PROCEDURES PLANNER FOR AN A.U.V.

Magali Barbier
Office National d'Etudes et de Recherches Aérospatiales
Department of Systems Control and Flight Dynamics
Toulouse, France (www.onera.fr)
Magali.Barbier@cert.fr

Jérôme Lemaire – Norbert Toumelin
Groupe d'Etudes Sous-Marines de l'Atlantique
Brest Naval, France
{lemaire, toumelin}@gesma.fr

Abstract

The Redermor II experimental A.U.V. has been prepared to execute fully autonomous missions. Final objectives of a mission are the execution of survey, search and inspection procedures. This paper presents the planning of generic procedures for this Autonomous Underwater Vehicle. The execution control is performed with the ONERA ProCoSA tool. Procedures implemented in the control system are described and their execution is successfully validated on a complex scenario with a simplified simulator.

Introduction

The "Non Traditional Navigation Guidance and Control" project at GESMA aims at developing a fully autonomous system for the execution of missions in a partially known environment. This mission of a few hours consists in reaching several points where specific procedures have to be executed. The originality of the project is to associate classic navigation equipment with non-traditional sensors : the Side Scan Sonar and the Forward Looking Sonar are used to achieve the operations and to limit the drift of the classic navigation filter. After a presentation of a typical mission and of the system architecture, this paper focuses on the planning of procedures at mission points: description of generic procedures that could be executed, implementation in the global architecture, validation of procedures planner using a simulator. The conclusion highlights ongoing works.

Mission and System Architecture

A typical mission (Figure 1) lasts a few hours. The final objective of the vehicle is to execute procedures at mission points defined offline by the operator. An itinerary planned for the vehicle can also contain bypass points (defined to surround forbidden areas) and landmark points (used to increase vehicle location accuracy).

The vehicle must be equipped with :

- a Forward Looking Sonar for the estimation of the successive movements of the vehicle ping after ping, for obstacles avoidance and for the object inspections,
- a Side Scan Sonar for the localization of the vehicle according to known landmarks and for the execution of several operations.

In this project, the at sea test will be achieved with the Redermor II [DEV 00] experimental platform.

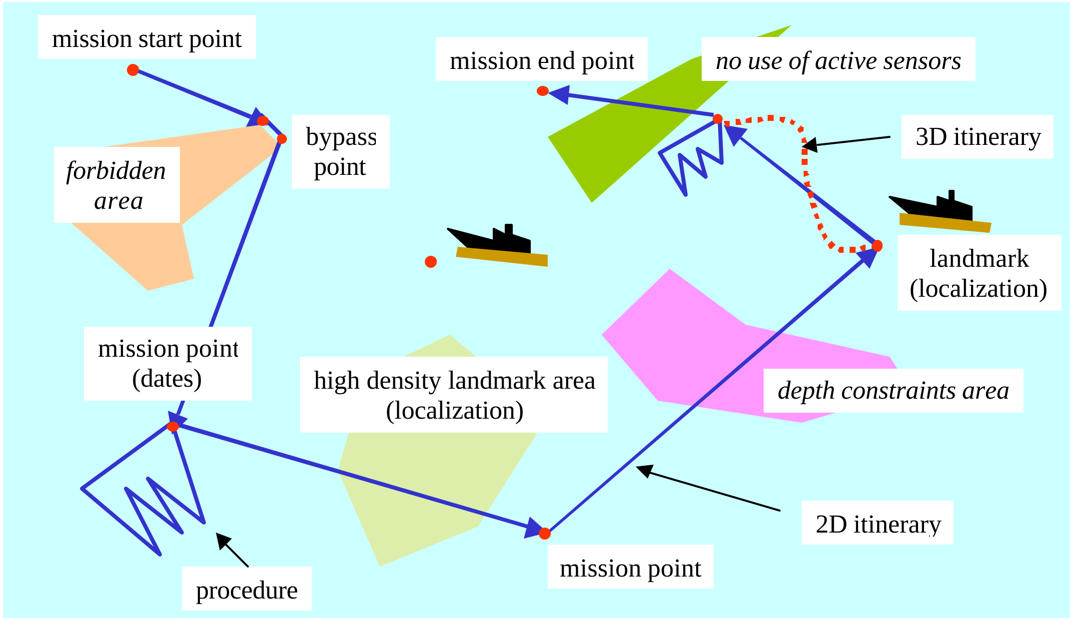

Figure 1. UUV mission.

