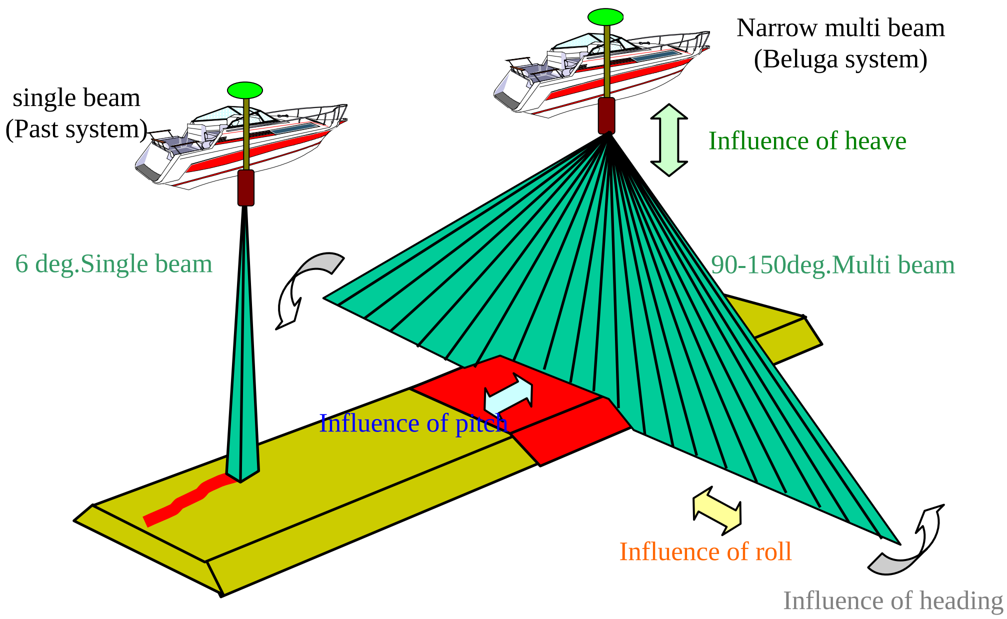


Figure 1. Difference between single beam and NMB method.

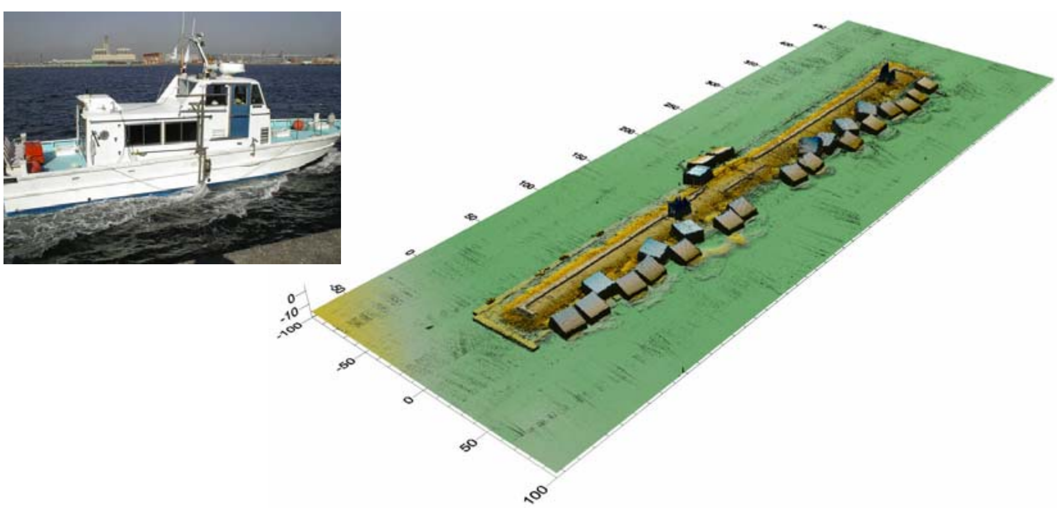


Figure 2. Seafloor sounding by Beluga System (photo) and output example with a bird's eye view.

The Beluga System has software "to display the sounding results as soon as possible for use in daily work." Therefore, it can compute in real time the mesh of water depths during sounding and allows the client to instantaneously browse contour drawings of water depths via e-mail, network communications, or storage devices.

The features of the system are:

- High-density seafloor data are obtainable from a wide area in a short time.

--> Information on the seafloor can be visualized.

- Acquired data can instantaneously be converted into mesh data, and a report of the contour can promptly be displayed. The analysis procedures are unnecessary for a simple water depth map.

--> Measured data can swiftly be computed and analyzed to immediately adapt the results for construction work.

- The system can be applied to an ordinary waterway measurement.

--> The system can easily output the mass calculation, color plane contours, bird's eye views, and cross sections.

System Configuration

In NMB sounding, ship motion (rolling, pitching, heaving) and azimuth angle (yawing) will have great effects on the measurements. Consequently, it is essential to offset in real time the changes in ship motions detected by the motion sensor for data processing. To ensure accurate information processing, the Beluga System is configured with the NMB sonar for sounding, RTK-GPS to locate the ship in the plane together with the azimuth angle, motion sensor to detect the changes in ship motions, and a personal computer for data processing.

The personal computer and the measuring devices are connected by RS232C or Ethernet for data communications.

