An Experimental Testbed for Mobile Offshore Base Control Concepts

Anouck R. Girard[1], Daniel A. Empey[2], João Borges de Sousa[3], Stephen C. Spry[4] and J. Karl Hedrick[5]

The University of California at Berkeley

ABSTRACT

The concept of a Mobile Offshore Base (MOB) reflects the United States' need to stage and support military and humanitarian operations anywhere in the world. A MOB is a self-propelled, modular, floating platform that can be assembled into lengths up to 2 kilometers, as required, to provide logistic support of U.S. military operations where fixed bases are not available or adequate. A MOB would house personnel, accept cargo from rotary and fixed wing aircraft and container ships, maintain equipment, and discharge resources to the shore via a variety of surface vessels and aircraft. (Taylor and Palo, 2000).

In most concepts, the structure is made of three to five modules, which have to perform long-term station-keeping in the presence of winds, waves and currents. This is usually referred to as Dynamic Positioning (DP). In the MOB, the alignment is maintained through the use of thrusters, connectors, or a combination of both. In this paper, we consider the real-time control of scaled models of a MOB. The modules are built at the 1:150 scale and are kept aligned by azimuthing thrusters which are commanded by a hierarchical hybrid control scheme.

This paper describes a physical testbed developed at the University of California, Berkeley under a grant from the Office of Naval Research, for the purpose of evaluating competing MOB control concepts.

Keywords: Mobile Offshore Base (MOB), Physical Testbed, Real-Time Control Systems, Distributed Control Systems, Hybrid Systems.

INTRODUCTION

A Mobile Offshore Base (MOB) is intended to provide forward presence anywhere in the world. It serves as the equivalent of land-based assets, but is situated closer to the area of conflict and capable of being relocated. In operation, it would be stationed far enough out to sea to be easily defended (Taylor and Palo, 2000). As presently envisioned, a MOB is a self-propelled, floating, prepositioned base that would accept cargo from aircraft and container ships and discharge resources to the shore via a variety of surface vessels and aircraft (Remmers and Taylor, 1998). All platforms would provide personnel housing, equipment maintenance functions, vessel and lighterage cargo transfer, and logistic support for rotary wing and short take-off aircraft. The longest platform (nominally 2 kilometers in length) would also accommodate conventional take-off and landing (CTOL) aircraft, including the Boeing C-17 cargo transporter (Polky et al., 1999).

The effort of the University of California, Berkeley and California PATH is part of the MOB technical base effort devoted to determining the feasibility of dynamic positioning of multiple MOB platforms, as described in

[1] **anouck@eecs.berkeley.edu, Ocean Engineering Graduate Group, 230 Bechtel Engineering Center #1708, Berkeley, CA, 94720-1708**

[2] **empey@path.berkeley.edu**

[3] **sousa@eecs.berkeley.edu**

[4] **sspry@newton.berkeley.edu**

[5] **khedrick@me.berkeley.edu**

(Remmers and Taylor, 1998). In this project we have developed an automated multi-module dynamic positioning control system for the MOB, and a simulation template to uniformly support DP control systems testing and evaluation. The virtual demonstration consisted of the simulation of several different MOB control methods under a set of environmental conditions, and we compared control system performances using an evaluation toolkit that was also developed during the project. The interested reader is referred to (Sousa et al., 1998) and (Girard et al., 2001).

Under this project the team was also tasked to physically validate the key design issues with scale models of the MOB. This paper will concern itself with a description of the physical experiments that have been conducted to date using this testbed.

The next two sections of this paper present an overview of the MOB control testbed and fundamental control concepts for the MOB. The final section will discuss MOB control techniques and results obtained from the physical testbed.

MOB CONTROL TESTBED

The PATH (Partners for Advanced Transit and Highways) Program at UC Berkeley has developed a 1:150 scale physical model of a generic Mobile Offshore Base (MOB) concept. This concept utilizes three or more independently operable deep-sea going semi-submersible platforms that are used in conjunction with one another to create a stable sea based runway for large cargo and other aircraft. The model consists of three 6' x 2.5' independent floating "modules", each equipped with four controllable (azimuth and thrust) thrusters and sensors to indicate both "global" and relative position. The models are operated in a 50' x 100' x 2.5' deep tank, located at the UC Berkeley, Richmond Field Station. The system is controlled by a real-time computer system located at the side of the tank.