Constraints on the mission execution are induced by :

- vehicle specificity (limited energy, consumption vs. velocity, mobility performances, sensors performances),
- environment (isolated landmarks, high-density landmark areas, currents map, sea bottom map),
- the mission itself (mission area, forbidden areas, depth constraints areas, earliest and latest start times for procedures…).

Uncertainties due to the knowledge of currents, relief, vehicle location during the mission, trajectory tracking and procedures execution have required the development of on-board adaptive planning.

The integration of perception, decision and action is performed thanks to the ProCoSA tool [BAR 99] (software for programming and execution monitoring of autonomous systems). The basic functions of the system architecture have been defined according to above mission specifications and implemented in several independent sub-systems:

– the global planner selects an optimized itinerary according to present situation whereas the local planner optimizes trajectories between itinerary points [BAR 98],
– the guidance navigator generates high level orders (speed, immersion and attitude) to follow optimal path while avoiding obstacles whereas the dynamic control computes final effort towards actuators,
– the mission controller supervises the different phases of the mission and the correct execution of procedures,
– the state estimator computes the vehicle state,
– the feature map processor and generator analyze the sonar images and give fixes to the state estimator.

Description of Procedures

The objectives of the mission are described in the database by a list of mission points with the procedure to perform. A procedure is defined by its type, a priority level (for selection when abnormal situation), a maximal duration and specific parameters. Procedures implemented in the "Non Traditional Navigation" system are generic:

– area survey,
– pipe survey,

– sea bottom object search,
– sea bottom object inspection,
– column water object search,
– column water object inspection,
– station keeping,
– resurface and descent.

Side Scan Sonar offers better images when the advance of the vehicle is straight and when the vehicle moves at a depth of 12m above sea bottom. Procedures using this type of sensor can thus be modeled as a succession of lines (scan mode) and course changes, called the operative sequence.

For the execution of the different phases of a mission, three navigation modes have been implemented in the guidance navigator:

– the "tracking" mode is used to follow a trajectory between two procedures, bypass or landmark points and to perform the scan of the sea bottom (lines of the operative sequence) in several procedures; the algorithm is based on the target tracking method [KHA 86] with obstacles avoidance and current modeling;
– the "gyration" and "heading" modes are used to perform a course change between two points defined by x, y, z coordinates and vehicle heading; in the first mode, the vehicle turns round according to a specific ray, whereas in the second mode, the vehicle goes straight according to the given heading; a course change (Figure 2) is then the combination of a gyration, an advance heading and a second gyration; the algorithm computes rotation directions, in-between heading and slope changes, taking into account current constraints.

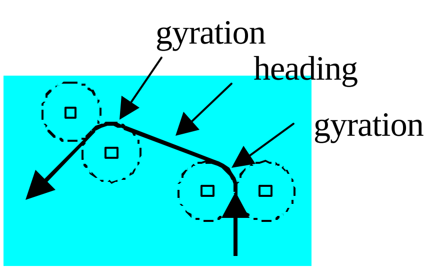

Figure 2. Modeling of a course change.

When the procedure has been executed, a course change can be required to join the mission point before carrying on the mission. The following sub-sections describe all implemented procedures.

1 - Area Survey Procedure

Two specific parameters define this procedure: the type of the survey (Figure 3) and the area. This area is expanded to take into account the location uncertainty of the vehicle.

