CONTROL AND IMPLEMENTATION
OF AN AUTONOMOUS SAILBOAT

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Abstract
This paper presents the extensive review on modelling and control of non linear autonomous sailboat system using Conventional PID controller (CPID) and PID controller with Particle swarm optimization technique (PSO). A large heeling angle, a lot of rolling motion due to wind rush can cause the boat to capsize. Sailboats cannot move in the up-wind direction so one has to move in a zigzag pattern to sail in the up-wind direction. This mainly focuses on the way of lively controlling the sail angle and rudder angle of the sailboat to reduce the heeling angle and rolling motion caused by the wind. The sail angle is optimized and rudder angle is controlled for the given wind direction and desired moment. The main object is to allow long permanence autonomous mission.

Key Words:Sailboat, sail angle, rudder angle.
1 Introduction

Sailboat played an important role for mankind. Sailboats were mainly used for fishing, trading, and transportation etc. Now a days priority of sailors moved from transportation to sport or vacation. For some people sailboats are not just a boat, they are their passion, which they used to participate in competitions, like Volvo Ocean Race or the famous Americas Cup.

A sailboat can be actuated by two devices, the rudder and the sail as shown in Figure 1. The rudder floats through the water and steers the boat by using hydrodynamic forces. The sails use the power of wind to move the boat forward and to speed it up. They are built to use the winds aerodynamic optimally. Sails are producing thrust by using aerodynamic forces. The procedure for adjusting the sail angle is called sail trim, if the forces in the sail do not stream in the optimal way, it can result in unusual sailing behaviour. One way of reducing such behaviour is to use an autopilot. Commercial autopilots control the rudder only, they are not able to control the sail angle. It must also be able to adjust the sails automatically and to react on changing conditions like a change in wind stream or a wrong sail position or an unusual sailing behaviour. Hence the sail angle should be controlled for proper movement of the sailboat. Various control schemes can be applied to control the sail and rudder angle of the sailboat.

Figure 1 Model of a sailboat
2 LITERATURE REVIEW

In [2] it is shown how a simple controller for sailboat is implemented. This approach uses the proportional controller to actuate the rudder. This results in large number of oscillations. In order to avoid the swinging behaviour of the system, the controller with integrative and derivative term is illustrated in [4]. The IBoat project [5] was designed using a Fuzzy controller for sail and rudder control which is not stable. The HyRaii, a catamaran with T-shaped foils, equipped with steerable flaps. The HyRaii team [6] found the prospects to reduce the haul of operating foil flaps by less steering than with mechanically controlled foils. In [8] the roll stabilization control for sailboats is done using linear quadratic regulator controlling the moment created by the sail.

3 PROCESS DESCRIPTION

The sail provides forward thrust for the movement of the sailboat. There is an optimal angle for the sailboat that gives the highest forward acceleration for a given relative wind direction. Thus a map is created between relative wind direction and velocity of the wind. A sailboat can be Lee helm, Weather helm or neutral. Weather helm is the force acting on the sail which turns the boat towards the source of the wind. Lee helm is the force which turns the boat away from the source of the wind. The automated sail actuated control is feasible for sailboat autopilots. If the sail is not optimal or the wind direction changes, then the boat can be either lee helm or weather helm, assuming that the boat is on an upwind course. There are two upwind courses one is close hauled and close reach. The upwind course denotes the course where the boat travels diagonally to the wind direction is shown in Figure 2. This manoeuvre is also called Tack. It is asailing manoeuvre where the lee and windward side of the boat are changing.

Figure 2 Tack manoeuvre on an upwind course.
The desired course in the same direction as that of wind direction is called as downwind course. The two downwind courses are broad reach and running. While sailing on the downward course, some manoeuvres are executed. The manoeuvre on the downwind course is called jib. The starboard side of the boat is windward side before manoeuvre and leeward side afterwards. The jib manoeuvre is shown in Figure 3.

![Figure 3 Jib manoeuvre.](image)

The sailing behaviour depends on many factors. This paper focus on changing behaviour of the sailboats caused by aerodynamic and hydrodynamic forces. Depending on the aerodynamic force and hydrodynamic force, the angle of the sail and the rudder angle is being altered using Conventional PID (C PID) and PID with PSO.

4 CONVENTIONAL PID CONTROLLER

Conventional PID controller also called as three term controller. This type of control action employs proportional, integral, and derivative control action together in a control system so as to derive the advantages of all the control actions into one. By using Zeigler Nichols tuning method, the closed loop response of the system is obtained by formulating the PID parameters.

**A. Rudder Control**

The sailboat should maintain the desired course in order to reach the destination, which is triggered by rudder and the autopilot system steers it automatically. In order to achieve the course from 00 to 3600, the rudder position should be controlled. The input value is provided by the Cartesian co-ordinates. The PID controller consists of three different stages. The foundation system is the proportional controller, even though the integral system increases the overshoot it reduces the steady state error, and derivative control increases the stability by reducing the tendency to overshoot. By
simply adding the three required control components, it generates the response of PID system. The closed loop response of the system is obtained and shown in Figure 4.

