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GPS and GIS Integration in Cable Laying Applications

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ABSTRACT

Cable laying applications require real time positioning related to information included in maps. GPS technology provides the most reliable real time positioning and timing while GIS is the most appropriate environment for managing maps in digital form. Experience from projects already undertaken has shown that it is crucial to enrich the positioning information with spatial and dynamic data. Specifically, cable laying activities need position to be combined with information related to seafloor morphology, seabed geomorphology, coastline, etc. together with information like sea current velocity, laid cable length, cable tension, etc. Based on the above approach, the design of a navigating and monitoring system for cable laying is introduced. The system is built on a GIS platform connected to the appropriate spatial database and is attached to GPS receiver and the necessary sensors.

KEY WORDS. Differential GPS, navigation, cable laying, data modeling, Geographic Information Systems.

1. INTRODUCTION

Submarine laying of power and telecommunication cables are applications which have been widely used during the last decades to interconnect the continent with islands, island with island or even neighbouring areas which could be connected also through conventional land cables. The main advantages of submarine cable use are low operational cost and improved quality for power and telecommunication services. On the other hand, significant drawbacks for the substitution of the conventional equipment are the high cost and the long time demanded for installation. In order to lengthen the life of the cable and protect it from natural and man-caused disasters a careful study (hydrographic, geophysical and geological) of the area of interest must be carried out before the beginning of the operation. After that the optimum route of the cable must be chosen.

Accurate positioning and navigation are necessary during study and cable laying. Especially during cable laying, the accuracy and reliability of the navigation system used is crucial. Today the use of GPS technology (Wells et al., 1986) in differential mode known as DGPS (Denaro et al., 1986) provides the demanded accuracy. Cable laying needs not only a navigation or hydrographic software package but an integrated monitoring system especially implemented for such an application since it is a delicate procedure in which many parameters influencing its quality must be taken into account. While laying, except of the information for navigation, several other parameters like the tension of the cable, the inclination and bearing with which it is going out of the vessel, the depth of the sea, the seafloor relief, etc. are necessary in order to control the whole operation.

All this information must be provided continuously and presented with the most friendly and easy retrievable way to the operator who has to know at any time the current status of the system and prepared for what is going to happen next. A Geographic Information System (GIS) could be used for the above purpose. In a GIS environment, spatial information can be manipulated and portrayed by different media as maps or graphs combined with images or texts. A compact data set for spatial and non-spatial information can be provided, organized in a database containing both graphic and alphanumeric elements. The computer display can be the platform of representing retrieved data from the database in the form of maps or graphs, with high quality graphics, tailored to the users' expectations. These graphics are representations of real world phenomena and can be altered instantly by the user, who can easily focus on any location he is interested in by zooming. The user can have the means of overlaying different kinds of information. Data retrieval can be executed using an extended set of queries represented by alternative sets of symbols. Finally, all these tools function in a user-friendly environment, directed by a user interface software.

Most GIS applications refer to spatial analysis or to the process of creating digital maps (Burrough, 1986; Parker, 1988; Maguire and Dangermond, 1991; Antenucci et al., 1991; Cassettari et al., 1992). Among them, applications to be found are based on data collected using GPS technology (Gresh, 1993; Hsu et al., 1993). In this paper an effort was made to develop an integrated environment combining GPS and GIS technology in real time in order to satisfy the needs of cable laying monitoring activities. This integrated environment is capable to log and capture data from several sensors, provide information for accurate navigation and combine this information with both spatial data (depth, currents, seafloor maps, geology, etc.) and the current status of the cable while laying (tension, inclination, etc.).

