Application of Fuzzy Sets to Autonomous Robot Vehicle Navigation Using the PIC18F452 Microcontroller

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Introduction

In CS105 (Computer Environment II):

- Students programmed RC cars and trucks to obtain autonomous vehicle navigation.
- The intelligent use of ***sensor input*** was a key factor in obstacle avoidance.

One potential driving algorithm:

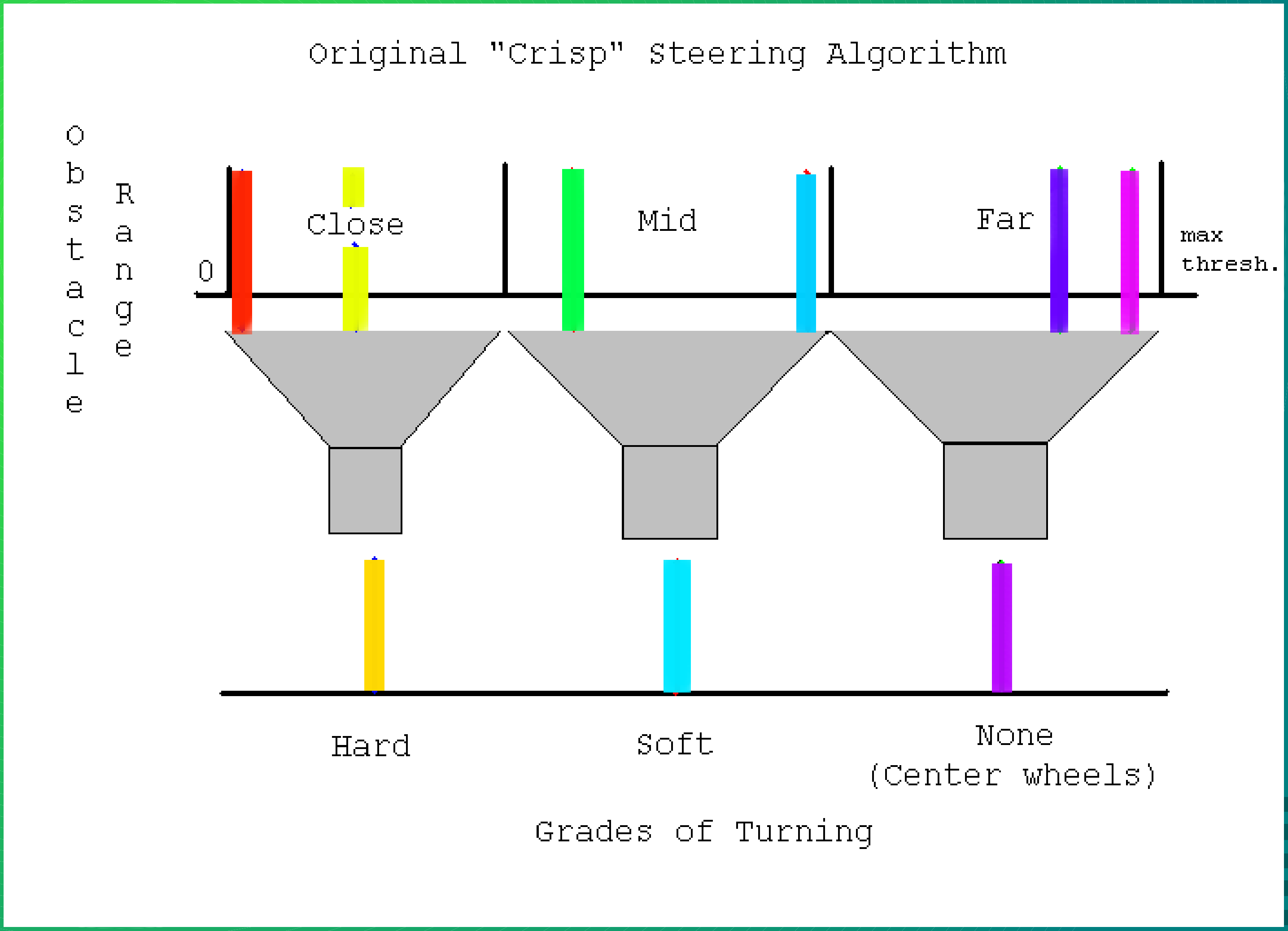
- Set a few discrete thresholds for sensor ranges which then map to steering output voltages (resulting in an angle of turning).