![Figure 4 Rudder control of sailboat](image)

**B. Sail Control**

The sail control system controls the angle of the sail. The foundation for sail control system depends on the current wind direction. When the behaviour of the boat changes it determines the type of change and handles different situation. If the boat is Lee helm the sail angle of the main sail is closing by 1 degree. This is repeated every second until the boat behaviour is in the neutral state again. If the sailboat is Weather helm the sail angle of the main sail is opening by 1 degree, until the boat comes to the neutral state again. The sail angle is adjusted by controlling the offset value for head sail and main sail. Here a conventional PID controller is employed to control the sail angle.

**TABLE I PERFORMANCE INDICES OF CPID CONTROLLER**
5 WIND PLOT

Due to abnormal weather condition the wind direction and velocity are unpredictable. Here the plot between wind velocity and wind direction is shown in Figure 5. The graph is plotted in polar co-ordinates, in order to generate random values it has been converted into Cartesian co-ordinates.

\[\text{Figure 5 Polar plots of wind direction and velocity}\]

The standard deviation is used to calculate wind velocity. Movement of wind is calculated for certain distance. Hence the boat moves in a constant speed to reach the destination. The plot between wind velocity and distance is shown in Figure 6.

\[\text{Figure 6 Wind velocity is controlled}\]

6 PID WITH PSO TECHNIQUE

The Proportional-Integral-Derivative (PID) controller is the most popular controller used in the industry because of their repeatability, effectiveness, simplicity of implementation and broad application. The tuning of these controllers is a time consuming procedure
and not easy. This paper presents the tuning of the (PID) controller by particle swarm optimization (PSO) algorithm for a sailboat control. This approach has great features like increasesimple implementation speed, simple calculation, can be used for both scientific research and engineering proposals. The automatic tuning PSO-PID for sailboat using mat lab is shown below. Simulation results for the proposed method gives optimum input/output tracking and error equal to zero is shown in Figure 7.

![Figure 7 Error is nullified using PSO technique](image)

**A. Rudder Control**

Rudder is one of the major part of the sailboat which should be controlled for the proper movement of the boat. The rudder angle should be within their limits so that the boat balances i.e. can remain in neutral position without titling and causing great damage. So that the boat can reach the desired destination. The error and fluctuations are controlled by using PSO tuning technique. Initially, PSO algorithm is discovered through simplified social model simulation. In PSO each particle in swarm represents the solution to a problem and it is defined with its position and velocity. The rudder control is shown in Figure 8.

![Figure 8 Rudder angle control using PSO technique](image)

**B. Sail Control**
The main sail and heading sail of the boat is changed by the blowing wind. In order to control the boat the sail angle should be optimized. The tacking and jib manoeuvre is done to bring the boat to neutral position. In PSO technique a population of particles is initialized with random positions and the each particles fitness in the swarm is evaluated. For every iteration, comparison is made between each particle fitness and its previous best fitness obtained is shown in Figure 9. If the current value is better than the previous best fit value, then assume the best fit value is equal to current value. Compare the best particle with each other and update the swarm global best location with the greatest fitness. The velocity and position of the particles are changed according to the equations in PSO optimization technique.

![Figure 9 Iteration comparisons in PSO technique](image)

The sailboat variation in direction is predicted using standard deviation is plotted in the Figure 10. The fluctuations are minimized and the values are obtained correspondingly using PSO technique.

![Figure 10 Sail control using PSO technique](image)

TABLE II PERFORMANCE INDICES OF PID CONTROLLER USING PSO

| PID Controller Using PSO | Performance Indices | 8 |
The comparison between Conventional PID and PID with PSO is made. Figure 11 represents the difference between the settling points.

**TABLE III COMPARISON ON ISE, IAE, ITAE VALUES**

<table>
<thead>
<tr>
<th>ITERATION</th>
<th>ISE</th>
<th>IAE</th>
<th>ITAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>8.541</td>
<td>9.242</td>
<td>92.42</td>
</tr>
<tr>
<td>100</td>
<td>0.1748</td>
<td>1.322</td>
<td>13.22</td>
</tr>
<tr>
<td>500</td>
<td>0.00269</td>
<td>0.17</td>
<td>1.7</td>
</tr>
<tr>
<td>1000</td>
<td>0.000551</td>
<td>0.081</td>
<td>0.81</td>
</tr>
</tbody>
</table>

7 COMPARISON OF CPID AND PID WITH PSO

The comparison between Conventional PID and PID with PSO is made. Figure 11 represents the difference between the settling points.

![Figure 11: Comparison on settling point](image-url)

**TABLE III COMPARISON ON ISE, IAE, ITAE VALUES**

<table>
<thead>
<tr>
<th>CONTROLLER</th>
<th>ISE</th>
<th>IAE</th>
<th>ITAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPID</td>
<td>6.554</td>
<td>15.77</td>
<td>7883</td>
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<tr>
<td>PID WITH PSO</td>
<td>0.000651</td>
<td>0.081</td>
<td>0.81</td>
</tr>
</tbody>
</table>
8 CONCLUSION

The target of this paper is to show the feasibility of the sailboat with automated sail actuation. The sail angle and the rudder angle has been changed due to the changing weather conditions (aerodynamic and hydrodynamic force). Thus the sail control system is able to react on changing weather conditions. Using two different types of tuning methods for a single controller accurate control is obtained in short span of time, which is considered as an advantage of this paper. Compared to conventional controller, PID using PSO has reduced error in large amount.

References


[8] Roll Stabilization Control of Sailboats Kristian L. Wille, Vahid Hassani, Florian Sprenger