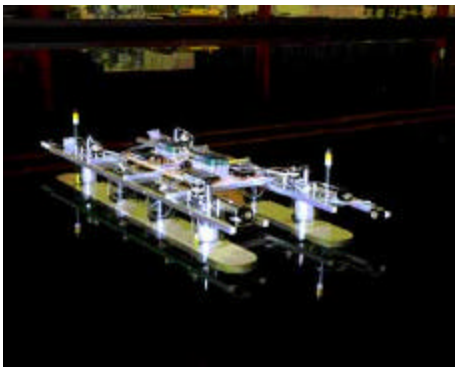

Figure 1. Scaled MOB Modules

Scaled MOB Modules

The heart of the MOB physical model is the 1:150 scale module, constructed from closed cell foam, acrylic plastic and aluminum tubing. The scale module is base on a full sized "generic" module developed by researchers at the US Naval Academy. The scale module is 6 feet long, 2.5 feet wide has a draft of about 8 inches, and weighs close to 200 lbs. One module is shown in figure 1. Each module is equipped with four azimuthing thrusters, one mounted at each "corner". These thrusters were designed and fabricated at UCB and represent true scale representation of the actual thrusters that would be used on full-scale modules (Spry et al. 2001). On each thruster, a variable-speed ducted propeller driven by a dc servomotor produces a variable thrust level while a stepper motor controls the azimuth of the unit.

Figure 2. Scaled Thruster for the MOB Control Experiment.

Visually, the most impressive feature of the models is the thruster indicator mounted on top of each of the

thrusters. When in operation, a red LED "bar-graph" indicates the direction and magnitude of the thruster force vector. The tests will be videotaped from above, and the indicators will allow the video to be used as a first order of magnitude check of the system function. The indicators also give a quick visual reference as to what each module is doing and are quite useful for troubleshooting.

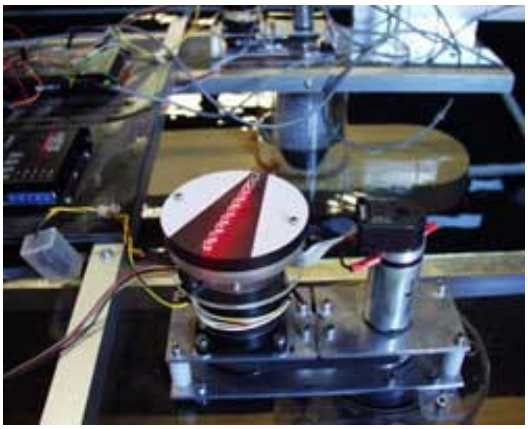

Figure 3. Thruster Indicator.

The modules are equipped with both absolute and relative position sensors. The absolute sensor system consists of a laser beacon/position transponder system using two "shore" mounted rotating laser beacons and two position transponders on each module. This system measures the position of the position transponders relative to the fixed beacon baseline on the side of the tank. Because there are two transponders on each boat the position and orientation of each module can be determined in a fixed coordinate system. The accuracy of the system is approximately ±2 cm.

The relative position measuring system consists of six ultrasonic sensors, three for each "gap" between the modules, which measure both longitudinal and lateral separation of the modules. The accuracy of this system is about ±2 mm.

Computer Control System

The scale modules are controlled from the "shore" of the tank by a network of computers. The control signals are passed to the modules via an overhead "umbilical" one to each module. The computer system is composed of four computers, one that interfaces directly with the hardware and three that run the complex control algorithms. The interface computer is equipped with digital and analog I/O boards that connect to the modules via the umbilical cables; this computer in turn is connected to the other three computers with serial and Ethernet links. All of the computers run the QNX real-time operating system.

