Abstract – A new type of surface vehicle/buoy is needed for marine biological studies, physical oceanography, environmental impact assessment and integrated marine environment management. It is proposed within this document to present the development of an autonomous self-mooring vehicle (ASMV) that collects meteorological, acoustic, and physical data, while simultaneously obtains water samples for chemical analysis through mass-spectrum analysis from littoral and estuary waters. The ASMV is programmed to use and analyze the oceanographic and meteorological data in its guidance system to track and analyze a specific phenomenon. During the project several scientific surveys will be performed to test the abilities of the vehicle. For example, the assessment of the biodiversity of organisms (e.g., phytoplankton) that live at a specific region will be conducted. All operations will be completely autonomous with the exception of the high level communication between the vehicle and the operations center. The vehicle houses commercial and student designed measurement units containing instruments such as multi-chemistry analyzer, conductivity, temperature, depth gages, and a fluorimeter that detects various chemicals such as chlorophyll, rhodamine, and fluorescein.

Index Terms— Autonomous Marine Vehicle, Autonomous Mobile Buoy, Coastal Observatories, Self-Mooring Vehicle.

I. INTRODUCTION

Over the past few decades, a range of monitoring strategies and techniques has been used to monitor the sea. More recently, the role of monitoring has been expanded to include the use of autonomous vehicles to perform ocean surveys. With these vehicles it is now possible for the scientist to make complex studies on topics such as the effect of metals, pesticides and nutrients on fish abundance, reproductive success and ability to feed; or contaminants such as chemicals or biological toxins that are transported in particulate form and become incorporated into living organisms (plankton, bivalves, fishes) or deposited in bottom sediments. The scientist or environmentalist may desire to detect hazardous substances in the ocean such as the chemicals eliminated from an underwater vent or to detect toxic algae such as red tide. Additionally, the military's detection of mines, biologic, chemical or radioactive threats are also very important in the monitoring of the seas.

These considerations explain today's pressing need for a new class of autonomous vehicles with integrated sampling equipment able to perform a wide-range of fully automated monitoring surveys.

Consequently, the objective of this project is to develop a new technology to survey and monitor the sea environment in a cost effective manner where the end product will be an autonomous vehicle combining survey capabilities, simultaneous water sampling and environmental data gathering capacities that are not available on other systems. The basic system concept is a completely redesigned NOMAD buoy with the ability to pull up anchor and traverse under power to a new location and then redeploy its anchor for a new set of surveys.

The project consists of three consecutive phases: the design, development and testing of the vehicle; the technological
phase for development and integration of all scientific components (camera and acoustic systems in addition to the in situ measurement systems) into a functional tool; and the scientific phase for testing and demonstration through a series of surveys that address a variety of marine ecosystems.

The ASMV is designed specifically for the needs of the Coastal/Lagoon scientist that requires greater control over the collection of data in those regions. The vehicle has the space for a number of scientific instruments and can also be used in deep water surveys and data collection without mooring by dynamic positioning using the GPS.

The more information the scientist is able to accumulate, the better he or she will be able to determine the status of the coastal/lagoon ecosystem and document the specific ecosystem parameters. Using ASMV, pollution of ocean/coastal waters can be detected and quantified in an automated way. Thus, dangerous substances in the coastal waters can be detected earlier and their harmful effects can be dealt with quicker.

II. SCIENTIFIC PHASE

The ASMV is targeted to be used by the scientist or environmentalist for surveying and monitoring the lagoon or coastal environment with respect to geological, biological, physical and chemical phenomenon in a cost-effective manner.

To achieve this, local scientists were questioned as to their research in the Indian River Lagoon and near shore coastal regions along the Florida east coast so the vehicle could have the corresponding sensors. The topics mentioned were the monitoring of pollution & sewage outfall: biological, chemical, and mineral; the monitoring of various organism habitats and health; fisheries, fauna and flora surveys; dredging and sediment disposal; oil spills from ship or boat wreck leakage; natural resources assessment; state of the environment determination; and reduction or elimination of the use of humans in sample and data collection.

