DYNAMIC POSITIONING CONFERENCE

APPLICATIONS

DP Performance Analysis Requirements for Mobile Offshore Bases

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1. Introduction

A fully assembled Mobile Offshore Base (MOB) will involve several floating units connected together or positioned so that there is a continuous, straight horizontal deck (runway). The length of the runway could vary from 300 m to at least 1500 m in the fully deployed mode. Each individual floating unit or module (referred to as Single Base Unit, or SBU) will be selected from within or similar to the general class of marine structures called floating rigs or platforms. These could be monohull vessels such as tankers, barges or column-stabilized drilling units such as MODUs, etc. Although mooring is an option for the individual modules in the laid-up mode, the fully deployed MOB can, practically, only be dynamically positioned. While the offshore petroleum industry uses Dynamic Positioning (DP) to hold the absolute position of their drilling platforms precisely over a fixed location (the drill hole), the MOB requires no such precision in absolute positioning. The MOB could drift slowly while on site with no significant effect on air operations, as long as the nearly head-to-wind orientation of the runway is maintained. However, the feasibility of the MOB platform concepts depends solely on the performance of a multi-module DP system (MMDPS), particularly to maintain a continuous and straight runway in all sea conditions. Further, the MMDPS performance is also critical to the at-sea connection/disconnection of the individual modules. The various operations that may be expected on a functional MOB are shown in Figure 1.

Efforts are underway at ABS to develop a guide specifying the standards for classing the MOB structure as a whole, as well as emphasizing the safety aspects of the stationkeeping and transiting requirements of the multi-module DP systems. This document will specify minimum standards that will need to be met by DP systems designed for multi-module MOB platforms. An outline of the performance analysis requirements related to the dynamically positioned MOB-type platforms including automatic control are discussed here.

2. Purpose of DP System for the MOB

There are three distinct scenarios for MOB operations. These include pre-positioning, transit and deployment. When fully deployed, the MOB may operate in the connected mode (Figure 2), or in the independent- module mode. In the connected mode, the modules will be mechanically linked, while in the independent-module mode, they will not be physically connected but held relative to each other using dynamic positioning techniques. In both the above modes, the global position of the platform will be dynamically maintained through the use of thrusters and controls. The functional requirements of a DP system installed on the MOB can be listed as follows:

- Maintain heading of a connected MOB nearly head-to-wind
- Maintain relative headings and positions of an independent-module MOB
- Provide propulsive control for connect/disconnect operations
- Provide propulsive and steering capability for transit

Maintaining a head-to-wind orientation is one of the primary requirements for aircraft operations that is applicable to both the connected and the independent-module mode of operations. The second and third requirements are more stringent in that the error bands associated with these are necessarily small. The transit capability is achieved by the use of the thrusters as the main propulsion and steering systems.

In addition to the above operational requirements of maintaining the integrity of the runway, the DP system has a major role to play in the safety and structural integrity of the MOB. This role, involving the capability to avoid collisions between the individual modules, is of particular interest in the Classification of the MOB structure.

3. Approval Analysis Process

In the simplest possible terms, evaluation of the overall dynamic positioning performance of the MOB involve four tasks:

a) determination of the “demands” on the platform
b) analysis of the “response” characteristics of the platform
c) determination of the “capability” to meet the imposed demands
d) “evaluation” of the resulting performance against given, established “criteria”

The demands on the platform, in the case of the MOB, are based on the necessity to provide and maintain a runway for aircraft operations either in the fully connected mode, or in the independent mode of operation. The responses are dependent on the site-specific environment the MOB is expected to operate in. Two types of responses are anticipated with the MOB. In slack weather, the relative movements of the independent modules are likely to be random (Figure 3), while in moderate to high sea states, the responses are expected to show identifiable patterns (Figure 3). Methods of determining the capability to meet the demands may vary with the designer. At present , a set of full criteria have not been established, but minimum requirements are specified.