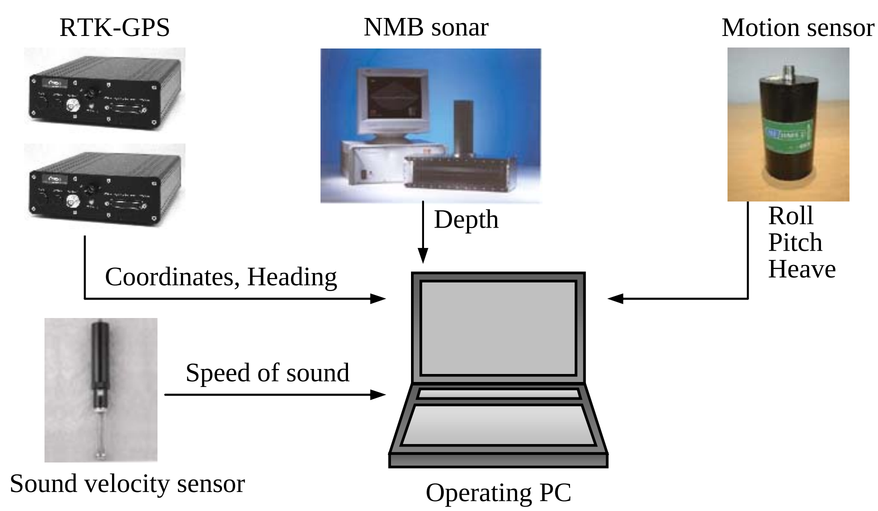


Figure 3. General configuration of the Beluga System.

Narrow Multi Beam (NMB) Sonar

The NMB sonar can send beams in sectorial directions to extend broadly in the lateral direction but the beam width is narrow in the longitudinal direction. The echoes from the seabottom are received by many acoustic receivers that have wide sensitivity distribution to the longitudinal direction but narrow in the lateral direction. Therefore, the water depth of a wide area can be measured in a single navigation.

This system corresponds to the SEABAT series of RESON A/S.

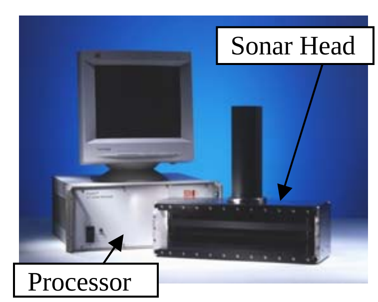


Photo 1. Seabat 8125.

Table 1. Types of NMB sonar available for Beluga System.

Type	Seabat 9001	Seabat 8101	Seabat 8125
Product company	RESON	RESON	RESON
Frequency	455 kHz	240 kHz	455 kHz
Depth Resolution	50mm	12.5mm	6mm
Path Coverage	90 deg.	150 deg.	120 deg.
Depth Range (below transducer)	140m	500m	120m
Number of Beams	60	101	240
Track Beam width (Along x Across)	1.5 deg. x 1.5 deg.	1.5 deg. x 1.5 deg.	1 deg. x 0.5 deg.
Max. Update Rate	15Hz	30Hz	40Hz

GPS

The system usually uses two sets of 2-wave cycle Real Time Kinematic GPS (RTK-GPS) or the combined system of one RTK-GPS and GPS compass. These assemblies are very important to gather accurate data from the wide seafloor area with the NMB sonar and reproduce measured data of 3-dimensional coordinates and azimuth angles. Particularly, a magnetic compass is not applicable to measure azimuth angles because of magnetic field interference. Instead, two sets of RTK-GPS are used to measure azimuth angles, or one GPS compass is employed for the purpose. (* Figure 4 shows mounted locations of GPS antennas: Top indicating two sets of RTK-GPS and bottom, one RTK-GPS and one GPS compass.)

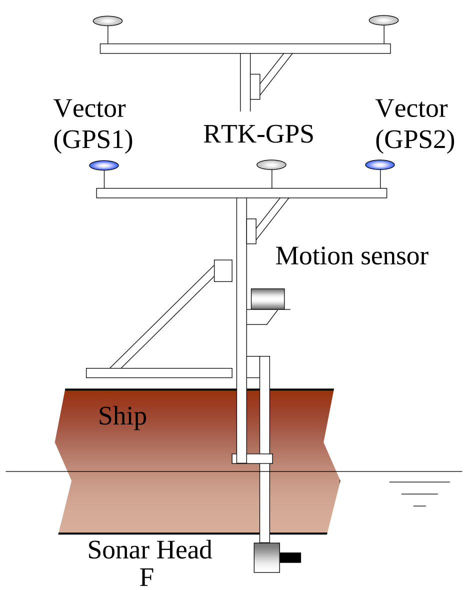


Figure 4. GPS assembly.

Motion Sensor

The motion sensor measures heaving, pitching, and rolling of the ship to output digital data of the motions in real time. This sensor, even if mounted on a small ship, accurately works under rough sea conditions and helps NMB sonar sounding greatly.

Table 2. Motion sensor specifications.

Type	DMS-05 (TSS Ltd.)	
	Heave	Roll & Pitch
Dynamic accuracy	5cm	0.04°
Max. range	±10m	±60°
Bandwidth	0.05 to >30Hz	0 to 30Hz
Data output rate	200 Hz	
Dimensions	172mm x 99mm diameter	
Weight	2.3kg	
Power requirement	15-30Vdc	
Depth rating	3000m	

Photo 2. Motion sensor.

Sound Velocity Sensor

The sound velocity sensor is applied to measure the “sound velocities in water,” and the beam reflex time that the sonar emits is converted into the distance. The sound velocities and the depth of the sensor head are simultaneously output as data values. Even if in a water area with different water temperatures according to water depth, the sound velocities can be measured accurately at each water depth. In addition, the sound velocity sensor is used before and after sonar sounding.

Table 3. Sound velocity sensor specifications.

Type		Smart SV&P
Measurement accuracy	Sound velocity	±0.050m/s
	Depth	±0.05% (F.S.)

Photo 3. Sound velocity sensor

Operation PC

The operation personal computer uses the standard MS Windows operating system, and recording and computing software provided for this system are necessary for operation.

Internal Operation

Operation PC software of the system carries out the following operation: Corrects latency of respective data measured by measuring devices, appends the time stamp to, and saves in the hard disk (for use in detailed analysis after measurement). At the same time, mesh data (x, y, and z) for position and depth are processed, and the result is displayed as a contour.