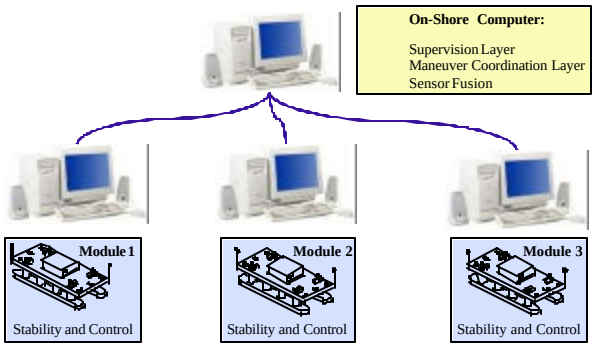

Figure 4. Computer Control System.

Test Facility

The system is operated in a large indoor tank of about 50' x 100' x 2.5' deep. This facility allows the testing of the small-scale models in the absence of outside disturbances such as wind, but will also provide the opportunity to inject know disturbances into the system and measure the response.

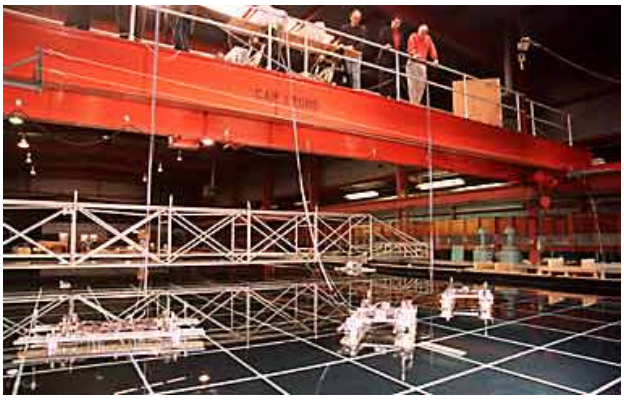

Figure 5. UC Berkeley Test Facility. Three modules are being operated from the bridge. The central computer is located on the bridge, and the umbilical cables that connect the central computer to the modules are visible on the picture.

CONTROL CONCEPTS FOR THE MOB

In order to achieve support air and sea operations, the MOB is required to

1. assemble at sea,

2. remain aligned and assembled to allow for landing of aircraft and cargo transfer from ships,

3. align in the wind to facilitate the landing of aircraft,

4. disassemble if the environmental conditions become to severe or in case of emergency.

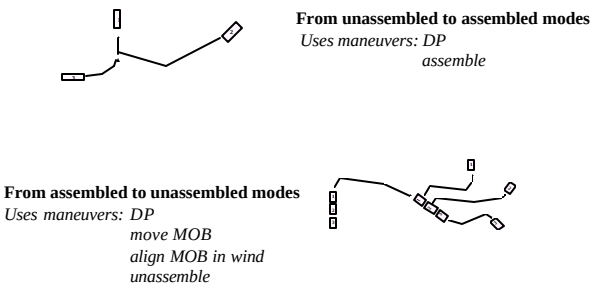

Figure 6. Mission Scenarios for the MOB.

The dynamic nature of the problem stems from the existence of multiple vehicles whose roles, relative positions, and dependencies change during operations. To meet these complex system description requirements, the architecture is modeled as a dynamic network of hybrid systems.

The Mobile Offshore Base can be viewed as a string of modules that have to be kept aligned. All modules are homogeneous, that is they are assumed to have the same dynamics and properties. It is possible to have heterogeneous agents within the MOB. Ships can position themselves side by side with the MOB for transfer cargo. Another case in which we have heterogeneous agents in the MOB is if we have a major failure in one of the modules, for instance if all thrusters fail on one platform. Limited operations can still occur, by having the functioning modules follow the one with the failures. If two of the modules have major failures, the MOB ceases to be functional and some of its modules must separate. This allows us to reconfigure the string dynamically if problems arise, such as if all thrusters of a given module fail.

The most significant requirement is that the modules have good relative position control with respect to each other. The relative position requirements are quite tight. The (very large, very slow) modules must be within $^{+}/-5$ meters of each other in the sway and surge directions, and within $^{+}/-1$ degree of relative alignment, in disturbances up to sea state 6 (5-meter significant wave height, 17 m/s wind, 1 m/s currents). The string, however, is allowed to drift in terms of its global position. This allows for a reduction in the power consumption (cost) in lower sea states, and focuses all the control effort on maintaining the relative alignment in high sea states. The environment in which the modules "live" (the ocean) is assumed to be unconstrained, that is at this time we do not envision obstacle avoidance other than collision prevention between modules.