There are a number of operational requirements that need to be taken into account in the approval process:

- In the independent mode, each individual module must maintain a prescribed position and orientation.
- In the assembled mode, the MOB must maintain a general position and orientation, and the individual modules must maintain relative positions and orientations.
- In preparation for mechanical connection/disconnection, the module positions and orientations and the associated velocities must be controlled.
- In transit (Figure 4) from one site to another, the propulsion systems of the modules must be independently controllable.

4.0 Special Environmental Effects

The special environmental effects particular to the MOB include the spatial variations of the wind, wave and current fields along the length of the structure, which have not been addressed in stationkeeping studies of large structures [1]. In this context, the spatial coherence in the horizontal direction is important. The variability of the wind, wave and current parameters over a mile or more of the ocean surface has not been measured or estimated. The need to account for the wind and wave coherence effects that account for the variability of the environmental parameters along the length of the MOB is particularly stringent for the stationkeeping capabilities of the MOB platform. The spatial coherence of wind fields over land has been studied and reliable estimates can be obtained. Wind engineering models could potentially be adapted for modeling the coherence of wave fields, but this has not been established.

An example of the wind horizontal coherence effects is given here. Atmospheric turbulence is spatially imperfectly correlated. Most common measure is the coherence function which varies from +1 (representing perfect correlation) to –1 (representing perfect anti-phase correlation). Coherence is an important consideration in the design of structures with large dimensions against the effects of wind, e.g. tall buildings, long-span bridges. Models of coherence for wind engineering applications are typically represented as the square-root of coherence in terms of the non-dimensional parameter, $\frac{f\Delta z}{U}$.

where f = frequency
Δz = spatial separation
U = wind speed

One of the simplest models is as follows:

$$\sqrt{coherence} = \exp\left(\frac{-Cf\Delta z}{U}\right)$$

where, C = coefficient depending on component of turbulence, direction of spatial separation
The equation suggests the following physical interpretation: Large-scale gusts, which have low frequencies, tend to be better correlated over large distances compared with high frequency small-scale gusts. Similar easy-to-use wave coherence models have not been identified for application to DP performance analysis.

5.0 Control Issues for MOB DP

The safety issues of the MOB DP control system go directly to some of the fundamental problems that control engineers constantly struggle with. These are:

(1) The basic specifications required for the designs of the control system are essentially unknown.
(2) The difficulty, given the enormous size of the modules and the associated large environmental forces, in determining the necessary specifications for the control transient response characteristics and steady-state errors that would be acceptable for the various environmental and operating conditions. The control transient response is characterised by the time constant, which is changed by changing the feed-back gain. The steady-state response (applicable only to PD controls) involves the effects of the steady offsets due to wind, current and wave drift.
(3) Choice of closed-loop controller bandwidth is unclear. Based on preliminary simulation studies, it has been postulated by some designers, that a 0.01 rad/s closed-loop controller bandwidth would meet the positioning requirements of the independent MOB modules. This may be adequate for the control of the overall motions of a single vessel. However, such constant bandwidths may be overly simplistic, for the case of multiple vessels trying to hold relative positions.
4) The various failure modes have yet to be addressed. There are some striking differences between the DP systems used in the offshore oil industry and those required for the MOB. In the case of the oil drilling rigs, sensor failures often result in them simply being driven off their station position, possibly causing riser failure. In the MOB operational mode, for example, if there should be sensor failure, the SBUs of the IM MOB could have a serious collision, resulting in structural damage and/or sinking. In the case of the connected module concept, undue asymmetric connector loads may be imposed, resulting in possible connector failures.
5) Finally, no guidance can be given at present to the design of the thruster control logic. The competing safety and cost requirements of simultaneously maintaining small differential errors between SBUs, while minimizing fuel consumption, must be designed into the thruster control logic.

The above issues still remain to be addressed. However, in the following section, we will discuss the significance of these questions primarily from the safety viewpoint and identify the tasks that need to be undertaken to resolve these, so that reasonable guidance can be provided without sacrificing safety.