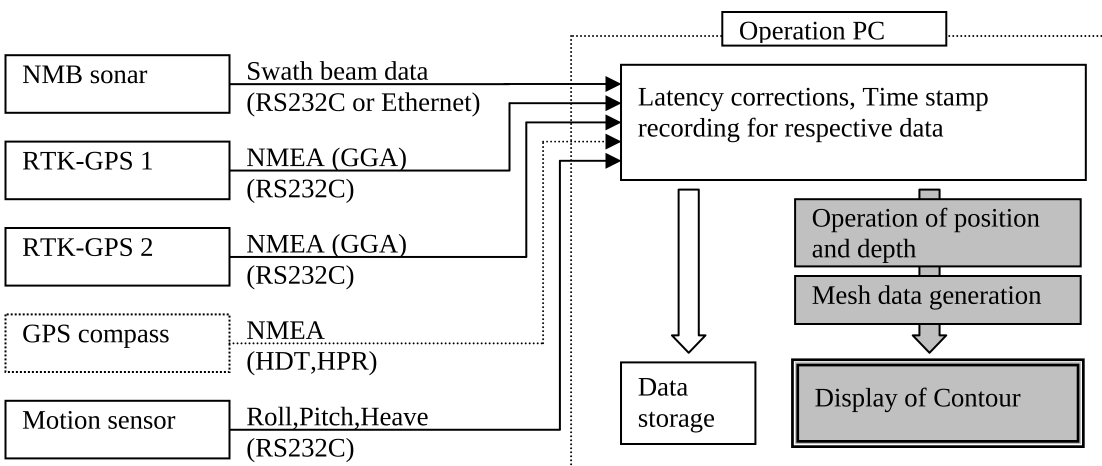


Figure 5. Internal operation flow.

Latency Correction and Data Supplement by Proportional Distribution

Measured data from all sensors have latencies (which are differences between the measured time by the sensors and the output time to the operation PC), and the values also vary by each sensor. Consequently, exact time synchronization is required for sounding correct positions and depths at the beam reflection points. Moreover, the data-updating interval differs by the sensors (NMB Sonar: abt. 15Hz, RTK-GPS & GPS compass: 5Hz, Motion sensor: abt. 20Hz). Data supplement is achieved by adapting both output intervals of RTK-GPS and GPS compass to that of NMB sonar.

Thus, latency correction and data supplement by proportional distribution becomes necessary. The procedures are described below (refer to Figure 6).

(Step 1): When receiving raw data (NM-1) from NMB sonar, the trigger for corrections is generated.

(Step 2): Data before the period, T_{G1} (T_{G1} : represents latency difference between NMB sonar and RTK-GPS), are sorted, and then (G1-1) is calculated by the proportional distribution method using the preceding and succeeding data, (a , b)

(Step 3): G2-1 , GC-1 , and MS-1 for the RTK-GPS2, GPS compass, and motion sensor can be calculated in the same manner as (Step 2).

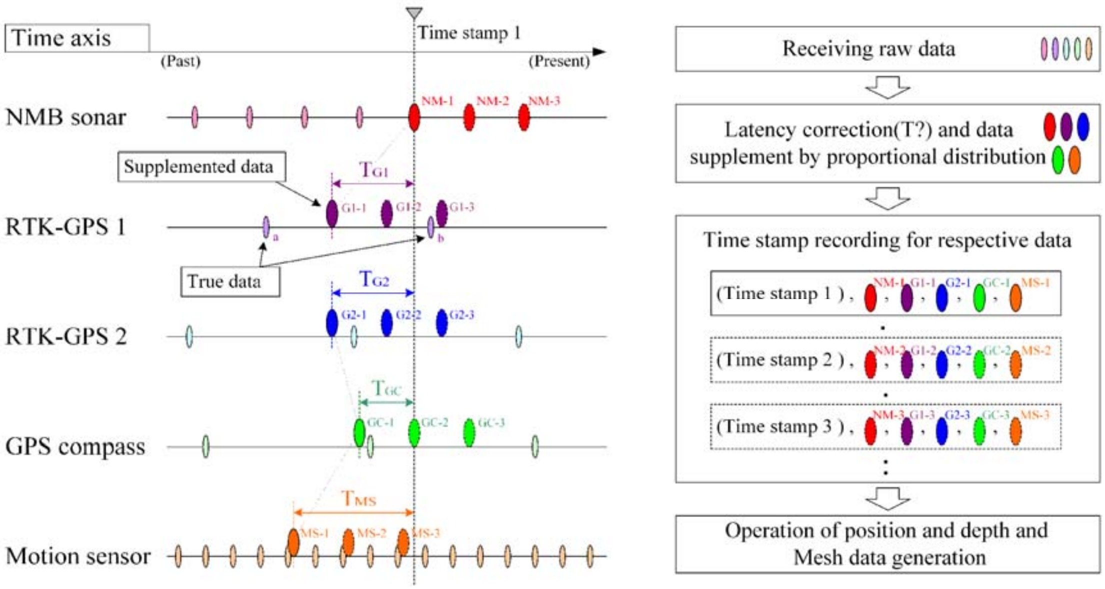


Figure 6. Latency correction and data supplement by proportional distribution.

Sound Velocity Correction

When the beam emitted by the sonar has a directional angle, theta, and the sound reflex time is M sec. in one way, the followings are expressed:

Slant-range from sonar to ground, S[m]: = M x SV (SV: Sound velocity value [m/sec])

Vertical distance, L[m]: = S x cosine theta

Naturally, the sound velocity varies by water depths due to water temperature, salinity, and sunshine conditions, and accurate water depths cannot be obtained from the above expressions.

As a solution, the sound velocity corrections are achieved using the Snell laws of refraction, as follows:

sin theta1 x C2 = sin theta2 x C2 (theta: incidence･outgoing angle; C: sound velocity)

E.g., when a beam enters from the layer with a sound velocity of 1,500m/sec into the layer of 1,490m/sec, the expression is as follows:

sin (45 deg.) x 1490 = sin (theta) x 1500

theta = sin-1 (0.70710678 x 1490/1500) = 44.62 deg.