Some of the data that the scientist would like to obtain are: salinity, temperature, wind, depth, turbidity (suspended sediments), chlorophyll, digital photos or acoustic “pictures” (especially if visibility is an issue) of the bottom either via video/photo to determine bottom composition, and via plankton measuring instruments such as a fluorometer or other means to measure primary production: particle counters, lasers or some other sophisticated visual or acoustic method to break plankton down into sub-groups, and hydrophones to characterize man made and natural sounds.

As mentioned by one of the scientists, one of the most important biological groups in the life cycle of higher ocean organisms (e.g., fish) and consequently very important in the research of all marine organisms are the phytoplankton.

1 Phytoplankton are microscopic plants that live in the ocean. There are many species of phytoplankton, each of which has a characteristic shape. Collectively, phytoplankton grow abundantly in oceans around the world and are the foundation of the marine food chain. Since phytoplankton depend upon certain conditions for growth, they are a good indicator of change in their environment. Consequently, for these reasons, and because they exert a global-scale influence on climate, phytoplankton are of primary interest to oceanographers and environmental scientists [1].

Phytoplankton play a fundamental role in the ocean's biological productivity and directly impact the climate and it is important that scientists determine how much phytoplankton the oceans contain, where they are located, how their distribution is changing with time, how much photosynthesis they perform, and what organisms such as marine invertebrate larvae feed upon the phytoplankton [2].

Another important biological group that effects the life cycle of higher ocean organisms is the algae, which at times is responsible for Red Tides or harmful algal blooms (HAB). HABs occur throughout the world, affecting European and Asian fisheries, Caribbean and South Pacific reef fishes, and shell fishing along the coasts of the United States. Recently, the blooms have been proven to be responsible for the deaths of hundreds of whales, dolphins, and manatees in North American waters. These HABs are caused by several species of marine phytoplankton, microscopic plant like cells that produce potent chemical toxins. For example the Florida red tide is caused by blooms of a dinoflagellate that produces potent neurotoxins, which in turn causes extensive fish kills, contaminates shellfish and creates respiratory irritation to humans along the shore [3].

In addition to biological investigations, the chemical make-up of all areas surveyed, specifically where samples were taken, are important for the scientist to obtain a complete understanding of that region. The chemical layout and the corresponding biological data are normally for a specific transect, but this might not be on a traditional grid pattern. For example, the scientist may desire to obtain samples within a polluted area with a specific concentration of the pollution. To accomplish this mission non-traditional approaches of navigation are required to acquire the desired scientific information. Data from geophysical and acoustic sensors are combined and analyzed by a neural based navigation system that is then able to control the vehicle with respect to the chemical information supplied. Part of the research in this project is to show that changes in various geophysical parameters can be used as navigation cues. To verify this method of phenomenon based navigation detailed measurements will be made on standard transects of the site and compared. Transects will be made by the vehicle specified by the scientist and will vary according to where the organism under investigation can be found.

The results of this study will provide improved knowledge of the geophysical environment where biological samples are

2 Red tide is the result of a massive multiplication (or "bloom") of tiny, single celled algae called Karenia brevis (previously classified as Gymnodinium breve), usually found in warm saltwater, but which can exist at lower temperatures. It is a natural phenomenon, apparently unrelated to manmade pollution. In high concentrations, K. brevis may create a brownish red sheen on the surface of the water; in other instances, it may look yellow green, or may not be visible at all. Some red tides have covered up to several hundred square miles of water [3].
obtained. In addition, the characterization of this data will provide the input required to validate the use of a novel navigation method for autonomous surface operation.

Scientists at Florida Institute of Technology are currently studying the Indian River Lagoon (IRL) on the east coast of Florida in Brevard County. The IRL is one of the largest lagoon areas in the country measuring a total length of 156 miles and is the most diverse estuary in North America [4]. Marine/lagoon biological oceanography studies will collect data such as salinity, temperature, depth, chlorophyll, rhodamine, and fluorescein. A snapshot of the bottom is obtained via video/photo (when visibility allows it) and the bottom’s acoustic signature: mud, sand, vegetation, etc. The information will also be analyzed to determine local patterns of estuarine circulation and measure plankton concentrations. Instruments such as a fluorometer will measure primary plankton production and digital photo images are to be analyzed for particle numbers and to break down the plankton into sub-groups. Also planned is the implementation of a wave sensing system to be able to characterize the lagoon system.

