Yacht match race simulation

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Abstract

There are many factors that can determine the winner of a yacht match race. The major factors include weather conditions observed during the race, tactical decisions made while sailing and the dynamic performance of each yacht. Weather conditions observed during the race can be modelled from actual weather data. Tactical decisions made while sailing can be modelled using logic that approximately simulates tactics that would be carried out during an actual match race. The dynamic performance for each yacht can be estimated using performance measures obtained from a velocity prediction program (VPP). After designating a course to race on, a simulation of a yacht match race could be run with two different yacht designs to determine the winner.

By running the simulation many times in different weather conditions, the probability that one yacht design beats another could be estimated for that set of weather conditions. The simulation model could also be useful in the design process, giving the ability to look at different design tradeoffs, such as upwind speed versus downwind speed. It could also be used to help choose the most suitable portfolio of yachts to defend the America’s Cup. Finally, it could also be used to trial different tactical strategies whilst racing.

1.0 Introduction

Presently an object-oriented yacht match race simulator is being constructed to help estimate the probability that one design of yacht beats another. It is being built to use output from a VPP so that a yacht can be tested and evaluated quickly once the design is finalised within a suitable computer design package. Some of the work mentioned within this paper is still in progress.

There are three major areas that need to be modelled accurately for a simulation model of a yacht match race to obtain realistic results. These areas relate to the major factors that can determine the winner of a yacht match race. By combining appropriate models for the weather conditions observed while racing, tactical decisions made while sailing, and the dynamic performance of each yacht, two yachts can be raced in a discrete-time simulation on a designated course to determine the winner.

Weather conditions observed during a race are difficult to model. The wind must not only vary with time but also location, as races can be won or lost on wind shifts that one yacht receives before the other. Tactical decisions made while sailing are also difficult to model since decisions are not only based on sailing competitively, but also on adhering to the rules of yacht match racing. Little effort has been put into these areas within race modelling programs in the past.

Much effort, however, has been put into modelling the performance of yachts, both steady state performance [7] and dynamic performance [2]. Steady state performance is modelled using a VPP, whereas dynamic performance is modelled using a yacht simulator. Both of these models make use of Newton’s second law of motion, which can be worded in several different ways. Both VPPs and yacht simulators require complex hydrodynamic and aerodynamic models, and in-depth information about the hull, sails and appendages to calculate the forces acting on the yacht.

The following wording of Newton’s second law forms the basis for a VPP. “For any body which is not accelerating [steady state] the sum of the forces and moments in each of the three directions must be zero.” Hence, in its simplest form a VPP solves a set of simultaneous equations relating to the forces on the yacht which are nonlinear functions of the yacht’s speed, leeway angle and heel angle. The solution for a set of given conditions gives the equilibrium yacht speed, leeway angle, heel angle and the equilibrium forces [7].

The following wording of Newton’s second law forms the basis for a yacht simulator. “The resultant force on a body is equal to the product of its mass and the acceleration of the body in the direction of the force.” Therefore, a yacht simulator determines the forces and moments acting on the yacht to get the resulting accelerations. These are then integrated over time to update the yacht’s velocity and orientation and to determine the path of the yacht [2].

There has been extensive research into the area of VPPs. There has also been much research into yacht simulators [5], although not directly related to race modelling. These models, unfortunately, are slow due to their complexity. This is undesirable in a discrete-time simulation where calculations are repeated at each time step. Hence, to model the dynamic performance of a yacht relatively quickly, simplification to what physically happens is required. Approximating the dynamic motion of the yacht using equilibrium performance measures obtained from a VPP can do this.

The outline of this paper is as follows. Section 2 outlines some of the potential uses for such a simulation. Section 3 contains a general description of the overall simulation model along with the individual weather, tactics and dynamic performance (yacht) models. Finally, section 4 presents conclusions relating to the current state of the simulation.

2.0 Potential uses

2.1 Estimating the probability of winning

To calculate the probability that one yacht beats another, a simulation of a match race can be run many times in different weather conditions sampled from a postulated distribution. From the win or loss outcome for each simulation the probability that one yacht beats the other, in that set of weather conditions, can be estimated.

Some care needs to be taken that the results are meaningful and not an artifact of statistical fluctuations. The variance of results obtained by the simulation provides some measure of its reliability.

2.2 Estimation of design tradeoffs

For the simulation model to be useful to designers, the dynamic performance model for each yacht must use information that is readily available once a design is finalised within a suitable computer design package. This is achieved by using equilibrium performance measures obtained from a VPP to model the dynamic performance.

Yacht design involves many important design tradeoffs, such as sacrificing upwind speed for downwind speed, or acceleration for straight-line speed. For example, would you sacrifice one second per mile upwind to gain one second per mile downwind? Each yacht would complete the America's Cup course in the same predicted time, yet one is likely to be a better racing yacht. Creating two yachts with contrasting design tradeoffs and then calculating the probability that one beats the other in a match race could identify the better design tradeoff.

2.3 America’s Cup Portfolio selection

Since yachts perform differently in different weather conditions, the best portfolio of yachts to defend the America's Cup may not necessarily include the overall fastest two yachts [6]. Ideally the yachts should be chosen so that the probability of winning is maximised for all weather conditions. The best portfolio of yachts could be chosen using further statistical analysis once the relative probabilities that one yacht beats another are known for all yachts in all weather conditions.

2.4 Determining best tactical strategies

The simulation model could also be used to trial different tactical strategies whilst racing to help determine the best strategy. Implementing different tactical strategies for identical yachts and seeing which yacht has the better probability of winning a match race could do this.