Consequently, the outgoing angle becomes 44.62 deg. against the incidence 45 deg. Thus the beam is slightly refracted.

Based on this procedure, the sound velocity corrections are achieved to calculate the distance to the object i.e., the depth (altitude) of the surface of the sea floor.

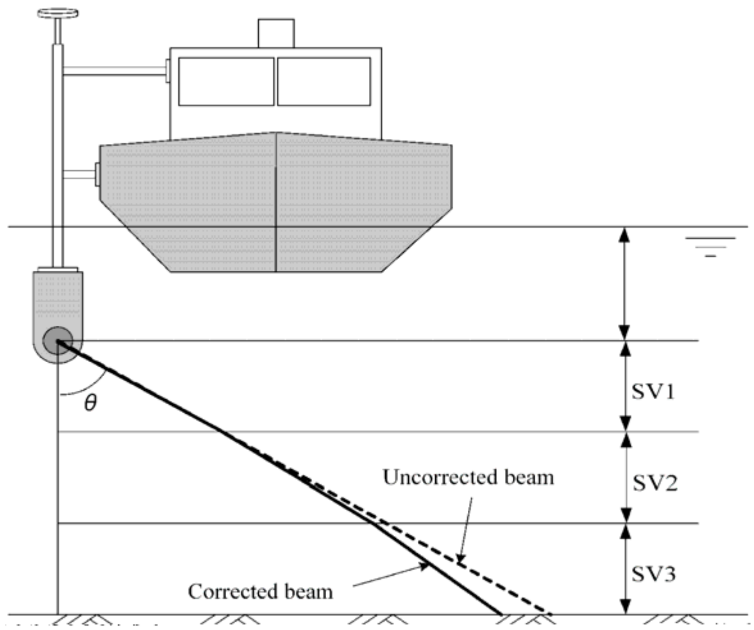


Figure 7. Sound velocity correction.

Mesh Data Generation

When carrying out mesh computation of optional position and water depth (X, Y, and Z) based on the various measured data, the mean, minimum, and maximum values can be used for each datum group in a square area centered on a targeted coordinate point. Any of these values can be selected to fit the use of the measurement results, and the mesh unit can be modified within the range of 0.1mm to 20mm.

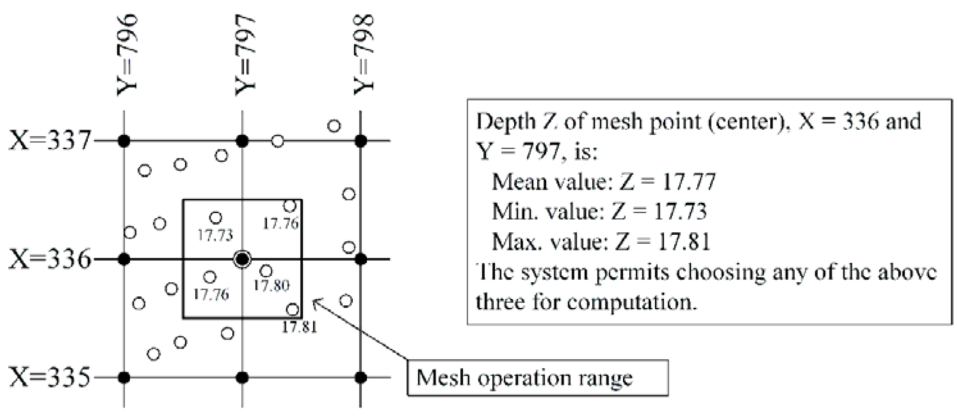


Figure 8. Mesh operation summary.

SONAR-SOUNDING METHOD

Figure 9 shows the flow of sonar sounding and analysis with the Beluga System.

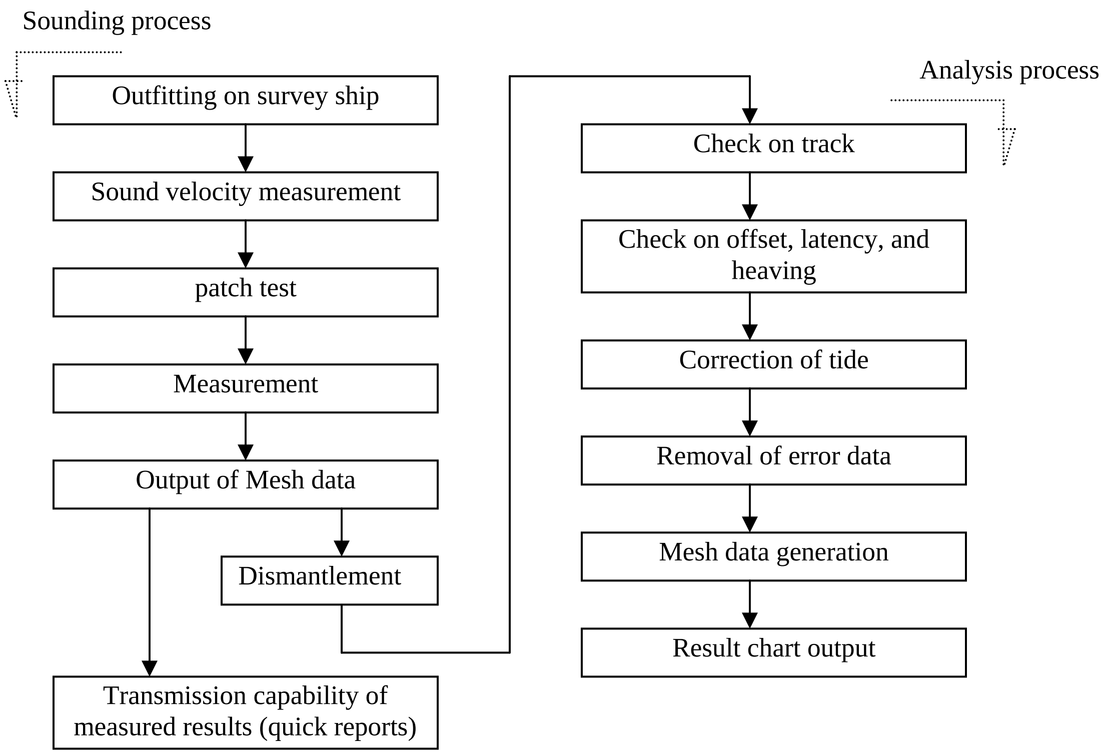


Figure 9. Sonar sounding and analysis flow.