6.0 Controller Design

The DP controller for the MOB will be required to function in a number of operational modes, some of which are perhaps still to be determined, but several of these are quite well understood, as discussed in section 3.0. Perhaps the most stringent operational requirements will be related to the connection or re-connection procedure when the independent modules come together, and either have to be mechanically linked or held together under the action of the DP system. There may be less stringent requirements involving heading control in the connected mode supporting flight operations**.** In addition to heading control in the connected mode, DP control is also envisaged to be of use in minimising and managing connector loads.

Preliminary simulation studies have indicated that a 0.1 rad/s bandwidth PID controller would meet the operational requirements and there appears to be a growing concensus that this would be the baseline PID controller design. However, many fundamental questions remain unanswered.

One of the more important safety related issues is whether one wants the same controller design for all the SBUs. If we designate one module (SBU) as the lead SBU and the others as follower SBUs, then to control the three SBUs so that they all continuously maintain a fixed position and heading, we would implement a high-gain, high-bandwidth controller on all three SBUs. (From an owner/operator viewpoint, this option would use considerable fuel). The other alternative is to perhaps implement a relatively low gain low bandwidth PD controller on the lead SBU. We may choose to implement only the PD controller on the lead SBU instead of the PID controller, because the lead SBU does not need to maintain near-zero-state error, and it is the integral component of the PID controller that forces the steady state error to zero. One could allow the lead SBU to drift somewhat from its set station. On the other hand, the differential errors between the lead SBU and the followers must be held relatively small, only about 20 ft. based on preliminary criteria. The control loop around the differential erros would have to be under high-gain PID control. The resulting effect of such a strategy would be that the entire connected MOB structure could drift off station under the action of the environmental forces and the follower SBUs would, in some sense, be dragged along with it. This controller concept is illustrated in Figure 5.

The next question is should the controller design be different at different sea states. Consider the following situation. The sea severity is relatively large, of the order of Sea State 7, but one still wants to maintain the connected structure, perhaps to land aircraft under hostile conditions. In this situation, one may not want to control the lead SBU in position and allow it to be driven off its station, however you control only for heading and use the remaining thruster action (that would have been used to control for position) to help maintain an acceptable differential error. The feasibility of such techniques should be investigated through simulation studies.

Other control strategies for the MOB are also being considered other than the PID/PD control structure. The use of model predictive control is being postulated, one could also consider adaptive control strategies and various fuzzy control strategies. There will also be numerous other control ideas proposed as the technology of MOB control matures. However, it is the opinion here that the baseline control should have the fundamental PID structure because of its robustness and well known properties, nevertheless, other could strategies could easily be implemented in parallel or superimposed on the PID controller. Figure 6 illustrates how we envision this would be implemented.

7.0 Sensors and Measurements

One of the common causes of drive-off in the offshore industry is erroneous sensor output. A drive-off event, in the case of a MOB, may be prevented by a connected MOB, but would induce undue asymmetric connector loads that might result in connector damage. In the case of an IM MOB, the drive-off at any one module will result in complete unavailability of the runway. How can one guarantee that drive-off would be a very rare event? How can one design the system such that a single or even a combination of sensor failures do not cause the SBUs to be driven off their stations? The position sensors on the MOB can be a combination of numerous technologies. Obviously, GPS and differential GPS will play an important role. One can envision GPS antennas and distributed processing of GPS information throughout the MOB structure. Other sensor measurements can include inertial sensors to help or aid the GPS system during times of brief outages or poor satellite geometry. Other systems such as acoustic systems, taught wire systems and laser ranging systems may be available.

In the case where the SBUs are in contact, but not mechanically attached, it may be possible to instrument the points of contact with sensors (such as potentiometers) can measure differential position with a very high degree of accuracy.

One can design an intelligent sensor and measurement integration filter that could not only accurately estimate the global position of the MOB but also alert the system of sensor failure and even poor sensor performance. The idea would be to use the statistical properties of the measurement filter as well as information about the thruster performance to continuously predict in advance the sensor measurements. Each sensor measurement would also have a statistical error profile that can be used to determine whether the sensor is operating within its specifications. The measurement filter would then discount or ignore poor and unreliable measurements. Therefore, one would be using a redundant set of measurements to predict position and heading and to internally validate the sensor measurements.

