Intuitive Control Algorithm Development of 4WIS/4WID Using a SpaceMouse

Kent School Guild Presentation
Tyler (Taewook) Kim ’20

2019.04.16

4WIS/4WID

4 Wheel Independent Steering/Driving:

a steering system for a four-wheeled vehicle that allows for separate speed and direction controls for each wheel.

Related Works

Mecanum Wheels

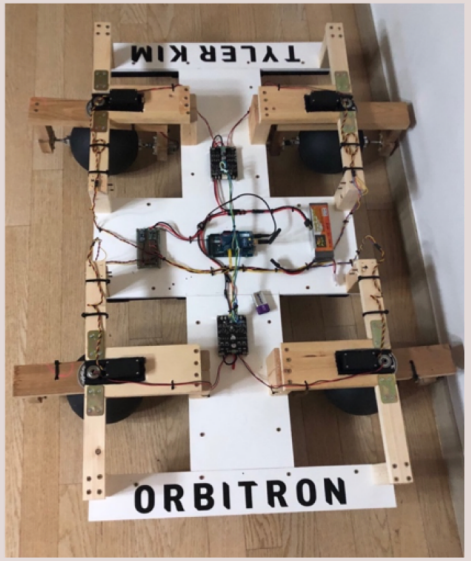
Inexpensive and only requires four driving motors to operate.

Not ideal for rough terrains.
All wheels have to be in contact with the surface to function properly.

NASA MRV(Modular Robotic Vehicle)

Capable of versatile motions and high maneuverability.

Ineffective controlling mechanism.
Involves a steering wheel and a joystick; Not intuitive for common uses.



Orbitron + Control Algorithm

Capable of versatile motions and high maneuverability.

Expensive.
Needs eight motors to function:
4 DC motors and 4 Servo motors.

NASA MRV - Video

Related Works

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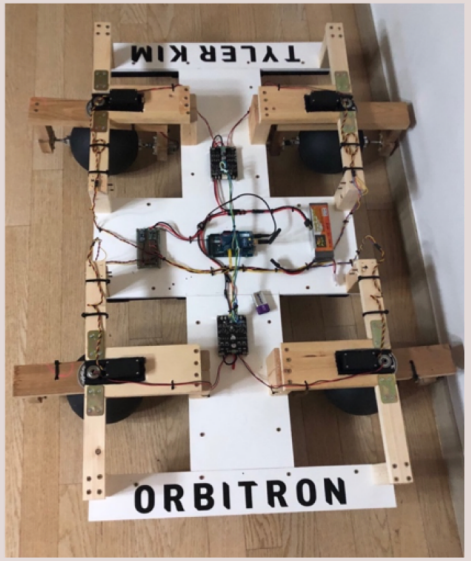

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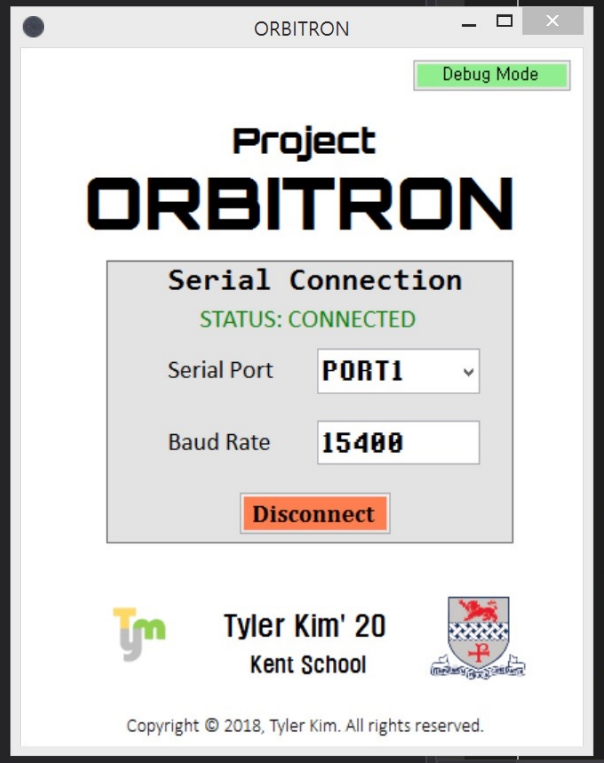
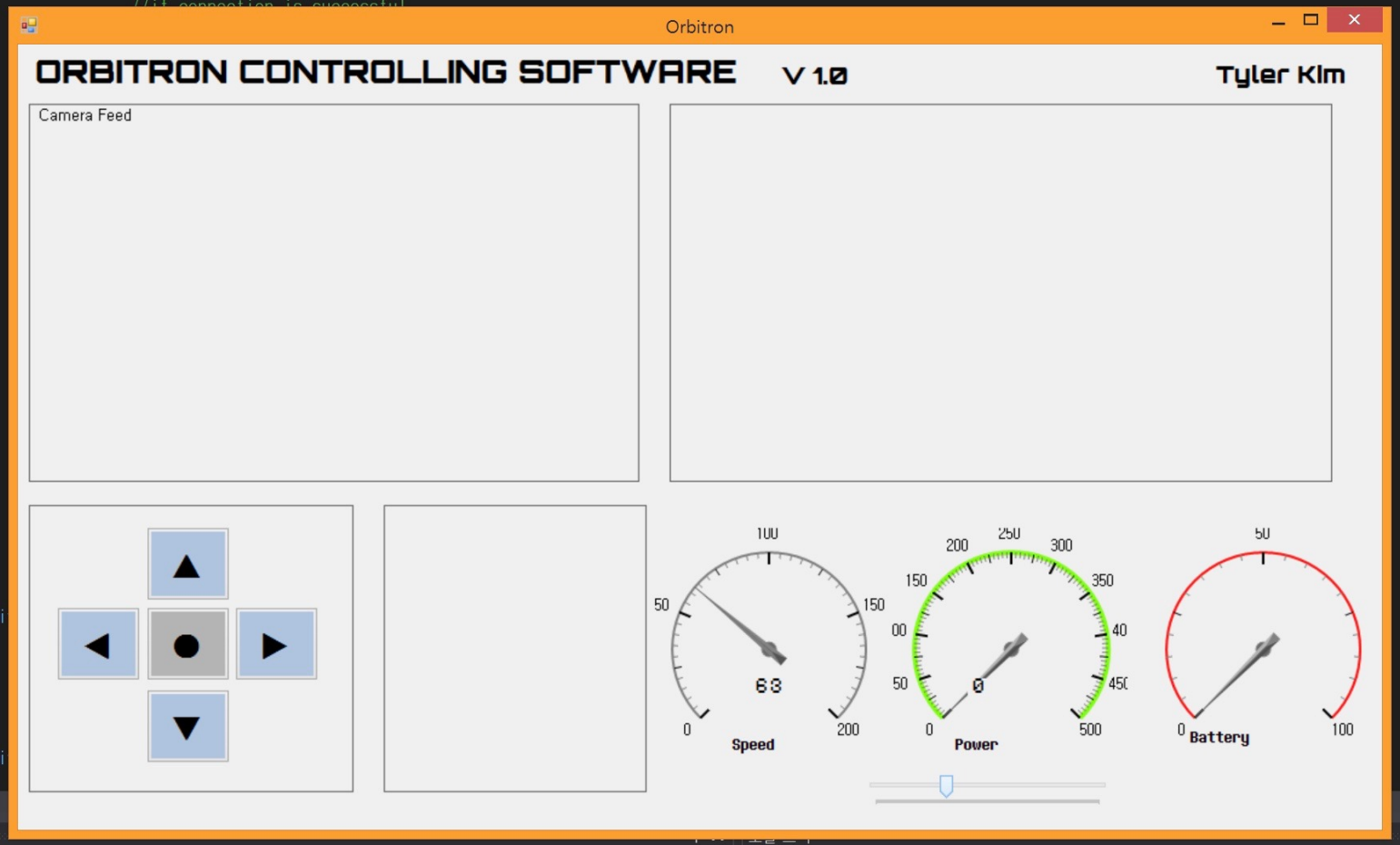
Problem Statement

Controlling two parameters (direction and speed) for each wheel results in eight parameters in need of simultaneous control. To our knowledge, neither a keyboard nor a joystick, including a dual joystick, can fully convey the motions that 4WIS/4WID steering mechanism is capable of.





ConnectForm.Hide();

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Our Goal

1. Find a controller that can easily convey the driver's intention.

2. Develop an algorithm that understands the driver's intention and control all four wheels in a cooperative manner.

This development will allow for an intuitive maneuver through spaces that are difficult to navigate in conventional two-wheel steering vehicles.