Sounding Process

Outfitting on Survey Ship, Sound Velocity Measurement, Patch Test

First, outfitting of every equipment and devices are mounted on the survey ship, and measurement generally uses a survey ship made of steel, which is about 20 gross tons and over. Brackets and pole are outfitted to the ship's side shell for mounting measurement devices. NMB sonar head, motion sensor, and RTK-GPS (GPS compass) antenna are arranged as seen in the figure (right). Assuring the draft of the sonar head, relative distances and heights between the measuring devices are measured.

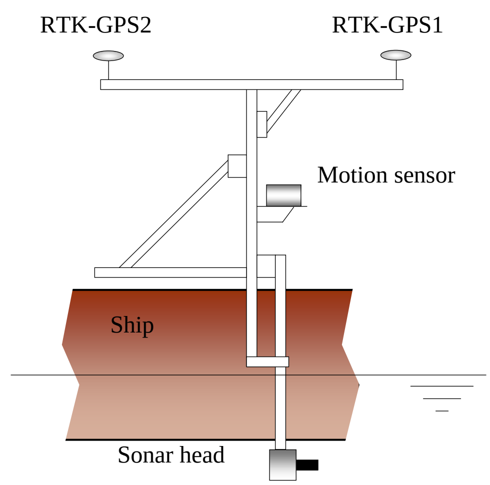


Figure 10. Arrangement of sensors (side view).

Next, measurement of the sound velocity is conducted at the water area to be sounded.

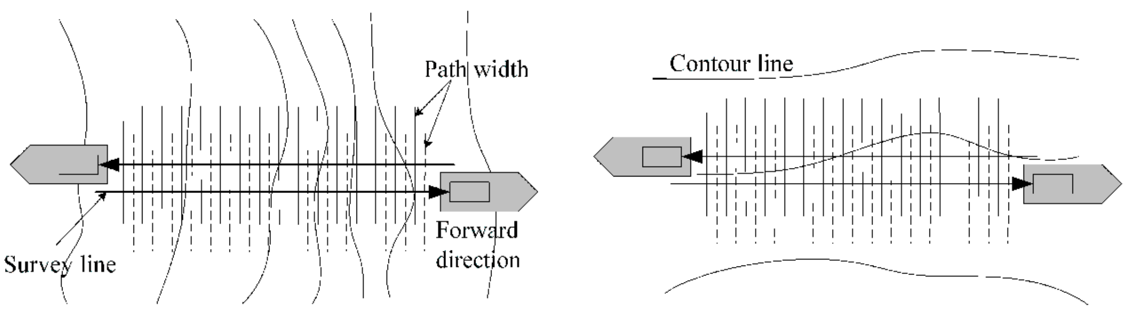
Depth [m]	Sound velocity [m/s]
1	1497.26
2	1497.63
3	1497.76
4	1497.95
5	1497.96
6	1497.95
7	1497.88
8	1497.84
9	1497.84
10	1497.88
11	1497.86
12	1497.85
13	1497.87
14	1497.88
15	1497.91
16	1497.73

Photo 4. Sound velocity measurement (photo) and measured results (Table).

In the following process, the patch tests are performed to acquire offset and latency values of the ship's pitching, rolling, and yawing. The patch tests are essential not to lower the sounding accuracy of the outward beam.

Measurements of the offset and latency values of pitching are performed as follows: deciding a survey line that crosses contour lines, the survey ship makes a round-trip along the line while emitting the sonar. The offset and latency values are automatically calculated.

When measuring the offset values of rolling and yawing, a survey line is decided between and along the contour lines, and the survey ship makes a round-trip along the line while emitting the sonar. The offset values are automatically calculated.



(a) Pitching offset measurement:
By making a round trip on a survey line crossing the contour lines with the deformed points of landform

(b) Rolling offset measurement:
By navigating with a round-trip over the comparatively even sea floor area

Figure 11. Patch tests summary.

Measurement

After entering the offset and latency values of rolling, pitching, and yawing in the operation PC, an area to be sounded as well as navigation lines are decided on the computer for the start of the measurement. During navigation, the measured data area is displayed as a color fill contour shown in Photo 5. The color fill area increases according to the ship's progress.

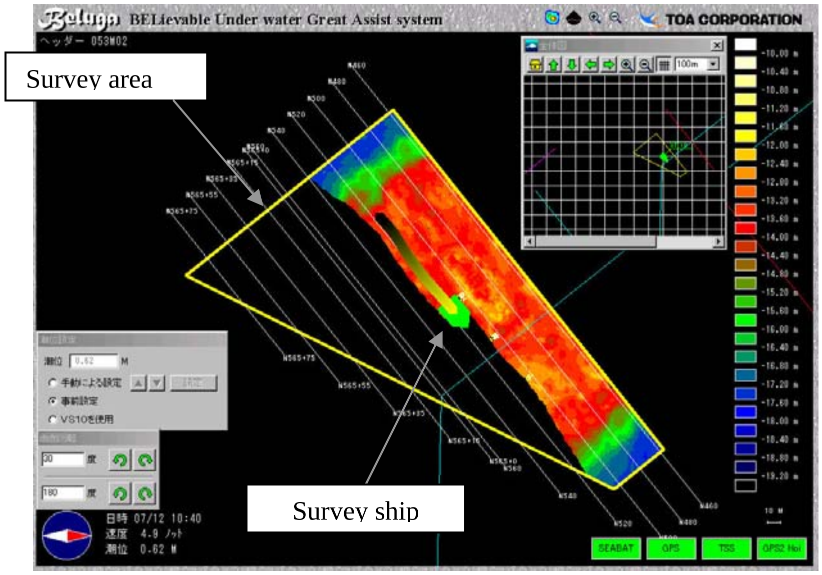


Photo 5. System screen during measurement.

