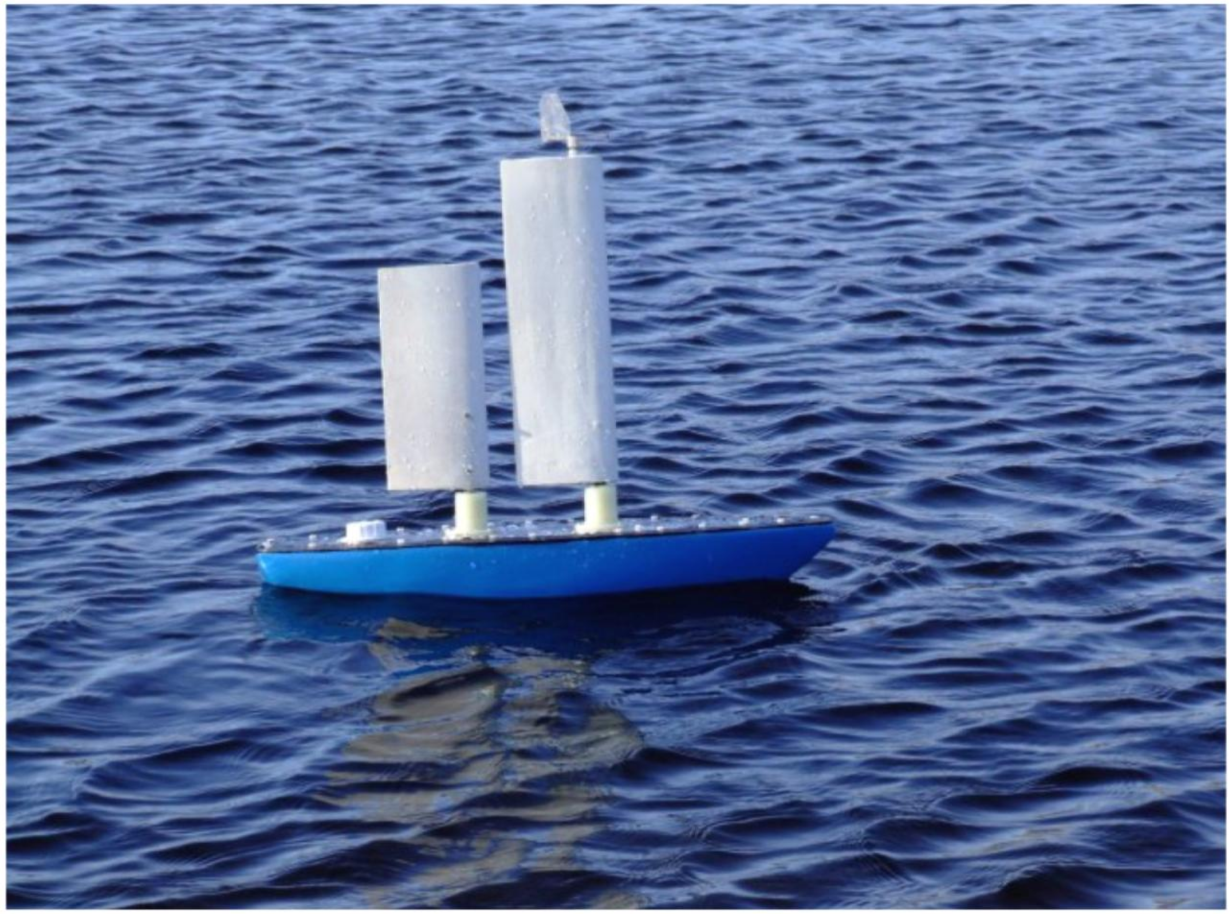

An investigation into a mechanism for selection of fuzzy logic type based on noise & uncertainty

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Talk Outline

- Motivation & background
- Fuzzy Logic
- Introducing FLOAT-S
- Tracksail Simulator
- Experimental work
- Future work

Who am I?