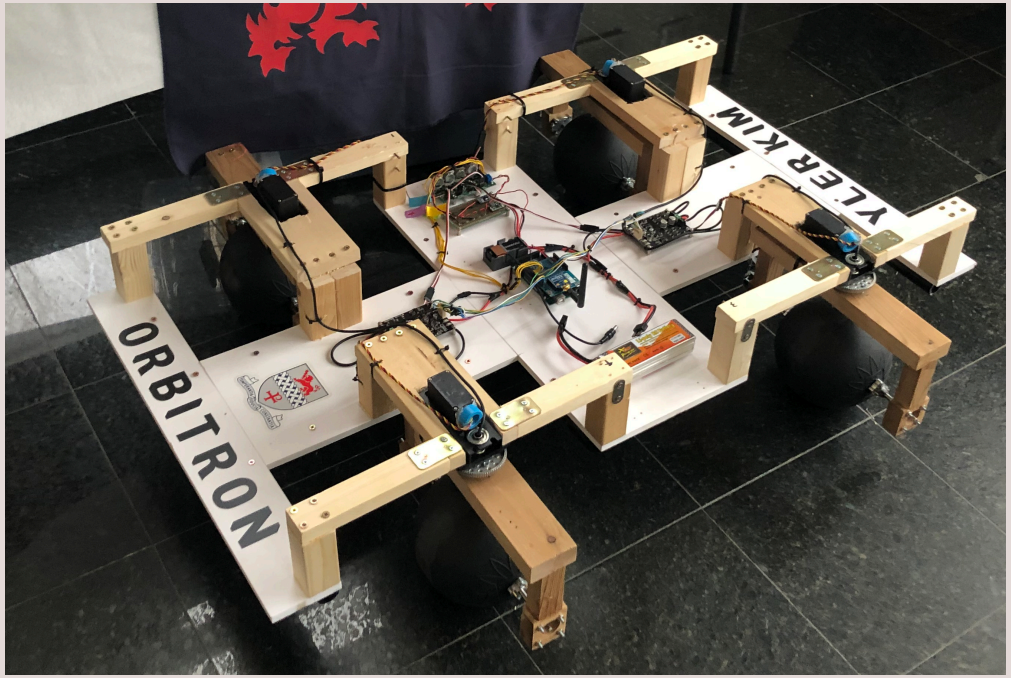
Controller - SpaceMouse

Controller Device 3: SpaceNavigator

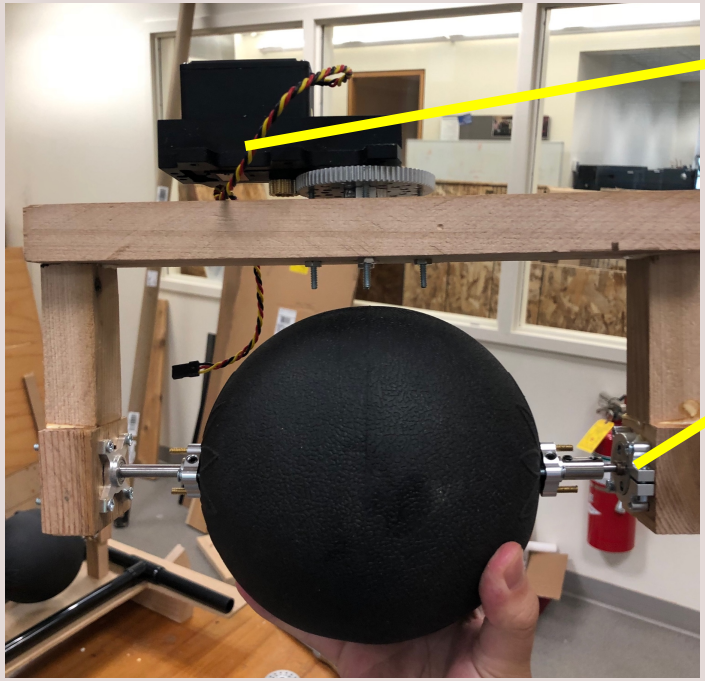
Manufacturer	3Dconnexion (1133)
Raw Product Name	"SpaceNavigator"
Raw Product ID	50 726
Device Type	Mac OS X Human Interface Device
Raw Controller Type	Multi–Axis Controller
Wolfram Language Controls	*12 controls*
X	0.
Y	0.
Z	0.
X1	0.
Y1	0.
Z1	0.
X2	0.
Y2	0.
Z2	0.
X3	0
B1	False
B2	False
Show Dynamic Values	
Raw Controls	*9 controls*
X Axis	0.
Y Axis	0.
Z Axis	0.
X Rotation	0.
Y Rotation	0.
Z Rotation	0.
Button 1	False
Button 2	False
GenericIndicator Button	False
Show Dynamic Values	

X	X Axis; Moving the mouse on a plane (X)
Y	Y Axis; Moving the mouse on a plane (Y)
Z	Z Axis; Lifting/Pressing the mouse
X2	X Rotation; Tilting the mouse(Front-Back)
Y2	Y Rotation; Tilting the mouse(Left-Right)
Z2	Rotation; Twisting the mouse
B1	Button 1; Boolean value for the left button
B2	Button 2; Boolean value for the right button

Prototype - Orbitron



- Built in Kent School Pre-Engineering Center
  - 2018.03.02 ~ 2018.09.05
- Replicates the 4WIS/4WID steering mechanism using a servo motor and a DC motor for each wheel.

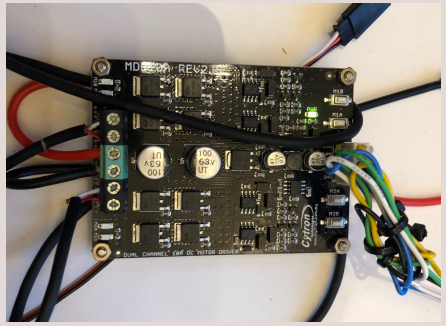


TM-785HB Winch Servo
- "Turns" the wheel

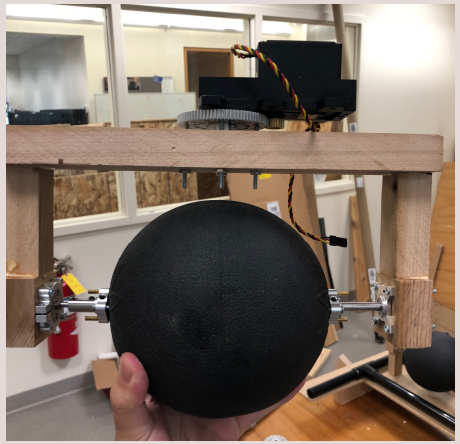
170-RPM Econ Gear Motor
- "Drives" the wheel

