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Adaptive Pid Control Of An Autonomous Sailboat

B.Puviyarasi, N.Nithyarani, T.Tamilselvi, K.Srivdya

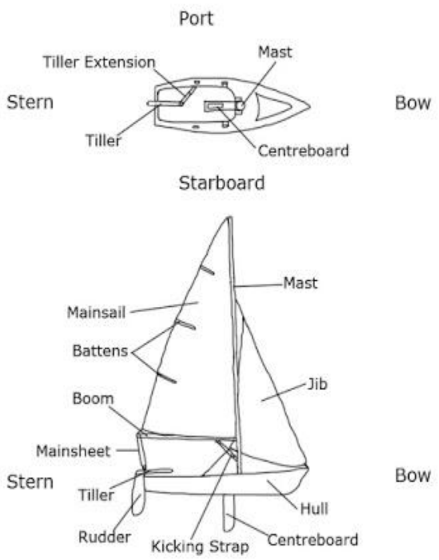
Abstract:- This paper discusses the control architecture for autonomous sailboat navigation. The control of non linear autonomous sailboat system is done by using Conventional PID controller (CPID) and Adaptive PID controller (APID). This mainly focuses on the way of dynamically controlling the sail of the sailboat to reduce the heel angle and roll motion caused by the wind. A large heeling angle, a lot of roll motion due to wind gusts can cause the boat to capsize. Sailboats cannot sail directly up-wind either and one have to move in a zigzag pattern to be able to sail up-wind. The sail angle is optimized and rudder angle is controlled for the given wind direction and desired moment. The main goal is to allow long endurance autonomous mission.

Keyword-Sailboat, sail angle, rudder angle.

I. INTRODUCTION

Sailboat played an important role for mankind. Sailboats were mainly used for fishing, trading, and transportation etc.now a day's 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.



II. 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] designed uses a fuzzy controller for sail and rudder control which is not stable. The hyraii is a catamaran with t- shaped foils equipped with steerable flaps. The hyraii team [6]found the potential to reduce the drag 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.

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* Correspondence Author

B.Puviyarasi*, Assistant Professor, Department of Electronics and Instrumentation, Sri Sairam Engineering College, Chennai, Tamilnadu, India.
(Email: Puviyarasi.ei@sairam.edu.in)

N.Nithyarani, Assistant Professor, Department of Electronics and Instrumentation, Sri Sairam Engineering College, Chennai, Tamilnadu, India.
(Email: nithyarani.ei@sairam.edu.in)

T.Tamilselvi, Assistant Professor, Department of Electronics and Instrumentation, Sri Sairam Engineering College, Chennai, Tamilnadu, India.
(Email: tamilselvi.ei@sairam.edu.in)

K.Srivdya, Assistant Professor, Department of Electronics and Instrumentation, Sri Sairam Engineering College, Chennai, Tamilnadu, India.
(Email: srividya.ei@sairam.edu.in)

III. PROCESS DESCRIPTION

The sail provides forward propulsion for the movement of the sailboat. There is a optimal sail angle 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 a sailing manoeuvre where the lee and windward side of the boat are changing.

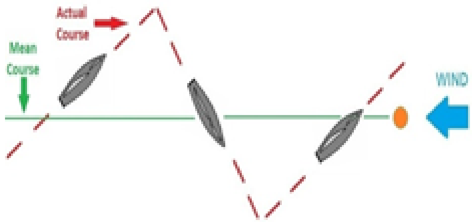


Figure 2 tack manoeuvre on an upwind course.

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.

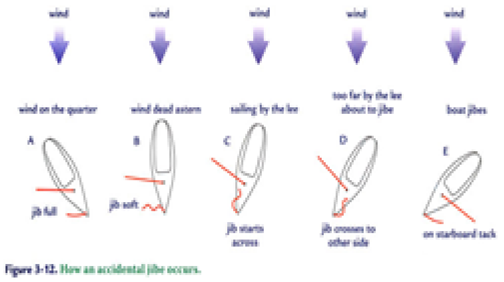


Figure 3 jib manoeuvre.