- Undergrad degree in CS @ U.Nottingham, *2005*
- Thales, London, *2005 -2008*
  - SATCOM embedded systems
- PhD in IMA @ U.Nottingham, *2008 – Present*
- Initially researched optimisation of data centres
  - Many issues regarding data collection
- Follow my interests in fuzzy control systems
- Real world applications

Introducing Fuzzy Controllers

- Need to control systems which operate under under uncertainty
- Uses fuzzy logic to control systems such as robots
- Uses *if then else* rules in conjunction with *Adjectives* defined by membership functions
- Examples include:
  - Home appliances
  - Manufacturing robots

What is Fuzzy Logic?

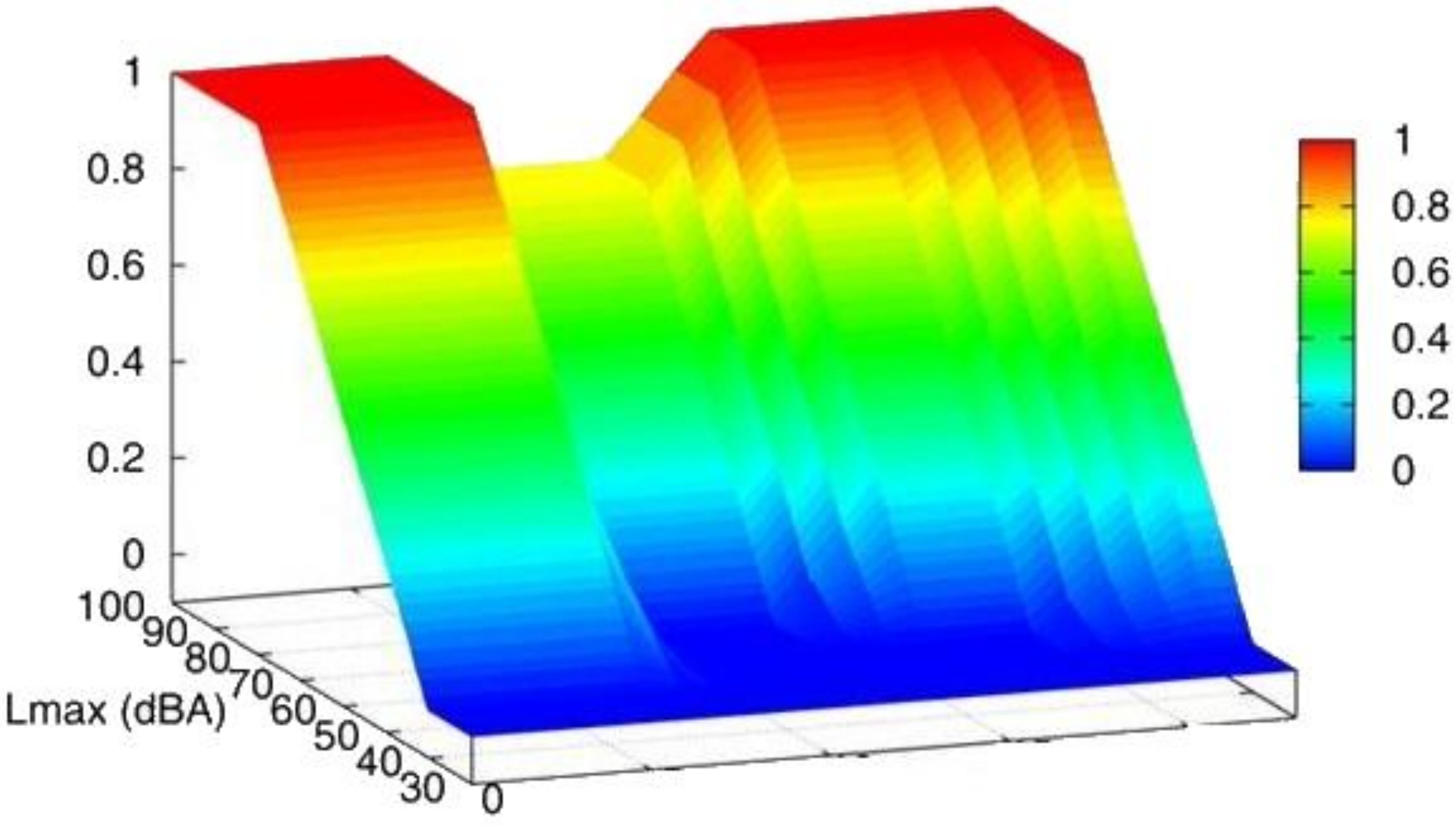
- *Derived from Fuzzy set theory which uses membership values between 0 and 1 instead of binary to assign class membership*
- Specified membership functions determine the degree to which a variable belongs to a fuzzy set
- Numerous different types of fuzzy logic based system:
  - Type I and Type II, plus non-stationary
- Various applications in a range of disciplines usually involving decision making, decision support and control systems
- Fuzzy membership is not a measure of probability!