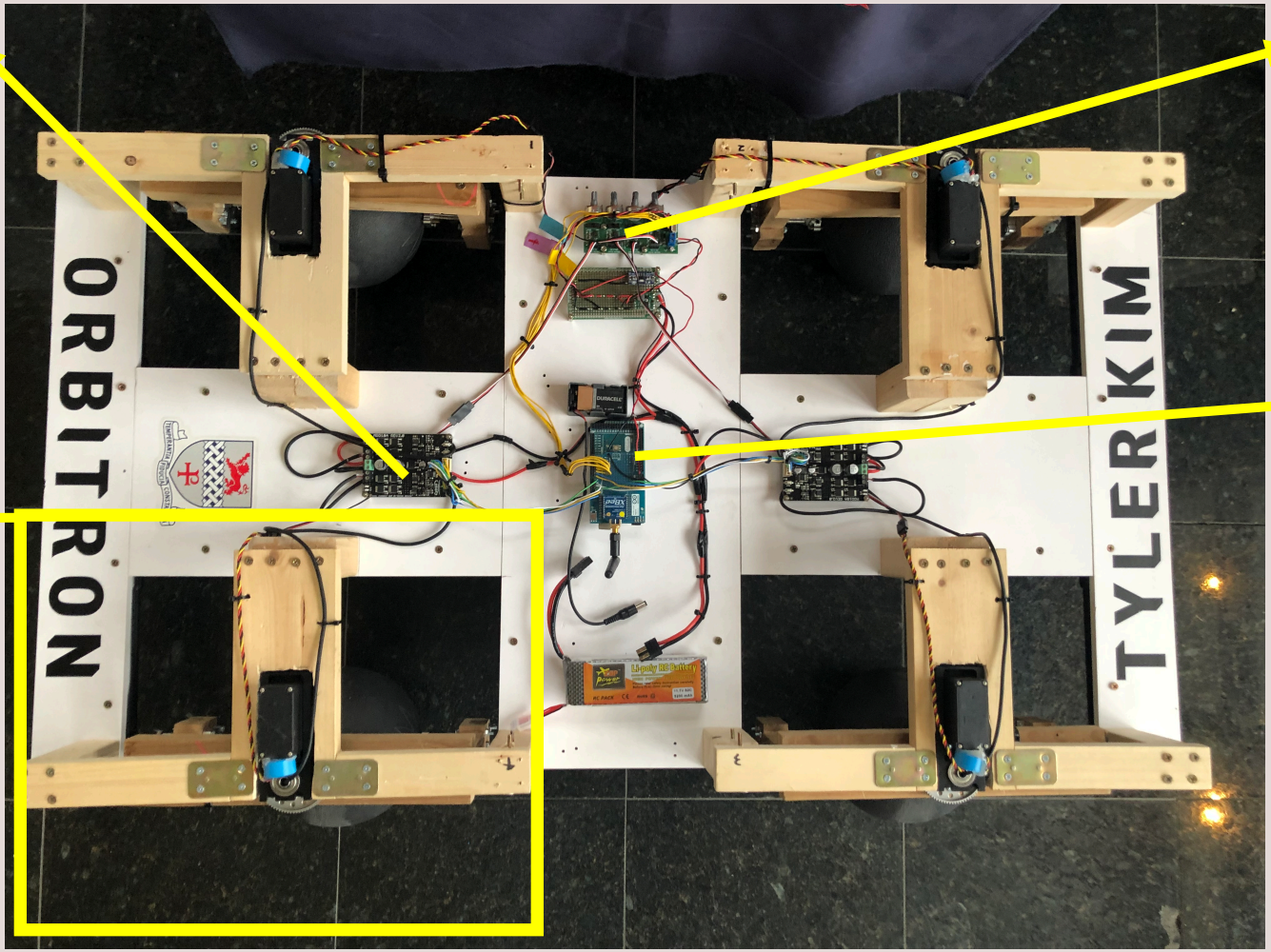
Prototype - Orbitron

Dual Channel DC Motor Driver

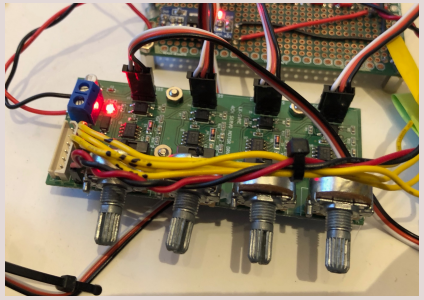


Wheels

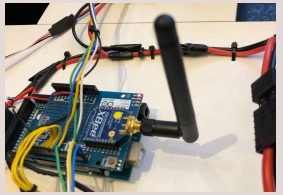




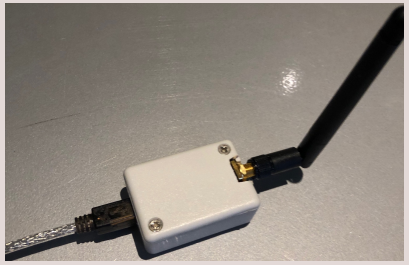
Servo Motor Hub



Arduino Mega 2560 Board



Xbee Wireless Module



Algorithm Setup

SpaceNavigator

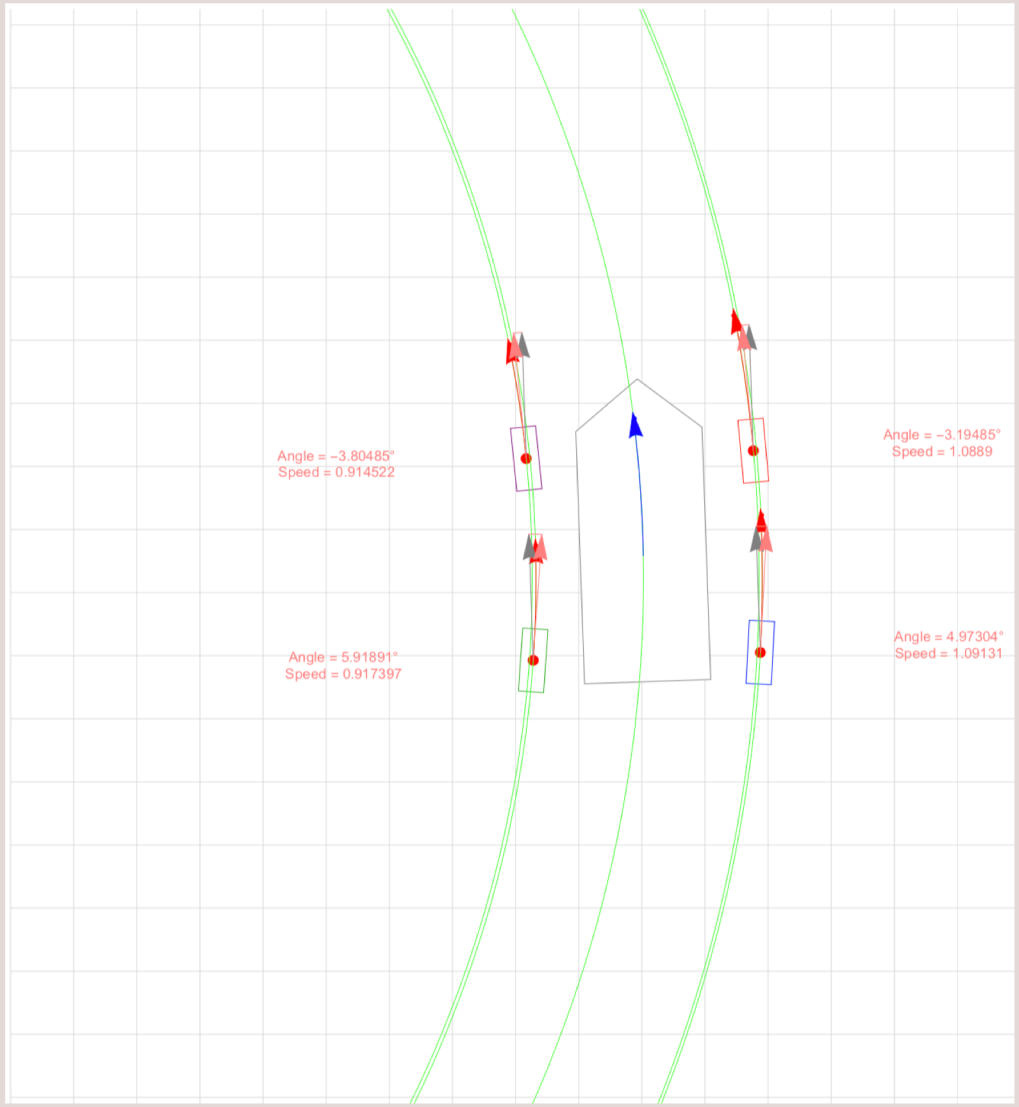
Input
X
Y
Z
X2
Y2
Z2

Mathematica Algorithm

- Variables.nb
- Graphics.nb

Output
A1
A2
A3
A4
S1
S2
S3
S4

Core Concepts of the Algorithm - 1



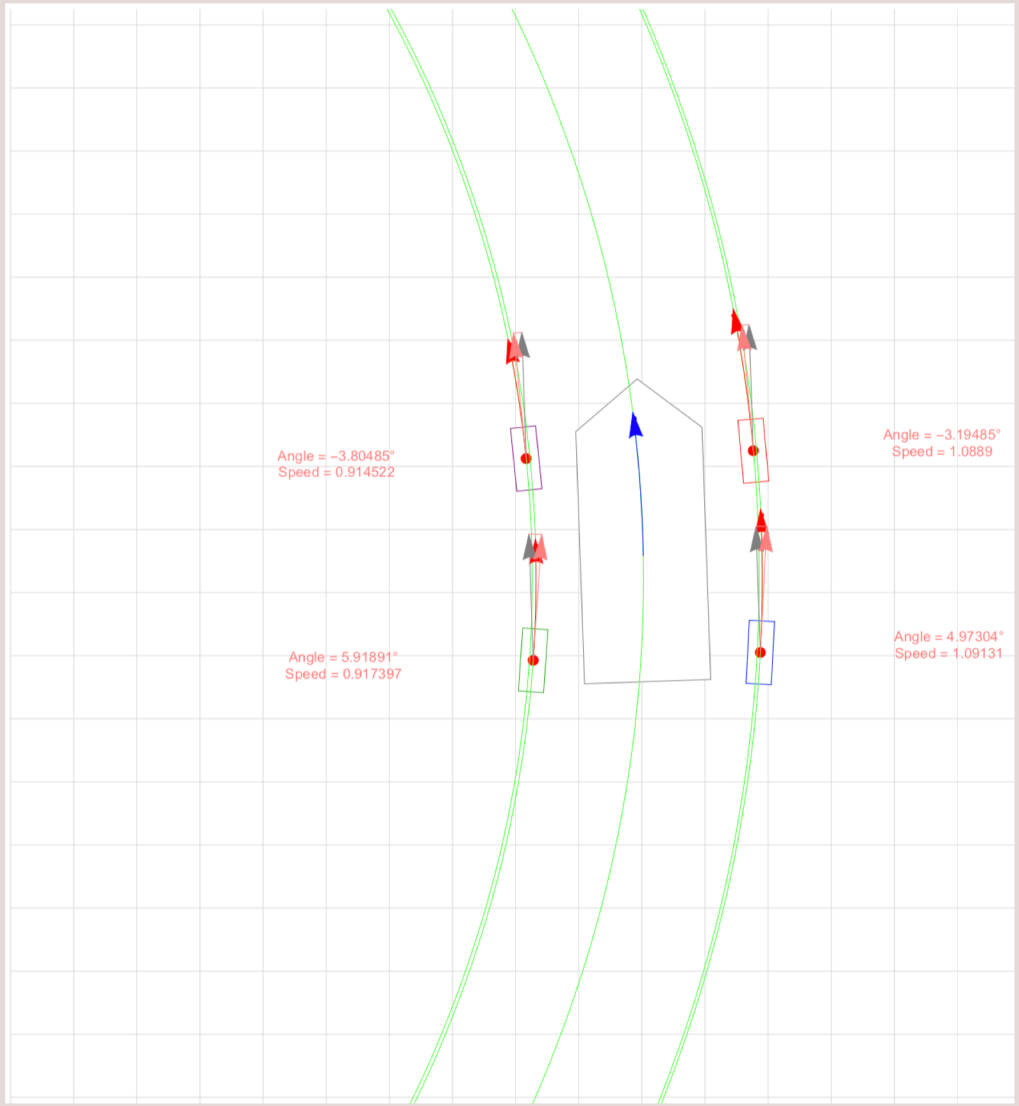
Core Concepts

1. Every motion is a circular motion.
    - Even straight motion can be considered as a circular motion with an infinite radius of curvature.
2. Each wheel's angle and speed always depend on the concentric circles.

How it's calculated

1. Direction
    - Direction of each wheel is simply set to be tangent to each concentric circle.
2. Speed
    - Radius of the concentric circle based on vehicle's center is normalized as 1.
