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THE LOCALIZATION PROBLEM FOR AN UNDERWATER SWARM

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AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE,
L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

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Abstrac

*HARNES*S (Human telecontrolled Adaptive Robotic NEtwork of SensorS) project is dealing with an underwater multi body robotic systems (swarm). A swarm is able to perform tasks in a more fast and robust way with respect of a single machine. Moreover a swarm has the advantage of a simple way of interfacing with the human users, overcoming the problem of controlling a large number of individuals; the system is adaptable to the environmental characteristics and the geometrical distribution of the multi robot system is linked to the communication channel.

The aim of the project is the integration between individual, collective and communication controls of the swarm to maximize performance of the system. The project is founded by Italian Institute of Technology (IIT).

Localization problem of the swarm relatively to themselves and to a reference system is one of the most challenge to be overcome.

In this paper we give an overview of the used systems and propose some hypothesis that can be applied to our case. A large literature is examined.

Key words: *Robotic, Sonar, Security, Subsea Environment.*

Riassunto

Il progetto HARNES

S (Human telecontrollati Adaptive Robotic rete di sensori) si occupa di un sistema robotico multi corpo sottomarino (sciame). Uno sciame è in grado di svolgere compiti in modo più veloce e robusto rispetto ad una singola macchina. Inoltre uno sciame ha il vantaggio di avere un modo semplice per interfacciarsi con gli utenti umani, superando il problema del controllo di un gran numero di oggetti; il sistema è adattabile alle caratteristiche ambientali e la distribuzione geometrica del sistema multi robot è legato la canale di comunicazione.

L'obiettivo del progetto è l'integrazione tra i controlli singoli, collettivi e di comunicazione dello sciame allo scopo di massimizzare le prestazioni del sistema. Il progetto è finanziato dall' Istituto Italiano di Tecnologia (IIT).

Il problema della localizzazione dello sciame relativamente tra di loro e rispetto ad un sistema di riferimento è uno dei compiti da superare.

In questo articolo diamo una panoramica dei sistemi utilizzati in letteratura e proponiamo alcune ipotesi che possono essere applicate al nostro caso.

Parole chiave: Robotica, Sonar, Sicurezza, Ambiente Sottomarino

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Premise

This paper is related to an important task of the HARNESS (Human telecontrolled Adaptive Robotic NEtwork of SensorS) project: underwater localization of the swarm and of the single machine.

A reasoned bibliography of the state of art is proposed in the following pages and at the end some proposal and cases study are examined in more details.

In the introduction we expose the importance and the possibility of localization of an underwater swarm. Successively we examine the methods for localization of a single machine and for a swarm; every methods is referenced and advantages and negative aspects are exposed together with its application field.

Finally a proposal for our system is exposed

Document reference

The project

HARNESS	Human telecontrolled Adaptive Robotic NETwork of SensorS
WP3	Swarm Control
<i>Line 1</i>	Individual Control System

Table 1 The project

References document

Reference	Description
<i>The research project</i>	Human telecontrolled Adaptive Robotic NETwork of SensorS Project Seed italian institute of Technology IIT Anno 2009
<i>Self Organising Complex Creatures</i>	Rapporto tecnico ENEA
<i>Harness Control Basics</i>	Rapporto tecnico ENEA

Table 2 References documents

Introduction to the swarm and aim of the work

Underwater robotic

The use of underwater robotic vehicles in oceanic surveys, inspections, pipe and cable tracking, has been well established in the field of marine engineering since many years ago [1]. Today surveillance of ports and of other maritime environments, is assuming an increasing importance for naval and customs services [2]; also a nuclear waste pool too has been considered as an interesting target to be controlled by autonomous underwater vehicle (AUV) [3]. Marine robotics technology has undergone a phase of dramatic increase in capability in recent years [4] and many autonomous underwater vehicle systems have moved from the prototype stage to scientific, commercial, and military uses. To make sense, by an economical point of view, an AUV must be a real cost alternative to other available technologies, such as manned submersibles, remotely operated vehicles (ROVs) and towed instruments led by ships. The benefits of using autonomous data gathering have to be compared against the difficulties faced by AUVs in power, sensing, information processing, navigation, and control. In fact untethered operations impose severe restrictions on power consumption and present challenging problems in intelligent control. Navigation is one of the principal challenges that limits our capability to use AUVs; the continuous knowledge of good navigation information by a control center is essential for safe operation and recovery of an AUV; moreover the data gathered by an AUV must be accurately referenced in space and time. Having a good estimate of one's location is critical for manned and unmanned vehicles, but it is particularly important for autonomous vehicles as unsupervised decisions are made based on the location estimate. Furthermore the quality of the data collected is directly dependent on how well measurements can be referenced to a geographic location.

An underwater vehicle may carry a large variety of sensors depending on the dimensions, the technology of the vehicle and the requirements of the mission; one of the role of the above sensors is to provide the vehicle controller with a sufficient precision during the navigation. To perform a navigation plan it is mandatory to know the position of the robot with respect to a reference system and self-localization of an underwater vehicle is particularly challenging due to the absence of Global Positioning System (GPS) reception owing to the well known attenuation of electromagnetic waves in conductive media.

Based on preceding statements therefore, localization and (eventually) mapping are the essence of a successful navigation in autonomous mobile platform technology and are fundamental tasks in order to achieve high levels of autonomy in robot navigation and robustness in vehicle positioning and values of the data. Robot localization and mapping is commonly related to cartography, combining science, technique and computation to build a trajectory map that reality can be used to correlate spatial information with the data collection. Therefore an autonomous robot should be able to construct (or use) a map or floor plan and to localize itself in it.

The introduction of Simultaneous Localization and Mapping (SLAM) technique has become the key enabling technology for mobile robot navigation. SLAM joint the problem of acquiring a spatial map of a mobile robot environment while simultaneously localizing the robot relatively at this model.

. The localization make sense not only for the localization of the robot itself but also to reach some objective, as example some sensor posed on the sea floor and gathering the data or some specific position in the sea to monitorize [5], [6]. Therefore we shall distinguish different scenarios for localization of the robot.

Based on these statements we shall give now a sharp look to the different used methods to localize single robot machine into the water, relatively and absolute to reach a proposal for our swarm.

State of art about localization

In the following chapter we discuss the problem of the localization for a single robot machine and a swarm. We distinguish the problems because they are heavily separate: localization of a single entity is a problem relevant to understand a metric of the space, possibly realized only by a sequence of reference points, and to place the entity in relations with the established metrics or with the reference points. Localization of a swarm underline the different techniques that can be used together with the different information that can be gained. Moreover we review some of the consolidated methodologies to localize a single underwater robot; they, of course, can be used also in the swarm case and we try to see how.

Some consideration on the localization

In this paragraph we are free discussing about the different kind of localization; a survey of methods, with some preliminary example, is explained together with what we need in our case to do apply the method. We also introduce the concept of landmark and how their are used in classification.

The localization concept does not necessarily coincide with the definition of a reference frame metric and Cartesian; for many animals, for example, localization may be related to different types of metrics such as that linked to research sources for something that is critical for their life (or for the swarm that is a more important economy). Food for the animals is the equivalent of a source of pollution in the mission of our swarm for the environment monitoring.

In this case we talk about identification on a physical field with gradients of arbitrarily complex shape; our position is therefore referred to the smell, great or little, of our reference parameter (i.e. oil presence) relative. We can move toward the higher value of the field, the oil wake to reach the source. In this case the geometric or geographic location, is meaningless for the purpose of the mission, but when we have to communicate to an human supervisor once again is important to the concept of geographical location.

Of course to perform this kind of localization related to a parameter the swarm must to be able to get the right parameters value, i.e. if we locate by the smell we must have a nose.

Another method, used by humans and animals, of tracking system is represented the construction of a map of the environment fixing in the memory a set of recognized items that are connected to each other. This kind of items are very general and it is not necessarily geographically (although it is now by far the most important type); moreover the human mind often does not work geographically. Rather, the mind associates the recognition of a number of characteristic features (houses, streams, odors) of other distinguishing features (other homes, streams, smells, plants) that have a characteristic of "proximity" with those who preceded them. The "map" thus becomes a multidimensional set of associations that allow you to switch gradually from a certain place (starting location) to another place (intermediate location of arrival) via a route typically (but not necessarily) geographically. The numbers of dimensions of this approach is very relative because it depends on many variables some of which are difficult to measure. Moreover for a human this number interested only in relation to other needs (e.g. the time it takes to go from one place to another).

The geographical approach supported by the geometric metrics it is a powerful tool that humans have developed and which allowed him to perform a very big step forward compared to most other creatures, but is not essential to the success of a mission and it is not the only one.

In the case of a swarm, or of a non rigid single machine (we shall see better later this concept), exist also the localization relative to the other members of the swarm and a collection of techniques and paradigm can be used. Because the shape of the swarm is very important for the mission the relative localization has the same importance of the absolute; we can use the same conceptual categories defined by absolute location once again not necessary geometric. As example the kinesthetic sense of human body is working with a sensitivity to muscle extension that is detected by non-metric variables; the brain provide later to relate these variables to make positioning the body in the world around them and then to a geometric structure.

However, leaving the pure conceptual world, and going on to basically concept we can say that its location can ignore these issues and extending beyond the location of geometric type. Now we can discuss about some kind of localization in metric form.

The more easy to understand is the metric localization using a Cartesian frame system, and in this contest the simplest form of localization is the open loop estimation; it has the mean of estimate position based on expected results of motion commands. Therefore no contribution from the sensor is required and no feedback is calculated.

Without an external reference, like for example an acoustic beacons at known positions, the vehicle has to rely on proprioceptive information obtained through a compass, a Doppler Velocity Logger (DVL) or an Inertial Navigation System (INS). [7]. To this, totally internal to the robot family belong one of commonest method, the dead reckoning.

The information that the robot gather can be divided into two kinds; idiothetic and allothetic sources. That has the mean of internal and external sensor source data; if a robot is counting the number of wheel turns this is internal source.

The allothetic source corresponds to the sensors of the robot, like a camera, a microphone, laser or sonar. A typical problem of this last method is "perceptual aliasing"; this means that two different places can be perceived as the same. For example, in a building, it may be impossible for to determine your location (sometime also for human solely with the visual information, because all the corridors may look the same.