Type I Fuzzy Logic

- First invented in the 1960s [Zaddeh, 1965]
- Approximate the human decision making process
- Uses 2D membership functions for fuzzy set assignment
- [Add standard diagram]

Type II Fuzzy Logic

- Type II – Still uses 2D membership functions but introduces uncertainty of the membership
- The value of the membership changes due to uncertainty
- Allows better modelling of noise and therefore potentially better performance than type I
- More computationally intensive than type one because of the extra values to compute


1
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100
90
80
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40
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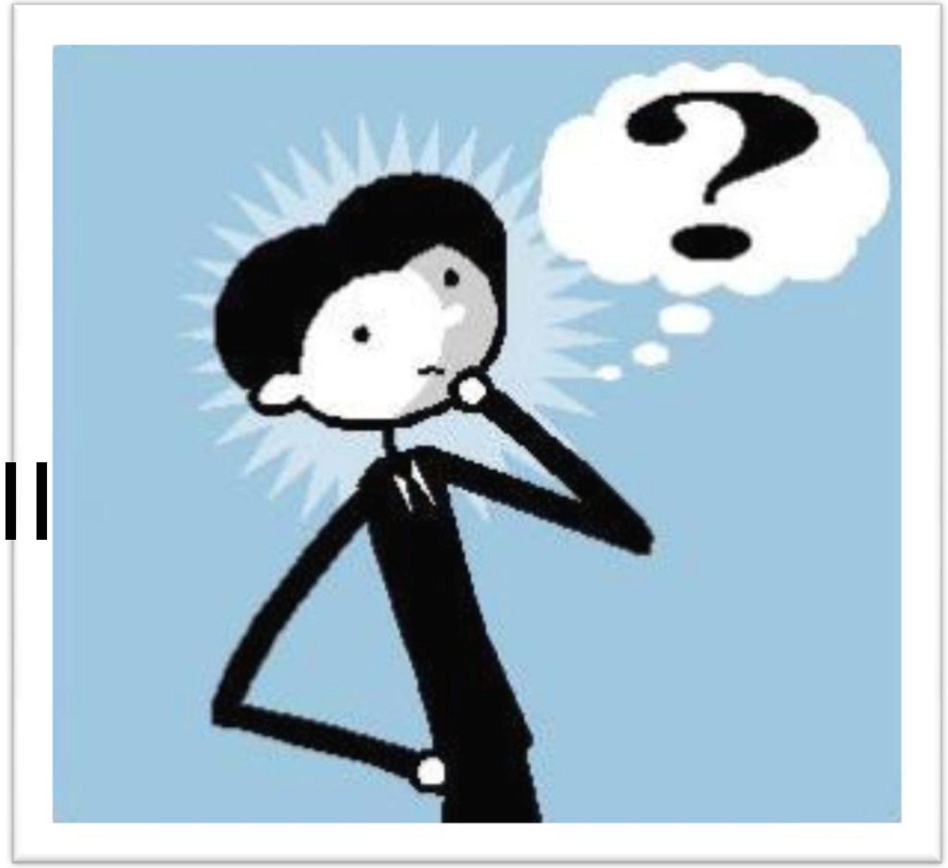
0
Lmax (dBA)
1
0.8
0.6
0.4
0.2
0

Which Fuzzy?