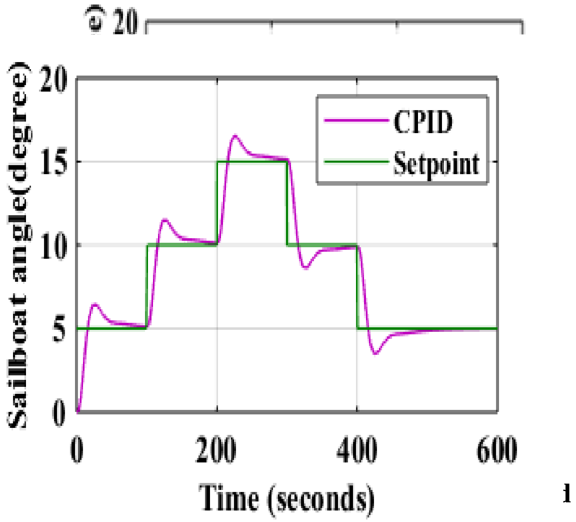
The sailing behaviour depends on many factors. This paper focus on changing behaviour of the sailboats caused by aerodynamic and hydrodynamic forces. Depending on the aerodynamic force and hydrodynamic force, the angle of the sail and the rudder angle is being altered using conventional pid (cpid) and adaptive pid (apid).

IV.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. Servo performance of sailboat

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 0^0 to 360^0, 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, the integral system reduces the steady state error but increases the overshoot, and derivative control increases the stability by reducing the tendency to overshoot. Simply adding together the three required control components generates the response of pid system. The servo response of cpid is shown in figure 4.



The sail control system controls the angle of the sail.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 1degree.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 1degree, until the boat comes to the neutral state again. The servo performance indices of CPID are reported in the Table i.

Table I Servo Performance Indices Of Cpid

Step Input	ISE	IAE	ITAE
5	163.8	79.3	79300
10	655.3	157.9	157900
15	1474	236.8	236800

B. Servo -regulatory performance of sailboat

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. Here to demonstrate the disturbance rejection capability of the cpid at nominal and shifted operated points a step disturbance is given at time=150 second and it again settles at time =300 second and it rejects the disturbance and makes the boat travel in a desired direction. The disturbance is provided as shown in figure 5.

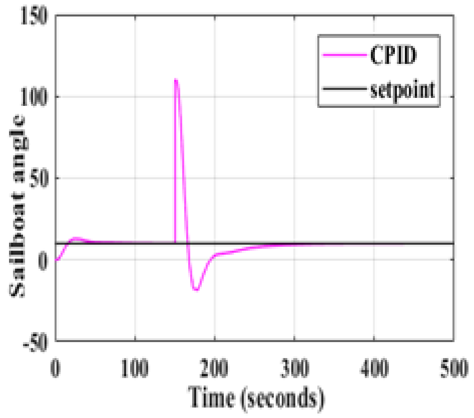


Figure 5 servo-regulatory response of sailboat

The performance indices, i.e. Integral square error ,integral absolute error and integral time absolute error is shown in table ii.

Table II Servo-Regulatory Performance Indices Of Cpid

PERFORMANCE INDICES	VALUES
ISE	92590
IAE	2115
ITAE	1058000

V. ADAPTIVE PID CONTROLLER

The proportional-integral-derivative (pid) controllers are the most popular controllers used in industry because of their remarkable effectiveness, simplicity of implementation and broad applicability. However tuning of these controllers is time consuming and not easy. Hence adaptive control for pid has been introduced. It is used to eliminate the effect of parameter disturbance upon the performance of control system. This approach has superior features including easy implementation, stable convergence characteristic and good computational efficiency over the conventional methods. The automatic tuning of pid for sailboat using mat lab is shown below. Simulation results for the proposed method gives optimum input/output tracking and minimum error.

A. Servo performance of sailboat

Rudder is one of the major parts 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 adaptive pid technique. The original algorithm is discovered through simplified social model simulation. 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. The response of apid controller is shown in figure 6.

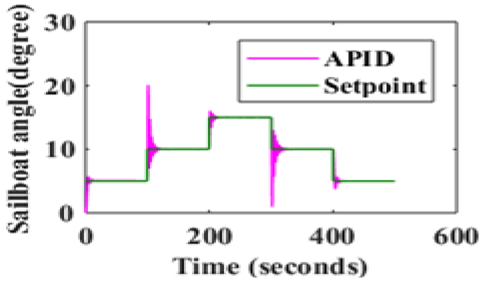


Figure 6 servo response of sailboat using apid

The performance indices of adaptive pid controller are calculated. The integral square error is decreased in total and it settles at minimum time. The output response obtained is faster compared to other controllers. The performance indices for servo response of apid is depicted in Table III.

