Fuzzy Logic-based Control Algorithm for Hybrid Propulsion Passenger Boat

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Agenda

- Introduction
- Overview
- Case Study Analysis
- Modified AOS910 Catamaran ferry
- Fuzzy Control System
- Implementation
- Simulation Results
- Conclusions

Introduction

- Development of cleaner and more efficient ship technologies in response to concerns about
  - rising fuel costs and
  - reducing greenhouse gas emissions
    - carbon dioxide and nitrous oxides.
- Hybrid propulsion and power generation represents the new research
  - optimized control algorithms
  - reduced component sizes and weights
  - reduced fuel consumption and
  - reduced air pollution and
  - more controlled global climate change.

Overview

- Electronic control mechanisms for a hybrid engine architecture for a typical passenger boat
  1. Employs two different propulsion technologies (diesel fuel and wind)
  2. On-board auxiliary power is generated by a hybrid system consisting of solar, wind turbine, diesel generator
- Controller is based on Fuzzy Logic theory
  1. receives data from various kinds of sensors
  2. alternates between different energy technologies depending on weather and sea conditions
- Allows the engine power to be dynamically adjusted for reduced fuel consumption
- Design is implemented and tested in software

Case Study Analysis

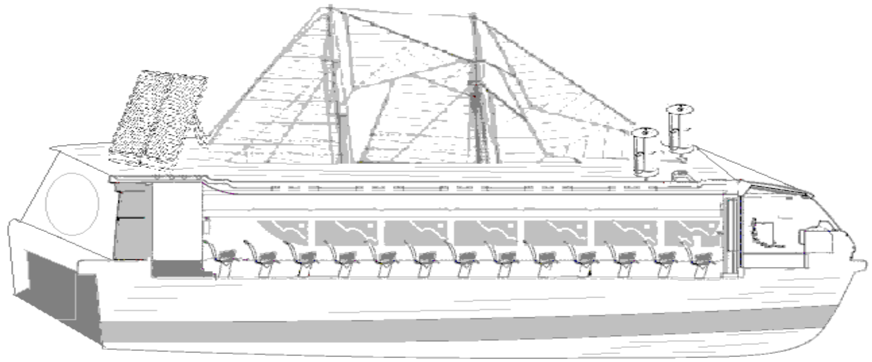
- Catamaran passenger ferries
  - could be upgraded with hybrid propulsion marine technologies
  - suitable for deployment in Fiji.

Ocean Quest is a regular Catamaran passenger ferry
21.946m long and 6.7056m beam
149 passengers
average speed of 18 knots
two 6125A 500 HP (240 kW @ 2100 RPM)
Lugger diesel engines

AOS910 is a new build Catamaran passenger ferry
15.80m LOA and 5.30m breadth and 4.85m depth
70 passengers
cruise speed of 20 knots
two D12 550 HP (410 kW @ 1900 RPM)
Volvo Penta diesel engines

Modified AOS910 Catamaran ferry

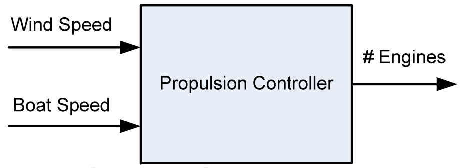
- Modified architecture with different propulsion and energy source technologies
  - solar
  - wind
  - electrical
  - diesel



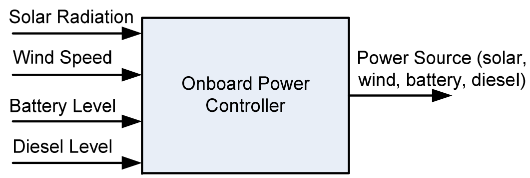
- (4.5 kW) 18 solar panels
- two Whisper 100 (1.8 kW) wind turbines
- (12 V/225Ah) Trojan SCS225 battery bank
- (15 KW) diesel generator
- AOS910 is a new build Catamaran passenger ferry
- 15.80m LOA and 5.30m breadth and 4.85m depth
- 70 passengers
- cruise speed of 20 knots
- two D12 550 HP (410 kW @ 1900 RPM)
Volvo Penta diesel engines

Fuzzy Control System

- Two fuzzy controllers are proposed
  - one for propulsion and
  - another for onboard electrical power



- Propulsion=> combination of sails and diesel engines is proposed.
- Control system determine the number of diesel engines (1 or 2) to use based on wind speed information
- 3 m/sec < wind speed at the seashore < 5 m/sec
- Onboard electricity => combination of solar, wind, marine deep cycle batteries, and diesel is proposed.
- 0 W/m^2 < solar radiation < 1300 W/m^2
- Based on the vessel specifications:
  - (4.5 kW) 18 solar panels
  - two Whisper 100 (1.8 kW) wind turbines
  - (12 V/225Ah) Trojan SCS225 battery bank
  - (15 KW) diesel generator