    - Using concept of linear and angular velocity, we calculate relative speed based on the ratio of concentric circles' radius.

Core Concepts of the Algorithm - 2



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$$v = r\omega$$

$r = radius\ of\ curvature$

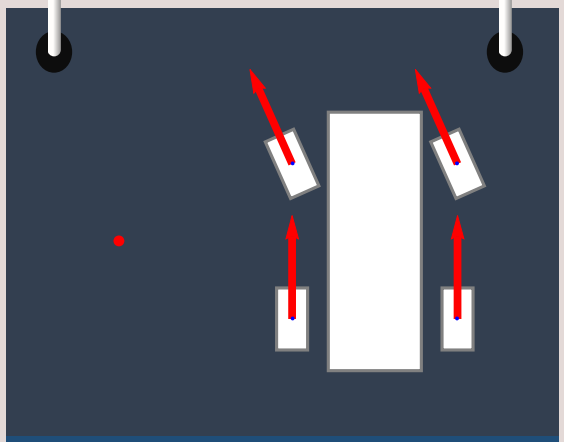
$\omega = angular\ velocity$

Equation 2 Linear Velocity

Steering Modes

2WS

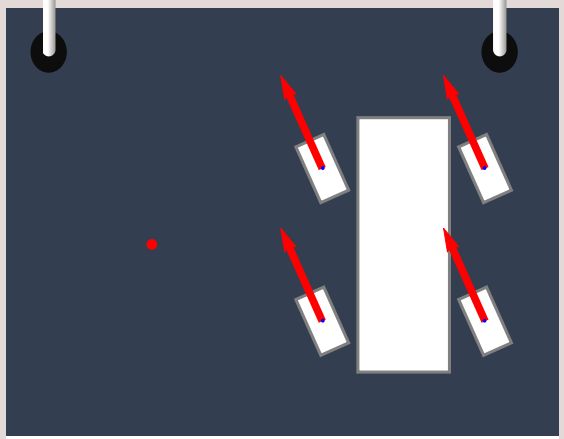
Ackerman Steering



The Ackermann steering mechanism is a mechanism that is generally used for four-wheel vehicles.

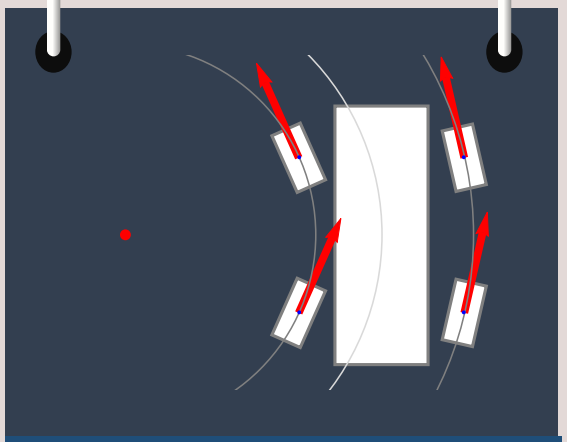
4WIS/4WID

Crab Steering



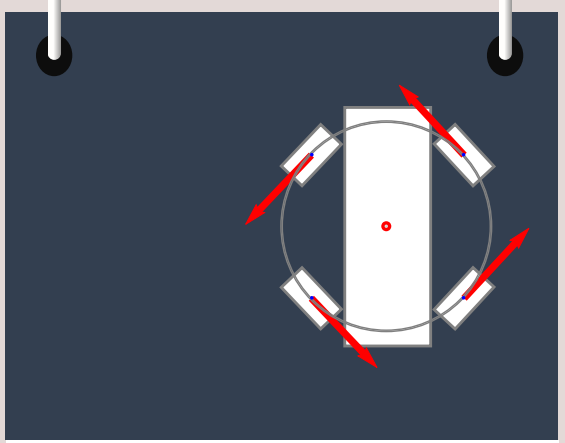
Crab Steering operate by steering all wheels in the same direction and at the same angle. It allows the vehicle to translate or glide to any direction.

AFRS



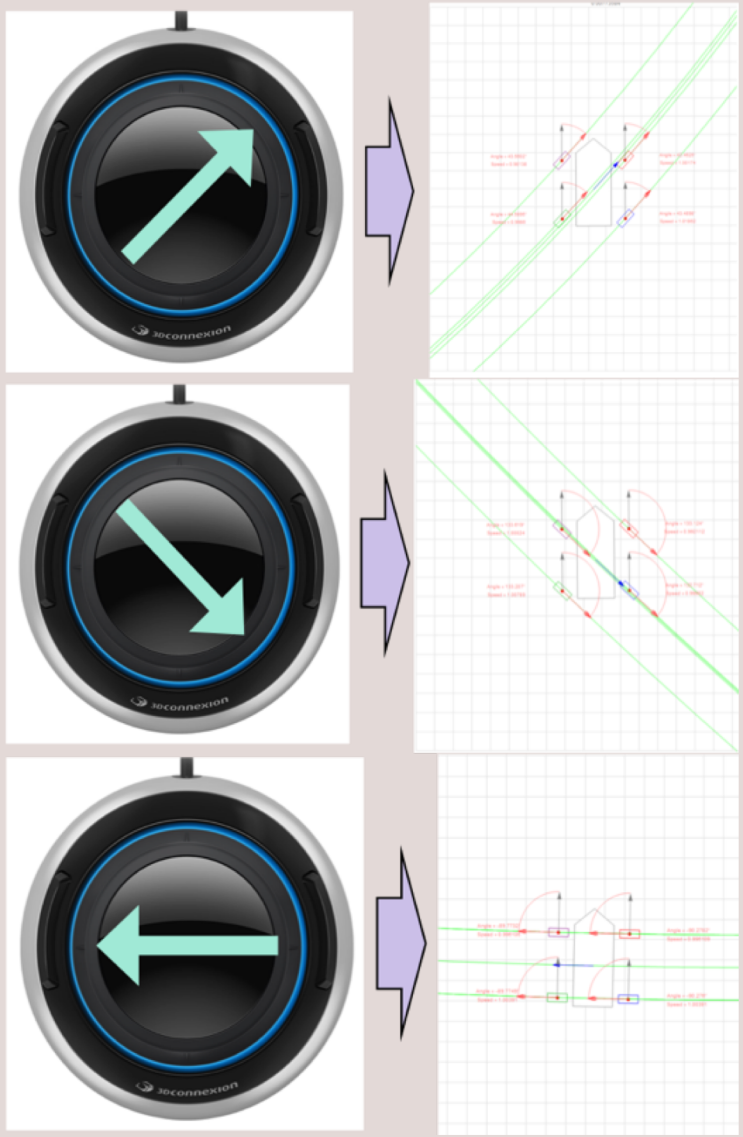
AFRS(Active Front Rear Steering) mechanism involves front and rear wheels turning independently for smaller turning radius and better cornering stability.