Marine chemistry surveys will analyze suspended sediments (i.e., turbidity) and other chemical parameters (e.g., chlorophyll) along with the bottom’s sediment composition. Additionally, meteorological data will be obtained at all times and at each location to acquire key meteorological events that may contribute to the chemical and biological makeup of the Indian River Lagoon.

III. BACKGROUND

Looking at the current situation in ASMV technology, one must first look at the current method of collecting coastal and littoral information. The primary method of coastal and oceanographic data collection is through a few fixed surface buoys and in some locations coastal oceanographic observations systems (COOS) such as the California’s SCCOOS and CeNCOOS, the Gulf Coast Ocean Observing System (GCOS), or the Southeast Coastal Ocean Observing System (SEACOOS) along the southeast coast of the United States where research institutes have stationary buoys to gather data [5]. The United States coasts are monitored only sporadically by some form of coastal ocean observation system. For example, Florida has a major coverage gap that extends from Miami to Jacksonville on the coastal side with the exception of four meteorological buoys (1 near Fort Pierce, 2 near Cape Canaveral and 1 near Jacksonville). On the inter-coastal waterway the Indian River Lagoon uses volunteers to daily monitor seventeen designated sites by hand between the Sebastian Inlet to Scottsmoor just north of Titusville [6].

Automation of data collection is vital and has been the subject of many COOS papers. Buoys, stationary platforms, ships and autonomous surface and subsurface vehicles are currently being used and investigated for data collection. The authors of the ASMV project are interested in data collection through moving remotely or autonomous surface vehicles that are able to carry research and commercial instrumentation. One of these systems is the Coastal Observation’s (CoastalObs) Ocean-Atmosphere Sensor Integration System (OASIS) (Virginia, USA), see figure 2, which underwent its first sea trials on November 15th 2006 under autonomous control. OASIS, developed by the Center for Innovative Technology, the National Aeronautics and Space Administration Wallops Flight Facility and the National Oceanic and Atmospheric Administration, is to “serve as a platform for operating any number of oceanographic and meteorological instruments. It is powered by solar panels and an electric motor, and can reach speeds in excess of three knots and is controlled remotely by satellite communication” [7]. The 18-foot long, 8-foot wide, 3000-lbs OASIS vehicle is able to achieve 2.5 sustained knots. The vehicle has a fully dynamic autopilot system with GPS positioning, Iridium satellite modem, freeware radio and wireless communication links and a payload capacity of over 500-pounds. Additionally, it has an IAS system on board to support active ship avoidance offshore [8].

Another system is the Robotic Marine Systems’ small autonomous surface craft, SCOUT (Gray, Maine, USA), see figure 3. The vehicle is a 10-foot long kayak consisting of a “main vehicle computer, battery system, propulsion and steering systems, radio control and Wifi communications system, GPS, compass and payload expansion slots” [9]. The SCOUT has a cruise speed and maximum speed of 3 and 5-knots respectively and an 8 hour duration.

The U.S. and other Navies are also “seeking ideas and solutions for unmanned Surface Vehicles (USVs)” [10]. For example Elbit Systems unveiled its new Unmanned Surface Vehicle (USV) “Stingray,” which is “equipped with autonomous navigation and positioning capability, cruise sensors, and a stabilization system which prevents capsizing. The Stingray can carry payload weight of up to 150-kg in two
watertight sealed compartments. It is also equipped with day and night electro-optical stabilized payload” [11]. Elbit Systems also unveiled the Silver Marlin “an autonomous, medium-sized Unmanned Surface Vessel (USV) featuring autonomous obstacle avoidance sensors and controls. The vessel is designed for autonomous, over-the-horizon operation, employing various sensors, and weapon systems on patrol, intelligence and littoral warfare missions” [12].