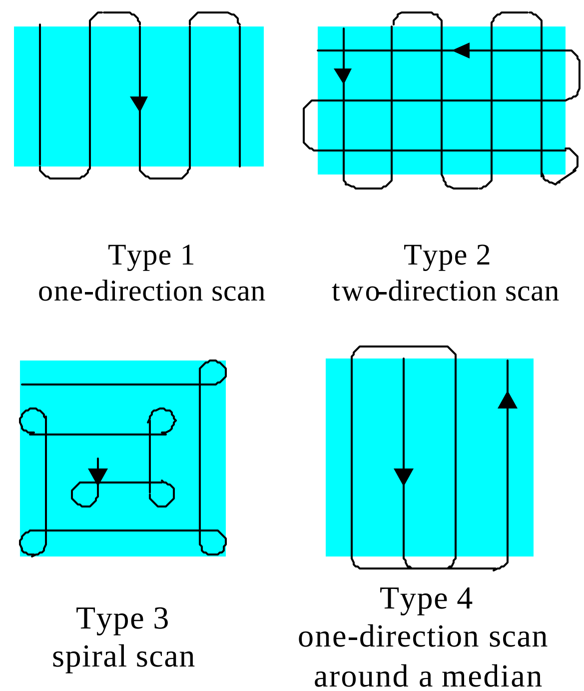

Figure 3. Survey Area Procedure.

The survey is then modeled as a succession of lines (tracking mode) and course changes. When the vehicle moves too much crabwise, Side Scan Sonar images are not usable. Thus, the current constraints the heading of the survey lines:

– when current velocity is over 17% of vehicle velocity, the vehicle is aligned with the current (front or rear) for types 1 and 4,
– when current velocity is lower than 34% of vehicle velocity, an angle of 45° with the current is considered for types 2 and 3,
– over this percentage, only types 1 and 4 are executable.

The procedure stops when the survey is finished or when the maximal duration has elapsed.

2 - Pipe Survey Procedure

To obtain better images of the pipe with the Side Scan Sonar, the vehicle makes a lateral shift of 50m. The parameter of this procedure is a list of points describing the pipe, the first point being the operation point. A course change is required between two segments (Figure 4) where the angle is over 10°.

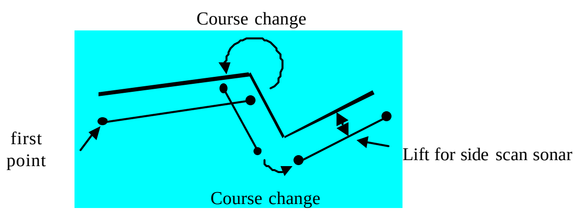

Figure 4. Pipe Survey Procedure.

The procedure stops when the survey is finished or when the maximal duration has elapsed.

3 - Sea bottom Object / Landmark Search Procedure

The parameter is the object to search, described by its location, the associated uncertainty and the best view (heading, left/right). This search is also executed when the vehicle arrives at a landmark point for localization on its itinerary.

This procedure is in fact an area survey of type 3 (spiral) if the current velocity is low or of type 4 (front or rear the current) otherwise. The operation point is then the highest location probability point of the object / landmark. The area to survey is dynamically computed adding location uncertainties of vehicle and object / landmark.

For this procedure, the gap under the vehicle the Side Scan Sonar can't view is taken into account either by nearing scans lines or using added gap-filler equipment. The procedure stops when the object/landmark has been recognized or when the maximal duration has elapsed.

4 – Water column Object Search Procedure

The search uses the Forward Looking Sonar. The parameters of the procedure are the object to search and its assumed depth. The vehicle stops 20m ahead the probable location, front the current, and turns 360º round. The effect of the current is neglected during the search. The procedure stops when the object has been recognized or when the maximal duration has elapsed.

5 - Object Inspection Procedures

The object (the parameter of the procedure) has to be recognized with a sea bottom or water column object search procedure before its inspection. If the object is on sea bottom, the inspection with Side Scan Sonar is an additional survey according to object best view (heading and right/left). If the object is at middle-depth, the vehicle executes hovering maneuvers (lateral moving around the object at a heady distance) taking into account current constraints.

6 – Station Keeping Procedure

The parameters of this procedure are the depth of the station keeping and its type: fixed point at mission point facing the current or drift accepted until 20m then moving again towards operation point. The procedure stops when the maximal duration has elapsed or when the system receives a stop-waiting event (from a other A.U.V. for example).