Spinning



Spinning is turning the vehicle's direction with zero turning radius.

Crab Steering



INPUT

Sliding the mouse

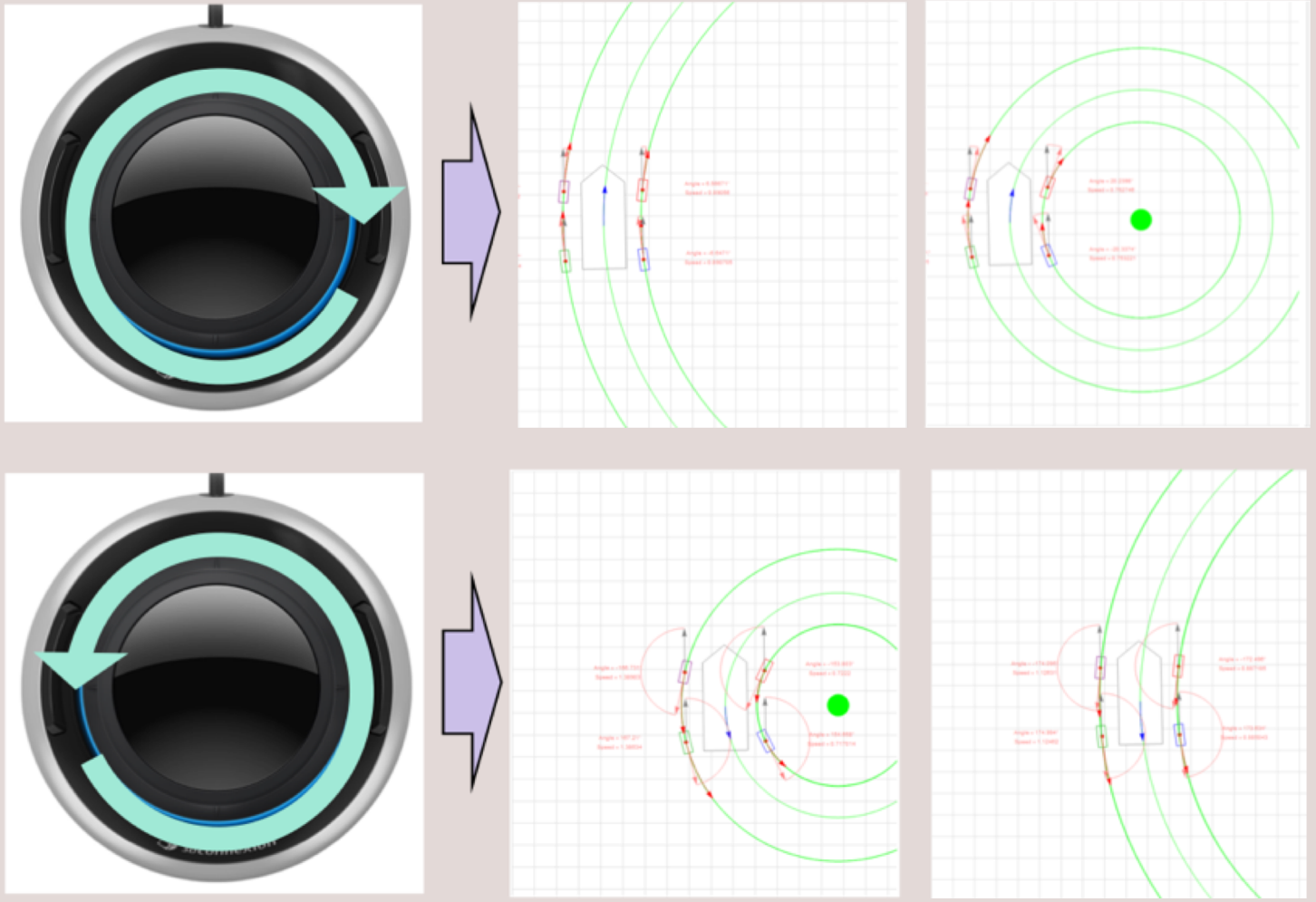
Direction

All four wheels are angled in the direction the mouse is pointing at.

Speed

When only crab steering is being used, speed for all four wheels will be constant.

AFRS(Active Front Rear Steering)



$$r \propto \frac{1}{\theta}$$

Equation 3 Radius of Curvature

$r = radius\ of\ curvature$

$\theta = twisted\ angle$

INPUT

Twisting the mouse

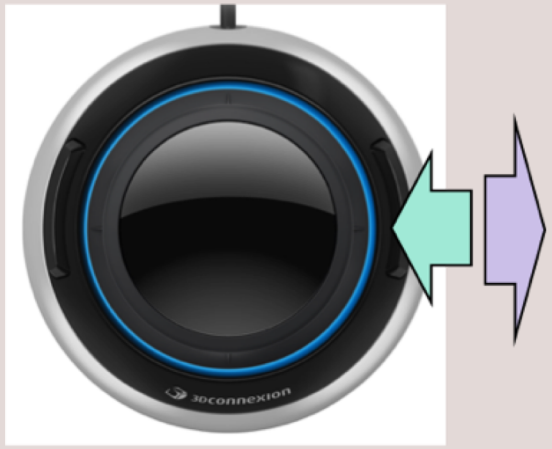
Direction

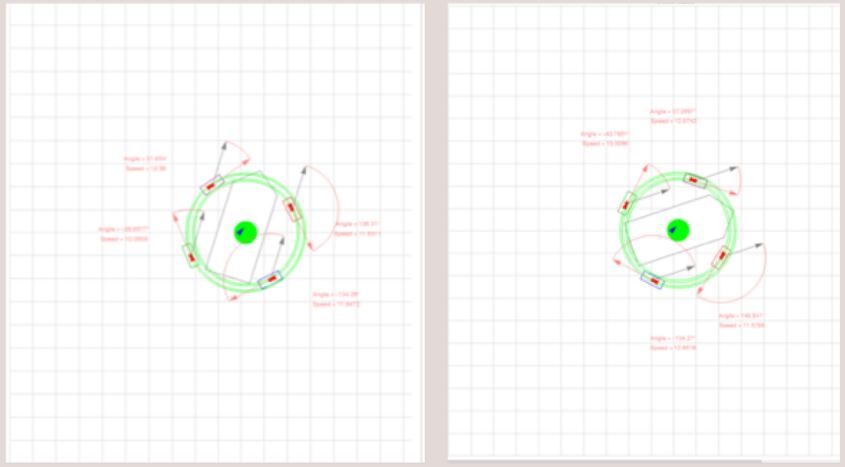
All four wheels are set to be tangent to each concentric circle.

Speed

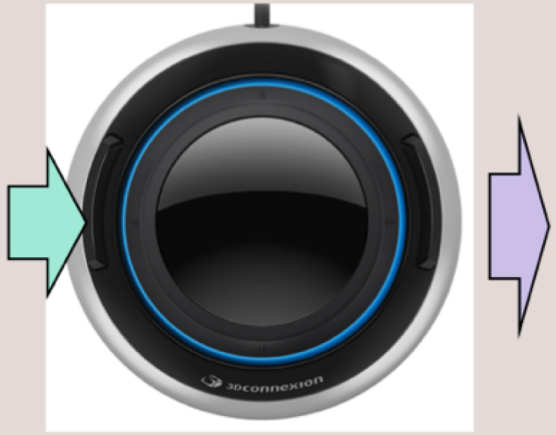
Determined as relative speed based on the ratio of concentric circles' radius.