After analyzing the surface vehicle technology the scientists at Florida Institute of Technology determined that an inexpensive, easily transportable science research vessel was necessary, especially with the capabilities to weigh and deploy an anchor, be able to remain indefinitely on site, use cell phone technology to communicate with other vehicles and the home-base while also being able to track a unique event or property through the use of a neural network navigation system.

IV. TECHNICAL PHASE

The design of an ASMV that is capable of obtaining biological/water samples and specify the environmental characteristics of the data field must possess devices to obtain the samples and possess a wide array of traditional oceanographic instruments that are useable by the vehicle’s control system to make navigational changes.

The oceanographic instruments and sensors will be combined into a scientific measurement module and integrated with the photographic/video and acoustic signal data that is stored on a local hard disk and marked with the identical time stamp. The data obtained from these instruments will then be used as inputs into the control system, aiding to the control of the vehicle in the region under investigation.

Autonomous vehicles are controlled by various techniques depending upon the vehicle's application: traditional feedback control systems, state-space, adaptive, switching control, neural networks, and fuzzy-logic. Of these, the traditional feedback control system is used primarily, since their missions are often the execution of a pre-programmed path with very little on-board intelligence (e.g., obstacle avoidance and appropriate fail-safe modes).

The ASMV primarily uses a traditional feedback (see figure 4) and a neural network control system (see figure 5) that will soon be implemented. The traditional feedback system is used for most typical surveys and will switch to the neural network system for multi-sensor information fusion using the data from the scientific instruments.

The design of the vehicle was based on the following:
• Transportable design: easily towed on a small Jet Ski trailer or carried in the back of a pickup truck.
• Quick assembly & disassembly of the vehicle components.
• Space for scientific & instrument payloads.

Additionally, a number of problems that need to be solved by the intelligence of the vehicle’s computers are:
• To determine an optimum transit trajectory to a pre-defined location within a few meters of absolute positioning.
• Identification of hazards underway and on site.
• Determine the target's relative position track in order to obtain an optimum approach trajectory.

V. TECHNICAL OVERVIEW

General Vehicle Design

The ASMV (made of 50-52 H32 and T6 marine grade aluminum) has a fundamental concept based on the NOMAD buoy. The vehicle is designed for easy transport, assembly, disassembly, and servicing. Furthermore, there is easy access to the batteries and the vehicle control system and scientific containment housings. The vehicle’s specifications are:
• Dry weight: 388-lbs (176-kg).
• Displacement : 570-lbs (258.5-kg).
• Length: 7-ft. (2.13-m)
• Beam: 3-ft. (0.91-m)
• Max. Height with weather station: 7-ft 10.5-in (2.40-m)
• Max. height without tower: 2-ft 8.5-in (0.83-m)
• Draft: 13-in (0.33-m)
• Total Wetted Surface Area: 16.5-ft² (1.53-m²)
• Theoretical Hull Speed: 6 ft/s (1.83-m/s)
• Design Speed: 4-ft/s (1.22-m/s, 2.73-mi/hr, 4.39-km/hr, 2.37-Knots), derived from the amount of power needed for the vessel to travel efficiently on its designed two-mile transects.
• Max. Anchoring Depth: 33-ft (10-m) based on the maximum design depth for safe mooring with a 100-ft (30.5-m) anchor line.

Propulsion - The vehicle is equipped with two 12-volt longitudinal thrusters capable of producing 30 to 50 lbs of trust each with an individual maximum 30-Amp draw. The thrusters are asynchronous 3-phased with an estimated motor.
run time based on the manufacture's published data (i.e., 0.85 * (Battery Amp Hour Rating) = (Hours of Running Time) * (Motor Amp Rating)) and running at an optimum speed between 4 to 6-ft/sec.

**Battery and Power Management** - The battery system is composed of three 50 Amp-hour 12 Volt Deep Cycle Gel Marine batteries where each propulsion thruster draws 14.32-Amps for sea conditions of two-foot wave heights, four-foot wavelengths, and fifteen-knot winds heading into the bow. Consequently, a two mile transect traveling at 4-ft/sec (2.73-mi/hr, 4.39-km/hr) along with raising and lowering the anchor will use 22.5-Amp-hours from the batteries. During this time 2-Amp hours at 12-VDC will be used for instruments and computers. This leaves a total of 125.5-Amp-hours to power the thrusters, computers, and instruments in extended transects, for dynamic positioning (in cases where anchoring is not possible, e.g., in environmental sensitive areas or locations deeper than anchor depth), or as reserve during cloudy days.