7 - Resurface and Descent Procedures

The resurface allows a GPS localization or external communication; it's also the procedure at the end of a mission (to pick up the vehicle).

Resurface and descent procedures (Figure 5) are performed by a stairway spiral moving at steady slope, with straight lines of 100m (vehicle aligned with the current) and course changes.

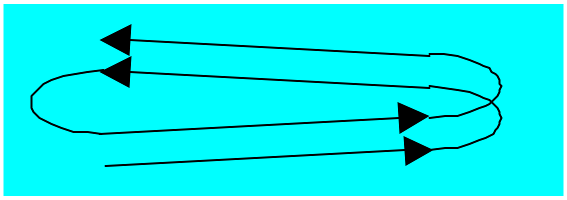

Figure 5. Resurface and descent procedures.

Procedures Implementation with ProCoSA

ProCoSA was originally developed at automatic department of ONERA for mobile robotic applications. This tool uses the Petri net formalism :

(i) to specify control processes of autonomous vehicles,

(ii) and to execute them.

ProCoSA is composed of:

- a graphic user interface for Petri nets generation (places for behavioral state, transitions for actions, events for messages),
- a Petri player automata (LISP) to run the system.

Functions or actions to be performed by an autonomous vehicle are implemented in independent sub-systems on a local network. Communication through Petri Player is sockets based.

The hierarchy of system states for the execution of a mission is defined as follows:

- mission high level management,
- itinerary and trajectory optimization (offline or online when abnormal situations),
- trajectory tracking between two operations, bypass or landmark points and procedure launching,
- specific procedure execution,
- operative sequence execution (trajectory tracking and course change succession),
- course change execution (gyration and heading modes).

Unforeseen procedures, constraints areas crossing, errors, end of ongoing mode and degraded reactions are related to above states.

This behavior of the system is totally reproduced in the main Petri networks:

- “Mission” manages the launch, waiting and abort phases of the ongoing mission,
- “Rplan” runs itineraries and trajectories planner using initial or updated objectives (a place models the execution of a plan),
- “Xplan” executes a plan by running (i) tracking mode if the vehicle is between two itinerary points or (ii) procedure when the vehicle arrives at a mission or a landmark point (a place models procedure execution),
- “Proc” runs the specific procedure (places model the execution of each type of procedure),
- “SeqZ” supervises the execution of the planned operative sequence for a procedure (a place models the vehicle performing the course change, another the tracking mode),
- “ChangeCap” runs the modes of a course change: gyration and heading.

Figure 6 describes “Proc” Petri net. The first part of the network checks that the operative sequence is consistent with measured current constraints. The “test0” place performs the “or” function on the procedure types. Places named BA, SF, RF, RO, INSP, AT, RE et DE model ongoing procedure. Specific transitions manage the end of the procedure (maximal duration or degraded situation).

