Development of a switched-beam, digital acoustic radar: an object oriented modeling and design approach

T.J.LIASKAS, D.MARTAKOS and G.J.STEPHANOU
Department of Informatics
National and Kapodistrian University of Athens
Panepistimioupolis, Ktiria TYPA, GR-15784, Athens,
GREECE

Abstract: - The Object Modeling Technique (OMT) has been adopted, during the processes of designing and developing a switched-beam, digital acoustic radar system (SBEDAR). Models of the system in all three levels required from the OMT are presented. Following these models, a design architecture based on the principle of reusability in both hardware and software level has been developed. An experimental prototype device, based on this architecture has been implemented and is being used in experiments. Successful tests of the device's operation have shown the validity of the models presented here. CSCC'99 Proceedings, Pages:6561-6565

Key-Words: OMT, modeling, state machine, dynamic model, digital, switched-beam, and acoustic radar

1 Introduction

Systems based on acoustic remote sensing are used for measuring parameters of the Atmospheric Boundary Layer (ABL). McAllister ([8]) presented the first device of this kind. The technological progress and the interest of scientists effected the development of a variety of devices better known as acoustic radars or sodars ([8], [9]). Current trend in sodars development is towards high frequency compact systems ([1], [2]) and usage of phased-array technologies ([3], [7]). A comprehensive historical evolution of acoustic radars, from a designer's point of view, in conjunction with the technological progress is presented in [6]. Progress mainly concerns improvement of features like the maximum sounding height, reliability, range resolution, expansion of set of measured parameters etc. Generally, every effort resulted in a new device, constructed from the scratch, in order to embed improvements like those listed above.

In this paper we introduce a design architecture and present a resulting system, based on Object Oriented Modeling and design Technique (OMT), overcoming the mentioned problems and offering the following advantages:

- Menu driven system set-up and configuration of the required parameters
- Flexibility on the number (up to 961) and type of elements constructing the array antenna and the selection of radar’s operating parameters
- Integration of data acquisition, storage, on-line processing and results presentation processes

The design architecture, based on the principle of reusability in both hardware and software level, has resulted in the implementation of a switched-beam digital acoustic radar system (titled SBEDAR), developed in the Department of Informatics. The overall system has been successfully tested in laboratory and has performed the first measurements in the ABL. Results of these measurements are presented in another work.

2 Object Oriented Design Aspects

A model is an abstraction of something, for understanding it before building it. The Object Modeling Technique (OMT) ([11]) used here, is a methodology for object-oriented development and a graphical notation for representing object-oriented concepts. The methodology consists of building a model of an application domain and then adding implementation details to it, during the design of a system. The OMT methodology uses three kinds of models to describe a system: The object model, the dynamic model and the functional model.

The **Object model** describes the structure of objects in a system: their identity, their relationships to other objects, their attributes and their operations. The object model provides the essential framework to which the two other models, the dynamic and functional, can be placed.

The **Dynamic model** describes the aspects of a system concerned with time and the sequencing of operations/events that mark changes, sequences of events, states that define the context for events and the organization of events and states. The dynamic model captures control, that aspect of a system that describes the sequences of operations that occur, without regard for what the operations do, what they operate on, or how they are implemented. It is graphically represented with state diagrams. Each state diagram shows the state & event sequences permitted in a system, for one class of objects. Actions in the state diagrams correspond to functions from the functional model; events in a state diagram become operations on objects in the object model.

The **Functional model** captures what a system does, without regard for how or when it is done. It describes the data transformations within a system and contains Data Flow Diagrams.

Object oriented development may take more time than conventional development, because it is intended to promote future reuse and reduce downstream errors and maintenance. Subsequent iterations of the object-oriented development are easier and faster than with the conventional ones, because revisions are more localized. Furthermore, less iteration are usually needed because more problems are uncovered and corrected during the development phase.

3 Operation of the SBEDAR system

A fully programmable, modular, switched-beam sodar system, has been developed (in an experimental prototype stage) in the Department of Informatics. The new architecture and the resulting SBEDAR system are based on Hierarchical Object Oriented Design principles.