The most common dead reckoning sensor is the INS. An INS measures the linear acceleration and the angular velocity of the vehicle using three accelerometers and three gyroscopes. Typical underwater external sensors used to correct accumulated errors from the integration of the INS measurements, are Doppler Velocity Log Sensors (DVL), Ultra Short Baseline (USBL) and Differential Global Position Systems (DGPS/GPS); this last only in the case the vehicle is operating at shallow waters and can come out of the water to fix (and eventually communicate) the position. .

Independent of the quality of the sensors used, the error in the position estimate based on dead-reckoning information grows without upper limit. Typical navigation errors some per cent of distance traveled for vehicles traveling within a hundred meters of sea. Lower errors can be obtained with large and expensive INS systems, but for vehicles relying only on a compass and a speed estimate can be higher than 10%, after one hundred meter. The error can be reset if the AUV comes to the surface by GPS, but sometimes this is impossible (under ice) or undesirable (security operation) [8]. The use of beacons to form a Long Baseline (LBL) array limits the operation area to a few square kilometers and requires a substantial deployment effort, to pose the beacons, before operations, especially in deep water. This reduce the advantages of AUV and required an expensive ship to support the operation; also for terrestrial robot odometry and dead reckoning systems suffer of multiple errors source, like wheel slip, gear backlash, noise from encoders.

Now we discuss bout landmark.

If we use external references the localization problem, like humans, we have to deal with their definitions and position on a map (metric or not). The definition of the problem together with an attempt of classification can be synthesized by the following statements [9] of aim:

1. To give some representation of the environment and determine robot position, through sensing, with respect to the specified representation of both.
2. Define, with respect to some frame or feature set, that is external to robot like (GPS), local coordinate frame (e.g. Ceiling or floor tiles) and environment features (e.g. nearby walls, corners, markings)

This can be done by the use of external "landmarks"; Any kind of landmark is subject to the following simple classification based on its attributes:

1. Is landmark passive or active? Must sensor emit energy to sense landmark?
2. Is landmark natural or artificial?
3. Which sensor can detect it? Vision, sonar, radio, tactile, chemical, ...
4. What are landmark's geometric properties? Plane, line, segment, point, diffuse source, ...
5. What is discriminability of landmark?

And as example we recall the following types (type and classification in parenthesis):

1. Wall corner (natural passive)
2. Texture patch (natural passive)
3. River bend (natural passive)
4. Earth's surface (natural passive)

5. Sun, North star (natural active)
6. Magnetic dipole (natural active)
7. Pressure gradient (natural active)
8. Mineral vent presence (natural active)

9. Surveyor's mark (artificial passive)
10. Retro reflector (artificial passive)
11. Lighthouse (day) (artificial passive)
12. Buoy, channel marker (artificial passive)

13. Chemical marker (artificial active)
14. Radio beacon (artificial active)
15. Lighthouse (night) (artificial active)
16. Loran (artificial active)
17. GPS (artificial active)

Moreover they can be detected by the following family of measurement:

1. Range to surface patch, corner (Sonar return)
2. Bearing (absolute, relative, differential) (Compass; vision (calibrated camera))
3. Range to point RSS, Time Of Flight from RF/acoustic beacon, cricket (beacons based on TDoA, Time Difference of Arrival, of acoustic & RF pulse)
4. Range and (-relatively to the body) bearing to object, Radar return, Laser range scanner return, Vision (stereo camera rig)
5. Distance to sea surface, floor (Pressure (depth), bathymetry (depth, altitude))

One of the task required to the robot is the discriminability to use the landmarks; this is depending on the resolution of the sensor linked to the quality we are measuring. The following questions must be satisfied.

1. Landmark Detection; Is landmark distinguishable from background?
2. Landmark Measurement and data Fusion; sensor gives a noisy, quantized measurement of landmark geometry (bearing and/or range): How accurately can a measurement localize a landmark? How can multiple corrupted measurements be combined into one accurate localization estimate of a landmark?
3. Landmark Identification; To which element of representation (i.e., map) does the detected and measured landmark correspond? To which previously-observed landmark (if any) does the currently observed landmark correspond? This is also known as the "data association" or "feature correspondence" or "matching" problem

Moreover the identification of a landmark often suffer of ambiguities problems, owing to the multiple solution of the associate equations.

A set of feature location position estimates can basically be thought of as a map. The challenge is to combine INS/dead-reckoning and other information with sensor observations of features to build a map, locally or globally referenced.

A more modern idea consist in to match measurements of one or more geophysical properties, such as bathymetry, gravity, or magnetic field, to an a priori environment map. If there is sufficient spatial variation in the

parameters being measured, there is potential to reduce navigation uncertainty without avoiding the use of acoustic beacons. Also the turtles migration is monitored by magnetometers, measuring the earth's magnetic field variations. However often these techniques requires a priori map of the environment that is not available. The marine turtles migrations are monitored by three axis magnetometer, but the resolution is 35 nautic miles. [10] [11]

In the next paragraphs we explain, for each method, the general principles, the methodologies, the advantages and the mismanages, the application field and the feasibility in our case.

Swarm robotic

The interest in multi-robot systems has origin from the attempt to develop complex robotic systems which could display features like versatility, robustness or capacity to perform complex tasks in unknown environments better than single robot machine. Multi-Robotic search it has been inspire by biological behavior, like bee, since long time and the idea comes from the observation of social activities; these are based on concepts like labor division, cooperation and communication. The job organization can be more efficient in such a way with respect of single machine operation. One of the principal difficult relative to a single machine approach is that it is difficult project a robot able to perform different and various tasks in varying environmental conditions; another problem is that the single-robot approach suffers that failures of the robotic unit may prevent the success of the whole task. On the contrary, a multi-robot approach can benefit from the parallelism of operation to be more efficient, from the versatility of its multiple units and from the inherent redundancy given by the usage of multiple agents. We shall give now some literature definitions about multirobot system to achieve that of our interest.

Definition of multi-robot systems has different meaning, therefore a classification is quite difficult, but we can consider the following.

As an attempt the multi-robot systems can be divided in Collective Robotics where the knowledge is shared, the Second-Order Robotics based on single unit robot (first order) that can physically connect one to the other, forming a bigger structure (autopoietic unit). Moreover there are the Self-Reconfigurable Robots made by groups of robotic modules that have little or no independent mobility and very few sensors, but are capable of connecting among themselves in various ways to form complex physical structure; they can autonomously change their physical connections and configurations under computer or human command to meet the demands of the environment and of the assigned task.

The Self-Assembling Robots can be considered an improvement of the last category to overcome the lack of full autonomy at the level of the single robotic modules; in fact this implies that the modules have to be connected to other modules and are able to move, therefore every unit is autonomous. Typically, modules are initially assembled by the experimenter, while subsequent connections and disconnections are possible only if modules assume specific positions in a well-defined lattice.

Finally the Swarm Robotics, that is that of our interest; we have just stressed as Multi-robot systems often draw inspiration from biology, looking at the social characteristics of insects and animals. [12, 13]. Insect life is very complex; as matter of fact, despite noise in the environment, errors in processing information, in performing tasks by single unit, and the lack of global communication system, social insects can coordinate their actions to perform tasks that are far beyond the capabilities of a single individual.

To explain the mechanism leading to the efficiency and robustness observed in social insects when performing global tasks like ant it has been posed the hypothesis that "the swarm intelligence comes from the swarm behavior".

It is difficult to say what has swarm behavior and what no, therefore we mentioned four criteria [14] for a system to be considered as swarm.

As first the system should be composed by quite homogeneous object and the control system has to deal with the whole rather than the single machines.

Second scalability and high redundancy is necessary.

Third the system has to be composed by robots with and limited sensing and communication abilities. The above criteria highlight the main characteristics of a swarm robotic system and is linked to the last.

Fourth, but this is not a characteristic of the machine, the assigned task cannot be solved, in a reasonable way, by a single robot.

Moreover, according with the third statement, the recent tendency in robotics are pushing towards a miniaturization of the machines and this has the mean of a lower complexity of the controller at the individual level; this should be counterbalanced by a high number of locally interacting individuals in order to be able to coordinate to success the task and, sometimes, observe the emergence of a complex behavior.

No words are necessary on the well known concepts of flexibility and robustness. As known a flexible system is able to adapt with change of the boundary conditions; robustness is directly linked to decentralization of the control system, able to continue the task also in case of failure of some single unit, owing to the principles of homogeneity and redundancy of the swarm. Careful must be posed when we talk about reliability of a swarm. On this concept the authors have just write [15] about the possibility to extend the concept of dependability (That is simplifying an extension of the reliability concept) for a robot society composed by heterogeneous systems.

Therefore as principal characteristic of a swarm the controller must be distributed, flexible, robust and, probably, show the emerging of a complex behavior as in Nature. This because a centralize control is not only contrary to the philosophy of a swarm, where all the individual machine are interchangeable, but also unfeasible. In fact a single supervisor that defines the action performed by each robot are unpractical if the dimension of the swarm is large, also for the communication system, and failure of the central control mean the death of the whole swarm. On the contrary distribution of the decision by decentralization make each robot responsible for its action, like insects, leading to a reduction in the complexity of the control system. Not all the elements of the swarm need to have the whole knowledge but only what they locally need; the clever behavior could be an emergent quality. Typical defect of this kind of control are that stagnation situation of the control system are possible; stagnation make the system in a decision loop unable to escape, because many decision taken by individuals can be canceled each other. Additional rule, able to recognize such situation, must be added to the control system of the single machine but could be not enough. Moreover the assignment of the task to the swarm thought as one unit must be formalized in a different way. In fact the man machine interface is dealing not with a single machine but with the whole swarm, otherwise our efforts are meaningless. Therefore the control system have a layer more to translate the dealing between the man and the swarm to all the machine.

So far a swarm should be composed by robots with local and limited sensing and communication abilities, owing to the simplicity of the machine and difficult in the communication underwater channel. Moreover in some cases explicit communication does not result in any advantage, as when the information is already available within the environment; for example if a robot leave a trace of its passage. This imply to be particularly clever to get information from little and is largely used by insect, of course as form of indirect communication. Therefore we can leave a trace of our work to make decision to another robot. This concept is known as "Stigmergic communication" and is useful to reduce the complexity of the control and communication system and scale well with increasing the number of the robot. This can be useful especially in underwater environment where the communication band pass is limited and you have to interpret on yourself every perception you get from outside.