- Differences are evident between Type I and II
- Type 1 performance:
  - Good performance in many situations
  - Does not handle uncertainty
- Type 2 performance:
  - less well tested and not as widely applied
  - more computationally expensive
  - Uncertainty measure gives potential for increased performance

How to Choose?

- Lots of informal guidelines in literature about how to decide aspects of a fuzzy system
- No solid reasoning why Type II should be used over type I.
- Hope to define a novel method based on our research



Noise & Uncertainty

- Many sources of noise & Uncertainty in systems:
  - Sensor noise
  - Processing Noise
  - Output noise

- Can we use a measure of uncertainty to help us decide which fuzzy system?
- Find an interesting, noisy and useful application

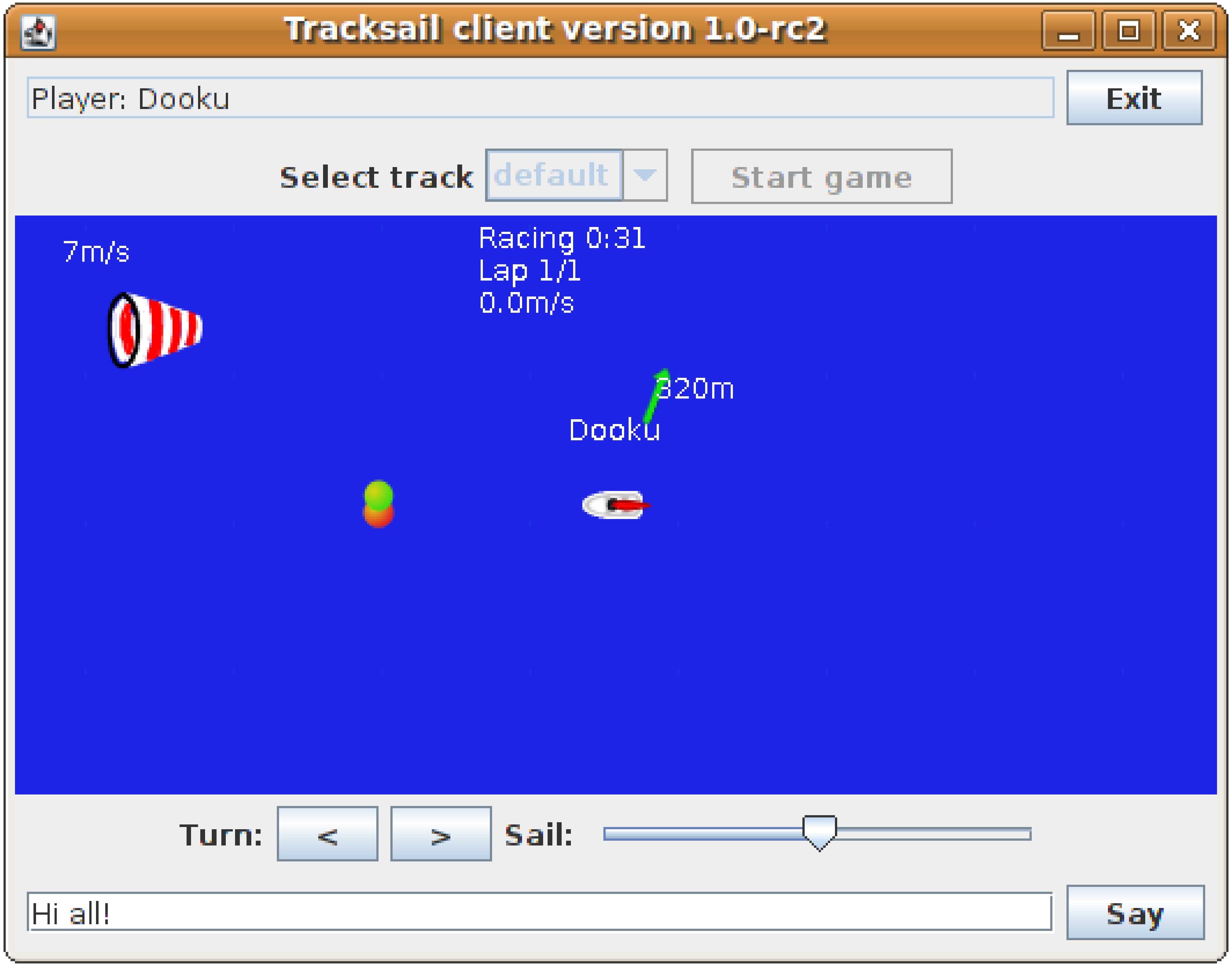
FLOAT-S

- **F**uzzy **L**ogic **O**perated **A**u**T**onomous **S**ailboat
- Constructed by researchers at the U.Aberystwyth
- Contains:
  - Twin Kevlar Wings/Sails with motor controls
  - Moveable Rudder
