Comparing Modular and Integrated Autonomous Vehicle Systems in a Model Urban Environment

SER102

Motivation

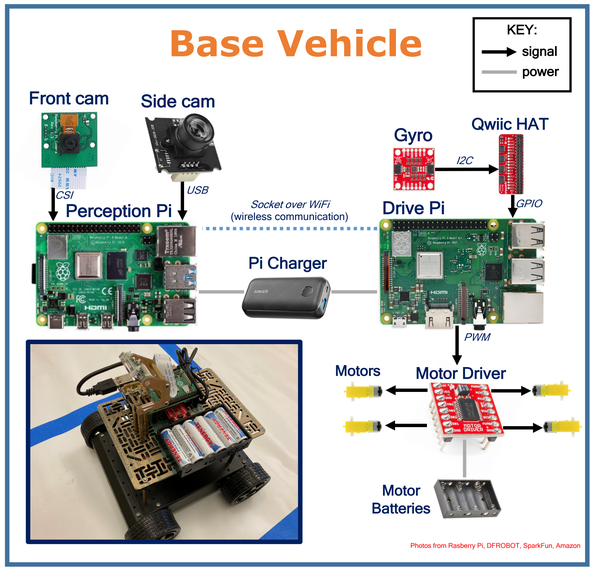
- safe mobility is limited for minors
  - bus driver shortage due to COVID
  - Uber & Lyft unavailable for minors
    - due to incidents where drivers kidnapped & raped young riders
  - many kids abducted at their bus stops
- proposed Solution: Autonomous Vehicle
  - reduce need for human driver → **safe** mobility

Photo from "Amid Bus Driver Shortage, Guilford County Schools Asks Teachers, Part-Timers to Consider Picking up a Route."

Driving Criteria

- get passenger to destination while…
  1. driving within straight & curved lanes (using front cam)
  2. turning into intersections (using cams & gyro)
  3. stopping at stop signs (using neural network)
  4. waiting for people to cross (using neural network)
- safety requires vehicle to follow above criteria
  - street map

Base Vehicle



Photos from Rasberry Pi, DFROBOT, SparkFun, Amazon

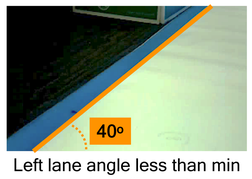
Basic Driving

Perception Pi

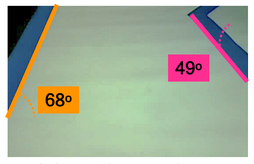
Get image from Front Camera
↓
Find all lines (Canny & Hough)
↓
Separate lines into L & R
↓
Select 2 lane lines (closest to robot)
↓
Find lane line angles
↓
Calc robot move using angles & thresholds (straight, turn left, turn right)
↓
Send robot move msg to Drive Pi

Drive Pi

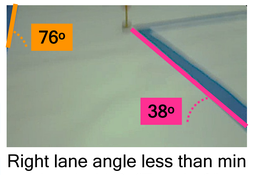
Listen for robot move msg
↓
Move robot accordingly



Left lane angle less than min threshold → "Turn Right"



Left & right lane angles over min thresholds → "Straight"



Right lane angle less than min threshold → "Turn Left"

Integrated v. Modular

Uncited figures were taken or created by presenter

Integrated
single, general components


Photo from "Tesla AI Chief Explains Why Self-Driving Cars Don't Need Lidar."

Tesla's integrated HW & SW → 12 deaths

What is the safest design?

Modular
separate, specialized components

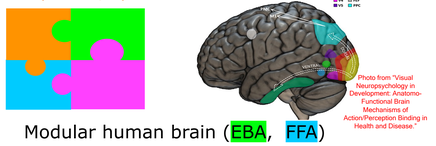
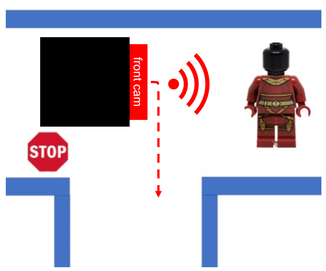


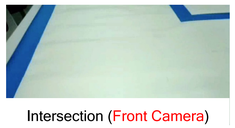
Photo from "Visual Neuropsychology in Development: Anatomo-Functional Brain Mechanisms of Action/Perception Binding in Health and Disease."

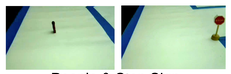
Modular human brain (EBA, FFA)

Integrated Sensing (HW)

single, general sensor



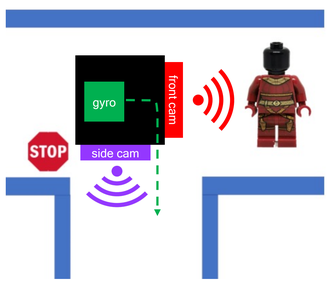

Intersection (Front Camera)

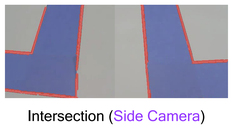

People & Stop Sign (Front Camera)

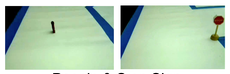
Front Camera
senses *lanes*, *stop signs*, *people*, *intersections*

Modular Sensing (HW)

multiple, specialized sensors




Intersection (Side Camera)


People & Stop Sign (Front Camera)

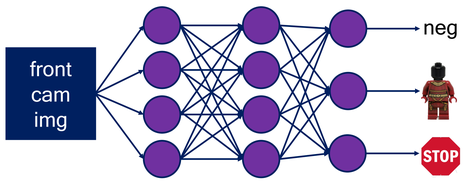
Front Cam
senses *lanes*, *stop signs*, *people*

Side Cam
senses *intersections*

Gyro
helps robot turn into *intersections*

Integrated Detecting (SW)