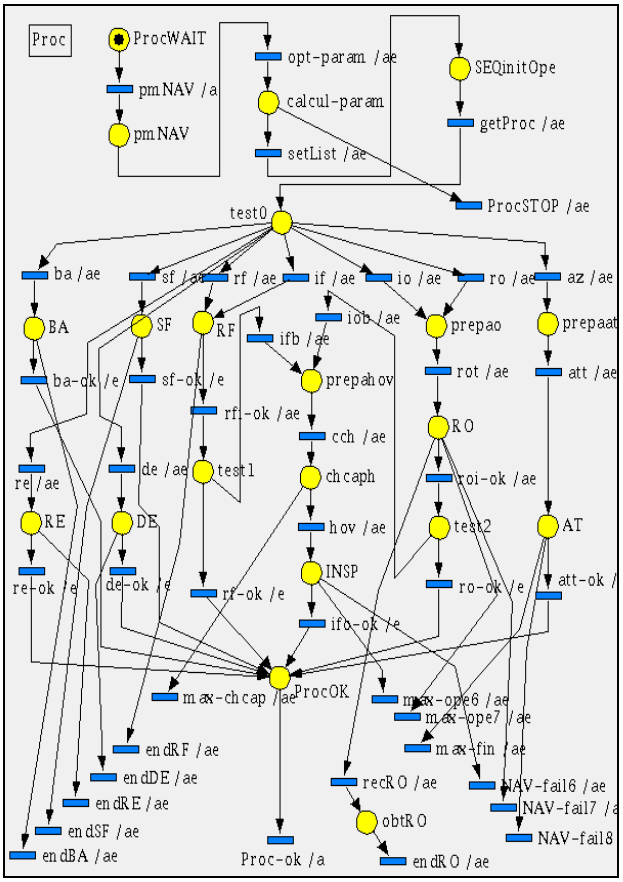

Figure 6. Petri net for the execution of a procedure

Validation of Procedures Planner

The validation is performed using a cinematic simulation model that integrates the controls computed by the guidance navigator on a 0.5s sampling time (no integration of dynamic control towards actuators, state estimator and feature map generator). The execution of each procedure has been verified independently, with and without current.

This paper presents the execution of a global mission in nominal situation (abnormal events not described here have been implemented in the system allowing the validation of global / local online planning and of mission abort with resurface).

The test area (Figure 7) is an indented coastline of 17x12km^2, with at least one instance of environmental items: forbidden area, area where the use of active sensors is prohibited (then increase of the drift), depth constraint area, isolated landmark and high-density landmark area (then decrease of the drift). Four mission points are defined ("Cpt" being the initial location of the vehicle): the procedure at "mi1" is an area survey, at "mi2" a water column object search, at "mi3" a pipe survey (the pipe has a lightning shape to validate many different angles) and at "mi4" a resurface procedure at the end of the mission. Six bypass points and six landmark points are selected.

Location (x, y, z coordinates), heading, depth, consumption and drift of the vehicle during the simulated mission have been stored for analysis. (x, y) coordinates of the vehicle are displayed on Figure 7 for the case without current: itinerary planned by the system is "Cpt – mi1 – bp1 – mi2 – bp1 – bp3 – ld4 – mi3 – bp4 – mi4". Figure 7 details the execution of area survey, pipe survey and resurface procedures. Trajectory tracking and course change are correctly executed. The mission lasts 6h50, the vehicle has traveled 55km at a mean velocity of 4.1 knots.