8.0 Thrust Control Logic

Some guidance in the basic design of thrusters for offshore use are available [2]. However, control of these thrusters for adequate MOB functionality is still an operational as well as safety issue. In the case where the MOBs are not attached the thruster control logic can be similar to what one would normally use within the offshore industry. However, once the MOBs are attached either physically or connected under the action of the DP system, the thruster control logic should likely change. The idea being that the lead MOB and the follower MOBs may all work together to achieve particular control specification on the position of the lead MOB and the relative positions of the follower MOBs. Therefore, some of the thruster control action on the lead MOB may be available to help correct for the differential errors of the follower MOBs. Therefore, it may be more important for the MOBs to be aligned so that the MOBs can support air operations than to remain in some particular location. As such, as sea states increase one may switch the thruster control logic and perhaps the control specification such that the MOBs remain aligned, differential position error remains small and air operations can continue.

A more difficult problem arises when a thruster fails. How does one re-configure the thruster allocation when a thruster has failed or has been destroyed? How long can air operations be maintained when thrusters are failing and one is in a hostile environment or a high sea state? One would have to analyse the controllability of the overall system to determine what control specification can continue to be achieved. The next problem is what does one do when both measurement sensors and thrusters are failing due to a hostile environment? The idea would be to try and maintain air operations for as long as possible.

9.0 Concluding Remarks

The dynamic positioning performance of a Mobile Offshore Base that is designed to operate in the open ocean can only be guaranteed through careful analysis as outlined above. The DP performance has a direct bearing on the functional requirements of the MOB, that are governed both by safety and operational considerations. The analysis efforts required are significantly larger than those for conventional single vessels. These should include environmental loads that are unique to such long structures, type of controller, its required bandwidths over the entire operating range, sensors and measurements required and the thrust allocations appropriate to the various modes of operations. Some of the above aspects are currently being addressed and specific criteria are expected to be developed in the near future. These include the following: The choice of controller bandwidths for the individual modules, the need for variation of gains with environment severity, and the protection and reconfiguration of measurement filters in the event of sensor failures. Considerations for thruster allocation under normal operating conditions and possible methods of reconfiguring thruster allocation in the event of one or more thruster failure have to be identified. Consequences of combined sensor and thruster failures are outlined and the need to respond to such events are to be addressed.

10.0 References

1. 1.Winkler, R.S., "Positioning of Very Large Floating Offshore Structures", Proc. of the First Intl. Workshop on Very Large Floating Structures, VLFS '91, Honolulu, Apr. 1991.