The architecture allows without modifications in the support electronics ([6]), changing the antenna or using the system with the same antenna in different configurations (monostatic, switched-beam etc). This is achieved by proper programming of the digital interfacing signals. The device responsible for programming the interface signals is the beamformer. The features of the beamformer have been specified from the theory of beam switching for acoustic arrays ([10]) and the analysis of the errors in the beam switching direction, due to analog and digital phase differences ([4]). The digital device resulted, follows the design architecture presented in ([7]) and is actually a pattern generator device ([5]).

The SBEDAR system is able to operate in one of the following modes: monostatic, switched-beam tristatic, and switched-beam multistatic. System's features grouped in two main sets, the general ones, which the architecture allows and the currently selected and implemented, are presented in Table 1.

The operation of SBEDAR (as almost all sodar systems) is controlled by the radar control signals (fig. 1), valid for every radar system in general. The three digital signals titled TRANSMIT, RECEIVE and RAMP_CTRL are used for controlling the transmission, reception and ramp-shaped variable gain amplification operations. System is performing the corresponding operation while each of them is in HIGH logical state.

Since the whole system is programmable, an extra digital signal titled MASTER, has been introduced to switch the system between two

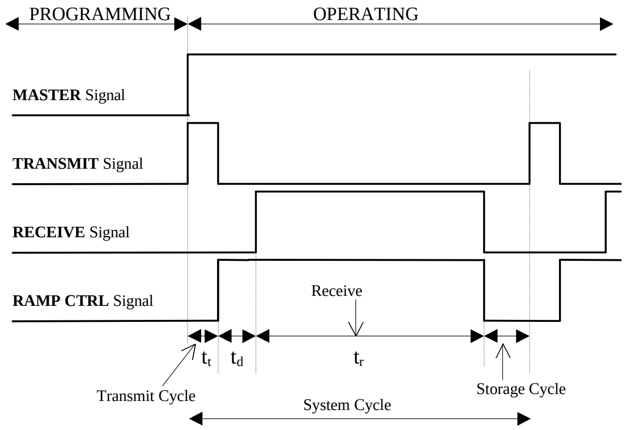

Fig.1:Signals controlling the operation of SBEDAR

possible main states, PROGRAMMING and OPERATING. During programming, data and commands are downloaded from the computer to system's memory. These data and commands are used to control the system while operating.

Timing sequence of signals is also presented in fig.1. The TRANSMIT signal remains in High state for a duration of t_t. The RECEIVE signal remains in High state for a duration of t_r. Between transmit and receive operations the system is idle for a duration of t_d, expecting the antenna to stop reverberating. Data are collected by sampling the received signals at the antenna, during reception and are stored after the reception operation is completed.

4 Object Model of the system

The Object Model of the SBEDAR system is presented in Fig.2. The graphical notation of OMT is fully adopted for presenting this model.

The whole system is a collection of the objects presented in fig. 2. It is constructed of three object classes, the computer, the support electronics and the antenna. The computer class needs no further analysis. The antenna is constructed from one or more active elements (tweeters) and an optional shielding. The support electronics object class is constructed from the beamformer, transmit modules, receive modules and (one or more) T/R switches.