RESULT:

- Simple, effective, and somewhat jerky driving.

Introduction

The former algorithm mapped all sensor data to just three singletons...resulting in a loss of **information** and **control**.



An experiment...

Question:

Could fuzzy sets and/or logic be used to improve the results of this "crisp" driving algorithm?

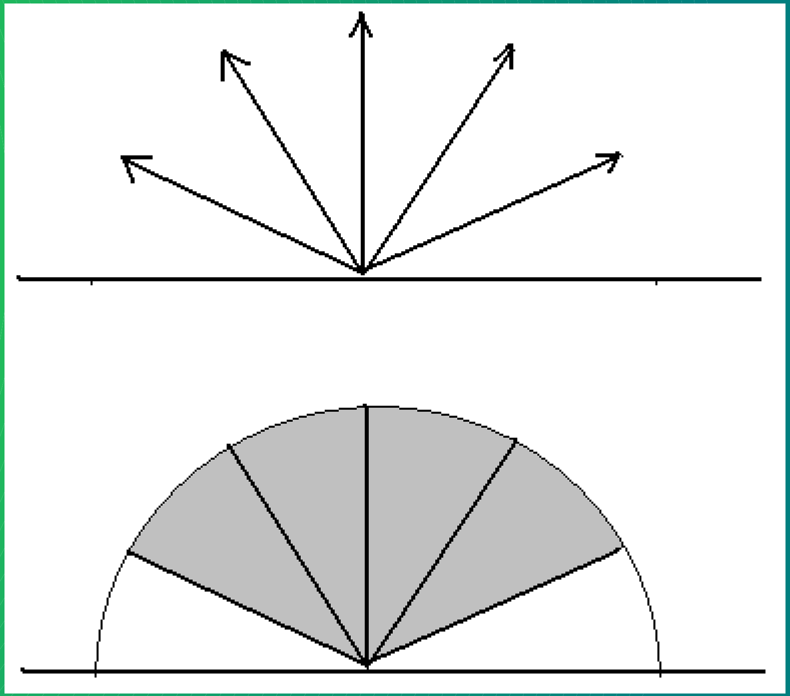
...after some work...

Project Goals

Using the linguistic expressiveness of fuzzy sets:

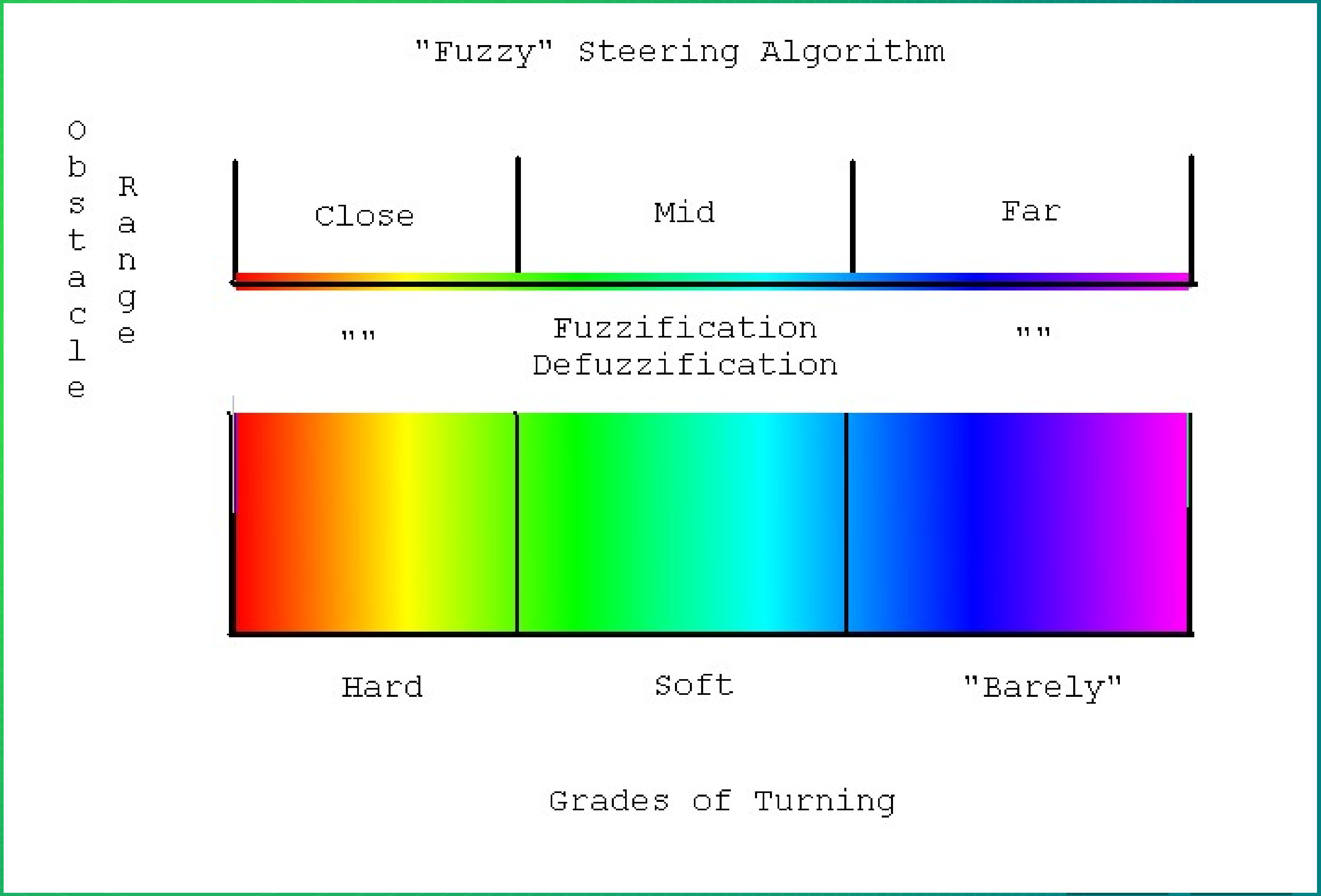
- **Preserve distinctness of sensor data**
- **Achieve smoother turning and a finer level of granularity of control over the vehicle's motion, filling in all the "shades of gray" between the discrete values of steering.**