Another feature that we desire in a swarm robotic system is the emergence of the global behavior from the local interactions among the robots and between them and environment to realize a task [16-19]. The global behavior of the swarm is not explicitly coded within the rules that govern each individual robot. It comes as results of the play between the individuals. Not every swarm robotics system presents emergent properties and is not strictly necessary. Anyway the importance of emergence behavior cannot not be neglected; in fact in such way a system that has to deal with high complexity task can be obtained by simple rules. Must be take in account that the relationship between simple local rules and complex global properties is not direct, so the definition of the individual behavior, in order to obtain a particular global behavior, is particularly difficult . This is the central part of the problem, how the single machine can be emerged with a clever behavior with the minimum amount of information and hardware.

A possible answer on how to do can come from the concept of Self-organisation creatures. Self-organisation can be defined as a process where the higher and global level comes from many interactions between the lower levels of the system component. Moreover the rules specifying interactions among the system's components are executed using only local information. In other words, a system self-organises driven by its own components, which interact relying only on local information, without any reference to the system as a whole.

Some important numerical consideration

Just to fix some ideas it must be take in account that we are dealing with a system think as a swarm of about 20 object; each object has a torpedo like shape length about one meter and 0.2 meter diameter. The distance between robots are between 1 meter and 50 meter. Therefore the maximum distance possible between two robots is about 1000 meters, as very particular alignment case; the average value of the distances is about ten meters. maximum speed should be about 3 knots. This numbers come out from the "Venus", the AUV realized by ENEA that should be the single machine component of the swarm.

Localization methods

The problem of localization for a single underwater robot

In the following we show some localization methods for single robot and, later, for swarm robot.

For each method we explain the general principles, the methodologies, the advantages and the disadvantages, the application field and the feasibility in our case. The literature is data. We try to give a sharp look of the following methods:

1. Open loop
2. Dead reckoning
3. Acoustic methods
4. Geophysical methods
5. Feature recognition
6. Laser methods DVL
7. Mapping

Open loop: technical description

The open loop navigation is the most simple form of navigation. The localization is derived by estimating the robot motion from the theoretical model of the machine and of the environment represented inside the machine:

Vantages and disadvantages

It is very simple but free from feedback signal and therefore from forces eventually present and not considered into the model. This makes it very imprecise because there is no feedback between the output of the system (as example the vehicle's speed) and the actual conditions encountered; that is to say, the system does not know and cannot compensate for unexpected forces, like ocean current (that are sometimes comparable to the cruise speed of the robot).

Application field

Very short path in controlled environment and poor computational power.

Feasibility for Harness

No feasibility for harness owing the lack of the precision on time

Dead reckoning: technical description

Dead reckoning (DR) is the process of estimating one's current position based upon a previously determined position, or fix, and advancing [20][19][19][15] the position based upon known or estimated speeds over elapsed time, and course [1]. It is the most obvious and longest established navigation technique, to integrate the vehicle velocity in real time to obtain new position estimates. Measurement of the velocity components of the vehicle is usually accomplished with a compass and a water speed sensor. While traditional methods of dead reckoning are no longer considered primary means [21], [22] of navigation, modern inertial navigation systems, which also depend upon dead reckoning, are very widely used.

Dead reckoning begins with a known position which is then advanced, by means of recorded heading, speed, and time. Speed can be determined by many methods. Before modern instrumentation, it was determined aboard ship using a chip log. A naval vessel uses a device called a pit sword (rodmeter), which uses two sensors on

a metal rod to measure the electromagnetic variance caused by the ship moving through water. This change is then converted to give a measure of the ship speed. Distance is determined by multiplying the speed and the time. This initial position can then be adjusted resulting in an estimated position by taking into account the current (known as set and drift in marine navigation).

Dead reckoning positions are calculated at predetermined time intervals that generally are maintained fixes.

Inertial measurements unit (IMU) generally consists of three accelerometers and three orthogonal gyroscopes to provide three dimensions measurements of accelerations and rotation rates about the three axes. The IMU is generally designed with an advanced Kalman Filter to correct and take in account the biases associated with the accelerometers and gyros.

The best performance of the most precise INS available, that is largely used in nuclear submarines, is expected to be with an error of about 0.01 km/h.

Before the development of the marine chronometer, dead reckoning was the primary method of determining longitude available to mariners such as Christopher Columbus and John Cabot on their trans-Atlantic voyages. Tools such as the Traverse board (a wooden table with holes used as memory aid) were developed to enable even illiterate crew members collect and remember the data needed for dead reckoning.

Vantages and disadvantages

A disadvantage of dead reckoning is that since new positions are calculated solely from previous positions, the errors of the process are cumulative, so the error in the position fix grows with time. Even using theoretical determination of biases, in practice the mathematical integration leads to unbounded growth in position errors with time due to the noise associated to the measurements. So an external measurements is necessary in order to correct the measurements of the IMU.

Moreover the presence of an ocean current will add a velocity component to the vehicle which is not detected by the speed sensor. In the vicinity of the shore, ocean currents can exceed 2 knots. Consequently, dead reckoning for power-limited AUVs, operating at small speeds (3-6 knots), involving water-relative speed measurements can generate extremely poor position estimates. In inertial navigation systems, the accelerations of the vehicle are integrated twice in time to derive the updated position. Position drift rates for high quality commercial grade INS units are on the order of several kilometers per hour. Cost and power consumption have historically made INS systems unattractive for small AUVs, however, this may change as systems is getting smaller and cheaper.

Application field

Very short path in controlled environment and poor computational power. The robot REMUS [23] is a lucky example.

Feasibility for Harness

No feasibility for harness owing the lack of the precision. Perhaps in free navigation.

Acoustic system: technical description

Electromagnetic energy cannot propagate appreciable distances in the sea with the exception of very low frequencies, that has low band pass. Acoustic energy propagates quite well in the sea, and hence acoustic transponders can be used as beacons to guide the motion of an AUV under the water without emersion. [24]

The most commonly used way to obtain position information underwater is through the use of underwater acoustic networks (UAV). These net are at known positions and the AUV obtains the range and/or bearing to several of these and then calculates its position through trilateration (intersection of spherical surfaces) or triangulation (locations of points by angle measurements).

Underwater acoustic networks can be composed by acoustically connected anchored nodes (beacons) or other autonomous underwater vehicles (AUVs); it is useful to have a surface link that serves as a gateway to transmit data to an onshore station and fix position by GPS.

In a localization system, several capabilities are necessary. First, the measurement techniques used to gain the information such as distance and other information. Second, the network protocol which concerns the communication between nodes. Finally, techniques of deployment of the information to the AUVs. [1, 8, 19]

The most popular measurement type is ranging. There are two methods used to obtain range measurements; timing and signal strength. Ranging is usually provided by estimating the distance to a neighbor by measuring the received signal strength (RSS) from that neighbor, by time of arrival (ToA) or by time difference of arrival (TDoA). Of course there are many possibilities to combine active or passive, ToA or RSS or TDoA methodologies. Later we shall choose the most reasonable for our aim.

In the ToA approach, the distance between a remote node and the beacon is measured by finding the one way propagation time between that node and the beacon. Geometrically, this provides a circle, centered on the beacon, on which the remote node must lie. By using at least three beacons to resolve ambiguities, the remote node's position is given by the intersection of the circles. In the TDoA approach, the time difference of transmission and reception at the beacons is used. By using this approach, the time synchronization can be eliminated. Time of arrival range measurement can be implemented using inquiry-response protocol. Another measurement method for node localization is Angle of Arrival (AoA) where the node estimates the direction from which a neighbor is sending a signal. It can be implemented either using an antenna array, or a combination of radio and ultrasound receivers. In this method, triangulation instead of trilateration, is used for the localization.

Two types of system have been primarily employed long baseline (LBL) and ultra-short baseline (USBL). Differences are principally in the used frequency. Both systems employ external transducers or transducer array, Many combinations of received/transmitted signals are possible between the AUV and the transponders. Of course it is better to avoid the transmission of signal from the AUV owing to the lack of power on board.

In LBL navigation systems, an array of transponders is deployed and surveyed into position. The vehicle sends out an acoustic signal which is then returned by each beacon as it is received. Position is determined by measuring the travel time between the vehicle and each beacon, measuring or assuming the local sound speed, and knowing the geometry of the beacon array. With this information the relative distances between the vehicle and each array node can be calculated. The two primary techniques are (1) to compute positioned by locating the intersection point of spheres of appropriate radii from the beacons in the array, and (2) to integrate the raw time of flight (TOF) measurements into an appropriate Kalman filter. The beacon positions are stored in the vehicle before starting so, the AUV can trilaterate or triangulate its position in the field limited by the beacons.

A typical LBL-configuration consider two or more beacons around the perimeter of the area in which the AUV will operate. These beacons are anchored and float on the surface or, particularly in deeper water, a few meters above the sea floor. Each unit listens to acoustic query pings on a common receive channel. After receiving a query ping from an AUV, each unit waits for a unique-specific Turn-Around Time (TAT) and then sends out a reply ping on its individual transmit channel. The AUV then receives the reply pings. The transmit channel as well as the TAT are different for each unit. A unique TAT ensures that two beacons will not interfere by transmitting at the same time and by using different transmit frequencies the beacons provide a way for the AUV to identify from which unit a reply ping was sent. The time difference between sending out the query ping and receiving a reply can then be used to determine the One-Way Travel Time (OWTT) that has the mean of a code.

As order of magnitude most LBL systems work at a frequency of approximately 10 kHz and provide position accuracy to within a few meters with a maximum range on the order of a few kilometers. Alternative systems operating at 300 KHz have been created that can provide positioning repeatability down to 1 centimeter resolution in a triangular operating area that is 100 meters to a side.