2. Guide for Thrusters and Dynamic Positioning Systems, American Bureau of Shipping Publication, New York, N.Y., 1994.

Session Index

Figure 1 MOB

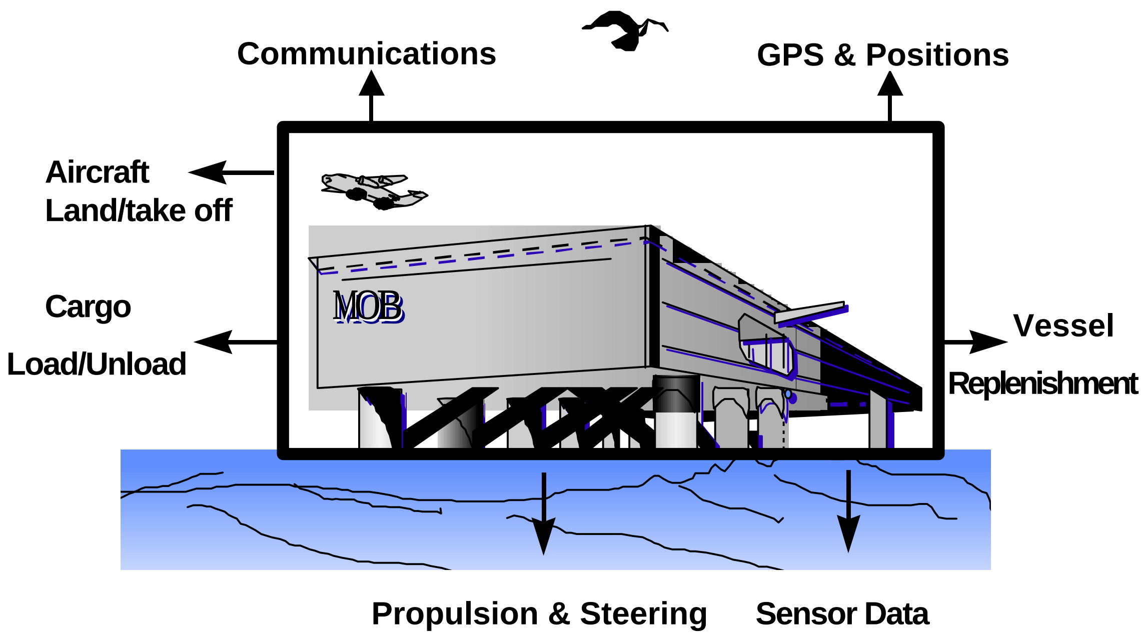

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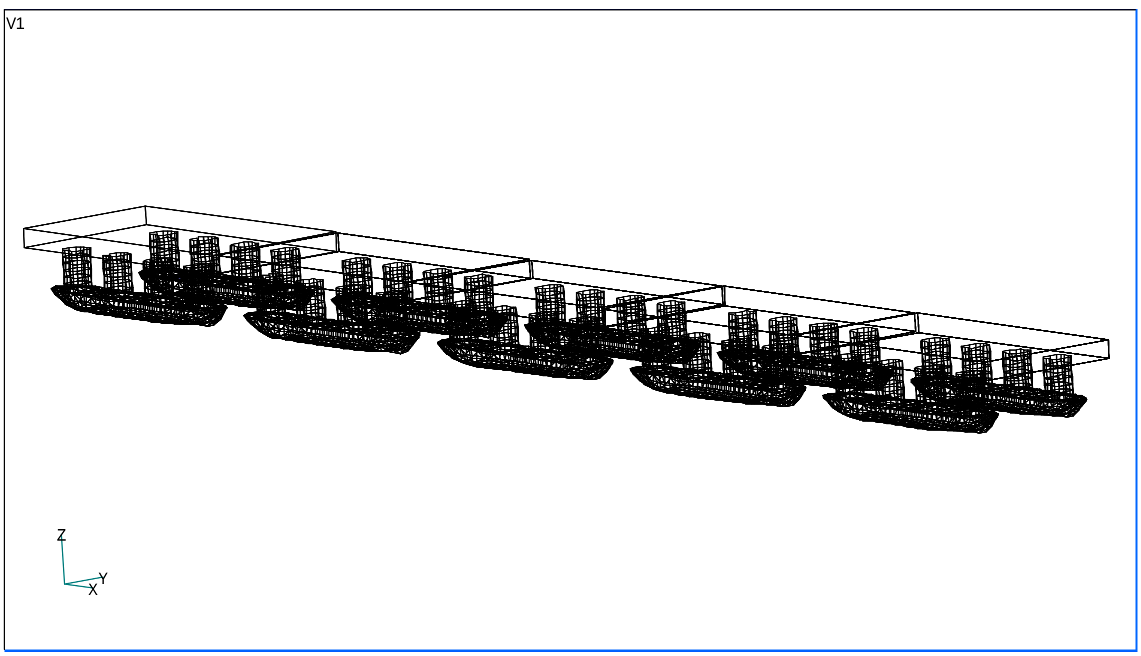
Figure 2
Fully Connected MOB