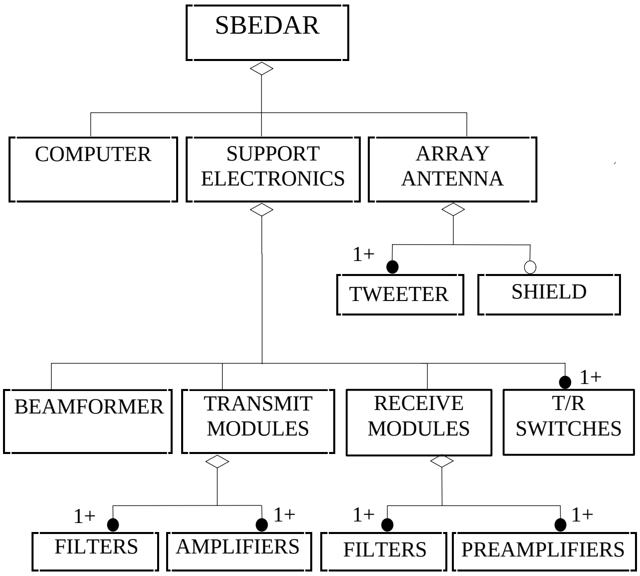

Fig.2: Object Model of the SBEDAR System

These T/R switches are used to switch the elements in the antenna between transmit/receive operating modes. The transmit modules object is constructed from a multiplicity of filters (low pass ones). The receive modules object is constructed from a multiplicity of filters (band pass ones) and low noise preamplifiers. Note that every multiplicity (the symbol "1+") in the above model, should refer to the same number of constructing objects (i.e. if an antenna consists of 25 tweeters, then there should be 25 preamplifiers, 25 T/R switches etc).

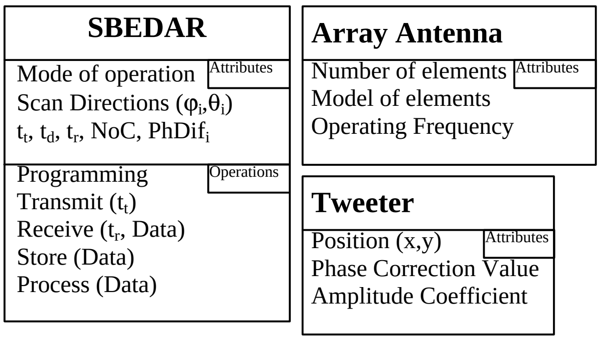

Fig.3: Detailed presentation of some classes from the Object Model

A detailed description of the most important objects of this model, along with their attributes and operations, are presented in Fig.3. The SBEDAR system, as an object itself, should have values for the attributes of: transmission duration t_t, delay time after transmission t_d, reception duration t_r, Number of Operating cycles NoC and set of phase differences PhDif$_i$ needed to point the beam to the desired direction(s). The Operations on this object are the: Programming, Transmit, Receive, Store and Process. The 'mode of operation' is the most important attribute, since it is controlling the whole system's operation. The sodars constructed up to now had architecture permitting only one mode and here is laying the tremendous difference of the SBEDAR system. The mode can be changed to the desired one, without any system modification, through programming of the proper signals ([6]).

The Array antenna has attributes of Number and Model of elements and Operating frequency. The values of these attributes are responsible for the performance of the antenna and subsequently of the whole system. Every element of the antenna is an object having attributes of Position (of placement in the antenna), Amplitude coefficient (for tapering) and Phase correction value (for eliminating the errors due to random phase differences among tweeters ([4]).

5 Dynamic Model of the system

The operation of the system may be described as a sequence of transitions between states. These transitions are due to the change in the level of the radar signals, as it has been described in Section 3. The dynamic model (as required by OMT) of SBEDAR system, which may be seen as a state machine, is presented in Fig.4.

The system starts operation with 'Power on'. This transition drives the system in a Random State, due to the solid state electronics startup. The dotted line used declares that the system remains in this state for a total time depending on the system's boot procedure. All precautions are taken to eliminate the risks of the system remaining in this state.

An initialization signal (INLZ) causes the transition to a clearly defined normal state (ready to be programmed) and the system remains IDLE. The user is now able to select the operating parameters from the menus provided. Upon completion of the selection, the computer downloads the proper values to the memory of the system. All these operations are grouped and form the "Programming State". This state is drawn with dotted line to declare that the system remains there for a total time depending on user. By setting the MASTER signal High, the system transits to the 'Programmed' state and is ready to operate as Radar. Monostatic operation may be regarded as transition from 'Store Data' state to 'Transmit ' state (there is no need to any extra programming. Multistatic operation may be regarded as transition from 'Store Data' state to 'Programming' state, since the data needed to switch the system in the next operating direction have to be used. Upon completion of the whole operation (i.e. the desired number of operating cycles has been