The coordinated control problem for the MOB was separated into two hierarchical parts, the reference trajectory generation (higher level) and coordinated control strategies (lower level). The trajectory generation level deals with selecting a string control strategy, maximizing the string alignment, and minimizing the global fuel consumption. The coordinated control level deals with the implementation of a string control strategy, and the stability and control of neighboring modules with respect to one another.

Hence, an important question that arose during the MOB project was that of the generation of reference points or trajectories for the modules. The approach that was adopted allows for the generation of either desired set points or trajectories for each module. A coordinated high-level controller generates the desired references. Several string control strategies have been studied in the MOB project, including first-as-leader, middle-as-leader and leaderless approaches. In a leaderless approach, each module tracks its own position as well as that of his neighbors. The importance of each term in the control law is governed by a single parameter that can be adjuste depending on the situation. A higher importance on the relative position terms will ensure good alignment of the modules, while allowing for drifting of the assembly, for example with currents, if necessary.

EXPERIMENTAL RESULTS

The user interface for the experiment is formed of a menu offering a choice of several maneuvers.

A maneuver coordinates the motion of one or several modules: legal maneuvers are shown in figure 7. They include moving one module to a new position and heading, assembling modules to form a bigger MOB, separating assembled modules, moving a string of modules to a new position and heading, and rotating a string of modules into the wind.

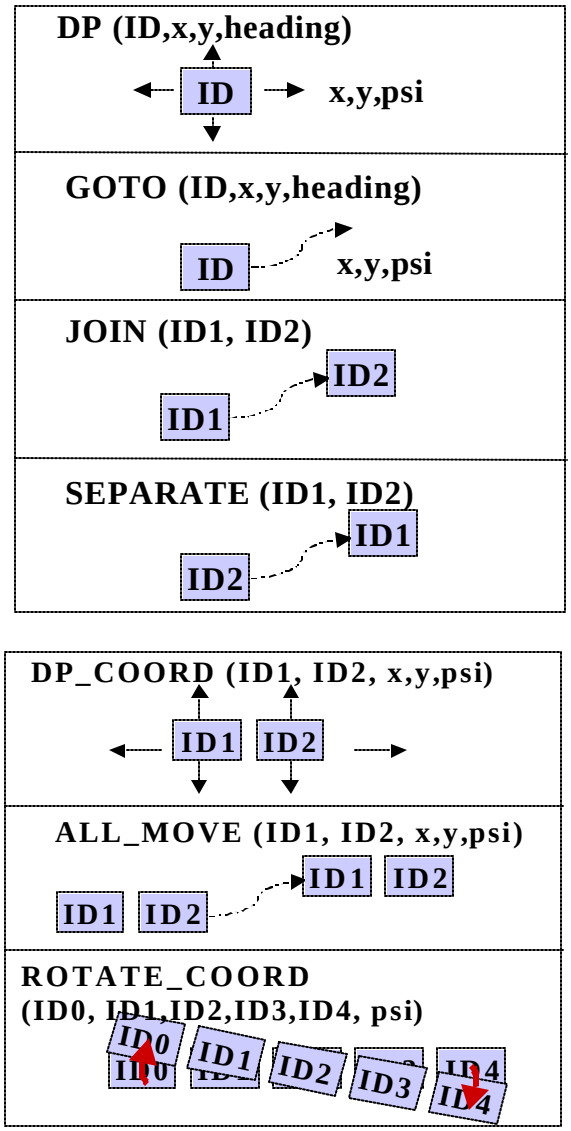

Figure 7: Legal maneuvers in the experimental setup.