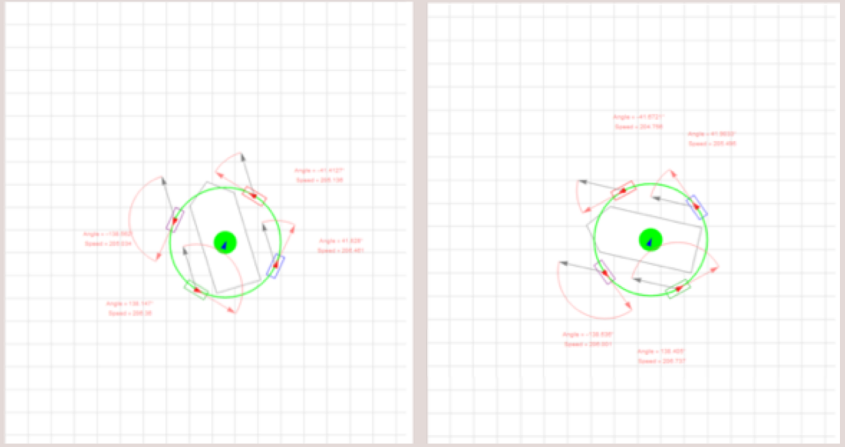
Spinning





$r = 0.001$





$r = -0.001$

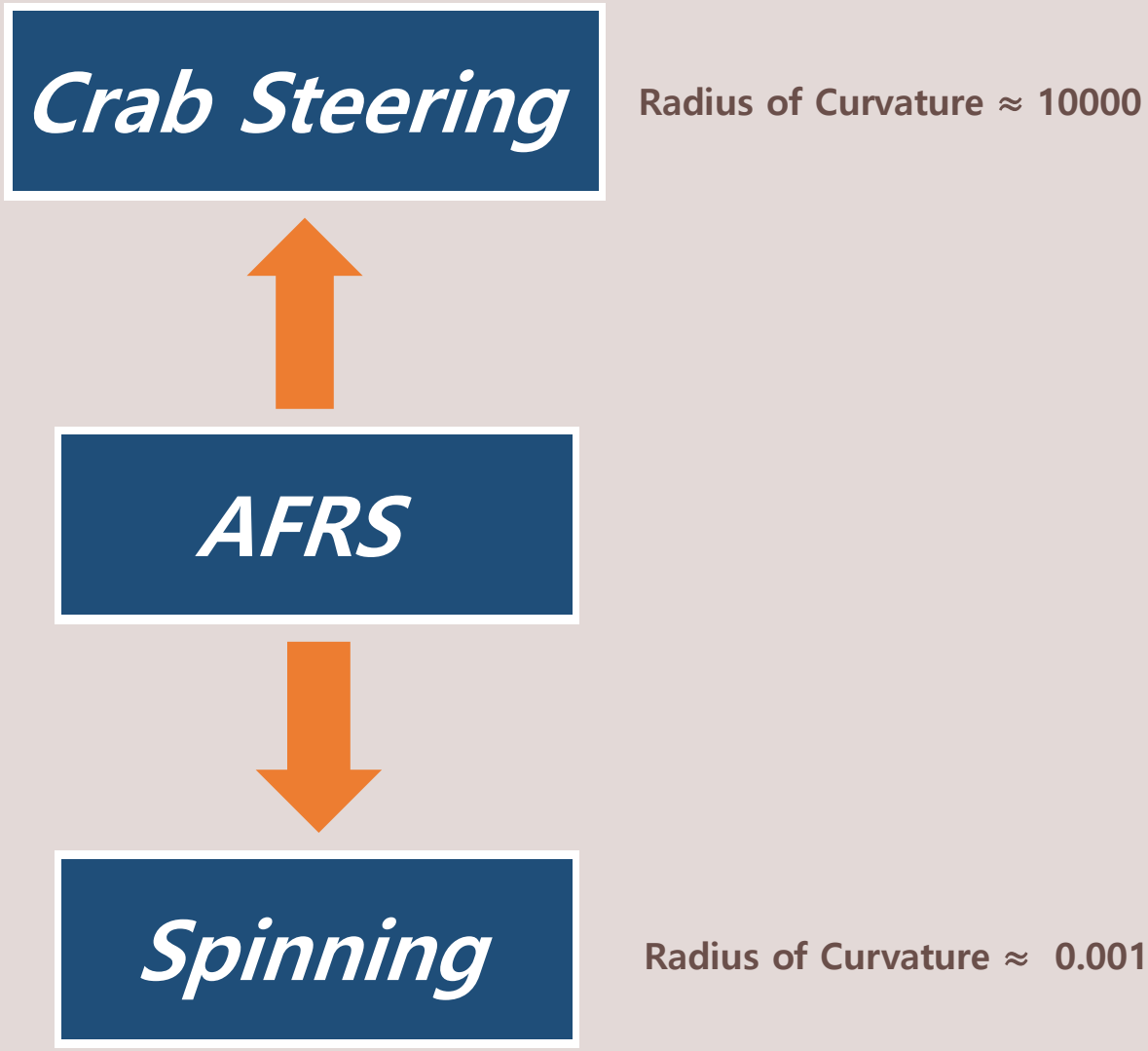
INPUT

Pressing the buttons on side of the SpaceMouse

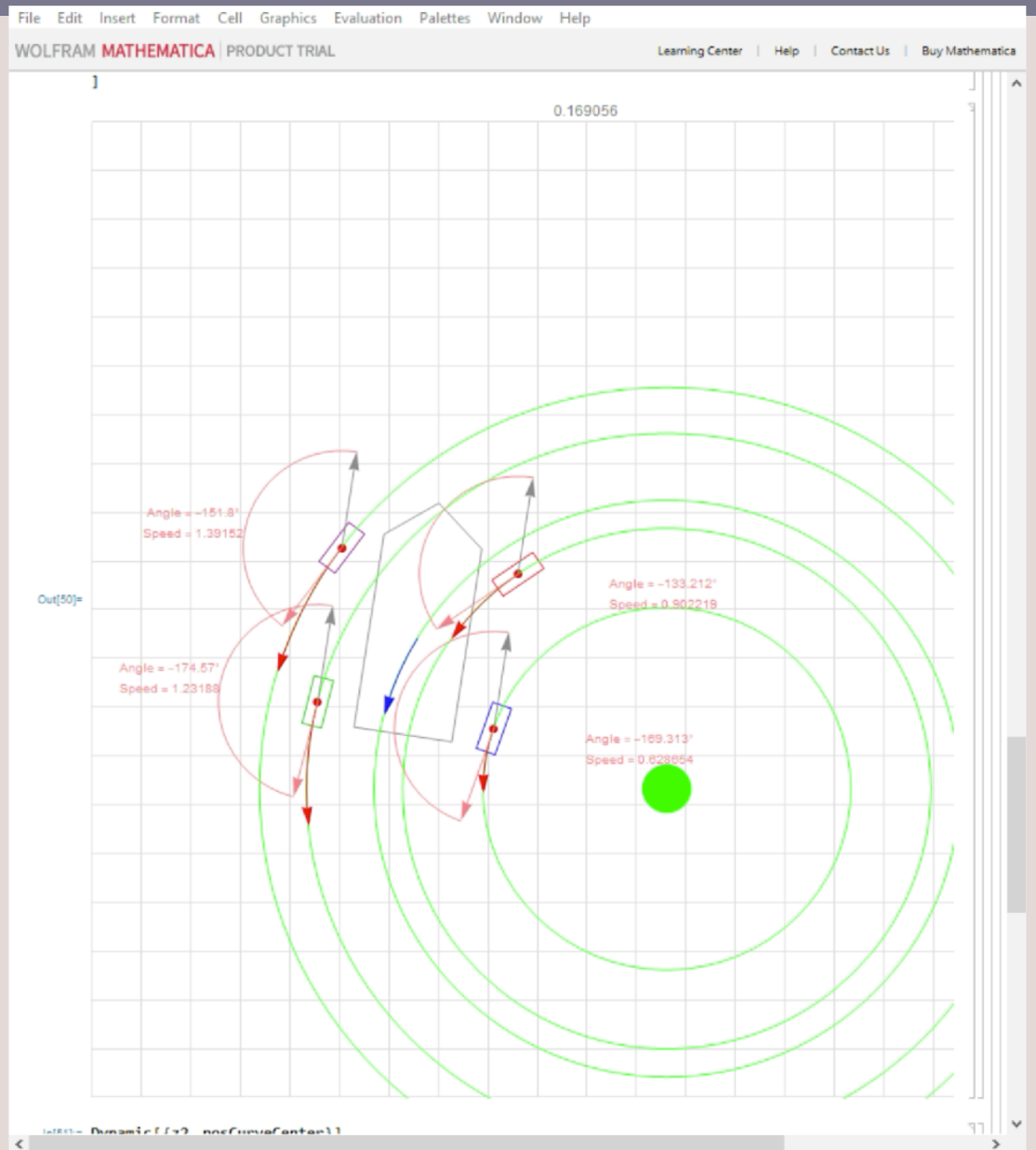
Center of concentric Circles

Set to be very close to the vehicle's center

Three Steering Modes



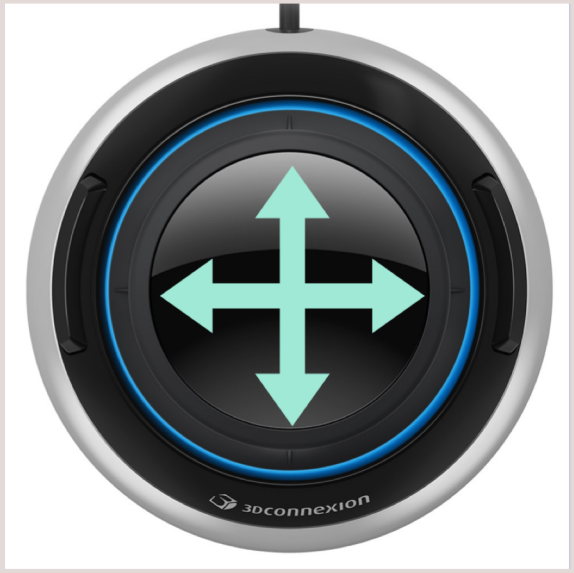
Video from the Algorithm