- Crisp



- Fuzzy

Project Goals



The Math

Using Fuzzy Sets

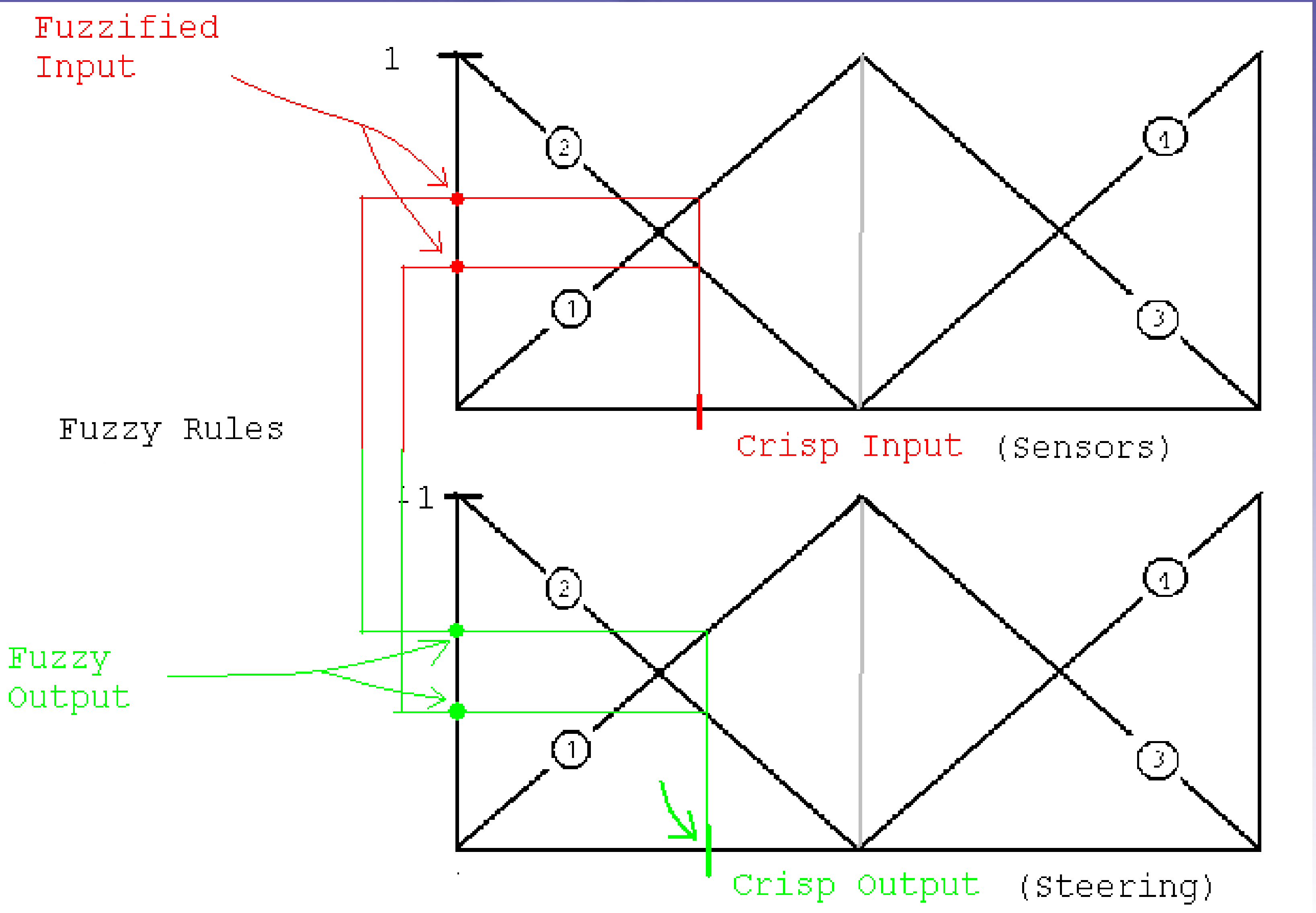
In order to achieve our project goals, we will:

(1) Fuzzify the input values received via the sensors, and

(2) Defuzzify these degrees of membership according to the fuzzy inference rules in the steering algorithm:

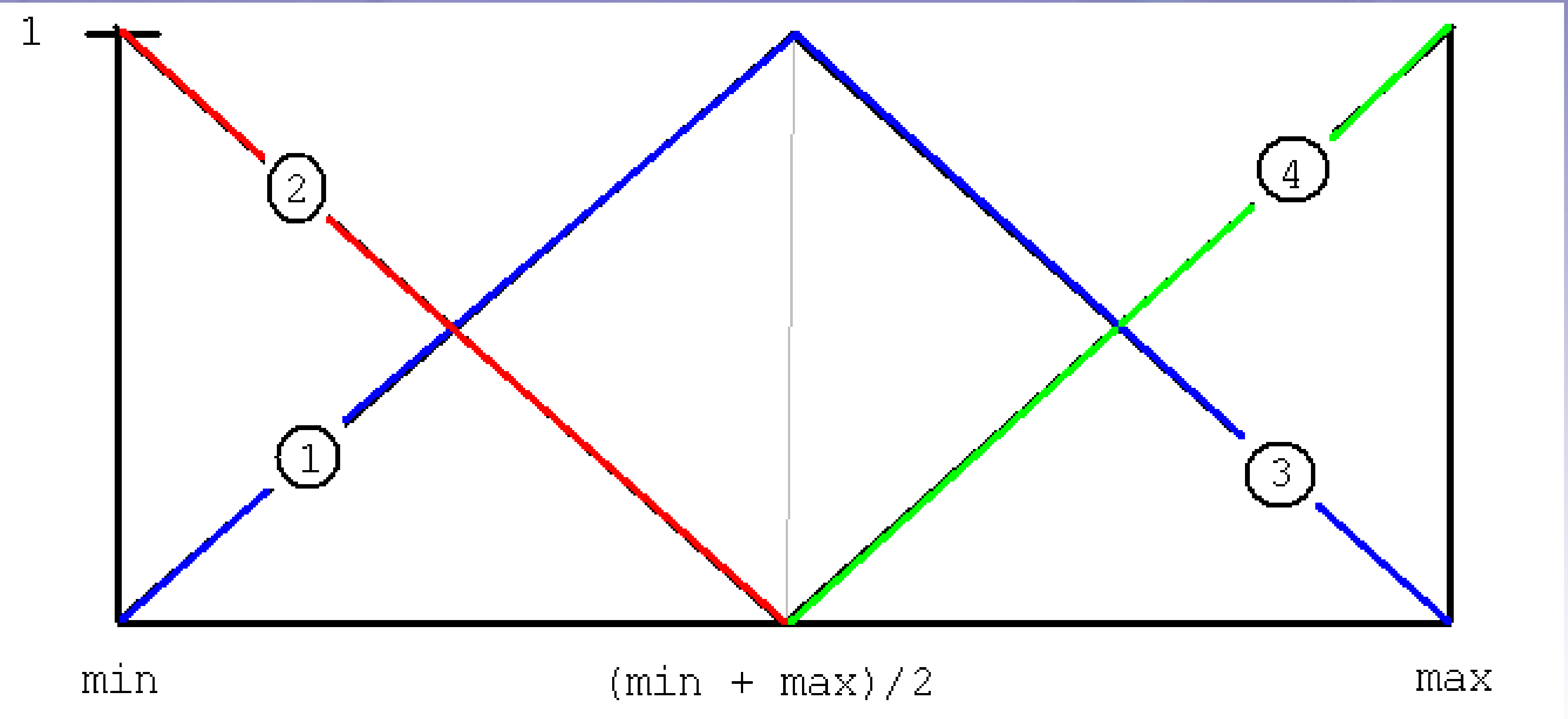
(The ***further away*** *an object is from the truck,*
the ***less*** *the truck will turn.*
The ***closer*** *an object is to the truck,*
the ***more*** *the truck will turn.)*