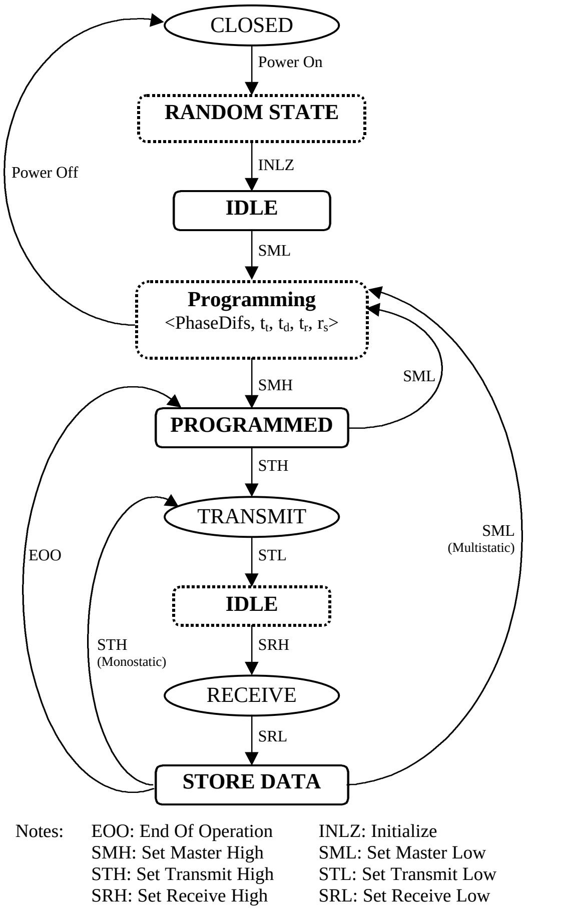

Fig.4: The SBEDAR System as a State Machine

reached, coded as EOO) the system automatically transits to the programmed state.

6 Functional model of the System

All processes relevant to selection of operating parameters, handling of the signals received during operation (i.e. data acquisition) and processing of these measurements are presented in Fig.5.

First, values for the operating parameters according to the desired mode of operation are selected through relevant menus and stored in a file named 'Experiment Parameters'. These values are used to program the beamformer, by downloading them to its memory, during the programming process. According to the values controlling the timing operations, the system operates and collects measurements, which are stored in the sequential data file. For each cycle of operation, the measurements are used to form a block, which is stored in the hard disk. A record constructed from the parameters of the system during the current cycle of operation is also stored in another file, titled LOG_FILE. Each record of this file is used during data processing or presentation, for tagging the data block. The data collected may be processed on-line or off-line, for getting the results. This processing is the extraction of the mean wind velocity, through Doppler frequency estimation, or the intensity of the

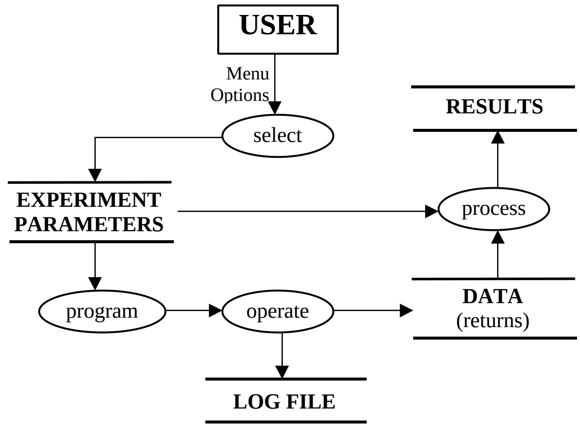

Fig.5: Functional model of SBEDAR system

returned signal for facsimile graph presentation. The Doppler frequency estimation is done by FFT or SHCC method ([3]).

7 Conclusions

The models of a switched-beam, digital acoustic radar system in all three levels required by the OMT are presented. Following these models, a design architecture has been developed, based on the principle of reusability in both hardware and software level. An experimental prototype system implementing this architecture, titled SBEDAR has been constructed.

Successful tests of the whole system's operation have shown the validity of all the models and the analysis presented here.