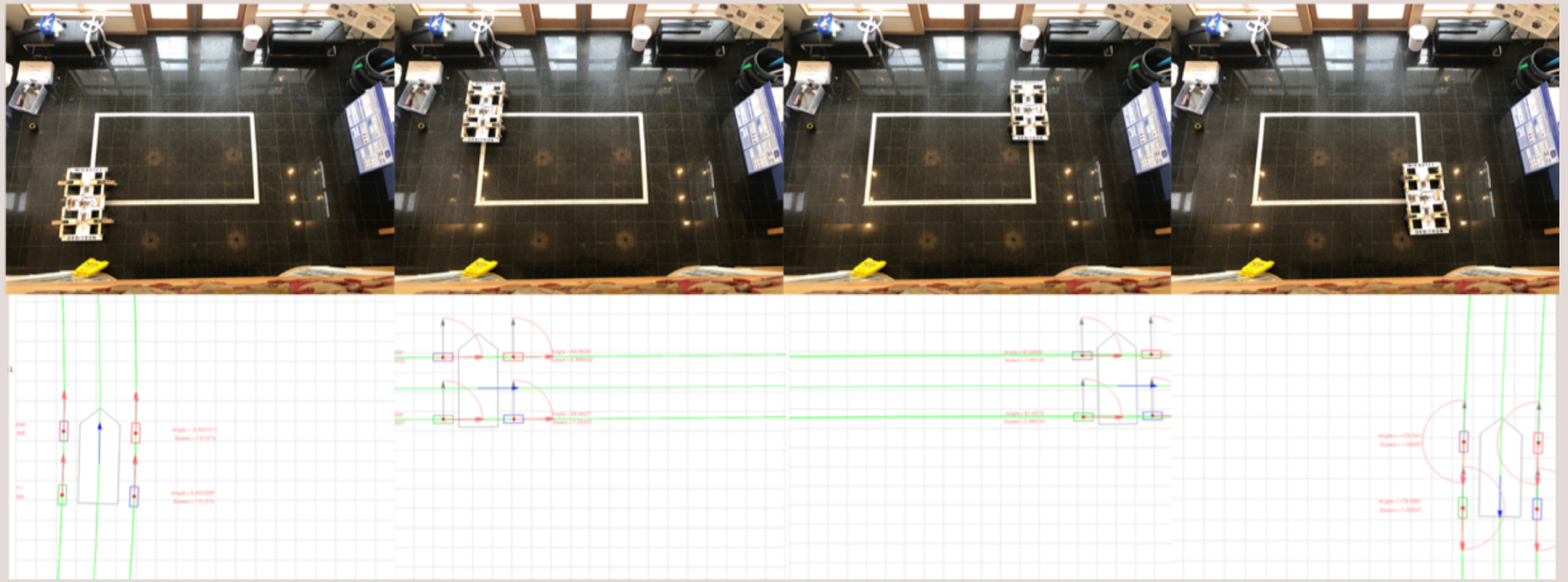
Experiment Setup

- Physical experiment was done in Pre-Engineering center's lobby to test the accuracy of the algorithm
  - 2019.03.02 ~ 2018.03.03
- Two cameras, iPhone from above and iPad on the table, keeps track of the vehicle's motion.
- After getting the footage of the vehicle's motion, it was compared with the algorithm's motion.