  - GPS navigation unit and wind direction sensor
  - PIC and Gumstix Microprocessors
  - WAN access point
- *How good are fuzzy controllers at autonomously sailing FLOAT-S?*

Simulation in Parallel

- Need precise control of inputs and sources of noise unachievable in real world
  - Unfortunately I cant control the weather
  - Impossible to achieve reproducible conditions
- Real life is too noisy for initial work
- Faster to reproduce runs in simulation
- Modification of an already existing simulation tool to perform verification and validation of physical experiments

The TrackSail Simulator



Methodology

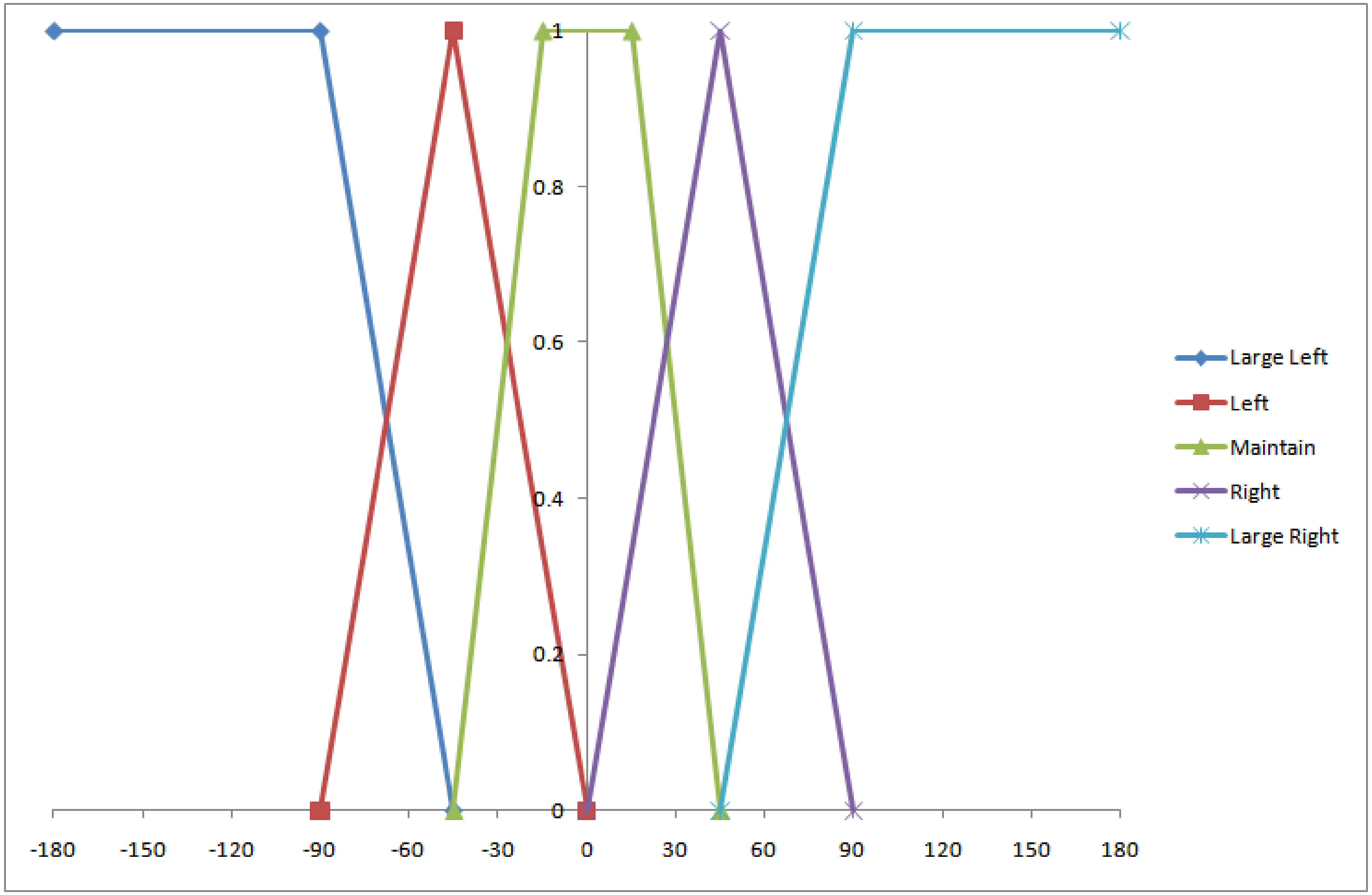
- Direct comparison almost impossible to achieve in reality
- Use the simulator to perform direct comparisons between Type 1 and Type 2 fuzzy controllers
- In sailing considerable noise is introduced into system by changes in wind
- By varying wind conditions we can observe how noise effects performance of various controllers
- Perform ultimate validation using FLOAT-S