In USBL navigation, the vehicle has a multi-element receiver array that enables it to measure the angle as well as the range to an acoustic beacon. This system is a variant of a popular system for tracking an underwater vehicle from a surface ship. By measuring the arrival time (phase difference) of a single sonar ping between two or more hydrophones, the bearing from the vehicle to the beacon can be determined. If the beacon responds to a vehicle interrogation, then the time delay (and hence distance, as with an LBL array) can be calculated. The phase difference between the signals coming from the different receiving elements allows the AUV to compute a bearing to the beacon. Combined with the beacon position stored in the AUV and the distance obtained from the

One-Way Travel Time (OWTT), the vehicle can compute its absolute position using only a reply from a single beacon. This type of system is especially effective for homing and docking operations.

Standard LBL systems such as the one described above are not well suited for large groups of AUVs because only one vehicle at a time can query the beacon network and get a position update. Moreover shadow effects can mask the signal in crowded situations. Thus the position update interval increases with the number of vehicles. Newer LBL systems, like the one recently developed by ACSA, have synchronized clocks in the beacons and the AUV transceiver units. The beacons broadcast a ping containing a unique identifier at fixed time intervals. When the AUV receives this ping, the beacon's known broadcast schedule and the synchronized clock's time ensure that the vehicle knows when a ping was sent and can directly compute the One-Way Travel Time (OWTT). The synchronized clocks thereby eliminate the need for query pings and allow all vehicles within range of the beacons to get a range.

Moreover the beacons can be free to fluctuate if they are able to sent transmit their GPS position along with the unique identifier. As with the system described previously, the vehicles do not need to query the beacons. With the position of the beacons embedded in the ping the beacons can float freely and it is not necessary to store their coordinates in the AUV before deployment; in some environment like arbors or Arctic there are some more difficult.

In such difficult acoustic environments, such as in shallow water or in the Arctic, it becomes difficult to distinguish between the direct arrival and multipath interference, and rejection of outliers becomes a key issue. In a computation scheme, one can rule out spurious signals, whereas in a Kalman filter-based system, one can gate the raw TOF values. A variant of this system is called hyperbolic navigation, in which the vehicle does not actively ping but instead listens to an array of beacons whose geometry is known. Each beacon pings in a specific sequence relative to the others at its specialized frequency. By knowing which beacon pings when and the geometry of the array, the vehicle can reconstruct where it must be in space in order to hear the ping sequence as recorded. This system has the advantage of saving the vehicle the power expenditure of active pinging, and is especially useful for multiple AUV operations. Multiple AUV operations require careful sequencing of the pings between vehicles.

Advantages and disadvantages

An underwater network has several limitations compared to radio networks, most importantly the propagation delays which are very long with limited bandwidth. Another restriction that needs to be considered in UANs is the incapability of modems to transmit and receive signals at the same time. To prevent this effect which causes loss of data, scheduled transmission is required. A localization system can be implemented that is based on RSS, ToA, TDoA or AoA, or a combination of these. However, due to a non-uniform signal propagation environment, especially in underwater acoustic networks, RSS methods are not very reliable and accurate. Antenna array is needed in the AoA method; it is impractical to employ in large networks because it is very costly. Furthermore, in this method, nodes may require additional hardware such as a digital compass to provide more information about the node's orientation. Even though ToA or TDoA may require additional hardware at the sensor nodes to receive a signal these methods have better accuracy and are most Modern beacon-based systems significantly decrease the pre-deployment effort when compared to early beacon based systems such as the standard LBL. However all beacon-based systems confine the operating area of the vehicles to a polygon of beacons or, as in the case of USBL, to the coverage radius of a single beacon. Thus beacon-based navigation is only feasible for operating areas of $O(10 \text{ km}^2)$ in size.

Errors in both LBL and USBL arrays come from many sources. The key sources of error can be broken down into two primary categories: errors in the assumed array geometry and errors in the assumed sound speed measure. Positioning error comes from inadequately or improperly survey in the relative and/or geodetic positions of the array beacons. In the event that only local navigation is desired, then only relative beacon positions are relevant. If the navigation is to be geodetic referenced, then the beacons must be located globally as well. Sophisticated software packages are available for accomplishing this. Self-calibrating beacons simplify the task by reducing the surveying task to only one beacon with the others determining their own positions relative to the first. However, this raises the possibility of relative position errors due to errors in the assumed local sound speed. A significant difficulty in acoustic navigation can be caused by an error in the assumed sound speed measure. An inaccurate sound speed will appear as a distance bias in the calculations. Rejection or multipath

errors will result in incorrect time-of-flight values and hence erroneous position. Typically, LBL works well in deep water and with array separations of a few kilometers. Over longer distances in shallower water, more complex propagation effects come into play and increase the frequency errors. If the topography is sufficiently severe, beacons may be occluded by rocks or other seabed formations. Some outliers are due to reflections from temperature and salinity. Even if the sound speed is known at the start of an AUV mission, the acoustic propagation environment can change during the mission. To address this issue, Deenbaugh has developed a technique for long-range LBL navigation in complex and dynamic acoustic environments, such as the Arctic. This approach uses the extra information provided by the multipath arrivals to invert for sound speed probe variations in space and time, and in the process provide a more accurate position estimate. This technique was motivated by the particularly challenging conditions of the Arctic, which once again is characterized by an upwardly refracting sound speed probe.

Moreover LBL acoustic navigation requires that an array of beacons has been deployed and calibrated, which is often not possible and quite always expensive.

Application field

Typically limited area, obstacle free.

Feasibility for Harness

In harbors and some other area where the job must be continuous it could be considered. In area where the cost of fixed buoy field can be sustainable.

Geophysical localization

Up to now we were dealing with systems that has no map of the environment; these systems are much more light and simple but we obtain a localization relative to the starting point in an empty space. In some cases, like the following localization systems, a map, or some landmarks are necessary.

For some applications of AUVs, the use of acoustic beacons is undesirable or impractical. If an accurate a priori map of the environment is available, one approach to globally-referenced position estimation is to use measurements of geophysical parameters, such as bathymetry, magnetic field, or gravitational anomaly. These approaches are based on matching sensor data with an a priori environment map, under the assumption that there is sufficient spatial variation in the parameters being measured to permit accurate localization. [25] [26]. Evidence suggests that animals like birds during migrations utilize the Earth's magnetic field for navigation and for orientation detection. Some animals, such as spiny lobsters and turtles, are not only able to detect the direction of the Earth's magnetic field they can even sense their true position relative to their destination. This means these particular animals are able to derive positional information from local cues that arise from the local anomalies of the Earth's magnetic field.

The Earth acts like a great spherical magnet that can be approximated as a dipole field. The axis of the dipole is offset from the axis of the Earth's rotation by 11° . This means that the north and south geographic poles and the north and south magnetic poles are not located in the same place. At any point, the Earth's magnetic field is characterized by a direction and intensity which can be measured.

The magnetic flux density of the earth varies according to latitude, the presence of man-made and natural anomalies, and even one's depth in the ocean, increasing from 6 to 30 nanoTeslas per 1 km of depth (0,01 % of the surface), depending on location. Additionally, there are small but predictable variations in the earth's magnetic flux from day to night, and large arbitrary changes during magnetic storms (11 year cycle of the sun); Unfortunately also if available magnetic maps can be rendered useless for the duration of such storms. Useful magnetic maps, generated by satellites or surface ships, can be employed by underwater vehicles by accounting for the daily field variations and by calculating the effective magnetic field at depth using a Laplace field equation, setting the boundary conditions at the ocean surface. Actually cheap magnetometer, used to localize turtles migrations, are able to give 35 nautical miles of sensitivity. This because there are not good map of magnetic field and the external interference are relevant.

Better conditions we can find inside modern building where the iron inside the structure lead to a modification of the Earth's magnetic field able to generate a useful map [27]. In fact static and extremely low-frequency (ELF) magnetic fields in modern buildings arise from the combination of both natural and man-made sources, such as electric power systems, electric and electronic appliances, and industrial devices. In general, any distinctive-environment feature that is specific to a particular area can be used to recognize its own characteristics as natural landmarks. As example the disturbances of the geomagnetic measurements sometimes due to the presence of ferro-magnetic structures (frames of glass doors), or due to the electromagnetic radiation of a wireless LAN transceiver.

Research into the nature of the earth's gravitational field has demonstrated that it is far from uniform and indeed possesses a varied topography. These variations are due to a variety of factors, especially the effects of local topography and density inhomogeneities. Variations in the earth's gravitational field on the ocean's surface relative to a regular ellipsoidal model have been measured to be on the order of 30-50 mgal (1 gal = 1 galileo= 1cm/sec²). Gravity maps were originally gathered on behalf of the US Navy for the purposes of inertial navigation system calibration because, for an INS, the effects of a change in the local gravitational field are indistinguishable from accelerations of the vehicle itself.

It has been proposed the use of a gravity gradiometer as an aid to inertial navigation systems.

Gravity gradiometry is used by oil, gas and mining companies to measure the density of the subsurface, effectively the rate of change of rock properties. From this information it is possible to build a picture of subsurface anomalies which can then be used to more accurately target oil, gas and mineral deposits. Gravity gradiometry surveys are performed in a similar manner as geomagnetic surveys. The quantity being measured is the gravity gradient tensor. Measuring systems are often mounted in aircraft to allow a longer time of acquisition and reduce the noise/signal ratio.

One type of gradiometer consists of two horizontally positioned gravimeters that are rigidly connected. The two gravimeters experience the same accelerations, earth tides, and latitude effects, etc. The gradient is the difference in the two gravimeter readings divided by the baseline distance between them. More advanced gradiometers consist of four non-coplanar gravimeters, these systems measure the full gravity gradient tensor.

Advantages and disadvantages

The error due to magnetic interferences is the most distracting one. The source of such interferences can be natural or artificial causes. The erroneous compass data, generated by the mentioned interferences, are positively considered as a natural signature by which a certain terrain can be depicted (self localization). The magnetic interference sources can be classified as the following;

Natural sources such as; magnetized rocks, cosmic fields, electric currents following in the earth's crust, ocean current and wind effects.

Artificial sources such as; ferro-magnetic structures, internal electrical components, mechanical vibration. Moreover the order of magnitude of magnetic fields variation could be not enough to be used as landmark.

In case of microgravimetry the drawbacks to such a system are the size, expense, and complexity of a gradiometer. In addition, the gradiometer must be mounted on an inertially stabilized and vibrationally isolated platform, making its use difficult on small, low-cost scientific AUVs.