TABLE 1: General and implemented features of the SBEDAR System

SYSTEM	GENERAL ARCHITECTURE FEATURES	IMPLEMENTED FEATURES
Antenna	Independent control on up to 31 individual elements or up to 31 groups of elements (maximum 31x31=961 elements in a row-column mode)	25 Motorola KSN1078 tweeters, placed as a planar 5x5 array Individual element control
	Amplitude tapering on elements	Natural tapering
	Elements' phase error corrections	Cancellation of measured differences
	Acoustical Screening	Screened with sound absorbing material
	1000s of beam-switching directions to select from ([4])	Scan beams tilted up to 30º from vertical, for the shielding used.
	Beamwidth depending on beam direction and configuration	Vertical Beam: 18º Beam tilted at 23º from vertical: 20º
	Maximum Power transmitted (electric)	25W
Support Electronics	Programmable Transmit Duration	t_t= from 9.6ms to 154ms in steps of 9.6ms
	Programmable Receive Duration	t_r=from 0.3s to 4.5s in steps of 0.3s
	Programmable recovery time after transmission	t_d=30ms
	Programmable frequency of operation f_{op}	f_{op}=3.4KHz
	Programmable Receiver's Bandwidth	BW=200 Hz
Data Processing	Selectable type of data Timing Window	5 types of Time Windows (Rectangular, Triangular, Han, Tuckey, Cooley)
	Selectable Doppler shift extraction Method	2 Methods: FFT and SHCC ([3])
	Mean values calculated for time or height integration	User Selected - experiment depended
Results Presentation	On line presentation on Screen or Printer	Colour screen graphs or Simulation of usual Facsimile records on printer's paper

References:

[1] Clifford, S., Kaimal, J., Lataitis, R. and Strauch, R., Ground-based remote profiling in atmospheric studies: An overview. *Proceedings of IEEE*, Vol. 82, No 3, 1994, pp.313-355.

[2] Coulter, R., Minisodars - Applications and Potential. *Proceedings, 5th International Symposium on Acoustic Remote Sensing of the Atmosphere & Oceans*, McGraw-Hill, New Delhi, 1990, pp.88-96.

[3] Ito, Y., Kobori, Y., Horiguchi, M., Takehisa, M. and Mitsuta, Y., Development of wind profiling sodar. *Journal of Atmospheric and oceanic technology*, Vol. 6**,** 1989, pp. 779-784.

[4] Liaskas, T., Stephanou, G. and Martakos, D., Beam pointing errors of phased arrays for digital switched-beam acoustic radars. *International Journal of Remote Sensing*, Vol.15, No. 2, 1994, pp.333-344.

[5] Liaskas, T., Martakos, D. and Kayafas E., A novel design of a digitally controlled multi-channel pattern generator. *Proceedings, 7th International Symp. On Modern Electrical and Magnetic Measurement,* IMEKO TC-4, Prague, 1995, pp. 442-446.

[6] Liaskas, T., Martakos, D. and Stephanou, G., Development of a modular switched-beam digital acoustic radar, *Proceedings 8th International Symp. on Acoustic Remote Sensing of the Atmosphere & Oceans*, Moscow, 1996, pp.3.43-3.48

[7] Martakos, D., Liaskas, T. and Stephanou, G., A microprocessor based beam-forming system, for a digital switched-beam acoustic radar. *Proceedings, 5th International Symposium on Acoustic Remote Sensing of the Atmosphere & Oceans,* McGraw-Hill, New Delhi, 1990, pp.135-140.

[8] McAllister, L., Pollard, J., Mahoney, A. and Shaw, P., Acoustic sounding - A new approach to the study of atmospheric structure, *Proceedings of the IEEE,* Vol. 57, 1969, pp. 579-587

[9] Moulsley, T. and Cole R., High frequency acoustic sounder, *Atmos. Environment*, 13, 1979, pp.347-350

[10] Stephanou, G. and Mavrakis, D., Switched-beam planar arrays suitable for high-resolution acoustic sounders. *IEEE Transactions on Geoscience and Remote Sensing*, Vol. GE24, No.5,1986, pp.745-750

[11] Rumbaugh, J., Blaha, M., Premerlani, W., Eddy, F. and Lorensen, W., *Object-Oriented Modeling and Design*, Prentice Hall, Englewood Cliffs, 1991