Transmission Capability of Measured Results (quick reports).

The Beluga System includes the Beluga-NET that has a function to transmit quick reports on the measurement results immediately after completion of the measurements. The Beluga-NET provides data transmission for the operation PC and remote PCs (clients) linked by a wireless LAN or cellular phones. This function is detailed in Chapter 5 with an example.

Analysis Process

The analysis process is an accurate analysis to be executed for obtaining the final results. At first, the offset amounts of rolling, pitching, and yawing as well as corrections of the latency and heaving must be reviewed. If any improper values are found, corrections will be made. Next, error data must be removed from all measured data after revising the tidal height of the sea level record. Then, the mesh size is decided by considering the resolution of sonar sounding and the scale of the resultant drawing. Subsequently, the contour, depth contour, and a bird's eye view drawing, which consist of the sounded values for every mesh, are made from the randomly-distributed measurement record.

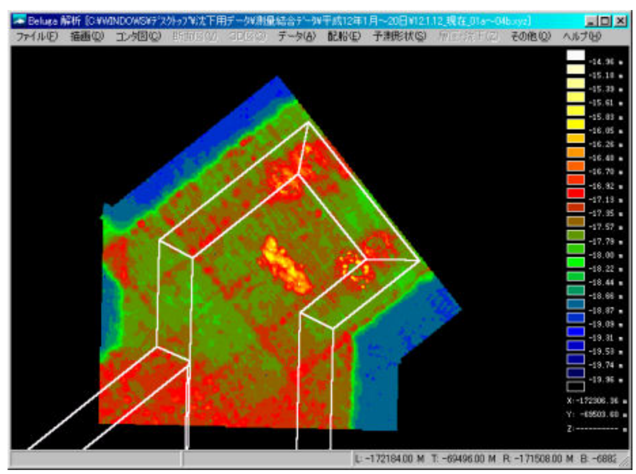


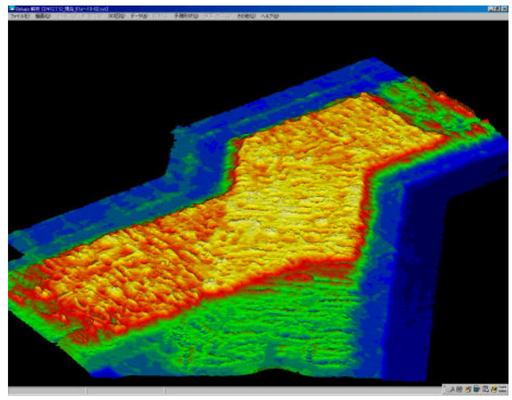
Photo 6. Example sounding results (contour map).

EXAMPLE SOUNDING RESULTS

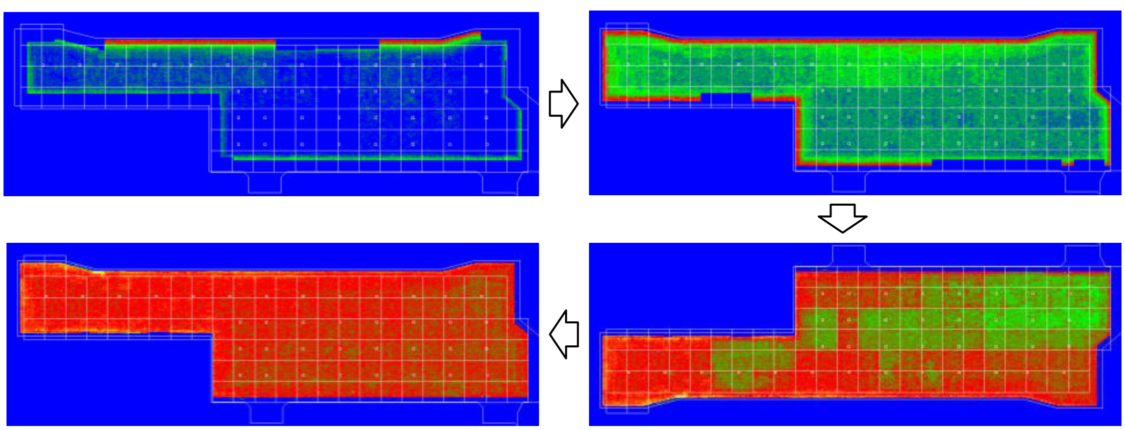
Phase II Airport Island Landfill at Kansai International Airport

This reclamation work was conducted on soft and weak seabed in deep water. Therefore, daily measurement was required to know changes in the seabed surface by reclamation, i.e., the reclaimed layer thickness, subsidence, and construction history. The Beluga System was employed.