Application field

Where some map of the geophysical properties are available with sufficient sensitivity. As example to monitor the turtles travel a mini magnetometer is enough.

Feasibility for Harness

In open water could be cheaper and useful, where the map are available, integrate also the magnetic data with the other. No possibility for gravimetric methods owing to the large dimensions of the instruments.

Mapping and SLAM

All forms of map-based navigation are motivated by the desire to operate at an arbitrary location without the additional expense or problems associated with the installation of artificial beacons. In principle, the process appears straightforward: gather information about the surrounding terrain and match that information to an on-board map or database of terrain information. When the vehicle has a match to the database, then it knows its location on the map. This is analogous to the method which humans use to navigate; we find our way to our destination by locating and identifying landmarks which are familiar to us. In practice this form of navigation is not so simple. The vehicle is attempting to navigate by matching a set of sensed data with an a priori map or dataset of stored data. Two key problems are the cost and difficulty of generating the a priori maps and the computational complexity of searching for a peak in the n -dimensional correlation surface, where n is the number of dimensions in the map or sensor data set. Typically, map making is governed by two problems, the data that being collected and the desired resolution of that data. It must be stressed once again the a map is not necessarily a metric one. In fact [28] have shown that evolutionarily shaped blind action may suffice to keep some animals alive. For some insects for example, the environment is not interpreted as a map, and they survive only with a triggered response. But a slightly more elaborated navigation strategy dramatically enhances the capabilities of the robot. Tolman (1948) has shown as it enable planning capacities, and use of current perceptions, memorized events, and expected consequences.

We have just stressed as the maps used in navigation include two major types: geometric maps and topological maps. Geometric maps represent the world in a global coordinate system, while topological maps represent the world as a network of nodes and arcs; there is a big difference between them and the choice is depending on the application case.

In any case determining the map resolution has a direct effect on the size and level of detail of the search needed to locate the vehicle in space. Since the vehicle could be in any of a large number of possible orientations relative to the original dataset, positioning on a map has the meaning to search over all possible locations and orientations. This is a potentially large search space, necessitating some simplifications assumptions in order to make the search more tractable. Typical simplifications are done restricting the types of map data stored (what sensor values, how many different sensors, etc..), lowering map resolution, restricting vehicle orientations (to reduce the correlation matching problem). In practice, often, an up-to-date, high-quality map may be unavailable in the operating area of interest. This motivates research into the problem of concurrent mapping and localization. The goal of concurrent mapping and localization is for the AUV to build a map of its environment and to use that map to navigate in real time.

Simultaneous localization and mapping (SLAM) is a technique [8] used by robots and autonomous vehicles to build up a map within an unknown environment (without a priori knowledge) or to update a map within a known environment (with a priori knowledge from a given map) while at the same time keeping track of their current location. SLAM in the mobile robotics community generally refers to the process of creating geometrically consistent maps of the environment.

The problem of Robotic mapping is related to cartography, but in a larger meaning. The goal is for an autonomous robot to be able to construct (and use) a map and to localize itself in it.

As known maps are used to determine a location within an environment and to depict an environment for planning and navigation. They support the assessment of actual location by recording information obtained from a form of perception and comparing it to a current set of perceptions. It must be taken into account however, maps generally represent the state at the time that the map is drawn; this is not necessarily consistent with the state of the environment at the time the map is used because some features can be changed.

Complexity of the technical processes of locating and mapping under conditions of errors and of noise do not allow for a coherent solution of both tasks. SLAM is a concept to bind these processes in a loop and therefore supports the continuity of both aspects in separated processes. Iterative feedback from one process to the other one enhances the results of both consecutive steps.

Mapping is the problem of integrating the information gathered by a set of sensors into a consistent model and depicting that information as a given representation. It can be described by the first characteristic question: What does the world look like? Central aspects in mapping are the representation of the environment and the interpretation of sensor data. This can be done in many ways, not necessarily metrics.

In contrast to this, localization is the problem of estimating the place (and pose) of the robot relative to a map. In other words, the robot has to answer the second characteristic question, Where am I? Typically, solutions comprise tracking, where the initial place of the robot is known, and global localization, in which no or just some a prior knowledge about the starting position is given.

SLAM is therefore defined as the problem of building a model leading to a new map or repetitively improving an existing map while at the same time localizing the robot within that map. In practice, the answers to the two characteristic questions cannot be delivered independently of each other.

In classical localization approach, before a robot can contribute to answer the question of what the environment looks like given a set of observations, it needs to know at least the following.

1. The robot's own kinematics,
2. Which qualities the autonomous acquisition of information has,
3. From which sources additional supporting observations have been made.

The problem can be decomposed in more than one way but the fundamental are few processes (Levitt and Lawton 1990 ; Balakrishnan et al. 1999) and are the following:

1. Managing of available information
2. Map representation,
3. Map learning and localization

and eventually later path-planning and robot navigation.

Therefore you have to manage these kind of information From operational point of view the steps are:

1. Sensing
2. Mapping
3. Locating
4. Modeling

The available information must be represented in a way to be matched to the map representation. SLAM will always use several different types of sensors to acquire data with statistically independent errors. Statistical independence is the mandatory requirement to cope with metric bias and with noise in measures. SLAM is tailored to the available resources, hence not aimed at perfection, but at operational compliance.

It is generally considered that "solving" the SLAM problem has been one of the notable achievements of the robotics research in the past decades. The related problems of data association and computational complexity are amongst the problems yet to be fully resolved. [9] :

Many complementary techniques are used during the SLAM, as example the PCA (principal components analyses). During the SLAM you are generally working with uncertain data. Therefore many techniques use probabilistic representations of the map are used; to reduce uncertainty probabilistic pattern recognition in eigenspace of PCA is also used. As example if you are using a sonar the received acoustic signals fluctuate seriously in underwater environment and to reduce the complexity and noise effects, all received signals are projected onto the eigenspace of PCA. Each projected feature is assumed to have Gaussian probabilistic distributions. Therefore, the location information can be easily obtained by probabilistic pattern recognition of projected features in PCA space. Note that in this case the underwater localization scheme is not affected by reflected signals, that can be filtered in such mode.

If at the next iteration of map building the measured distance and direction traveled has a amount of inaccuracies, by limited inherent precision of sensors and additional ambient noise, then any features being added to the map will contain corresponding errors. Over time and motion, locating and mapping errors build cumulatively, distorting the map and therefore the robot's ability to determine its actual location and heading with sufficient accuracy. Therefore a reset of the errors, performed by known landmark, needs or compensation operation by different methods.

There are various techniques to compensate for errors, such as recognizing sure features that it has come across previously, and re-skewing recent parts of the map to make sure the two instances of that feature become one. Some of the statistical techniques used in SLAM include Kalman filters and particle filters.

To give a map it is necessary to provide a representation of it that allow to utilize. The internal representation of the map can be "metric" or "topological":

1. The metric framework is the most common for humans and considers a three dimensional space in which it places the objects. The objects are placed with precise coordinates. This representation is very useful, but is sensitive to noise and it is difficult to calculate precisely the distances. We have just stressed that sometime could be more useful a non metric representation (gradient field).
2. The topological framework only considers places and relations between them. The map is then a graph, in which the nodes corresponds to places and arcs correspond to the paths.

Topological maps are a method of environment representation which capture the connectivity (i.e., topology) of the environment rather than creating a geometrically accurate map.

Of course an hybrid representation between metric and topological is possible.

Here we give some feature of the map and classification, without go inside The following classifications are useful in map representation

1. Free Space Maps
 - Spatial graphs
 - Voronoi diagrams
 - Generalized Voronoi Diagrams (GVD)
2. Object Maps
3. Composite Maps
 - Point grids
 - Area grids
 - Quad trees

And later follow the operation of
Map learning
and eventually
Path planning
Robot navigation

These last (Composite maps) employ the notion of a grid, but permit the resolution of the grid to vary so that it can become finer where more accuracy is required and more coarse where the map is uniform.

Several mapping paradigms have been investigated to model the robot's workspace. The most widely used methods are the occupancy grid, the topological graph and there are maps integrating both. Each of these methods has its characteristics, advantages and disadvantages. As example the vector mapping paradigm is often used; this technique is usable for robots equipped with a laser scanner as example. The robot is scanning the volume by a laser and detect obstacle from reflection of the light. The vector mapping is originally based on the occupancy grid with a reduced map size. The main idea of the vector mapping is to determine empty space as a region of cells between the laser scanner (robot's position) and the detected obstacles. In other words, these empty cells will be represented by end points of the laser rays (vectors) and the position of the laser scanner. The measurements of the vector mapping are generally given in a polar coordinate system whose origin is the position of the scanner (robot), while the end of the vectors is the obstacle boundaries. This map reduces both computational burden and memory requirements.

An important additional problem is to determine whether the robot is in a part of environment already stored or never visited.

The results from sensing will feed the algorithms for locating. Sometimes the decision on the occupancy of a cell can be performed by probabilistic algorithm, to reduce false signal According to propositions of geometry, any sensing must include at least one lateration and $(n+1)$ determining equations for an n -dimensional problem. In

addition, there must be some additional a priori knowledge about orienting the results versus absolute or relative systems of coordinates with rotation and mirroring.

Contribution to mapping may work in 2D modeling and respective representation or in 3D modeling and 2D projective representation as well. As a part of the model, the kinematics of the robot is included, to improve estimates of sensing under conditions of inherent and ambient noise. The dynamic model balances the contributions from various sensors, various partial error models and finally comprises in a sharp virtual depiction as a map with the location and heading of the robot as some cloud of probability. Mapping is the final depicting of such model, the map is either such depiction or the abstract term for the model.

For the navigation (out of the scope of this report) the path planning is the successive step. Path planning is an important issue as it allows a robot to get from point A to point B. Path planning algorithms are measured by their computational complexity. The feasibility of real-time motion planning is dependent on the accuracy of the map on robot localization and on the number of obstacles. Topologically, the problem of path planning is related to the shortest path problem of finding a route between two nodes in a graph.

Closing to the purpose: some instruments and fusion data

This section gives an overview of the useful sensors commonly used in underwater vehicles. It outlines their particular characteristics and shows how several sensors are used jointly to determine the vehicle's position. It is important to note that the cooperative navigation approach does not replace any of these instruments, but makes an attempt to gain information more precise by combining different measurements coming from physical sensors and from other vehicles. [29], [30], [19].