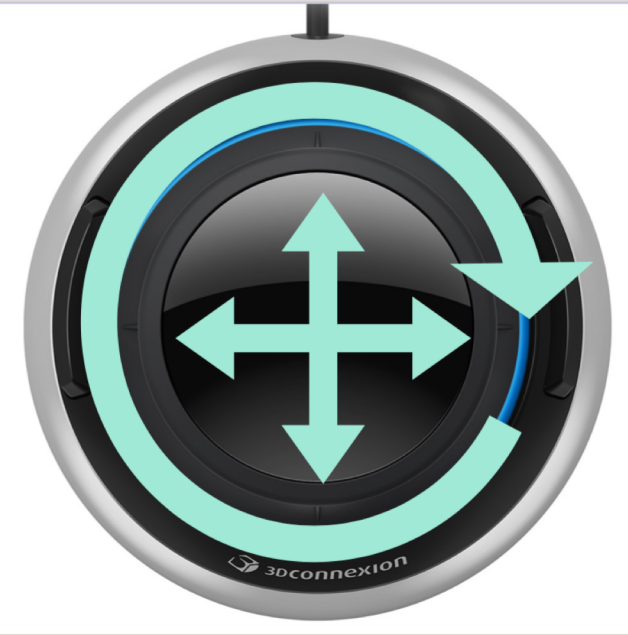
Rectangular Path



Crab Steering



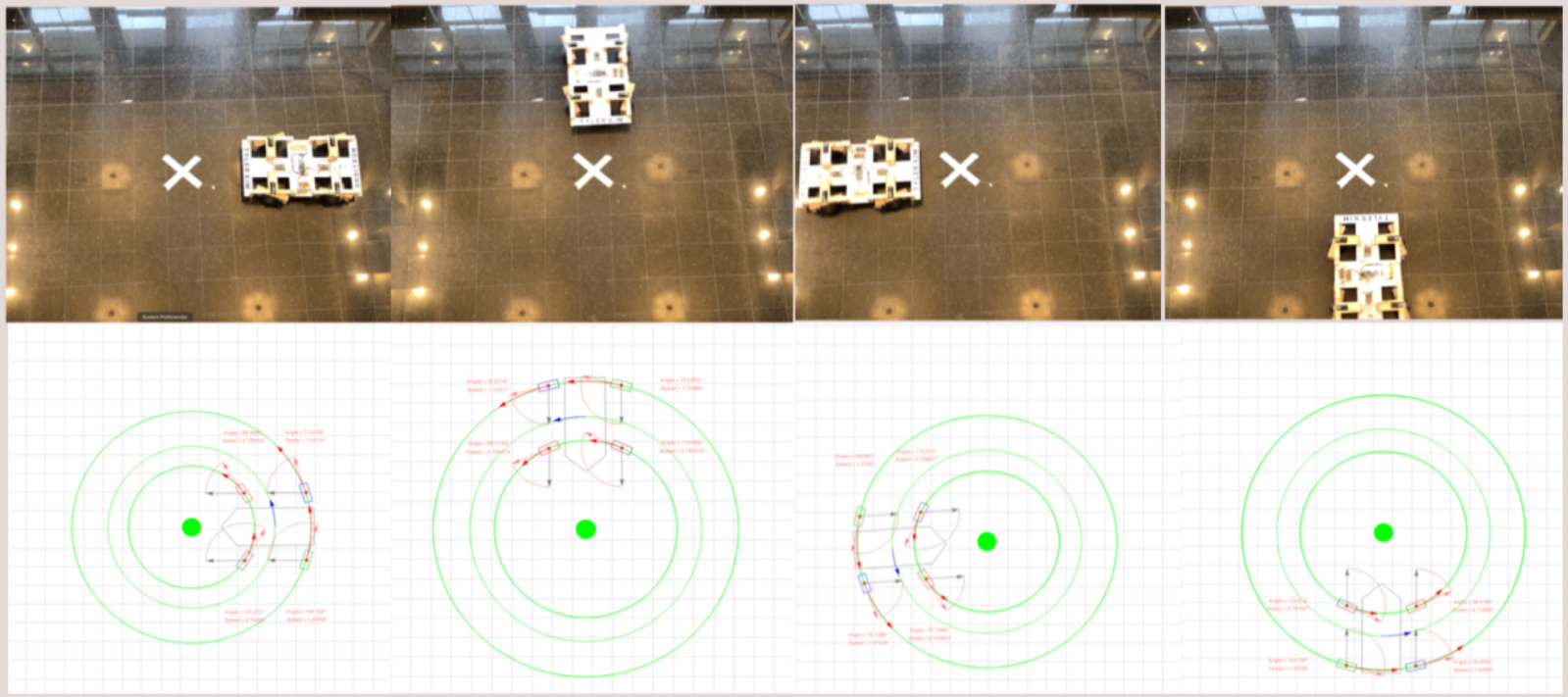
Circular Path



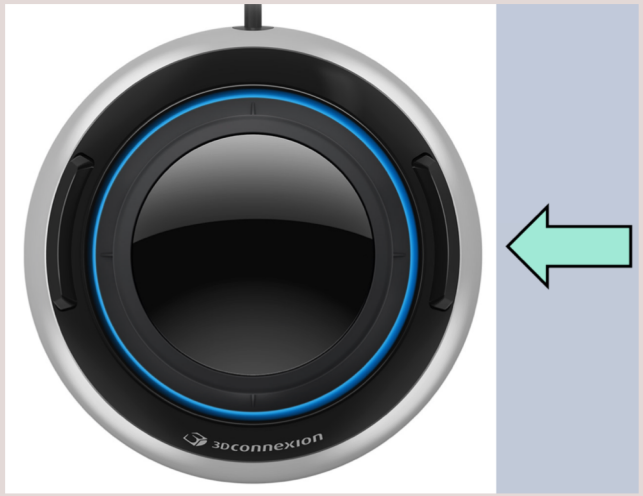
Crab Steering

+

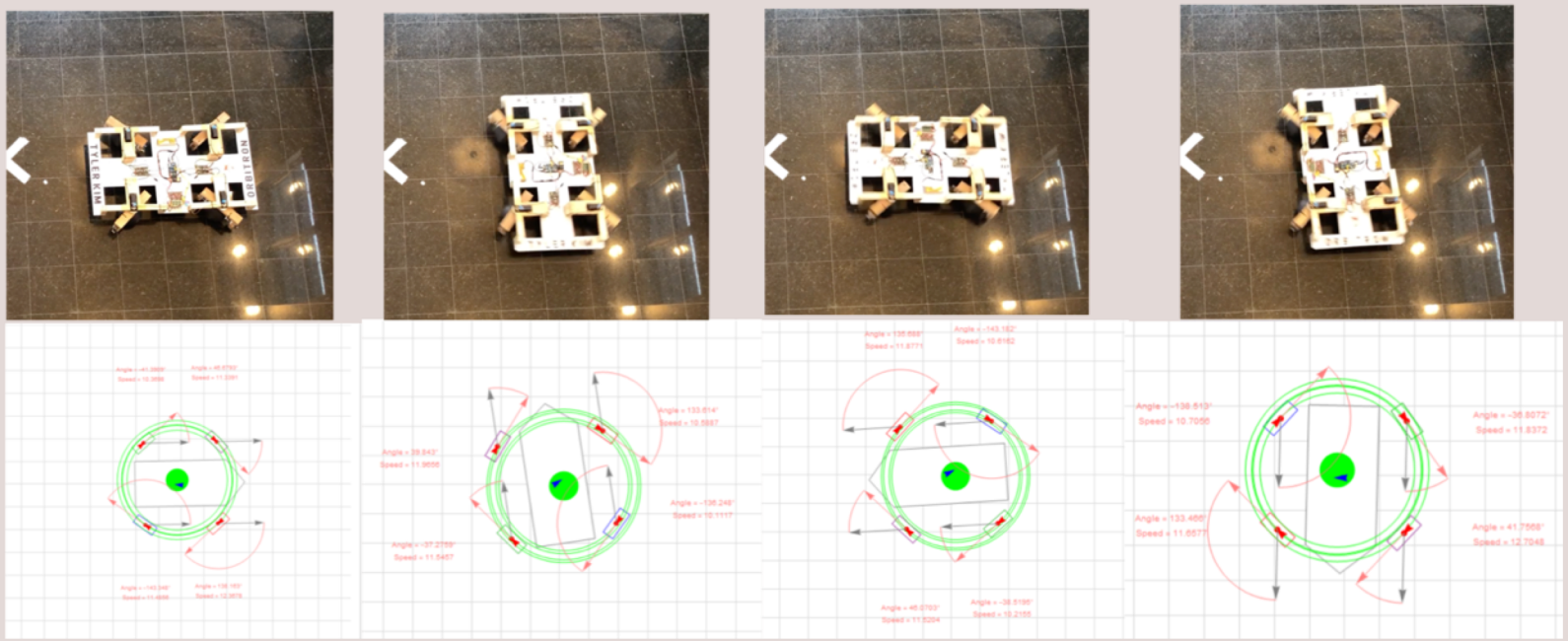
AFRS



Spinning



Spinning



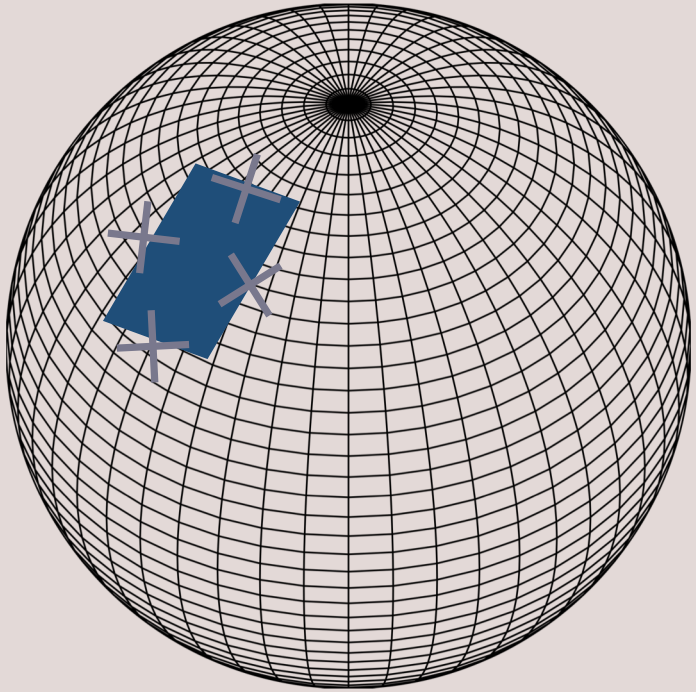
Conclusion – Okay, so WHY is this significant?

- Very intuitive: Slide n Twist!
- Possible with any number of wheels
- Lowers the boundary of 4WIS/4WID
  - One of the reasons why 4WIS/4WID is not common is because of the complex way to control.
  - i.e. Electric Wheelchair
  - i.e. Search & Rescue robots

How can I extend this project?

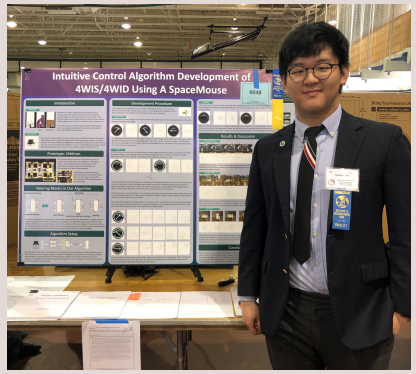
What if we consider all motions are..

Spherical?



So far...

Connecticut Science and Engineering Fair



- Presented the work on the 71st Annual Connecticut Science and Engineering Fair over spring break

Patent Application

특허청
Korean Intellectual Property Office

- Currently in progress of filing a patent application in Korea.
- (Expecting initial feedbacks mid-August)

Awards

Lockheed Martin Physical Sciences Awards, CSEF March 2019

Computer Science Awards, CSEF March 2019

Collins Aerospace Engineering Awards, CSEF March 2019

United Technologies Corporation Awards, CSEF March 2019

IEEE Awards, Connecticut Section, CSEF March 2019

Robotics And Beyond --- For Excellence in Engineering Design, CSEF March 2019

Barker Mohandas Awards for Transportation Research, CSEF March 2019

Future Plans

1

Attend International/Korean Conferences on vehicle control

- Currently finalizing paper to apply for Korean conferences.

2

Submit to junior science journals(ex. The Columbia Junior Journal)

- Planning to format the paper for each journals during this summer.

3

Extend the project!

- "What if we consider all motions were…*Spherical*?"

Acknowledgement

Dr. Nadire

- Director of the Pre-Engineering Department
- My AP Calculus BC teacher.
- Guild Paper Advisor

Mr. Saxton

- Director of the Mathematics Department
- My AP Computer Science A teacher

In Memory Of

Dong Min Lee

1997 - 2014

Thank you

Q & A