(a) Phase II of airport island of Kansai International Airport



(b) Measured results after sand dumping



(c) Reclamation progress for airport island

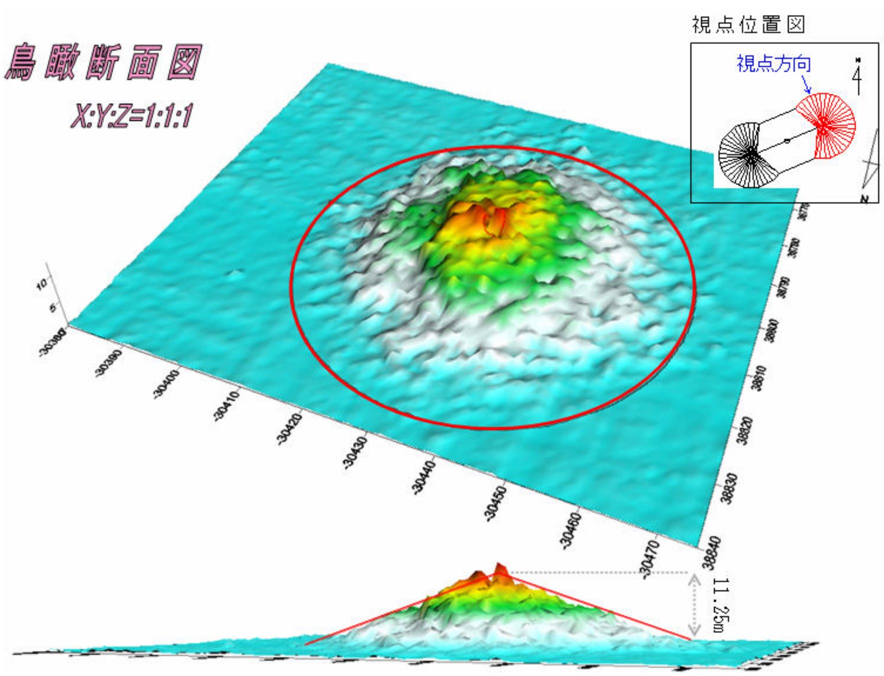
Photo 7. Measured results in reclamation work of Phase II airport island, Kansai International Airport.

Mountain-like Mound Construction on Sea Floor off the Coast of Nagasaki Prefecture

Under this project, a mountain-like mound was constructed using concrete blocks on the seafloor at about 90m depth. The mound helps generate upwelling of deep ocean water abounding in nutrients to form a good fishery. The blocks carried from land on a full-open door type barge were dumped (total: 64 dumpings by 8 navigations) to the designed target. After each dumping, mound formation was estimated using the Beluga System.

(a) Construction summary

(b) Scene of block dumping



(c) Bird's eye view of mountain-like mound

Photo 8. Measurement results of mountain-like mound construction on sea floor off Nagasaki.

INTRODUCTION TO DIVERSIFIED VERSION OF BELUGA SYSTEM

The Beluga System has diversified into new applications for specific purposes as described below.

Beluga-D, Parallel-run System for Measuring and Dredging Work

The Beluga-D system was developed as a parallel-run system for measuring and dredging work. The Beluga system and necessary devices were mounted on a suction dredger with a cutter head. This arrangement improved accuracy of dredging management since dredging proceeds by reviewing in real time the excavation surface on a monitor. Thus excess dredging can be avoided.

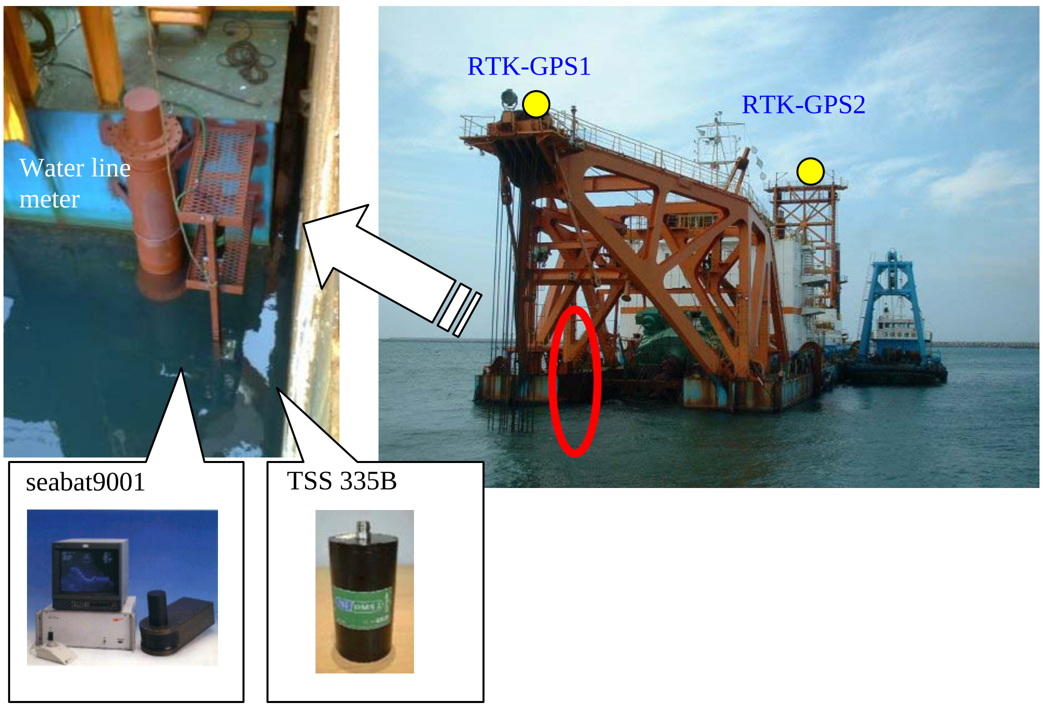


Photo 9. Beluga-D system and suction dredger.