2. SURVEY OF CABLE LAYING MONITORING TOOLS

In submarine cable laying accurate real time positioning is necessary to navigate vessel exactly over the preselected route. The reliability of the positioning system used is also crucial because operation, once started cannot be interrupted for any reason. The positioning system provides all information related with the movement of the vessel, additionally, continuous information concerning the status of the cable must be provided. This information which must be updated continuously is the length of the laid cable, its tension and the vertical and horizontal angles with which the cable is going out of the vessel. All the above parameters are adjustable while laying and must be kept under certain limits, as the spare cable is only a small percentage (2-3%) of the total length due to its high cost. This spare length allows to follow the seafloor relief and adjust the tension of the cable while laying. The length of the laid cable is used to compute the cable slack, i.e. the percentage of additional cable laid in comparison with the horizontal distance already covered. The slack covers the additional cable length needed for following seabed morphology and permiting to pull it up in case of damage. Cable tension must be also kept within some certain limits. Tension bellow a lower limit would result cables laid foul on the seafloor. On the other hand, too high a tension would cause the cable either to be suspended due to rough seafloor relief as it is going down stretched or to get damaged or even broken.The above problems could be avoided adjusting either the vessel's speed or by using cable brakes. The sea depth also influences the tension of the cable. In order to know the length of the cable hung behind the vessel and to define the exact position where cable touches the seafloor, horizontal and vertical angles of the cable have to be measured constantly and the depth of the sea has to be defined as well as the weight per meter of the cable.

From the above analysis it is obvious that not only the dynamic parameters of the cable but also spatial characteristics of the area, such as sea depth, seabed geomorphology and slope, influence the application. Furthermore, other spatial data such as coastlines or shoals and hazards, could be also known to the operator in order to allow full control of the procedure underway.

Thus, a complete system for cable laying should combine the following:

- Positioning systems
- Tracking equipment of cable dynamic parameters
- Spatial data
- Data presentation

2.1 Positioning systems

Radio positioning systems, range-range or hyperbolic working in the frequency of microwaves (Ingham,1974; Strang Van Hees, 1984) have been used in the past and are being used up to now in some applications. Their main drawback is that their range from shore is limited to the visual line of sight of the signal (De Munck,1984). The above limitation has been overcome with the use of Differential GPS (DGPS) which is the most commonly used positioning system today. GPS in differential mode can achieve the demanded accuracy for cable laying both nearshore and offshore.

GPS is a world-wide satellite system which provides real time, three-dimensional, all weather, 24 hours a day positioning. It has been developed by the USA Department of Defence and its accuracy has been intentionally reduced to ±100 meters at 99% of the time. This accuracy does not satisfy of cource the needs of cable laying applications and this is the reason why differential positioning (DGPS) technique is used. In DGPS positioning two GPS receivers operate simultaneously (figure 1). The first one is continuously observing over a known position computing real time differential corrections of range measurements to satellites. The second one is observing onboard the moving vessel. Differential corrections are transmitted in real time from the reference to the mobile receiver through a communication link. Assuming common geometry between each receiver and observed satellites, differential corrections are applied to the mobile receiver range measurements. Using these corrections positioning fixes can be computed by the receiver with an accuracy better than ±5 meters.

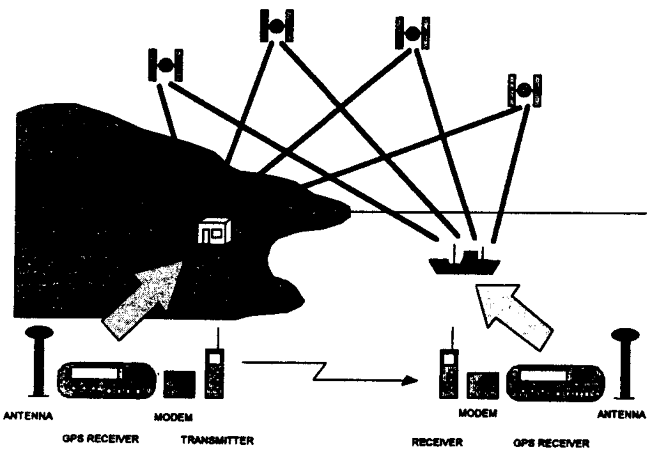

Figure 1 Differential GPS principle and components.