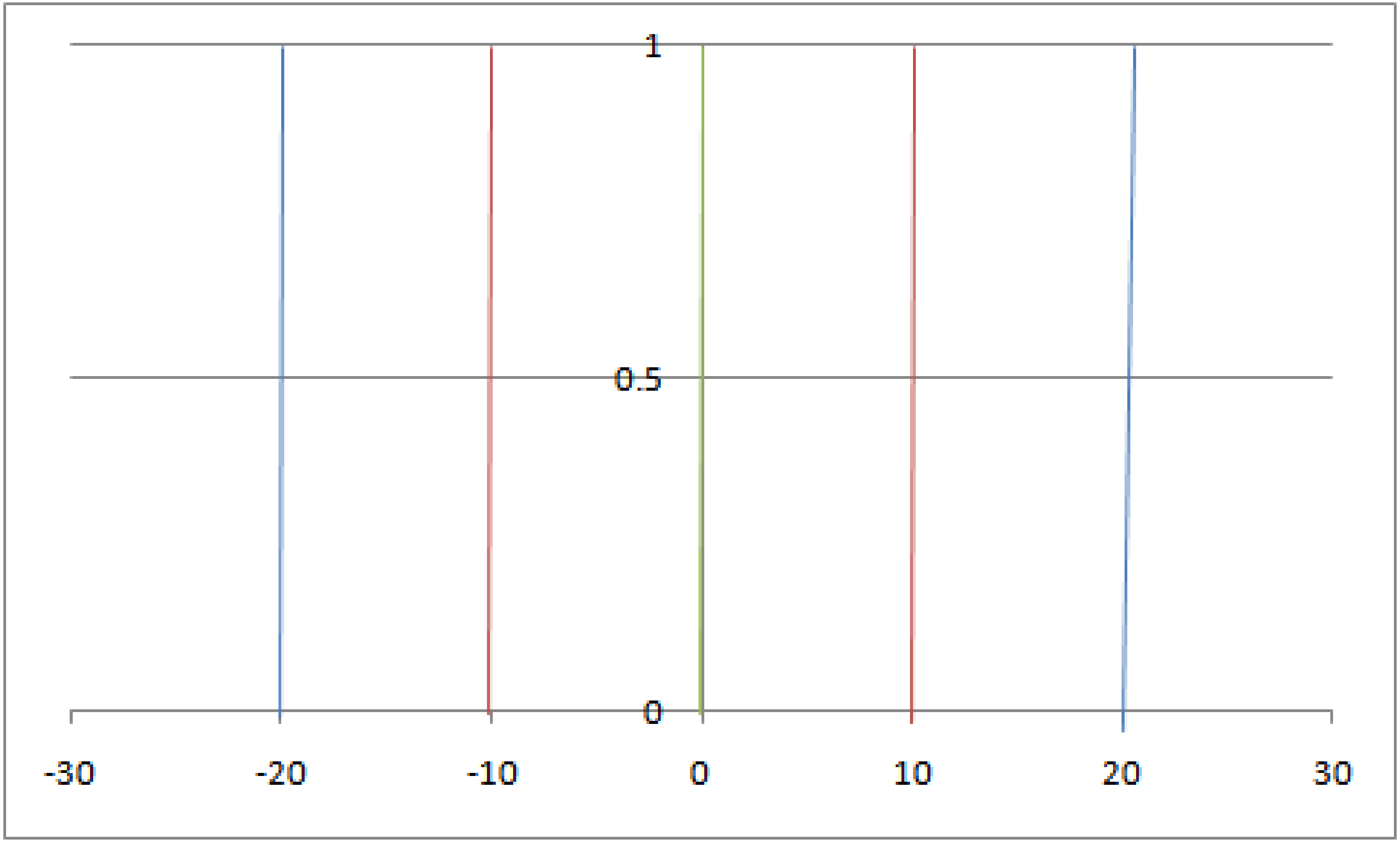
Type 1 Experimentation

- Experimented with 5 different noise levels
  - Gaussian distribution of noise
- Implementation of PI controller
- Comparison of basic PI versus Fuzzy Type 1
- Provides a benchmark against a standard approach
- Performance of 10 repeats of each system for each noise level

Type I Controller

- Based on another sail control [ref]




1
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-30
-20
-10
0
10
20
30

Benchmarks and a Fair Test

- PI Controller built by U.Aberystwyth
  - Run this controller on their “Microtransat”
- Fairly well tuned, they have lots of experience in this application domain
- Works on both real hardware and in TrackSail
- We extended and developed framework to perform comparable experiments with their controller
- Tacking rules, update rate and sensor interface kept constant

Difference in Results

- Experiments currently running, almost complete
- Basic analysis of variable wind direction performed
- Current results show performance of fuzzy within 60% of PI controller.
- Further work required to improve performance
  - Can be improved by altering design parameters
  - E.g changing the membership function shape
- Preliminary results look encouraging

Follow On Research

- To be completed in the next couple of months
- Implement Type II controller and validate its implementation
- Perform comparison with the currently running Type I controller
- Experiment with different “flavours” of Type II
  - Initial experiments with Interval Type 2
  - Move onto General Type 2
  - Potentially Non-Stationary Type I ??

Type II Controller Problems