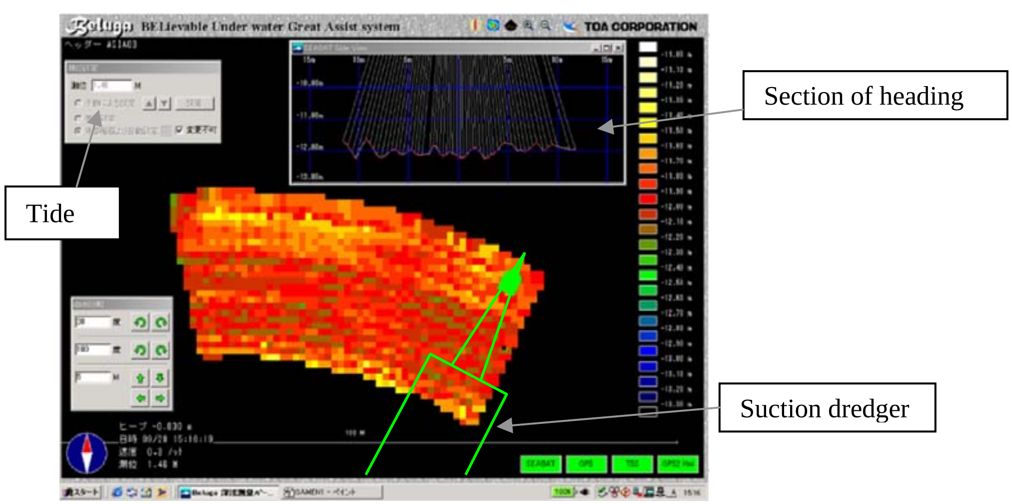


Photo 10. Screen display of dredging operation result.

Beluga-NET, A Seabed Data Transmission System

Applicable to restoration after disaster:

The Beluga-NET system can be used to collect information on the seafloor conditions and provide information for a remote user, which allows real-time monitoring as a high-informative construction management system via a wide wireless network including a wireless LAN and cellular phones.

The Japanese Islands lie on the route of typhoons. In September 2004, typhoon No. 8 came up on the route to the north, reached Hakodate in Hokkaido, attacked the caisson breakwater of Hakodate Port and broke up caissons in the water. Toa Corp. undertook the restoration work of the breakwater, and this project required shortening of the construction period. To meet requirement, the Beluga-NET was introduced to a grab dredger. It provided in real time the seafloor status for the dredger to remove the caissons. Thus parallel operations of caisson removal and measurement were achieved.

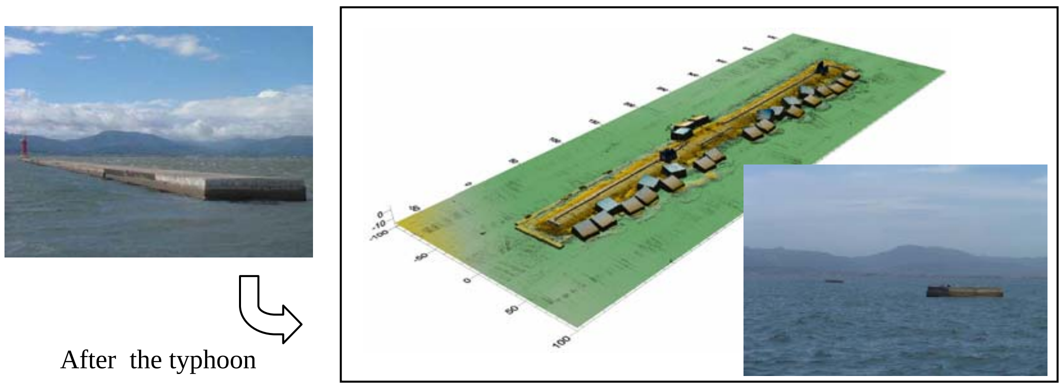


Photo 11. Collapsed caissons at Hakodate Port just after the typhoon.

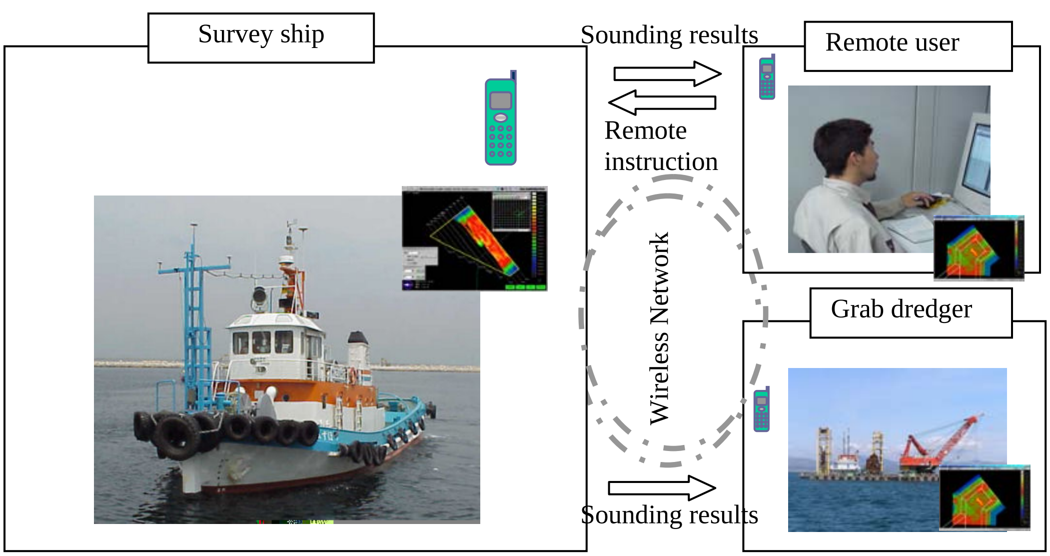


Figure 12. Operation example of Beluga-NET.

Photo 12. Screen display of remote PC (client).

CONCLUSIONS

The Beluga System developed in 1994 has made great advances over the 10 year operating performance. In this report, achievements in the marine engineering area have mainly been described. Other applications and developments are introduced below.

>Secular exploration of the accumulation of sand and soil in a dam-lake bottom

>Damage estimation of offshore structures (breakwater, Tetrapod) at the time of the typhoon disaster

>Development of a sounding system using an autonomous navigation ship (applicable to a shallow water area or a lake)

>Development of a wide area survey system on land using a 2-D laser scanner.

In the future, diversification of the Beluga System technology will be further improved to broaden applications to various fields, to develop an unattended operation system for disaster use as well as a transmission system for highly intensified information to meet specific needs.