At the present few technologies exist for reliable three dimensional navigation of underwater vehicles. Table 1 summarize the sensors most commonly used to measure a vehicle position with six degree of freedom. While depth, altitude, heading and attitude are instrumented with high bandwidth internal sensors, XY position sensing is usually achieved by acoustically interrogations of fixed seafloor (or floating) mounted transponder beacons. Inertial navigation systems offer excellent step down navigation capabilities, but are of limited utility in the low speed low acceleration regime typical for oceanographic robotic vehicles. The GPS provides superior three dimensional navigation capability for both surface and air vehicles; unfortunately the radio frequency signals are absorbed by seawater.

Therefore two problems with existing underwater navigation position sensing techniques severely limit the performance of fine maneuvering: precision and update rate. On board depth, heading and attitude sensors generally offer excellent precision and updates rates.

In table 1 and 2 we reassume the characteristics of the most used instruments. [31]

INSTRUMENT	VARIABLE	INTERNAL?	UPDATE RATE	PRECISION	RANGE	DRIFT
Acoustic Altimeter	Z - Altitude	yes	varies: 0.1-10Hz	0.01-1.0 m	varies	---
Pressure Sensor	Z - Depth	yes	medium: 1Hz	0.01-1.0 Meter	full-ocean	---
12 kHz LBL	XYZ - Position	NO	varies: 0.1-1.0 Hz	0.01-10 m	5-10 Km	---
Inclinometer	Roll and Pitch	yes	fast: 1-10Hz	0.1° - 1°	± / - 45°	---
Magnetic Compass	Heading	yes	medium: 1-2Hz	1 - 10°	360°	---
Gyro Compass	Heading	yes	fast: 1-10Hz	0.1°	360°	10°/hour

Table 1: Commonly Used Underwater Vehicle Navigation Sensors

INSTRUMENT	VARIABLE	INTERNAL?	UPDATE RATE	PRECISION	RANGE	DRIFT
Bottom-Lock Doppler (1200 KHz)	XYZ - Velocity	yes	fast:1-5Hz	±/-0.2% cm/sec	30m	---
Ring-Laser Gyro	Heading	yes	fast: 1-1600Hz	0.0018°	360°	0.44°/hour
300 kHz LBL	XYZ - Position	NO	1.0-5.0 Hz	±/-0.002 m typ	100 m	---

Table 2: New Sensors employed in JASON's new doppler-based navigation system.

Depth Sensor

All submersible vehicles are outfitted with a pressure sensor which allows them to determine their absolute depth with high accuracy and a high update rate. As a result all other underwater navigation systems are only used to resolve the 2D position, (i.e. longitude and latitude) and all underwater vehicle related localization problems are stated in 2D.

Magnetic compass

Like the pressure sensor, a compass is part of the basic navigation sensor suite of every underwater vehicle as it is an inexpensive and low-power device. It provides the 3D-vector of the local magnetic field. Before computing the heading from the magnetic field vector it is necessary to carefully calibrate the compass each time the vehicle's area of operation changes, as the difference between the orientation of the 3D magnetic field vector and the direction of true north (called "variation") depends on the geographic location. In addition to the spatially slow variation, there are highly localized "magnetic anomalies". The compass output is also affected by its position: they can easily be disturbed by electromagnetic sources (e.g. power lines, electromagnetic fields of robot internal components, fields of external instruments or large ferro-magnetic structures) present in the vehicle that can create magnetic fields which cannot be discerned from the Earth's magnetic field.

Global position System (GPS)

The GPS is able to provide absolute position information for outdoor land robots as well as Unmanned Aerial Vehicles (UAVs), but the strong absorption of electromagnetic waves by sea-water prohibits the use of the GPS by submerged AUVs. Nonetheless, almost all underwater vehicles today are equipped with a GPS receiver as it can be used to get a position fix before the start of the mission or during intermittent surfacing.

Flow meter

A flow meter consists of a tube, usually mounted in line with the main vehicle axis and is open to the surrounding water on both sites. It contains a propeller which is spun by the water running through the tube as the vehicle moves. A sensor attached to the propeller determines the rotational speed which can be converted into flow speed and thereby giving an indication of the vehicle's speed relative to the water body. Some other instruments use a warm wire and many other methods, but the aim is the same.

Attitude Heading Rate Sensor (AHRS)

An AHRS unit typically consists of a 3-axis linear acceleration sensor as well as a 3-axis gyroscope and a heading sensor (magnetic compass). Combining the measurements from these sensors, the AHRS can compute the 3 linear and 3 angular velocities and accelerations (rates) as well as the attitude and heading from the linear acceleration sensor readings and the compass.

Doppler Velocity Log (DVL)

A DVL is a device which typically has four transceiver units that emit acoustic pulses. When a DVL is used for navigation purposes it is usually mounted to a vehicle such that the transceivers are facing downward. If the DVL is close enough to the bottom, the transceiver will receive the reflected pulses ("bottom-lock") and as the

transceivers are mounted at an angle with respect to the sea floor plane, the received pulses will be subject to a Doppler-shift if the vehicle is moving. Combining the measured Doppler-shifts from all 4 sensors with the built-in roll, pitch and heading sensors the DVL can then compute the vehicle's 3D-speed vector in a world-referenced frame (Sea bottom).

The maximum operative distance between the DVL-unit and the sea floor depends on the operating frequency of the transceivers. Low-frequency (150 kHz) DVL can obtain bottom-lock for ranges up to 500 m, while a high-frequency DVL (1200 kHz) requires less than 30 m. moreover the ranges indicated above can only be obtained under ideal conditions. A soft sea floor or vegetation can absorb most of the energy of the incoming pulse and thereby significantly decrease the maximum range.

Another option is to mount the DVL in an upward looking configuration such that the acoustic pulses are reflected at the water/air interface ("surface-lock"). Then, the vehicle measures its speed relative to the water surface, but this strategy may introduce errors in the case of significant surface currents. If bottom-lock cannot be obtained with the downward-looking DVL the vehicle tries to determine its speed using the upward looking unit.

Recent developments greatly increased the accuracy of DVL-systems and errors as low as 0.2 % (1200 kHz) or 1 % (150 kHz) can be obtained.

Inertial Navigation System (INS)

The sensors of an INS are the same as those of the AHRS described above. In addition to the AHRS, the INS uses information from absolute position sensors (such as GPS or LBL) and integrates the rate sensor readings to compute the actual position. This process, as we have seen, is called Dead-Reckoning (DR). As the linear and angular acceleration sensors are subject to noise, the position derived from these sensors in the absence of GPS or LBL is subject to a cumulative error and the obtained position will drift with respect to the true position.

Typically the heading and rate sensors of an INS are less noisy than those of a comparably cheap AHRS which decreases the problem of accumulated drift. An INS which fits into the hull of an AUV shows typical drift rates of 1 km/h with the typical speed of underwater vehicle (1 kn/hr). The best performance of the most precise INS available, the ones found in nuclear submarines, remains classified, but is expected to be about 0.01 km/h but are very expensive.

Radio and satellite navigation systems

Radio and satellite navigation systems can provide an accurate position update provided the vehicle can travel at or near the surface periodically for a position fix. The maximum vehicle travel time between surfacing for a position update will be governed by dead reckoning/inertial navigation accuracy. Poor quality dead reckoning will dictate an unacceptably high frequency of surfacing. Also, vehicles operating close to the coast are in appreciable danger of collision with surface vessels if they need to frequently approach the surface for position fixes. For deep water applications, the time and energy needed by a small AUV for transiting to the surface from near bottom are very unfavorable. Finally, surfacing is impossible in ice-covered oceans.

Active beacon

We have just discuss about this method that computes the absolute position of the robot from measuring the direction of incidence of three or more actively transmitted beacons. The transmitters, usually using acoustics frequencies, must be located at known sites in the environment.

Acoustic pinger

Acoustic individual pinger on board can be used as sonar or, by using communication network, to transmit short codified message.

Landmark recognition

Artificial landmark

In this method distinctive artificial landmarks are placed at known locations in the environment. The advantage of artificial landmarks is that they can be designed for optimal detect ability even under adverse environmental conditions tailored on the available sensors. As with active beacons, three or more landmarks must be "in view" to allow position estimation. Landmark positioning has the advantage that the position errors are bounded.

Natural landmark

Here the landmarks are distinctive features in the environment. There is no need for preparation of the environment, but the environment must be known in advance. The reliability of this method is not as high as with artificial landmarks.

Model matching

In this method information acquired from the robot's onboard sensors is compared to a map or world model of the environment. If features from the sensor-based map and the world model map match, then the vehicle's absolute location can be estimated. Map based positioning often includes improving global maps based on the new sensory observations (SLAM) in a dynamic environment and integrating local maps into the global map to cover previously unexplored areas.

Vision system

Camera vision

The use of a camera for landmark recognition by artificial vision is used in large AUV and submarine. It needs strong calculation power and energy.

Livery recognition

The idea comes from the fish school where the individual are able to recognize quick movement of the neighbors for high reflecting fish livery. A very quick image analysis is able to detect movement of the neighbors.

Flash

Cheaper flash can be used in quite clear water, but also in turbid water for a short range, to communicate short pre codified message. Generally is not possible to vary the light time but a sequence of lamp would be used for codified message; moreover to detect them a photodiode could be sufficient instead of a camera, that use more computational power.

Laser vision system (LVS)

The LVS consists of two underwater Laser pointers and a single CCD camera mounted on the AUV. The LVS fuses data deriving from the projection of the laser pointers on the image plane while it tracks a target at the same plane using computer vision algorithms. The LVS calculates the position vector of the vehicle at a low frequency, with respect to the center of the tracked object. The IMU measures the accelerations and angular velocities of the vehicle at a high frequency. The fusion of the two sensors is based on a Multisensor Kalman filter.

The result is the calculation of the position vector at a high frequency, which can be used for a smooth closed loop steering control of the vehicle.