Furthermore, Dead Reckoning (D/R), consisting of gyrocompass and speedlog, is used frequently as a complementary positioning system (Grand and Wells, 1981). D/R can keep the accuracy of positioning under certain limits for several minutes in case of interruption of the main positioning system. This cannot happen for long as D/R accumulates errors proportionally with time. D/R is useful even while the main positioning system works. Its measurements can be combined with the measurements of the main system to improve accuracy and define the sea current direction and velocity while moving.

2.2 Tracking equipment of cable dynamic parameters

Dynamic parameter tracking system provides necessary information about the current status of the cable. This information is the laid cable length, its tension and the vertical and horizontal angles between cable and vessel axis, which is continuously updated. These parameters are obtained through sensors which measure continously and transfer this information either manualy or through communication ports to the monitoring equipment.

2.3 Spatial data

Since submarine cable laying is a very complicated application taking place into a particular geographical space, all relative information must be collected during the study which precedes it. In the study various data are collected including topographic and hydrographic surveys, land and submarine geology and stability study of the seafloor. Additionally scanning of the whole zone of interest is necessary, in order to secure that no obstacles dangerous for the cable like other cables, shipwrecks rough rocks or other, could destroy it. This information is useful not only while the optimum route is selected but also while laying. For this reason hydrographic, geological and other maps are produced and all the above information is taken into account in order to decide the optimum route of the cable which is another spatial information while laying.

2.4 Data presentation

Navigation packages currently used for submarine cable laying is able to communicate with several positioning systems, to give information necessary for navigation and to capture positioning data. This information is given either in alphanumeric form or graphically. The information given includes coastline of the area, selected route, total distance in route, position and speed of vessel, sea current if D/R is available, covered horizontal distance, cross track error etc. Some of this information is necessary to determine e.g. the slack or to adjust vessel speed. This information is given manually or through a communication port to another device where the necessary computations are carried out.

3. DESIGN OF CABLE LAYING MONITORING SYSTEM

The basic elements of the Cable Laying Monitoring System (CLMS) are presented here as an application of GPS and GIS technology. The system is designed to meet the most advanced technology in positioning (DGPS) and data manipulation (GIS) providing a market oriented product which at the same time stimulates the development of geographical information application as a vehicle for executing advanced spatial processing. Modern types of visual presentation to users not necessarily specialists in GIS or information technology are introduced. As a result of 10 years experience a submarine cable laying navigation system has been developed and used covering such applications (Liapakis and Anagnostou,1990 ; Liapakis,1991). Several updates of this software and hardware have been made since, keeping the system up to date. Parts of the old navigation system are used also in the one proposed here. This is the reason why main components of the proposed system like communication and Kalman filtering models (Kalman, 1960; Gelb, 1974; Schwarz et al., 1988) are discussed briefly.

3.1 CLMS basic characteristics

CLMS is based on an IBM PC compatible 80486 computer holding 8 serial communication ports. The software is working under WINDOWS environment. A special interrupt controller has been developed which is a software tool permiting DOS to communicate with more than 4 communication ports. The package is divided in three main parts. The first one is dealing with the communication I/O, while the second is charged with necessary processing for optimization of the provided vessel and cable positioning accuracy and the last with the presentation of the information to the user.

Regarding the communication of the system the following peripherals are used:

- DGPS receiver
- Gyrocompass
- Speedlog
- Cable dynamic parameters (tension, tilt etc.)
- Output devices

Integration of different positioning systems in order to accomplish the highest possible accuracy and reliability is one of the most crucial procedures (Wells and Grant, 1981). The proposed navigation system is combining the above mentioned positioning systems (DGPS & D/R) using a 9 state, constant acceleration, Kalman filtering model (Liapakis and Anagnostou, 1990; Liapakis, 1991). Using the above technique an accuracy of the order of 1m is accomplished.

The laid cable length is compared to the horizontal distance travelled to determine the slack of the cable, while the horizontal and vertical angles together with the tension of the cable and the depth of the sea are used to compute the alisoid curve the cable follows from asteam the ship until it reaches seafloor. Usually captured position fixes while laying are referred to the electric center of positioning system antenna. In fact the cable meets the seabed some hundred meters behind, depending, among other, on the depth of the water. In case the vessel follows a straight line the cable is laid exactly over the vessel's route but in case it turns the cable follows a quite different curve. Alisoid curve in combination with current position of the vessel and seafloor morphology can determine the coordinates of the touch points of the cable with the seafloor. If this information is available, it is easy to define whether the cable follows seafloor or it is suspended between sharp ends of the seafloor.