3.0 The simulation model

Each simulation of a match race requires a defined course for the yachts to race on. Typically the course will be the America's Cup 2000 course, a windward-leeward (upwind-downwind) configuration. When the course is defined the yachts can then be initialised and the match race started. Once the race is started, the position of each yacht is updated at discrete time intervals, typically every five seconds.

At each time step the observed weather conditions are calculated for each yacht. These depend on the type of weather model being used. A tactical decision is also made at each time step, dependent on the observed weather conditions and information about the opposing yacht. Once the new yacht heading has been determined from the tactical decision, each yacht is moved to its new position using the dynamic performance model. Time stepping continues until both of the yachts finish the course. This yields the winner along with the winning margin.

Contained within the overall simulation model are three individual models. Each of these models can be developed independently to increase the accuracy and complexity of the overall simulation model. These three individual models are:

- A **weather** model that returns wind, sea state and possibly tidal current conditions.
- A **tactics** model that returns a close approximation to decisions that would be made by the helmsman during a match race.
- A **yacht** model that returns the dynamic motion of each yacht in terms of its VPP performance measures.

3.1 Weather

The outcome of a yacht race depends vitally on the behaviour of the wind. Weather varies with location as well as time. It is not clear what effect this has on the expected result of a yacht match race. Therefore it is necessary to have a simple spatial-temporal model which can be constructed from weather data provided by Team New Zealand (TNZ). The weather model has to be fast to ensure that the overall simulation remains fast. Furthermore, the model has to be able to generate time-varying wind fields that depend on simple measurable parameters such as the wind speed and direction. This requirement is used to generate weather scenarios for calculating the probability that one yacht beats another for a given set of weather conditions.

Even though there is significant literature on modelling wind effects [3], the primary focus of this work is the impact of wind on building and structure design. Little attention has been devoted to the spatial behaviour of wind, probably because buildings and similar structures do not move! Temporal behaviour has been studied over long horizons that, while relevant to a building or structure's expected lifetime, are not relevant over the time scales associated with yacht match racing.

3.2 Tactics

The performance of a yacht in a match race depends on how it is sailed. Tactical decisions are required not only to make the yacht sail fast but also to sail competitively whilst adhering to the rules of yacht match racing. It is relatively easy to decide on the direction to travel so that the yacht sails around the course in the fastest possible time. The optimum direction to sail can be calculated using the yacht’s equilibrium speed polar, and the observed weather conditions. This depends on the strategy chosen where each strategy maximises the velocity of the yacht in a chosen direction.

Sailing competitively and adhering to the rules of yacht match racing is much harder to model. There will be many situations where sailing fast may not be competitive or may even breach the rules of yacht match racing. This requires close collaboration with sailors at TNZ to identify where modification is required to the optimum direction in order to sail competitively. The rules of yacht match racing will be used to create models that will enforce the major rules by forcing certain tactical decisions. By implementing a simple logic based tactical expert system in the simulation, tactical decisions will approximate the decisions made by the helmsman on a yacht during a match race.

3.3 Yacht

Ideally a yacht simulator would be used for the dynamic performance of the yacht within the simulation model. However, a yacht simulator uses complex hydrodynamic and aerodynamic models to compute the forces, and hence accelerations, on the yacht. This type of model is slow due to its complexity and hence not suitable for a repetitive simulation model. There needs to be a fast approximation for the dynamic performance of the yacht.

A good approximation to the dynamic performance of the yacht can be obtained by using a simplified force-balance model. The simplified model has only one degree of freedom, that being longitudinal translation, to determine the acceleration of the yacht at each time step in the simulation. Equilibrium approximations to forces that the yacht experiences in the longitudinal direction, obtained from performance measures output from a VPP, can be used to approximate the straight-line dynamic motion. Performance measures output from a VPP come in the form of polars. These give some equilibrium yacht performance figure, such as speed or thrust, for a given wind speed and angle to the wind.

The straight-line dynamic performance is essentially a quasi steady-state model. By calibrating variables in the dynamic performance model, so that output from the model is as close as possible to on board measurements recorded by TNZ during testing sessions, a good model for straight-line motion can be achieved.

Difficult manoeuvres such as tacking and rounding marks where the motion is far from equilibrium have to be modelled differently. Polars containing equilibrium data are not useful. Specific tacking and manoeuvring simulations exist for yachts [4]. However, these simulations are essentially yacht simulators which are complex and hence too slow for a race simulation. A simplified tacking theory has been created [1]. However, it requires information about the yacht that is not available to the simulation model from the yacht's polars.

An empirical model can be used to obtain realistic tacking results, similar to what actually happens, without explicitly simulating the physics of tacking. The same methodology can be applied to rounding marks since it is essentially the same motion as for tacking. Output from more sophisticated tacking models, and actual tacking data from TNZ, can be used to construct a good empirical model to use for both tacking and rounding marks.

It is not yet clear whether the use of polars to determine the yacht's dynamic performance will allow discrimination between competing designs in the simulation. This can be tested using perturbation techniques to determine the sensitivity of the dynamic modelling. If the dynamic model does not adequately discriminate between designs then further development of the dynamic model may be required.

4.0 Conclusions

At present the simulation consists of the three major models, although in very simple forms. Currently, the wind is assumed to behave identically over the entire course, and is read from a file of historical data. We have identified a (very) simple spatial-temporal model and hope to test it once a certain level of functionality in the simulation is achieved.

Very simple tactics have been implemented with regard to only one yacht at present. An efficient way of modelling the logistics of tactical decisions has yet to be identified for two yachts in a match race. However, simple models to enforce some of the major rules in yacht match racing have been identified.

The yacht dynamic performance model has yet to be calibrated with actual data from TNZ, and suitable empirical tacking and rounding mark models have yet to be identified.

5.0 References

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