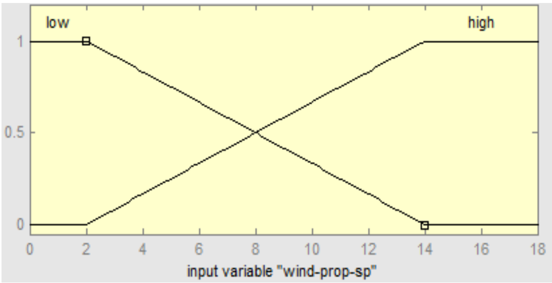
Implementation

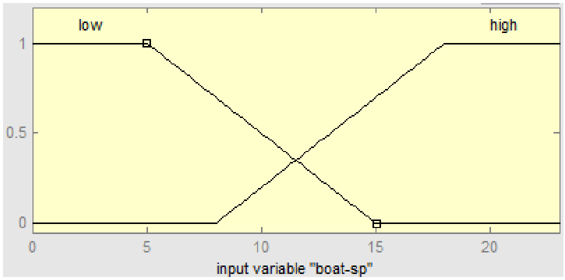
- MATLAB 2010a Fuzzy Logic Toolbox is used to develop the fuzzy controllers.
- Controllers are Mamdani type (MATLAB's default type).
- Basic trapezoidal and triangular membership functions are used for simplicity.
- Outputs of the various input combinations is viewed with MATLAB's surface viewer.
- MATLAB default settings are employed for the 'And', 'Or', 'Implication' and 'Defuzzification' functions.
- Parameter settings for the fuzzy inference functions are:

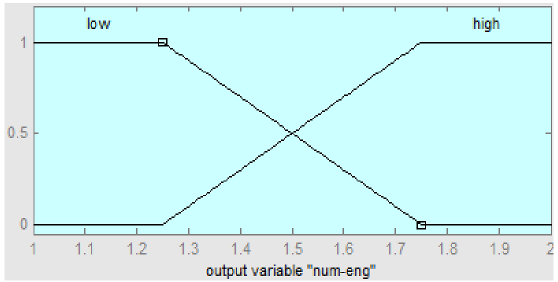
Function	**Method**
And	Min
Or	Max
Implication	Min
Aggregation	Sum
Defuzzification	centroid

Implementation (Con't)

- Below are illustrations of the input and output membership functions for the propulsion controller:





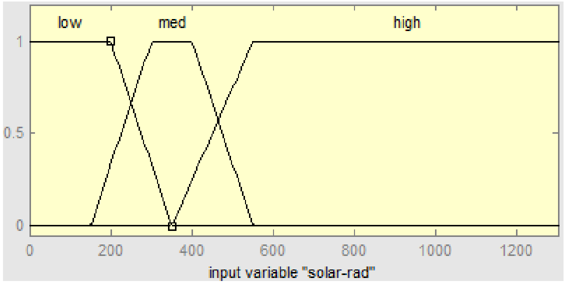


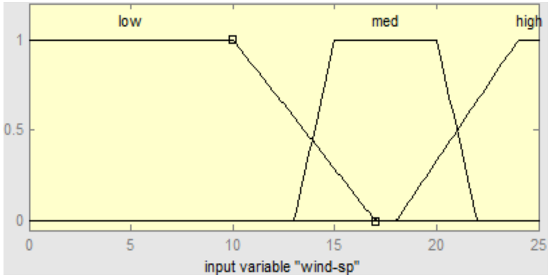
- The output membership function selects the number of engines (one or two) to be used for propulsion.
- the rule table for the propulsion controller is shown below:

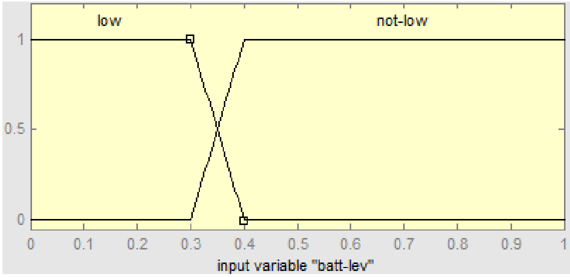
Wind Prop. Speed	**Boat Speed**	**Connection**	**# Engines**
Low	low	and	High
Low	high	and	High
High	low	and	High
High	high	and	Low

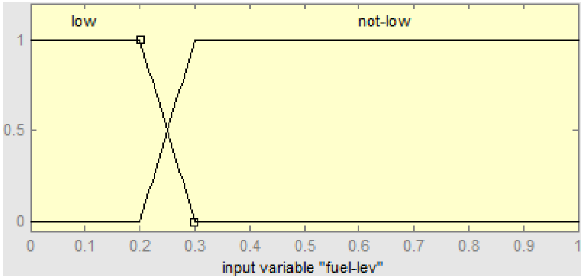
Implementation (Con’t)

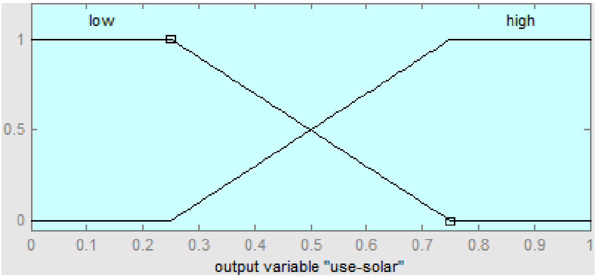
- Below are illustrations of the input and output membership functions for the onboard power controller.