With all these parameters updated at the same rate as the vessel's position, actual cable position is computed and the whole cable laying is checked concerning the tension of the cable, its slack and its final position on seafloor.

As it is obvious a large amount of parameters are taken into account in order to help user in decision making. Hence, continuous input from all system components is necessary for navigating, adjusting cable tension and avoiding obstacles. For this reason in CLMS some of this information like vessel position, cable tension, etc. is collected directly from sensors, while some other is computed in real time using data coming from various sources.

The third part of the system provides the most suitable media to answer appropriate logical and topological queries satisfying the users' needs by exploiting the analytical tools of a GIS. Information retrieval is given by silmutaneous presentation of different windows including maps (of various scales), tables, graphs or texts. Aiming at answering the queries defined previously, the framework on which the spatial data and the spatial relationships could be expressed graphically is performed by integrating the following aspects:

- Development of a data model which is first useful for the defined requirements and queries of the system and second easily updated and extended.
- Description of the operational process after consideration of the application peculiarities stated previously.
- Development of the user interface following object oriented programming.
- Consideration of the possible expandability of the system.

3.2 Data model

A data model designed for a certain system must provide the framework for describing specific sets of objects and, from the relations existing among them, the ones needed by the users. The design of data models appropriate for the different kinds of applications is a basic topic of research from the beginnings of the GIS development and is still a subject of recent studies (Egenhofer and Herring, 1991). The selection or the design of a data model must be based on the nature of the phenomena represented by the data and the specific manipulation processes set by the system requirements (Peuquet, 1984). A deeper analysis of these two parameters reveals certain factors which have to be considered before choosing or designing a data model for any system. These factors are:

- the specific database model that developing environment provides,
- the definition of the functional dimension of the different geographic phenomena. For example, though a shipwreck is a three-dimensional

object in the real world, in a digital environment appropriate for cable laying applications it can be successfully treated as a one-dimensional object.
- The reactions between spatial and non-spatial data.
- The data model must describe the location and the shapes of geographical features as well as the quality and capacity of the descriptive (thematic) information.

Considering the developing environment of the system, all data must be organized in an integrated space framed by a relational database model (Date, 1990), which in our case is actually a geo-relational data model because it is spatially concentrated. According to the information content, data is built into three *categories* having compact *objects*. These categories refer to:
- positioning
- topography and
- special characteristics

Each object has *geometry*, *attribute* and *annotation* as its components (figure 2). Thus an object can consist of points, lines or polygons following the vector data structure or of an analytical surface in case it is a continuous three-dimensional phenomenon.

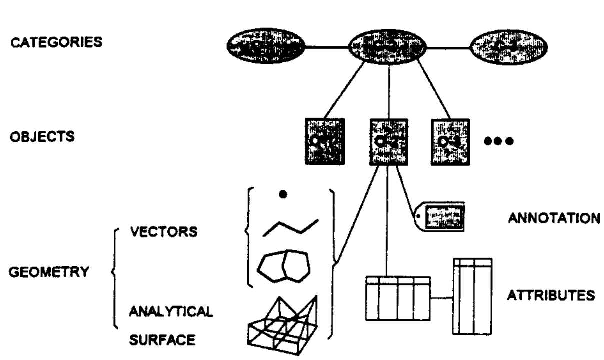

Figure 2 Data model definition scheme.

An appropriate way of implementing an analytical surface in digital form is a Digital Terrain Model (DTM). Also, geometry provides location and shapes of the spatial phenomena and, through them, any topological relation can be easily built up. Every object has also its attributes which express its descriptive information. Finally, object annotation is all labeled information requiring to be presented in the different views of the system. Attributes and annotation are translated into files (tables) and fields following the relational model (figure 2).