Return to text

Session index

Figure 3 Module Response Modes

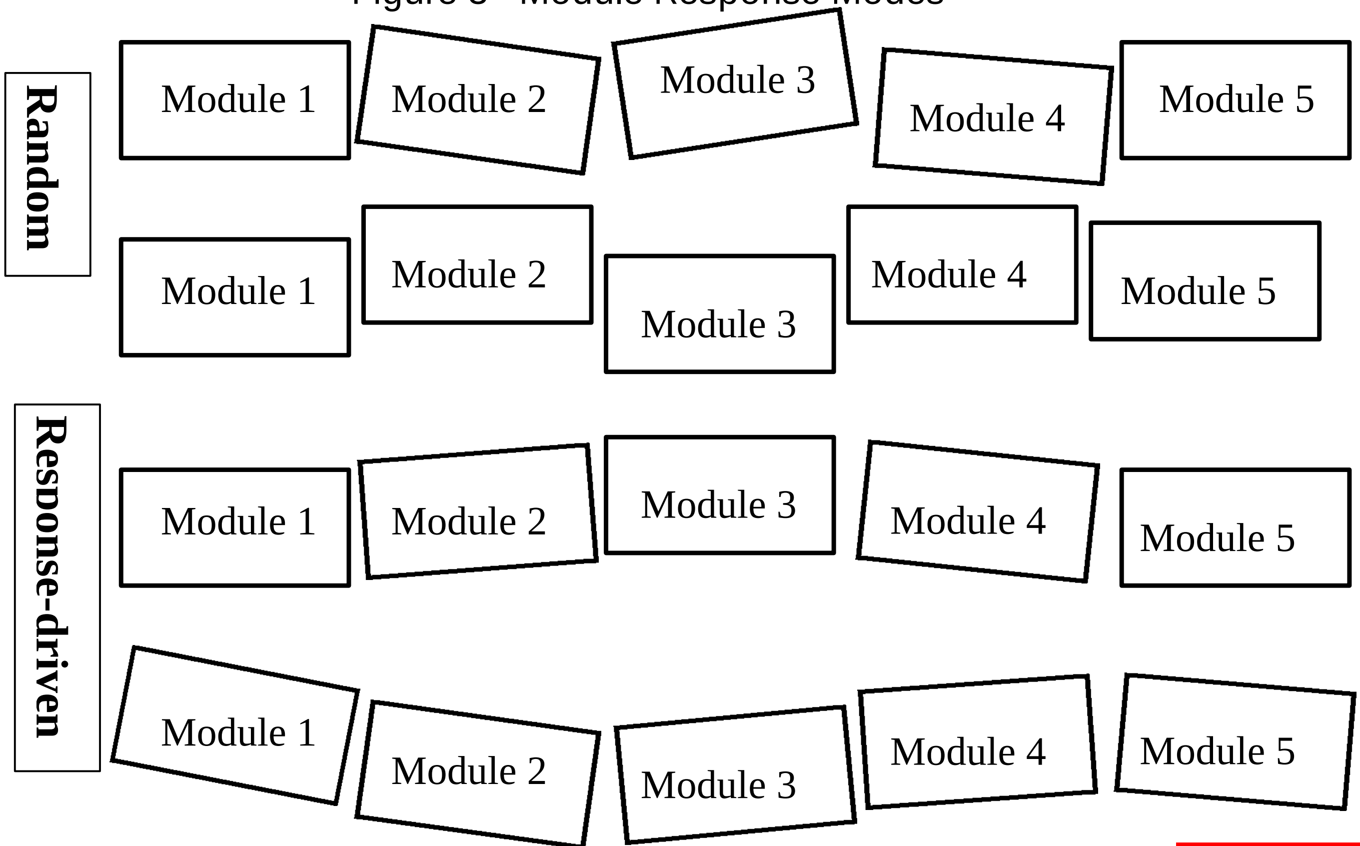


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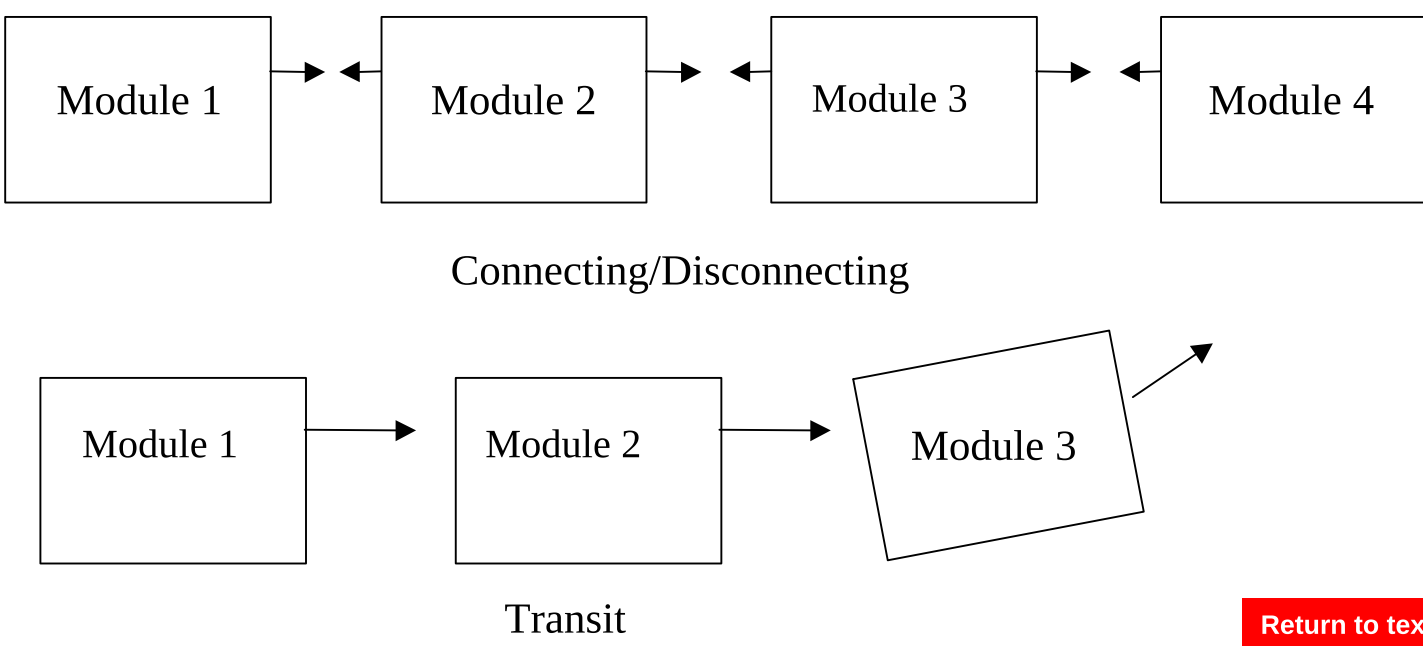