The batteries were chosen for their ease of operation, longevity, and recharging cycles, which greatly extend the vehicles operating range when compared with any other type of battery. The amount of electrical energy allows approximately 7.5 hours of continuous operation in calm conditions and approximately 5 hours in 2-ft seas with 15 knot winds. Both conditions were calculated at 4-ft/sec.

The recharging of the batteries underway and when on station is accomplished by two General Electric 30-watt photovoltaic panels that recharge at an average of 3.6 Amps per hour. When the buoy is moored, the electronics draw 1-Amp at intervals for data collection. Whereby, the battery can then charge at least 3-Amps per hour. Estimating the average amount charging time per day to be 4 hours, approximately 12-Amps per day will be recharged. Consequently, with these conservative estimates only one transect every two days can be planned for indefinite operation.

**Anchor System** - The anchor system consists of a Minn Kota Deckhand 40 (i.e., 40-lb lift capacity) anchor winch with 100-ft of 800-lb test nylon rope that is easily capable of lifting the Minn Kota 18-lb Crab Claw anchor with a movable ballast system that adjusts for different floor conditions specified for the vehicle.

**Communications** - two different communication methods are used:

1) Through a 802.11b Wireless Ethernet (WLAN) card for communications between the ASMV and a host PC allowing wireless communications with the ASMV while at the surface. This module can be configured for one-to-one communications with another WLAN card installed in a field laptop, or with a Wireless Network Access Point, giving the ASMV the ability to join a Local Area Network (LAN) and gain access to Internet resources.

2) An Arcom W-E-B Telemetry integrated cellular modem for communication with the home-base for mission updates and data downloading.

**Navigation** – The navigation process uses a EZ-Compass 3 Digital Compass module which also serves as a roll/pitch sensor and a differential EM-406 GPS receiver. The depth is determined by a UA-2 altimeter from J.W. Fishers Mfg., Inc. These altimeters have the pulse generation and return detection circuitry in the transducer to depths of 100 feet (30 meters).

**Control System and Supervision** – The whole system is managed by a control and supervision system that was developed using very standard Windows-based tools. As mentioned previously, the control of the vehicle will be a combination of a traditional feedback and a neural network control system depending on the navigational task. Standard grid pattern surveys use the traditional, while chemical or physical trace mapping would use the neural network control system.

**Collision Control System** – The operation of this prototype vehicle is primarily in lagoon and shallow water regions. This consequently presents many opportunities for potential collision hazards (e.g., recreational boats, navigation buoys and poles, fishing floats, floating debris and in Florida: manatees and alligators). Below the water’s surface the depth altimeter and a similar forward facing sonar unit will be the primary subsurface collision sensor. The propellers will be fitted with protection and flow nozzles to keep from harming manatees or alligators. Above water, a rotating acoustic sensor will focus on near (within 10 meters) collision obstacles. A digital camera will be mounted to take photos in direction of travel. These picture will be evaluated by software object detection algorithms for potential collision possibilities.

**Scientific Instruments**

The purpose of the autonomous self-mooring vehicle is to monitor the environment. Consequently, the selection of the sensor payload is important, so the vehicle was designed as an autonomous platform that can be adapted for various data collection missions simply by changing the sensor payload. The scientific instruments pass their data to the PC based computer for storage on a local hard disk. Some of the data to be collected are: wind speed and direction, current speed and direction, wave height and periodicity, air and water temperature at varying depths, chemical composition such as salinity, biological composition, particularly the density of chlorophyll-A, and visibility/turbidity.

The First primary sensor is the “Smart CTD” sensor package, manufactured by Applied Microsystems, Ltd., and the add-on Infrared Light-Scattering Turbidity Sensor (LSS) from WetLabs, Inc. These sensors are mounted on a bracket on the rear of the vehicle with the LSS attached such that it has a clear visual path into the water column.