Table III Servo Performance Idices Of Apid

Step Input	ISE	IAE	ITAE
5	44.26	23.06	23060
10	144.5	46.53	46530
15	356.8	72.92	72920

B. Servo- regulatory performance of sailboat

to demonstrate the disturbance rejection capability of the apid at nominal and at shifted operating points, a step disturbance is introduced at time = 450 second and is then removed at time = 455 second.apid is able to reject the disturbance quickly and tilt the sail angle to the desired direction. This clearly demonstrates that the controllers are able to reject the disturbance at nominal operating point. The sailboat variation in direction is predicted using standard deviation. The disturbance is provided as shown in figure 7.

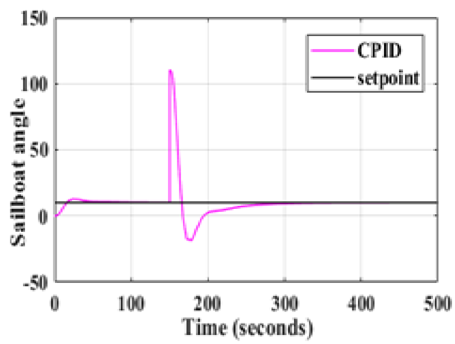


Figure 7 servo-regulatory response of sailboat

The performance indices, i.e. Integral square error ,integral absolute error and integral time absolute error is shown in tabulation II.

Table IV srvo-regulatory performance indices of apid

PERFORMANCE INDICES	APID
ISE	279.6
IAE	72.33
ITAE	72330

VI. COMPARISON OF CPID AND APID & RESULTS

A. Servo performance of sailboat

To demonstrate the controlling capability of the sailboat using apid and cpid, the set point variations are shown in figure 8.from the response it is inferred that the apid is able to move the sailboat in desired direction compared to cpid even though the wind is heavy. The boat comes to its correct form even there is disturbance in its moving path.apid control algorithm does it in effective manner than cpid. The performance indices of apid and cpid are reported in table v.

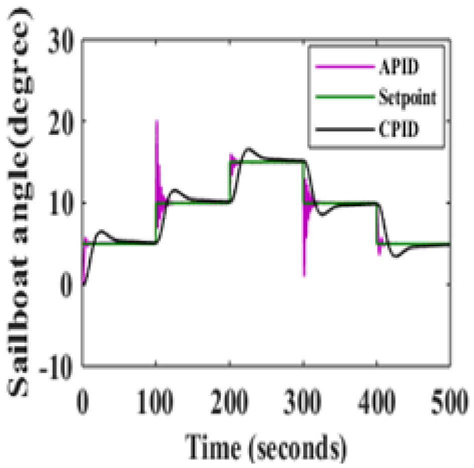


Figure 8 servo response of sailboat.

Table V servo performance indices of cpid and apid

Performance indices	CPID	APID
ISE	1134	333
IAE	465.3	100.3
ITAE	465300	60210

B. Servo - regulatory performance of sailboat

To demonstrate the controlling capability of the sailboat using apid and cpid, the set point variations are shown in figure 9.from the response it is inferred that the apid is able to move the sailboat in desired direction compared to cpid even though the wind is heavy. The boat comes to its correct form even there is disturbance in its moving path.apid control algorithm does it in effective manner than cpid. The performance indices of apid and cpid are reported in table vi.

Table VI Servo –Regulatory Performance Indices Of Apid And Cpid

PERFORMANCE INDICES	CPID	APID
ISE	92590	279.6
IAE	2115	72.33
ITAE	1058000	72330

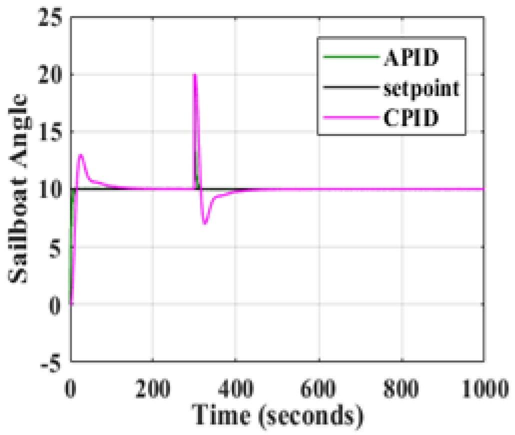


Figure 9 servo-regulatory response of sailboat

VII. CONCLUSION

We conclude that the rudder and sail angle of the boat is tilted and controlled. As the error in the cpid is more when compared to the apid. The error is reduced in the adaptive controller and the efficiency is improved. This paper compares the apid controller and the cpid controller.

1. From the simulation studies, it is observed that it has good set point tracking, disturbance rejection capabilities at entire region.
2. Further, it can be observed that the apid helps to produce response with no overshoot and settles to the set point faster compared to CPID

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