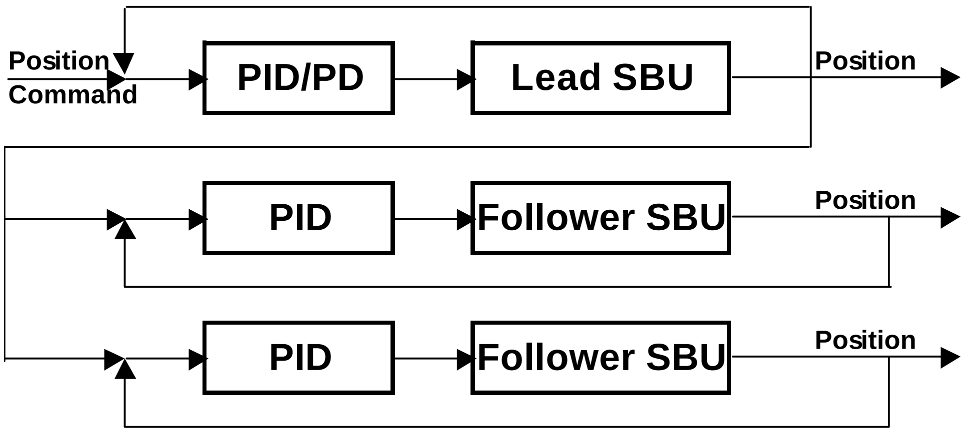
Figure 4 Connection, Disconnection, Transit



Return to text

Session index

Figure 5
Three-module Control Strategy



Return to text

Figure 6
Parallel Alternate Controls