A typical mission would include: dynamic positioning at initial location, bringing the modules into far apart positions on a straight line, docking the modules to form a string, performing coordinated station keeping (DP), rotating the string 10 degrees and bringing it back, performing a coordinated lateral maneuver, and separating the modules. A full run takes about 20 to 30 minutes. Video showing all these maneuvers can be obtained from the PATH web page: http://www.path.berkeley.edu under the Publications and Video heading or from the author's home page: http://path.berkeley.edu/~anouck

For the purposes of this paper we will present logged data from an actual experiment. The data from the complete mission is difficult to look at, so we will concentrate on the DP, docking, and coordinated rotation parts of the scenario.

Figure 8 is an x/y plot of a module station keeping in the tank, that is shows the motions of the center of gravity of the module in the x and y directions. The x and y position are given in meters, so the movements of the center of gravity of the boat are on the order of +/- 2 cm in either the x or y directions, which is about the accuracy of the absolute measurement system.

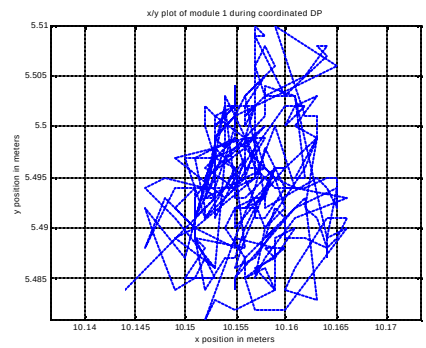

Figure 8: x position (in meters) vs. y position (in meters) of the center of gravity of one module while performing dynamic positioning at setpoint (10.15, 5.5).

Figure 9 is a plot of the heading angle of the module shown in figure 8, during the same period of time. The desired heading angle is zero degrees.

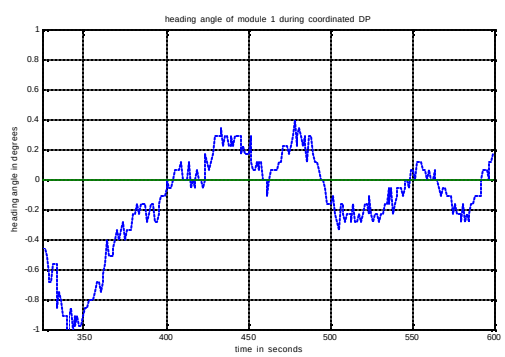

Figure 9: Heading angle of the module shown in figure 8 (in degrees), vs. time (in seconds), also while performing dynamic positioning. The angle is maintained within +/- 1 degree of its desired value.

Usually, at the start of a mission the modules station

keep for some time, then assemble. The assembly maneuver is split into two parts: in a first time, the modules align, far away from each other. Then the two end modules come in and dock precisely. Figure 10 shows the x locations of the three modules forming the experiment during a precision docking maneuver. Module 1 is shown on top, module 2 in the center and module 3 in the lower plot. The desired positions are shown in green and the actual positions in blue. Initially, modules 1 and 3 are not exactly at their desired position because of umbilical forces. Module 2 station-keeps during the whole maneuver.

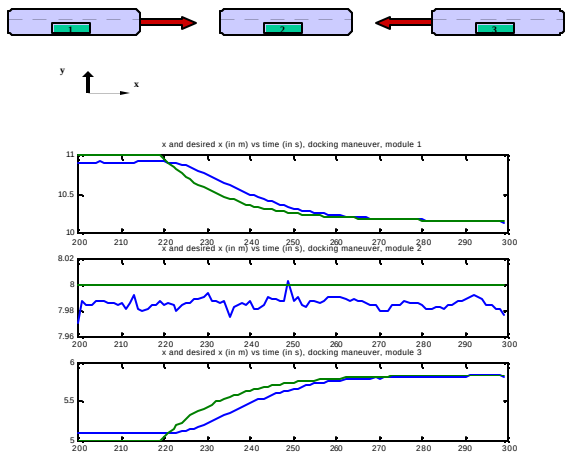

Figure 10: x position of the modules (in meters) vs. time, while performing a precision docking maneuver.