Overall View of the Translation Process



Generalized Membership Functions and Inference Rules Used

	Sensors	Rule	Steering
(2):	Far	1-to-1	Barely
(1),(3):	Mid-Range	1-to-1	Soft
(4):	Near	1-to-1	Hard



Analytic Form of Membership Functions Used

$$A(x) = \begin{cases} (1)\quad 2\dfrac{(x - min)}{(max - min)}, & \{x \mid \dfrac{(min + max)}{2} \le x \le max\} \\ (2)\quad \dfrac{(max + min - 2x)}{(max - min)}, & \\ (3)\quad 2\dfrac{(max - x)}{(max - min)}, & \{x \mid min \le x \le \dfrac{(min + max)}{2}\} \\ (4)\quad \dfrac{(2x - (max + min))}{(max - min)}, & \end{cases}$$

$$A : X \rightarrow [0,1]$$

Degrees of Membership Generated for Sensor Input Values

X	(1)DOM	(2)DOM
F	0.00	1.00
10	0.02	0.98
11	0.03	0.97
12	0.05	0.95
13	0.06	0.94
14	0.08	0.92
...		

- Notice how the sum of both columns in the left and right table add up to 1.0
- **This symmetry simplified calculations for fuzzification and defuzzification**
- **A previous graph illustrated such data redundancy**

X	(3)DOM	(4)DOM
7A	0.33	0.67
7B	0.31	0.69
7C	0.30	0.70
7D	0.28	0.72
7E	0.27	0.73
7F	0.25	0.75
...		