An analytical description of the information content of the system organized under the defined data model is given in the Appendix.

4. SYSTEM IMPLEMENTATION

CLMS is designed to incorporate both static and dynamic data into a unified database. The static data are obtained from the stage of study preceding an operation or may be digitized from existing maps. These data are processed in an external GIS package and, in order to be operational, the user has to carry out the following tasks:
- Study data entry and maps digitization.
- Creation of topology.
- Database population.
- Geographical orientation of thematic data.
- Data quality control.
- Data compression.

Afterwards, static data can be stored into the database of CLMS accessible to the user (figure 3). The static part of data refer to all objects of the topography category and to the way point object that belongs to the positioning category (see Apendix).

The remaining part of CLMS information content includes dynamic data. Following the basic characteristics defined in section 3.1, the system is built on three main modules: communication, processing and presentation. The first two modules manipulate the dynamic data. The first module handles communication from/to the computer and the peripherals (DGPS receiver, gyrocompass, speedlog etc.) and acts as interrupt controler. This module is active during an operation at the background of the system. The collected dynamic data are transferred immediately to the processing module. The second module provides the optimum both for vessel (2-D) and cable (3-D) positioning, applying the filtering and computational techniques described in section 3.1. Finally, all dynamic data are transferred and stored in the database (figure 3).

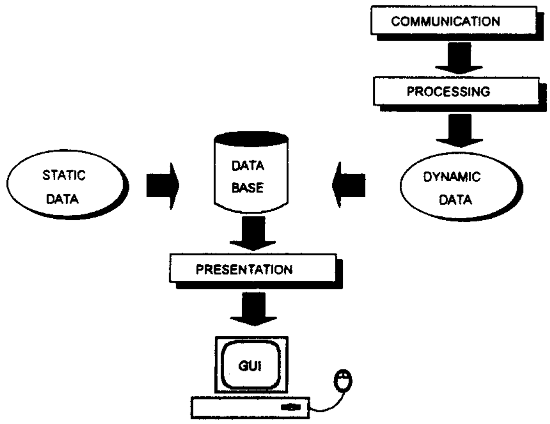

Figure 3 Data flow and main modules of CLMS.

Presentation module is actually a graphic user interface (GUI), which combines all advanced representation techniques provided by WINDOWS technology. The user easily opens and closes windows portraying the current status of the database using different groups of data. The graphic views are supplied with zooming function performing overall or specific spatial retrieval. The typical configuration of the computer display includes three graphic windows, for: planimery, profile and cross track error (figure 4) as well as presellected objects and several labeling windows displaying the dynamic data in alphanumeric form.

By terminating the execution of CLMS the content of the database is transfered to a full technical report of the operation including texts, tables and plots.

5. CONCLUSIONS

A real time monitoring system suitable for submarine cable laying applications has been introduced. CLMS (Cable Laying Monitoring System) allows user to determine high accuracy positioning, provided by an integrated navigation system. The main positioning component is a Differential GPS system while D/R is used as a complementary one. Navigation information is obtained after positioning is optimized through the integration of DGPS and D/R using Kalman filtering. Additionaly,