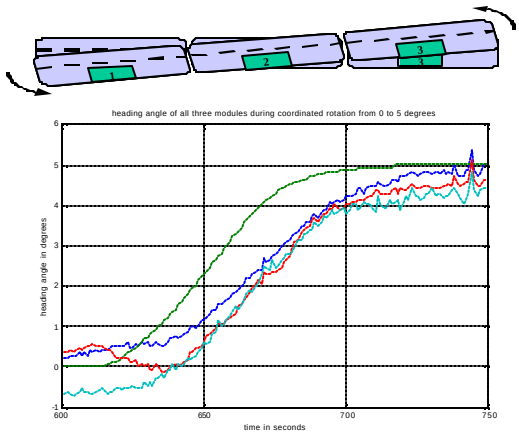

Figure 11: Heading angles of all three modules (in degrees) vs. time (in seconds) during a coordinated rotation maneuver from 0 to 5 degrees.

Finally, figure 11 shows the actual and desired heading angles for all three modules during a coordinated rotation maneuver. The heading angle is shown in degrees (vs. time in seconds) and the desired maneuver called for a rotation from 0 to 5 degrees. The actual response lags behind the desired heading angle but the alignment between all modules is kept closely at all times.

CONCLUSIONS

This paper presents a testbed for dynamic positioning control strategies for the Mobile Offshore Base that was developed at the University of California, Berkeley and California PATH between 1998 and 2001.

The MOB control testbed is presented, control strategies for the Mobile Offshore Base are discussed, and experimental results are provided.

Early experimental results obtained using the testbed have been encouraging. Improvements to the testbed could be made in two directions: the modules could be made wireless to extend their range of motion and to eliminate disturbance forces which are exerted on the modules by the umbilicals; a better absolute position system could be installed to improve the quality of the global position measurements.

ACKNOWLEDGEMENTS

The material is based upon work supported by the U.S. Office of Naval Research's MOB Program under grant N00014-98-1-0744. The authors would like to thank the Link Foundation, the Fundação Luso-Americana para o Desenvolvimento, and the Ministério da Defesa, Portugal for their support. The authors would also like to take the opportunity to the other students and staff members who have devoted their time and skill to the completion of this project.

REFERENCES

Fossen, T. (1994). “Guidance and Control of Ocean Vehicles”. John Wiley and Sons, Inc., New York.

Girard, A. and K. Hedrick (2001). “Dynamic Positioning of Ships using Dynamic Surface Control”, Proceedings of the Fifth IFAC Symposium on Nonlinear Control Systems, Saint-Petersburg, Russia, July 4-6, 2001.

Girard, A., J. Borges de Sousa, K. Hedrick, and W. Webster (2001). “Simulation Environment Design and

Implementation: An Application to the Mobile Offshore Base", Offshore Mechanics and Arctic Eng. Conf., OMAE01, Rio de Janeiro, Brazil, June 2001.

Hedrick, K., A. Girard and B. Kaku (1998). "A Coordinated DP Methodology for the MOB", in Proc. of the 1999 ISOPE Conference, Brest, France, June 1999, pp 70-75.

Polky, J., (1999). "Airfield Operational Requirements for a Mobile Offshore Base," Very Large Floating Structures, Vol. I, pp 206-219, Honolulu HI, September 1999.

Remmers, G. and R. Taylor (1998). "Mobile Offshore Base Technologies," Offshore Mechanics and Arctic Eng. Conf., OMAE98, Lisbon, Portugal.

Slotine, J. and W. Li (1991). "Applied Nonlinear Control". Prentice Hall, Englewod Cliffs, NJ.

Sousa, J., A. Girard and N. Kourjanskaia (1998). "The MOB-Shift Simulation Framework", Proceedings of the Third International Workshop on Very Large Floating Structures, Hawaii, USA, September 1999, pp. 474-482

Spry, S., Empey, D., and Webster, W. (2001) "Design and Characterization of a Small-Scale Azimuthing Thruster for a Mobile Offshore Base Module", Marine Structures Journal, v.14 (2001), pp. 215-229.

Taylor, R., and P. Palo, "U.S. Mobile Offshore Base Technological Report", Proceedings of the 23rd UJNR Marine Facilities Panel Meeting, May 2000, Tokyo, Japan.

Webster, W. and Sousa, J. (1998). "Optimum Allocation for Multiple Thrusters", in Proc. of the 1999 ISOPE Conference, Brest, France, June 1999, pp 83-89.