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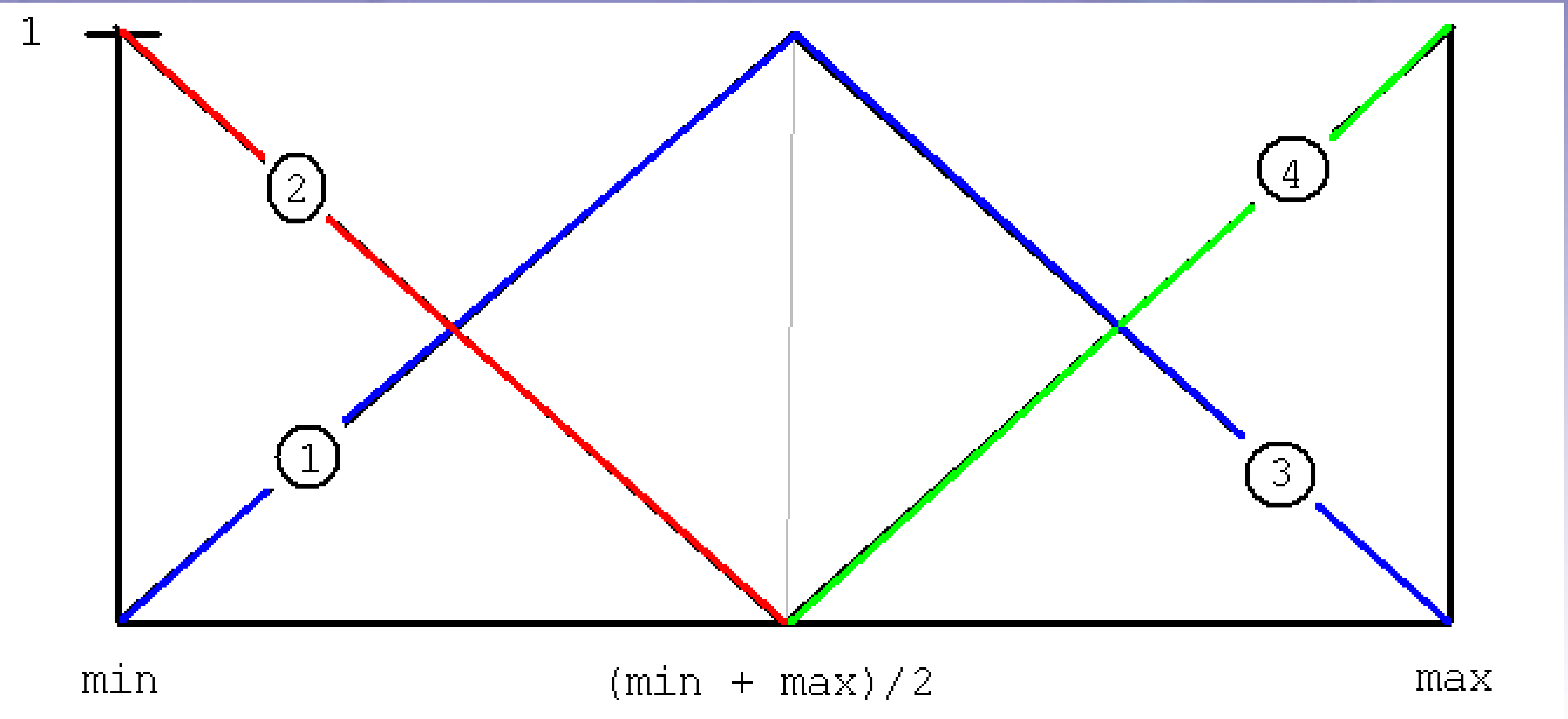

Final Algebraic Translation

Now that we have a degree of membership, A(x), for the sensor input value, let's find the steering output value.

(1) The domain of x will highlight two potential membership functions for y – pick either (symmetry).

(2) Set A(x) = A(y)

(3) Solve for y to obtain crisp steering output.

Note: Using x -> sensor input, y -> steering output

Engineering Considerations & Implementation Details

- **Accuracy** and **validity** of sensor data very important

SOLUTIONS

(1) ***Take the average of two readings***
- Adding two 8-bit values could overflow
- No built-in division operation
- **Fix:** ad hoc division and averaging functions created with microcontroller-supported op's (STATUS carry bit, rrcf)

(2) ***Bounds checking:***
- Input > Max ? . . . Input = Max
- Input < Min ? . . . Input = Min

Engineering Considerations & Implementation Details

OTHER CHALLENGES

(1) No floating point operations available

(2) MCU is slow (even in ASM...*up to* 10 MIPS)

Run-time calc.'s of membership fcts?

SOLUTION: LOOKUP TABLE

(1) Precompute all possible input/output values

(2) Load a table with these values into the chip at build-time

(3) Access the appropriate table value at run-time through the stabilized sensor reading

Lookup Table Generation & Other Membership Functions

The previous triangular membership functions were just a few of the candidates explored during this project:

Link to Install FuzzyGUI on your machine

steer left table   steer right table

Results

Corridor Comparisons

Crisp

Results

Corridor Comparisons

Fuzzy

Results

Stress Test 1

Crisp

Results

Stress Test 1

Fuzzy

Results

Stress Test 2

Crisp

Results

Stress Test 2

Fuzzy

Results

"Turn Hugging" Comparison

Crisp

Results

"Turn Hugging" Comparison

Fuzzy

Final Commentary

Even with the limited
computational resources provided
by an 8-bit microcontroller,
the concepts behind fuzzy sets
offer a simple yet effective way
to improve significantly
the quality of control
over robotic vehicle navigation.

Acknowledgments

Thank you for your time!

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