Each laser pointer projects a high intensity dot on the surface the target lies on. The two laser dots are visible in the optical field of the camera. Through an experimental procedure a mapping between the position of each laser dot on the image plane, and the range of the laser pointer from the target plane is obtained. Using the ranges of each laser pointer and their distance the position along the x-axis and the orientation about z-axis (yaw angle) of the vehicle can be computed

Inclinometer

It is a cheaper instruments able to give the yaw of the system.

Short range electromagnetic transmission

It is well known the difficulties to use electromagnetic waves in the sea water; however some low frequency short range modem are in progress [32].

Each of these techniques can fuse together. The integration of this information in the navigation by a Kalman filter can greatly improve performance.

The advantages and the differences of localization for a swarm underwater robot

For a swarm the localization we suppose problem can be divided in three tasks:

1. Absolute localization, that has the mean of localization with respect of a fixed reference system, of one member of the swarm (AL)
2. Relative localization of a member with respect of the others members.(RL)
3. Relative localization of a member with respect of the others members, but only neighbors; we call it immediate relative localization (IRL) and its meaning will be cleared later.

Different methodologies are required to solve the three tasks. In agreement with the swarm philosophy each element must be able, if connected with the other, to perform the localization job. Attention must be posed in the last affirmation. We mean not that each element must do all the job; often there is no need to know all machines position but we must be able to do using all the internal data, the external data communicate by the other elements and the external data measured by the robot, inclusive that deduced by environment observation.

Moreover, these types of localization can be articulated in different ways, principally three; this imply three having different architectures and sensory intelligence:

1. The geometric-geographic which focuses mainly sensory effort. In some ways is more difficult, but it is essential because we are carrying out an object that is not completely autonomous in the high level task decision but have to get them from an human operator; he has the need to know where is the swarm and how to bring him back
2. A localization related to some physical fields and their gradients, with respect to a source. In many missions could be the only form that makes sense, taking in account the preceding point.
3. The last related to the concept of identification and closeness to some landmark; this imply the availability if a chemical, physical or acoustic map.

We have stressed the relative location can be divided in LR and IRL; this last is very importance in the overall behavior of the swarm. It must be defined and understood before proceeding to the definition of a program work and its meaning lies in the temporal and spatial resolution.

The usefulness of this further categorization was designed to obtain a rapid response to variations in the environment of the entire swarm. If the system should await a thorough knowledge of its internal structure

before deciding on the type of response of each unit of the swarm the reactions time would be too slow, compared to the dynamics of environmental phenomena and the system has low chances of success in its mission. It is well-known the recognition mechanism used in the school of fish that allows them to change the position of the entire school in a very quick time just looking the movement of the neighbors. We can therefore speak of RL "local" and "global" and RL "immediate" and "deferred". The two concepts are linked together by physical means (sensory systems and means of transmission of information) that are available in the swarm. In principle also LR "immediate" is more easily achieved with simple signals (which are very fast and then be transmitted) based on physical fast transient, and possibly using a rapid propagation of fields such as electromagnetic; its need lies in a more quick reaction of the swarm. Later, if necessary, the swarm can compute the relative position of the whole system.

A advantages of the swarm, considered as a whole entity, lies in the possibility to parallelize very heavy computation. As example an image analysis to recognize landmark is a typical task that can be parallelize and distribute to the various machine, providing that an adequate communication network is available. An extended Kalman filter and many other calculation make possible the final calculation.

Needs of scenario

To address the localization problem to our swarm we define three types of operative scenario; this to evaluate the best method in different situations. Therefore we distinguish three operative situation:

1. The swarm is in open water going to the objective; eventually monitoring is allowed.
2. The swarm is operating very close to the objective.
3. The swarm is operating in a structured environment like arbor.

In these three different scenarios the strategy of movement and localization could be completely different.

Scenario number 1

In this situation the swarm is moving (and eventually is monitoring the environment) towards a precise point. This should be the simplest localization situation, one element of the swarm is on the surface and fix position by GPS. The relative position of the other members is measured by other methods. The shape of the swarm is not important if we are in travel mode only; on the contrary if we are monitoring a sea volume a precise swarm shape, depending on the monitoring job, is assumed.

Scenario number 2

An objective is assigned and it is close; the shape of the swarm is able to maximize the area covered just close to the objective. The movement of the swarm is led by the system control, compatibility with the assigned mission. Landmark of the objective are useful for localization.

Scenario number 3

This is the most difficult task because now are the aim of the mission (surveillance, pollution monitoring..) that determine the swarm movements and the shape must be take in account the constrained by the environment. In fact in such conditions some shape could be not allowed. As example in a arbor could be necessary to minimize the volume occupied by the swarm to avoid collision with the ship or similar, and the use of acoustic beacon could be convenient.

These scenarios have not the idea to give a complete set of operative conditions of the swarm but just is useful to focalize the problem.

Our proposal

Here we summarize the problem and expose some possible solution, together their feasibility. System requirements to perform these solutions are divide in "based requirements", which are the minimum instrumentation we auspicate to have on the single machine and "desire requirements" for enhanced instrumentation and better performance.

We also try to calculate quantitative specifications requirements we ask to the instruments to work in our conditions and their feasibility; next step (not in this report) is to choose the commercial (or not) instrument to employ.

A roadmap with the milestones to be delivered in a time table conclude the report.

Summary of the problem

We have to perform localization of a swarm robot. We have divided localization in three different classes: Absolute Localization (AL), Relative Localization (RL) and Immediate Relative Localization (IRL). Moreover we distinguish three different operative scenario (SC1, SC2, SC3) for localization. We have examined many possibilities of the literature and now we shall focalize for instruments required in the different conditions.

Each machine is characterize by six degree of freedom, but two of them (depth and heading) are very easy to measure. If the machine has cylindrical symmetry one is uninfluenced. Considering the yaw not important (we image the navigation into one plane with the exception of few moments) we understand that the really difficult is to give coordinate x-y, of the center of mass; the x-y plane is that parallel to the bottom sea.

Based requirements

The base equipments of all the machine is composed by:

1. Network communication
2. GPS
3. Depth meter
4. Inclinometer
5. Compass
6. Flash
7. Photodiode
8. Webcam
9. Livery on the vessel surface and/or permanent and/or electric magnet

All this equipment is cheap and available.

The base equipments of all the machine is composed by cheap instruments and a network communication (Useful in RL, AL , SC1, SC3).

Network communication

The network is a requirement that exist not only for the communications but must be used for data exchange; we are interest in its use like sonar ranging for RL. It provides to a local distances angle based measurements, working on synchronized clock and flight times. Of course the snapshot of situation is not in real time ma we freeze the situation of few second ago. (the delay will presumably from tenths of a second to second) and should

be sent, together with the estimated robot speed for the correction. A suitable algorithm to calculate relative position between all the robot, or a subset of them, must be developed to take in account the delay and to get the best efficiency possible, regarding error in position, shadow effects etc.. .

A protocol of localization mode must be employed by the swarm at fixed time or on demand.

Codified signals, able to give the signature of the transmitter, could be employed in case it needs to know which element of the swarm is a particular position; take in account that this is contrary to the philosophy of the swarm.

Swarm RL can be translate in AL if one machine (scout) has its AL and is able to communicate to the other.

It must be focus on the minimum characteristic of the network. It should be able to switch work frequency at least in two mode (low, about 100kHz and high 1Mhz) to allow different tasks. In fact we image the network for communicate and also for localization.

Quantitative consideration

Now we shall see the quantitative requirements we ask to the network.

The network should be able to shift the working frequency from 100 to 1000 Khz (at least two frequencies). This number comes out from consideration on data rate (for communication) and the use of the net as emergency ping or localization signal.

High data rate communication can be obtained with high frequency, useful for short distance, while a ping for localization can be used in lower frequency for long distance.

The distance we want to cover are that exposed (maximum 50 meter between the machines) in this report, and the data rate should be between 10 and 100 Kbytes/sec.

Other instruments

All the data available will be fuse and weighted with all the data coming from other instruments to be more precise in localization. More than an algorithm is desired, for example one more complex that use all the available data and one more quick using a subset of data and machine; this depending on the operative conditions and on the kind of localization required.

GPS is used for AL when a scout (single robot that have this task) is on the surface.

Depth meter can be realized in different technologies. At least a commercial depth meter must be present for AL in one dimensions.

A couple of inclinometer is useful to measure the angle of position with respect of the land. Another degree of freedom can be remove by compass; careful must be posed in case of the presence of magnetic disturbances.

Electronic compass are cheaper and easy to integrate. Careful must be pose to avoid interference from metallic mass and electric circuit.

A photodiode is useful to get flash lamp sequence for light communication; as example a codified sequence could send the heading of the machine to the other (close neighbors) to adapt themselves. Therefore to transmit simply codified message by flash we can transmit a sequence; working on color or flash time it is more complicate, standing the use of a cheaper flash unit. In some cases we can arrive to obtain an optical modem. This is a very cheaper and light instrument, but give not information on the position of the light source

A webcam must be used for image recording. Moreover together with an optical flash lamp. Using omnidirectional vision it is possible, with synchronized flash (or triggered by the first flash and using cumulative vision of few seconds) to get a qualitative information on the density of machine. Of course is not a metric information but the single machine can get the information if it is far or too left (for example) from the swarm. Moreover flash could be useful to rescue a single machine with difficult, together with a switch of the network toward lower frequency working to increase the range.

The camera can be used also in the livery lecture for IRL for fast reaction movement, but it needs a computational job that must be simplified; image analysis is too much heavy. This last work could be done as batch as for SLAM distributing the computational cost on a parallelized machined (the swarm itself if the network is adequate).

The single machine can be equipped with a strong permanent magnet give a average heading information to the neighbors. This is a very fast and cheaper system but has the problem that interfere with the compass measurements. It can masked mechanically or can be an electric one. In this last case we have the power energy cost. The advantage of e static magnetic field is the possibilities to transmit (like flash sequence) some information to the other machines. Moreover the hope is, differently from the light source, to get some quantitative information on the RL by the magnetic field vector.

At this point we can note that all this instruments should be enough to guarantee the three kind of localization for the three scenario we imagined. The GPS give AL and the network provide to RL, together with the data from compass, depth meter and inclinometer. IRL is provided by flash and photodiode. The most critical point is from RL by the network, therefore we would reinforce this point by magneto static localization

Quantitative consideration

Relatively to GPS, depth meter and inclinometers there is very little to investigate, because commercial unit are able to give the precision and the data rate we need.