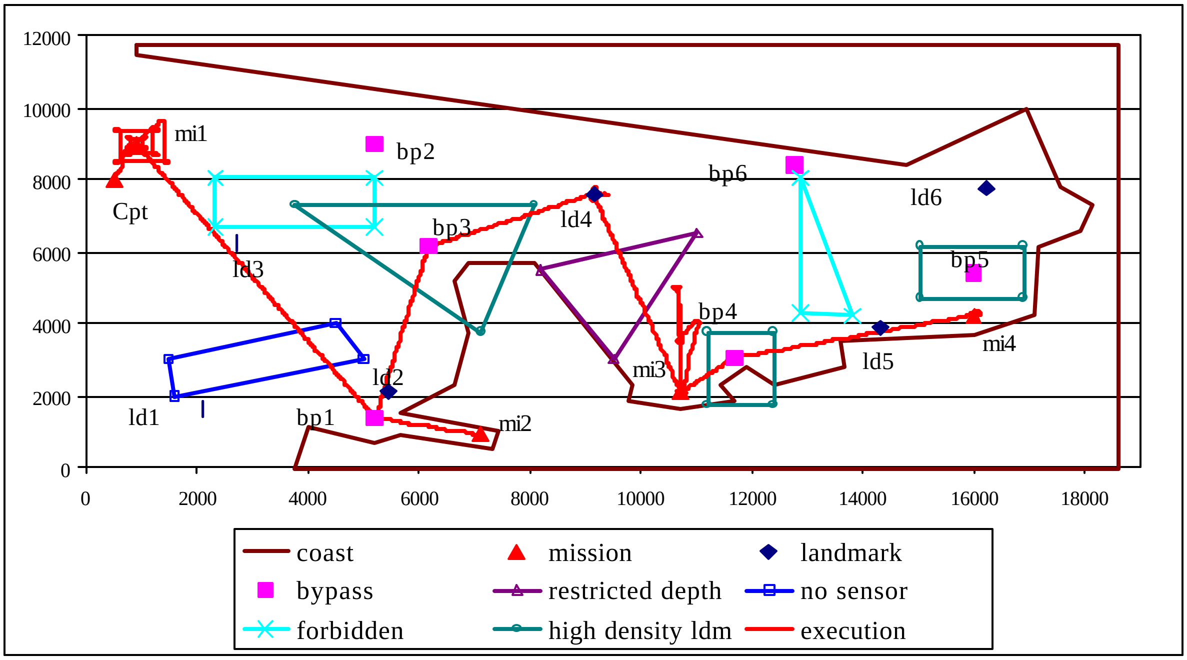

Figure 7. Test scenario and mission execution.

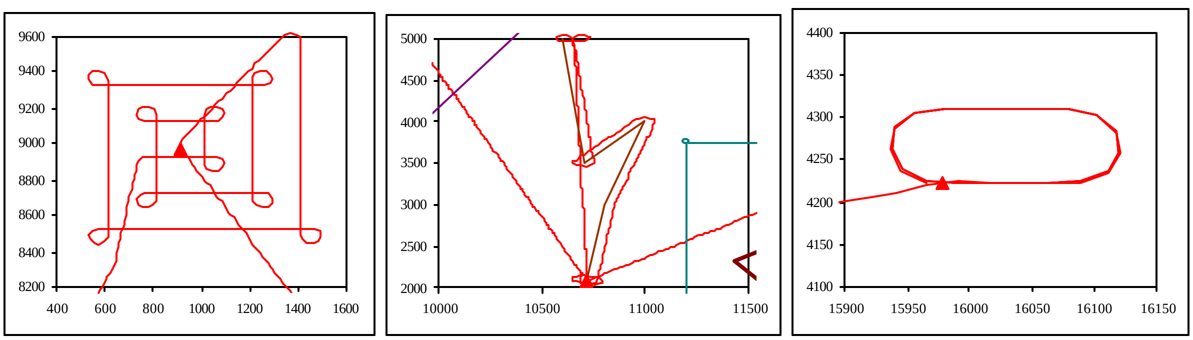

Figure 8. Area survey, pipe survey and resurface procedures execution.