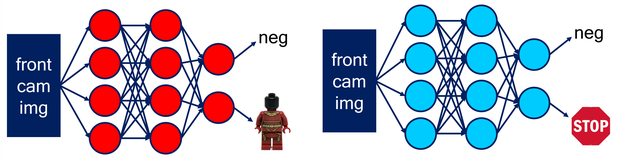
single, general neural network



Detects *people & stop signs*

Modular Detecting (SW)

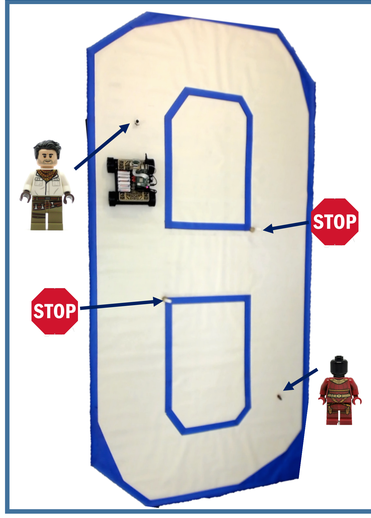
multiple, specialized neural networks (like modular human brain)



Detects *people* **Detects *stop signs***

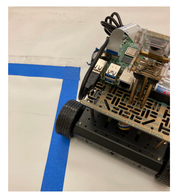
Experimental Evaluation

20 trials for each prototype

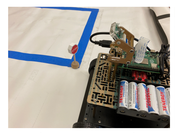


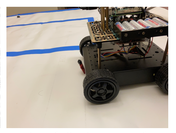
NAVIGATION ERROR	PENALTY/ERROR
failure to reach the 1st person	1
failure to reach the 1st stop sign	1
failure to pass the 1st intersection	1
failure to reach the 2nd person	1
failure to reach the 2nd stop sign	1
failure to turn into the 2nd intersection	1

SAFETY ERROR	PENALTY/ERROR
wheel touches lane line	0.5
wheel crosses lane line	3
failure to stop at stop sign	3
failure to stop for people crossing	3
stop due to falsely detected stop sign	3
stop due to falsely detected people	3


wheel touches lane


wheel crosses lane

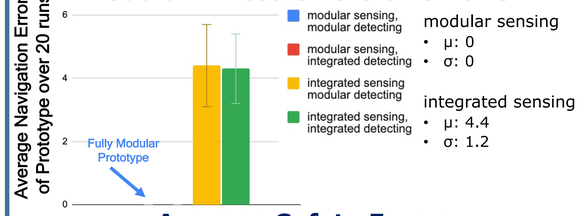

robot at a stop sign


robot failed to stop for people crossing

Results

Average Navigation Accuracy

modular → less errors & lower σ

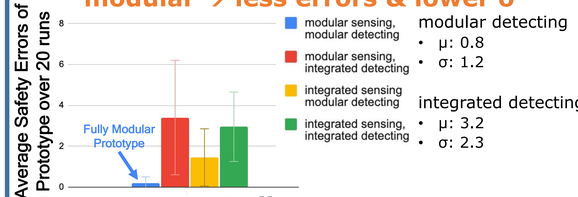


modular sensing
- μ: 0
- σ: 0

integrated sensing
- μ: 4.4
- σ: 1.2

Average Safety Errors

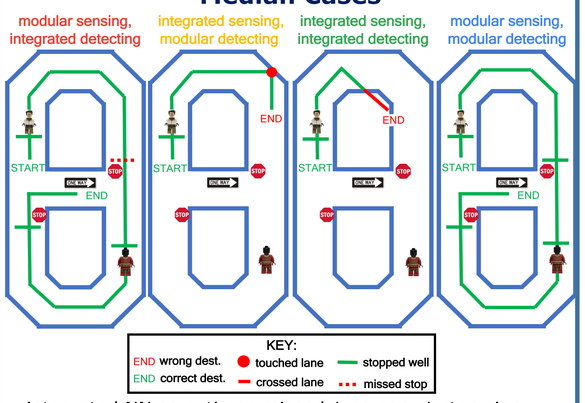
modular → less errors & lower σ



modular detecting
- μ: 0.8
- σ: 1.2

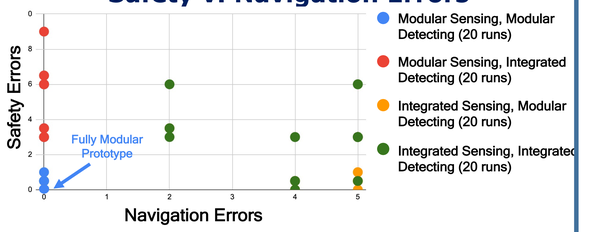
integrated detecting
- μ: 3.2
- σ: 2.3

Median Cases



- integrated NN sometimes missed 1 person, 1 stop sign, both people, both stop signs, or falsely detected stop signs
- integrated front cam falsely detects intersections

Safety v. Navigation Errors



Modular Neural Network
- less errors low σ
- simple, two-step decision:
  1. people or go?
  2. stop sign or go?

Integrated Neural Network
- more errors & higher σ → overfitting
- complex, one-step decision:
  1. people or stop sign or go?

- **complex integrated decision → more data needed**

Conclusions

- modular systems outperform integrated systems
  - modular NN structure doesn't require extra nodes, hidden layers, training images

Broader Impact

- w/ more complex tasks, like driving, autonomous systems need more modular designs like the modular human brain
  - Tesla: 1 integrated video system, 1 integrated NN
  - SAE says Tesla requires constant driver supervision
  - Waymo: multiple NNs, multiple sensor systems
  - SAE says Waymo doesn't need driver supervision

Future Work

- make robot design closer to human brain