Also the photodiode it must be able to resolve flash sequence of about 50 Hz; this is not problem for a commercial cheap photodiode. Some calculation must be done relatively to the flash lamp. A cheap flash lamp we have just used in another project is able to transmit a signal at about five meters in very turbid water, and could be mounted on the underwater machine.

The webcam, must be able to catch the livery change and with a sensitivity high enough to work in turbid water. Some investigation, also on the fast image analysis must be done to be operative. Enea has done a similar job in river water close to electric generator.

Electromagnetic transmission in sea water is going on some progress with respect of last years. A solution in the frequency window of low adsorption can be considered together with its power and dimensions cost [33], [34].

Magnetic methods require some words more. An attempt to localize Rfid by magnetic field it has been performed in air [33]. We start to consider the Earth magnetic intensity field. Its scalar value is about 20 microTesla at the equator and 70 micro Tesla at the poles (1 Tesla=10000 Gauss). We can consider it constant in our area of operation with some exceptions. Moreover if we want to generate an added magnetic field we have to know how much is the sensitivity of the magnetometer and what field we are able to generate in a cheaper way. The temporal anomalies of the magnetic earth owing to the interaction of electric particle with magnetosphere are of 500 nanoTeslas maximum, with a life time between 1 and 1000 seconds. Anyway underwater they will be shielded. A commercial magnetometer has a scalar sensitivity of 0.01 nanoTeslas but it is quite large (A torpedo like about 1 meter long with 0.1 meter diameter [34]). A very cheaper (40 euros!) micro magnetometer has a sensitivity of 10 nanoTesla [35]. We can take in account that the nature of the sea bottom can give peak of about 10 nanoTEslas or more but in an area of more than 100 meter side; this system also is used to detect cultural heritage goods on the marine bottom . We know [36, 37] as the magnetic field in empty space for a coil is given by the formula:

$$B_z(r, z) = 10^{-4} Ni * \left(\frac{\mu_0 / 2\pi}{\sqrt{(rag + r)^2 + (z - zpos)^2}} \right) * EllipticK \left[\left(\frac{4rag * r}{(rag + r)^2 + (z - zpos)^2} \right) \right] + \left(\frac{rag^2 - r^2 - (z - zpos)^2}{(rag - r)^2 + (z - zpos)^2} \right) * EllipticE \left[\left(\frac{4rag * r}{(rag + r)^2 + (z - zpos)^2} \right) \right]$$

$$B_r(r, z) = 10^{-4} Ni * (z - z_{pos}) * \left(\frac{\mu_0 / 2\pi r}{\sqrt{(rag + r)^2 + (z - z_{pos})^2}} \right) * (-EllipticK\left[\frac{4rag * r}{(rag + r)^2 + (z - z_{pos})^2}\right]) + \left(\frac{rag^2 + r^2 + (z - z_{pos})^2}{(rag - r)^2 + (z - z_{pos})^2} \right) * EllipticE\left[\frac{4rag * r}{(rag + r)^2 + (z - z_{pos})^2}\right]$$

Where:

Bz and Br are the axial and radial component of magnetic field B (in Tesla), rag is the radius of the circular coil centered on the z-axis at zpos; Elliptic are the complete elliptic integral of the first kind (K) and of the second kind (E). N are the numbers of turns and i the current.

From this we can plot the field and do some consideration; if we consider, as example, a solenoid with 1000 turns, 0.1 meter radius, the center posed 1m on the z-axis and 1 Ampere current we generate radial and axial magnetic field as shown in the following pictures (r and z in meters).

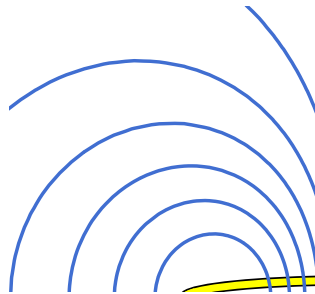


Fig.1 Force line of magnetic field generated by circular coil.

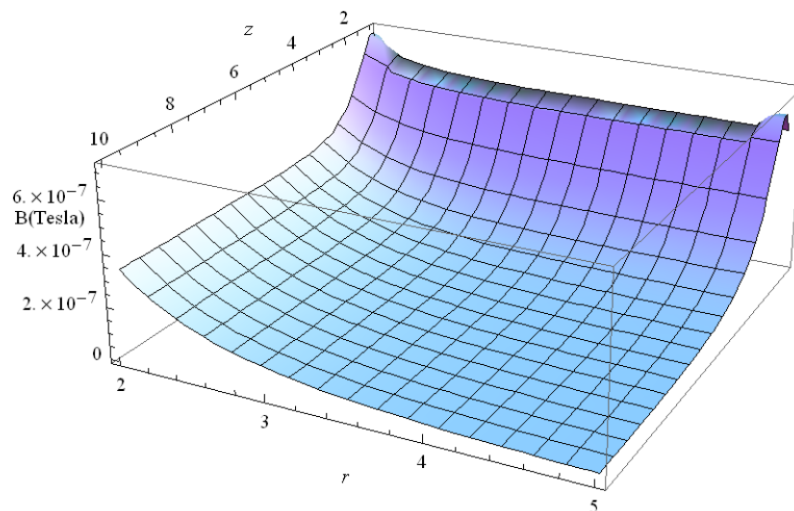


Fig.2 Modulus of magnetic field generated by our solenoid between r (2m to 5 meter) and z (2m to 10 meter); shorter distances show stronger field. .

Form these pictures we deduce that should be able to detect the spike on the magnetic field (about 100 nanoTesla) superimposed to the Earth's field we have generated into the sea. No information from the transient but we measure a change in the magnetic Earth fields. We have now two opportunities; one is a slow modulation of the field (to reduce attenuation) carrying some codified information, like flash lamp. The second is to make an attempt to calculate the position of the field generator. this has been done for two object in open space and for wired system for augmented reality and the mentioned case of rfid localization. It is an hard chances to do for multisystem into the sea. more calculation to investigate this possibility need. From these we deduced that are able to detect the magnetic we hope to get some information (distance or heading direction or some other) form these numbers.

Desired requirements

The following equipment can be considered to improve the efficiency in localization:

1. Acoustic pinger
2. LBL USBL device
3. DVL
4. AHRS
5. Electromagnetic devices
6. Gradient localization

The use of dedicated acoustic pinger should be carefully evaluated; we ask to the network to do this job. Pinger can be considered as emergency solutions otherwise is a not useful redundancy. If working frequency are low the range is large but the antenna is large and low directionality of the signal can be obtained. If the frequency is high the pinger can be substitute by the network.

LBL and USBL device can be useful for AL in SC2 and SC3. An arbor could be equipped with no so high cost, with respect to the normal cost of surveillance; an USBL system cost about 100k euros, so not so much for an arbor. To save power energy on board the fixed buoys must be active while the robots should be passive. The information gained will be later transmitted by the network form the buoys.

DVL can be mounted to integrate its data with cheaper AHRS (like XSense for example) for AL and RL (we avoid IMU for the cost).

A quantitative measure of absorption of electromagnetic waves in the water led to the not possibility to use Radio frequency modem in sea water. Anyway using some particular window frequency and other system some device, with very poor performance, it has been build. In the last time electromagnetic device for marine application had an improvement in their performance lead to commercial products[38, 39]; it needs to investigate on this new device also if their dimensions seems to be too large for Harness project.

The gradient localization can be used in case we are in a field of something measurable. For example an oil leak can be followed by a nose (or an instrument able to detect the field). This is an example of no metric localization but only topological. The movement can be obtained like the force field used in obstacle avoidance techniques. The swarm can be decider, as example to localize itself in a region of maximum oil content; to do this the control system drives the swarm using the gradient field techniques; of course we need the right "nose" to follow the line field.

Quantitative consideration

The characteristic of the LBL or USBL acoustic systems can be calculated as follow. In SC2 and SC3 we have two different situation; if the arbor is little also a USBL (generally 1km square range action) could be enough. Otherwise can be considered the use of more beacons, also to solve the shadow problem deriving by the

structure of the arbor. In SC3 if a centimeter precise positioning is required it needs a USBL used for docking; it must be take in account that so precise positioning is contrary to the swarm philosophy that use cheaper unit DVL and AHRS instruments can be commercial instruments that can integrate with the other instruments.

To make quantitative consideration on the gradient field theory the appropriate sensors must be decided; something of similar to the potential theory used in obstacle avoidance could be useful to drive the robot.

Roadmap

The following actions are proposed:

Network

1. Write the minimum characteristic of the network and of all based instrumentation to perform the task with assigned precision.
2. Trial and modeling of communication algorithm in uncertain conditions (shadow, missing communications etc..) for a swarm of 16 machine. The algorithm must be two. One that use all the data of all machine and another lighter, using a subset of data and/or machine. The trial data can be get from the STSS500 project (Only ping condition, non signature but different frequency)

Data management

1. Trial to combination all simulate (and experimental old data) data to have a estimation of errors in localization measurements both from single data measurements and using fusion sense.
2. Try a simulation of flash sequence lecture and message interpretation.
3. Trial of livery lecture by webcamera image; develop livery whose direction can be quickly evaluate without heavy image analysis (analysis of variation in the view area). Evaluation algorithm able to get new direction.

Simulation of magnetic field measurements to specify requirements for our case. Computational cost of power energy for using an electromagnet.

Other

4. To adapt and test an algorithm derived from obstacle avoidance theory to the case of oil leak (or something else).
5. Decide the sensors to be used to perform gradient field navigation and localization
6. To focus commercial instrument available and cost estimate
7. To investigate on new commercial electromagnetic marine modem

Conclusion

In this report a preliminary overview of the localization problem for a swarm robot it has been investigated. In a first part we have examined the need of localization together with some methods used for a single robot machine. Later we focused on the differences using a swarm robot instead of a single robot machine. Some used methodologies are proposed together with their advantages and disadvantages. Moreover typically application field and their feasibility in Harness project are investigated. In a second part we try to be more operative; to this aim we distinguish some operative scenarios, to understand the action frame. Different methods and kind of localization are considered and some solutions are proposed; by these solutions quantitative requirements and the necessary instrumentations are computed.

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