**Weather Station** - The Davis Weather Monitor II weather station was installed for basic meteorological measurements and is currently the only instrument onboard for meteorological data acquisition with an anemometer, external temperature, humidity and pressure sensors.

**Acoustic Hydrophones** are used to obtain an acoustic signature of all acoustic activities within the frequency range of the hydrophones (7-Hz to 22,000-Hz).

The AQUAtrack III, (soon to be installed) is a compact, lightweight, submersible fluorimeter for the detection of dye tracing, turbidity or chlorophyll-a. When connected to the CTD sensor the fluorimeter will provide measured values of Chlorophyll, Rhodamine, Amido Rhodamine, and Fluorescein. Applications: Chlorophyll-a and other fluorophor detection, Rhodamine and fluorescein dye tracing, particle concentration.
by light scattering, profiling, pollution monitoring, biogeochemical oceanography.

This instrument can sense chemical fluorescence or light scatter in the visible and near infrared (400 to 800-nm). Versatility is achieved by the selection of appropriate optical narrow bandpass filters to match the excitation and emission wavelengths of the fluorophor, e.g., chlorophyll-a, rhodamine or fluorescein. It may be configured as a nephelometer by using the same band pass filters for both excitation and emission.

The UV-VIS Spectrometer (soon to be installed) is a general-purpose miniature fiber optic spectrometer for absorbance, reflectance and emission measurements. Ultraviolet (UV) and Visible (VIS) light can cause electronic transitions. When a molecule absorbs UV-VIS radiation, the absorbed energy excites an electron into an empty, higher energy orbital. The absorbance of energy can be plotted against the wavelength to yield a UV-VIS spectrum. UV-VIS spectroscopy has many uses including component detection. See [13] for a more detailed explanation.

Computer - The Central Processing Unit (CPU) Housing is the “brain” of the vehicle; running all control, mission planning, and data-logging software. This “command center” ties all of the vehicle subsystems together. For the ASMV vehicle, a PC/104+ form factor was chosen. The main PC/104 stack consists of a Pentium-based single-board computer (SBC), serial port expansion card, 802.11 wireless Ethernet card, power supply, and hard drive.

Internal Communications - Internal communications with sensors, weather station, navigation system, motor drivers, etc., is achieved through an RS-232 serial network with 10 standard RS-232 serial ports (also configurable as RS-485 or RS-422). The advantage of this system includes the ability to add additional serial expansion cards to the PC/104 stack, and ease of interfacing with PIC Microcontrollers (DC Thruster Controller Boards and weather station). With the use of only standard ASCII text strings for data transfer, the software and hardware development is simplified and adds to the overall robustness of the system. Furthermore, commercial devices such as the on-board compass and CTD, readily offer RS-232 communications, simplifying future instrument additions.

External Communications - In order to set mission parameters, execute on-board software, and download data, a means of external communication with the vehicle is necessary. When the PC/104 stack is exposed, the CPU has the ability to directly connect to a standard keyboard, monitor, and mouse, as well as to floppy and CD-ROM drives. This is the simplest means of communication for making major changes and debugging problems.

However, when the stack is sealed in the CPU housing, access is limited. In order to eliminate the need for hard-wire communications and multi-pin waterproof bulkhead connectors, a low-cost 802.11b Wireless Ethernet (WLAN) card was selected for communications between the vehicle and a field laptop with a WLAN card.

Control Software - Ultimately, all datalogging, navigation, motor control, and mission planning functions take place on the main CPU. In the case of the ASMV, the Microsoft Windows 2000® Operating System was chosen for ease of use, availability, and rapid prototype development. In the future, the AUV’s software may be ported to a Real-Time Operating System, for increased robustness and real-time compliance.

The high-level vehicle software program was written in National Instruments’ LabVIEW®. This single, multithreaded application provides all necessary data acquisition, control, logging, and user interface features necessary to run the vehicle. The use of LabVIEW® was also chosen for its rapid prototyping capability, ease of use, and powerful hardware integration features.

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