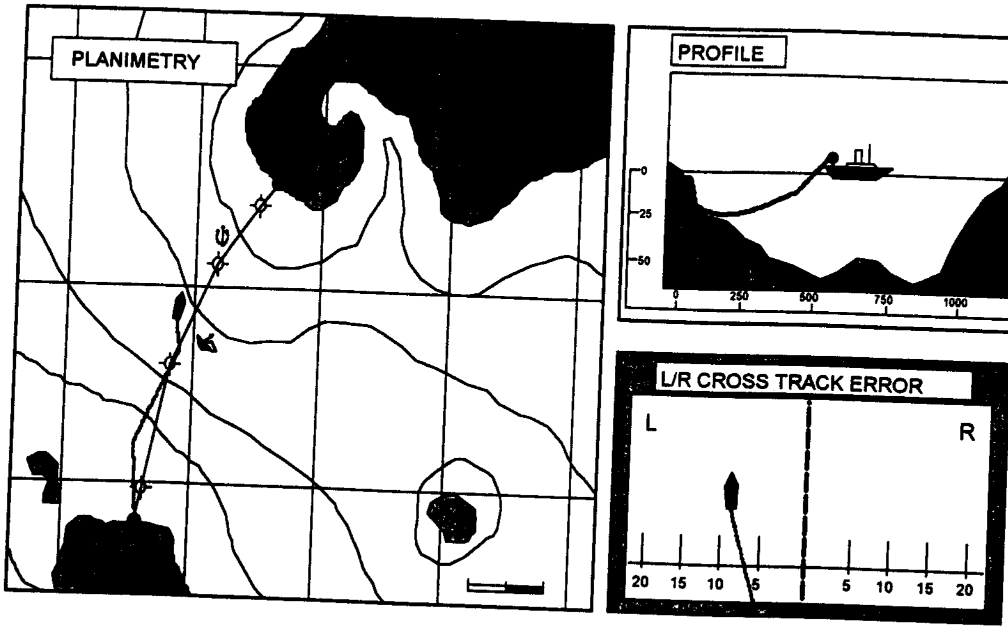

Figure 4 The three graphic windows of CLMS.

CLMS inputs continously cable's dynamic parameters through a suitable tracking device. This information is used to control those parameters while laying. The whole system functions in real time mode, handling a large amount of information flow which is coming in it at the highest possible rate. Thus, it is essential for its full exploitation have it registered in the most suitable way. For this reason the system uses the friendly environment of a GIS platform for information capture, retrieval and presentation.

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APPENDIX

CATEGORY	OBJECT	GEOMETRY	ATTRIBUTE	ANNOTATION
1. POSISIONING	FIX	POINT	LATITUDE/LONGITUDE/DEPTH	LATITUDE/LONGITUDE/DEPTH
			VELOCITY/HEADING	VELOCITY/HEADING
			ROUTE	ROUTE
			TOTAL DISTANCE IN ROUTE	TOTAL DISTANCE IN ROUTE
			DISTANCE MADE GOOD	DISTANCE MADE GOOD
			TIME TO DESTINATION	TIME TO DESTINATION
			DISTANCE TO DESTINATION	DISTANCE TO DESTINATION
			FROM/TO WAY POINT	FROM/TO WAY POINT
			BEARING TO NEXT WAY POINT	BEARING TO NEXT WAY POINT
			DISTANCE TO NEXT WAY POINT	DISTANCE TO NEXT WAY POINT
			L/R CROSS TRACK ERROR	L/R CROSS TRACK ERROR
			DATE/TIME	DATE/TIME
	WAY POINT	POINT	NAME	NAME
			LATITUDE/LONGITUDE	LATITUDE/LONGITUDE
			ROUTE	ROUTE
			DISTANCE BETWEEN WPs	DISTANCE BETWEEN WPs
			HEADING BETWEEN WPs	HEADING BETWEEN WPs
2. TOPOGRAPHY	COASTLINE	POLYGON	LAND/SEA	ISLAND's NAME
	GEOMORPHOLOGY	POLYGON	ROCKY/SANDY	
	WARNING	POINT	ANCHOR/REEF/SHOAL/CABLE SHIPWRECK	
	SEAFLOOR RELIEF	ANALYTICAL SURFACE	INTERPOLATION ALGORITHM	
	DEPTH CONTOUR *	LINE	DEPTH	DEPTH
	SLOPE CONTOUR *	LINE	SLOPE	
3. SPECIAL CHARACTERISTICS	SEA CURRENT	POINT	VELOCITY	VELOCITY
			DIRECTION	DIRECTION
	CABLE	POINT	TENSION	TENSION
			INCLINATION/DIRECTION	INCLINATION/DIRECTION
			LENGTH/SLACK	LENGTH/SLACK
	TOUCH POINT	POINT	LATITUDE/LONGITUDE/DEPTH	LATITUDE/LONGITUDE/DEPTH

* These objects are extracted from the analytical surface model of the seafloor relief.