- Computationally Expensive
  - Starting off running on desktop PC – do not anticipate many problems
  - Running same controller on Embedded ARM processor may be difficult/impossible
- However these challenges are interesting and must be addressed!
  - Fuzzy controllers designed to assist in such problems!
  - Relates to Dr. Phil Birkin's investigation with miabots

Future Work

- Additional Simulator Experimentation:
  - Vary distribution of noise
  - Inject additional sources of noise
  - Investigation of Type II
- Theoretical analysis of data, control surfaces and how they behave under varying levels of noise
- As much validation on the FLOAT-S as possible
  - Technical issues and time constraints

Challenges

- Implementing Type 2 not trivial
- Extracting meaning from large amounts of data
- Detailed theoretical and statistical analysis
- Good weather!

In Summary

- Fuzzy logic controllers have the potential to perform well in noisy systems
- Investigation of Type I and Type II Fuzzy when applied to a problem in autonomous sailing control
- Current work includes application of Type I and PI control in both simulation and FLOAT-S
- Continuation of work to extend to Type II
- Perform validation using FLOAT-S

References

[1] L. Zadeh, "Fuzzy sets," *Information and Control, vol. 8, pp. 338–353,*1965.

[2] R. Stelzer, T. Proll, and R.I. John. Fuzzy logic control system for autonomous sailboats. In
Proc. IEEE International Fuzzy Systems Conference FUZZ-IEEE 2007

[3] J. Mendel and R. John, "Type-2 fuzzy sets made simple," *IEEE Transactions on Fuzzy Systems, vol. 10, no. 2, pp. 117–127, 2002.*

Questions?