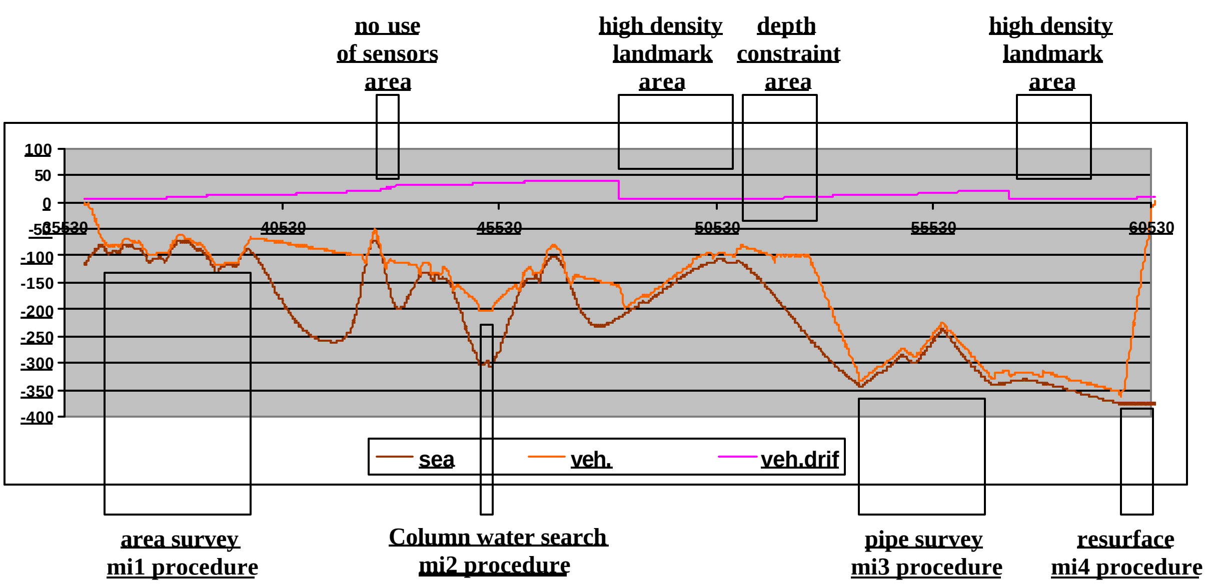

Figure 9. Temporal behavior during the mission execution.

Figure 9 shows on a temporal graph the sea bottom map, the immersion and the drift of the vehicle during the mission execution. The vehicle is at a fixed altitude for area and pipe surveys and in high-density landmark areas (use of Side Scan Sonar). The drift according to traveled distance increases regularly, until a fix is performed when encountering high-density landmark areas (in this scenario, the landmark “ld4” is not recognized).

The mission of the test scenario without current has then been fully simulated: the vehicle follows the nominal plan with the execution of all implemented procedures, taking into account environmental, mission and vehicle constraints. Consistent results are also obtained with a current velocity of 1.3 knots on the whole mission area: during 6h56, the vehicle has traveled quite the same distance at a lower mean velocity of 3.9 knots because the current heading was globally in the direction of the itinerary. Figure 10 shows the execution of the area survey procedure in case of current.

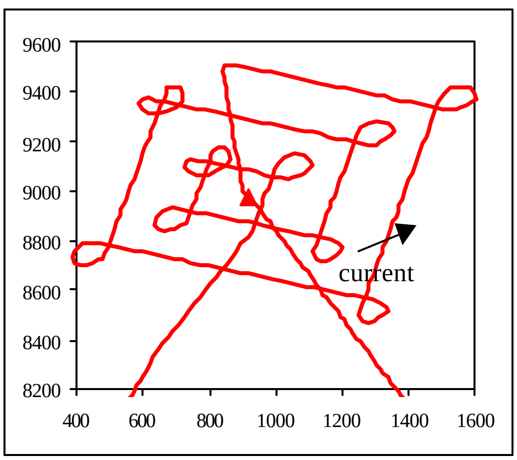

Figure 10. Area survey procedure execution with current conditions.

Conclusion

The ProCoSA tool has been successfully used to develop the execution control system of an A.U.V. The Petri net formalism is well suited to the description of the behavior of autonomous system. A cinematic simulator has allowed to simulate a complex mission and thus to perform the validation of the functions implemented in independent sub-systems and connected by ProCoSA. Generic procedures of area survey, pipe survey, search and inspection are planned online and correctly executed.

The final steps of this work in the “Non Traditional Navigation” project are to use a more complex simulation tool (developed by GESMA) in order to simulate the behavior of the system in a more realistic context. Several scenarios will then be tested in order to finalize the validation of the global system in normal and degraded situations. A full demonstration of the system with all functionality onboard the Redermor platform is scheduled by the end of the year 2001 (sea tests).

Bibliography

[BAR 98] BARROUIL C., LEMAIRE J., «An Integrated Navigation System for a Long Range UUV», *IEEE-OCEAN'98*, 28 Sept - 1 Oct. 1998, Nice, France.

[BAR 99] BARROUIL C., LEMAIRE J., «Advanced Real-time Mission Management for an AUV», *SCI NATO Restricted Symposium on Advanced Mission Management and System Integration Technologies for Improved Tactival Operations*, 27-29 Sept 1999, Florence, Italy.

[DEV 00] DEVIE F., LEMAIRE J., MAILFERT G., TOUMELIN N., «Redermor: Description and Results with a versatile tool for Autonomous Underwater Vehicle Research», *International UUV Symposium*, 24-28 Avril 2000, Newport, US.

[KHA 86] KHATIB O., «Real-time obstacle avoidance for manipulators and mobile robots», *International Journal of Robotics Research*, n° 5, 1986, p. 90-98.