- The outputs of the controller indicate whether a power source is to be used or not.
- The other two outputs ‘use-wind’ and ‘use-fuel’ have similar membership functions.

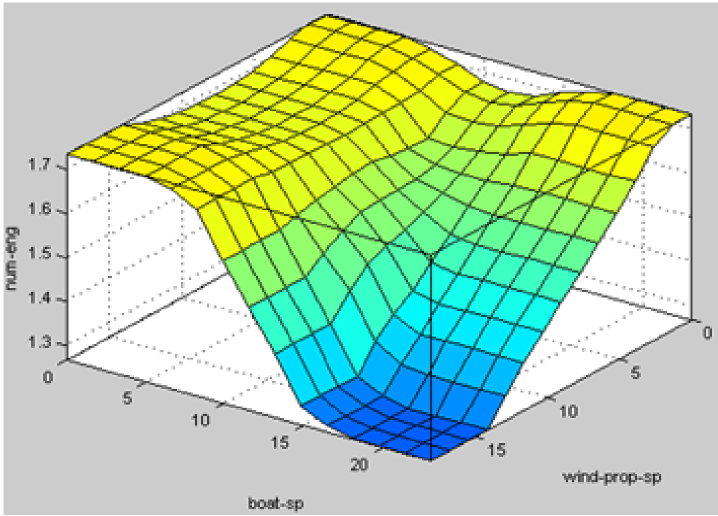
Implementation (Con't)

- the rule table for the onboard power controller is shown below:

Rule no.	Inputs				Inputs Connection	Outputs		
	Solar radiation	Wind speed	Battery level	Fuel level		Use-solar	Use-wind	Use-fuel
1	low	low	low	not-low	And	Low	low	high
2	low	low	low	Low	And	Low	low	-
3	low	low	not-low	-	And	Low	low	low
4	high	high	low	-	And	High	high	low
5	high	high	not-low	-	And	High	low	low
6	high	medium	low	-	And	High	high	low
7	high	medium	not-low	-	And	High	low	low
8	high	low	-	-	And	High	low	low
9	medium	medium	-	-	And	High	high	low
10	medium	high	-	-	And	High	high	low
11	low	high	-	-	And	low	high	low
12	low	medium	-	-	And	low	high	low

Simulation Results

- Number of engines to be selected based on wind speed and boat speeds.
- Smooth transition from one engine (# engine < 1.5) to two engines (# engine > 1.5) selection.



Simulation Results (Con't)

- Simulation results for the onboard power controller is shown below:

Rule no.	Inputs				Outputs		
	Solar radiation (W/m^2)	Wind speed (Knots)	Battery level	Fuel level	Use-solar	Use-wind	Use-fuel
1	100(low)	10(low)	0.3(low)	0.5(not-low)	0.27	0.27	0.73
2	100(low)	10(low)	0.2(low)	0.2(low)	0.27	0.27	0.5
3	100(low)	10(low)	0.4(not-low)	0.5(not-low)	0.27	0.27	0.27
4	800(high)	22(high)	0.3(low)	0.5(not-low)	0.70	0.70	0.30
5	800(high)	22(high)	0.4(not-low)	0.5(not-low)	0.71	0.30	0.30
6	850(high)	15(med)	0.3(low)	0.5(not-low)	0.71	0.62	0.29
7	850(high)	15(med)	0.4(not-low)	0.5(not-low)	0.71	0.29	0.29
8	800(high)	10(low)	0.4(not-low)	0.5(not-low)	0.73	0.27	0.27
9	400(med)	15(med)	0.4(not-low)	0.5(not-low)	0.70	0.57	0.30
10	400(med)	22(high)	0.4(not-low)	0.5(not-low)	0.69	0.59	0.30
11	100(low)	22(high)	0.4(not-low)	0.5(not-low)	0.30	0.70	0.30
12	100(low)	15(med)	0.4(not-low)	0.5(not-low)	0.29	0.62	0.29

- Each output (use-solar, use-wind and use-fuel) is switched 'on' if its output value is at least 0.5
- Desired energy source is selected based on the sensor inputs.

Conclusions

- Fuzzy controller for energy sources and propulsion technologies
- Boat prototype - modified AOS910 Catamaran ferry
  - connection from the two principle islands to other small islands
  - shipping passengers and significant essential products.
- Control mechanisms enable the engines to run at variable power for
  - optimal use of solar and
  - wind power and
  - reduced fuel consumption.
- Based on input data samples provided by wind speed, solar radiation, battery capacity, and fuel consumption sensors, numerical analysis and simulation results shows that
  - it could be possible to reduce fuel consumption by up to 50%.
- Simulator shows how different technologies could be deployed in parallel to
  - reduce diesel fuel consumption
  - reduce air pollution and
  - control greenhouse gas emissions.

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Questions?

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THANK YOU

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