Team A – Perception System using Stereo Vision and Radar

Amit Agarwal

Harry Golash

Yihao Qian

Menghan Zhang

Zihao (Theo) Zhang

Project Objective

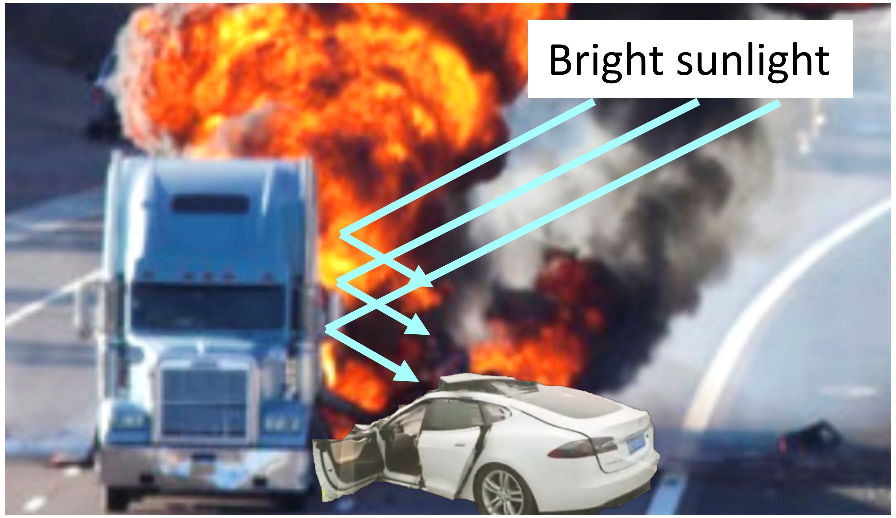
- Develop a standalone system to initially assist current autonomous vehicle sensor systems, and eventually replace existing systems.

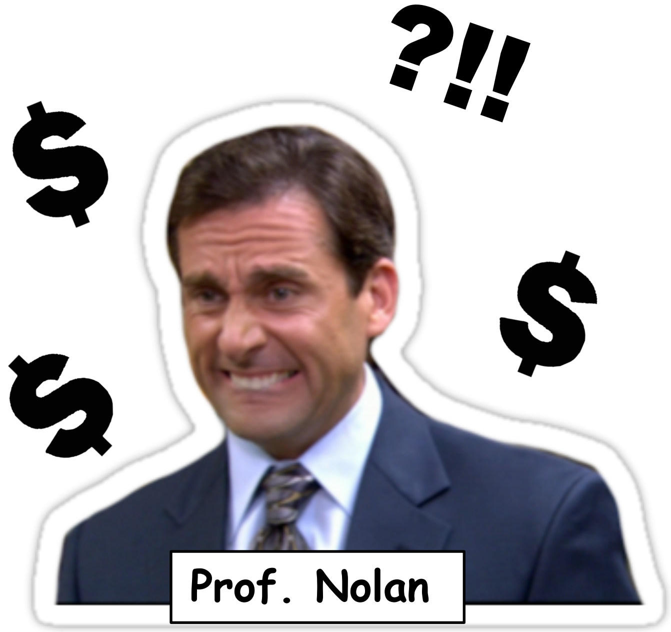
Project Description

- Sensor Fusion:
  - Stereo vision (2 Point Grey RGB cameras)
  - Radar (1 Delphi ESR 2.5 Radar)
- Simultaneously perceive long and short range info
- Create a robust 3D rending of the driving environment

Use case:

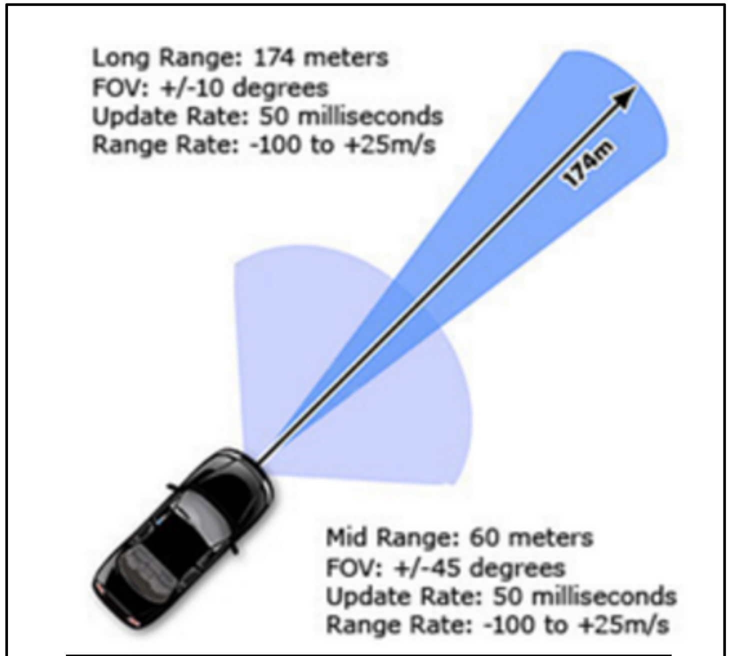
- Messla Motors' autonomous car hit a large white truck
- The car had an extensive, bulky, expensive sensor array
- Small entrepreneurs scared of the autonomous car business
- Prof. Nolan at BMU is one such entrepreneur!



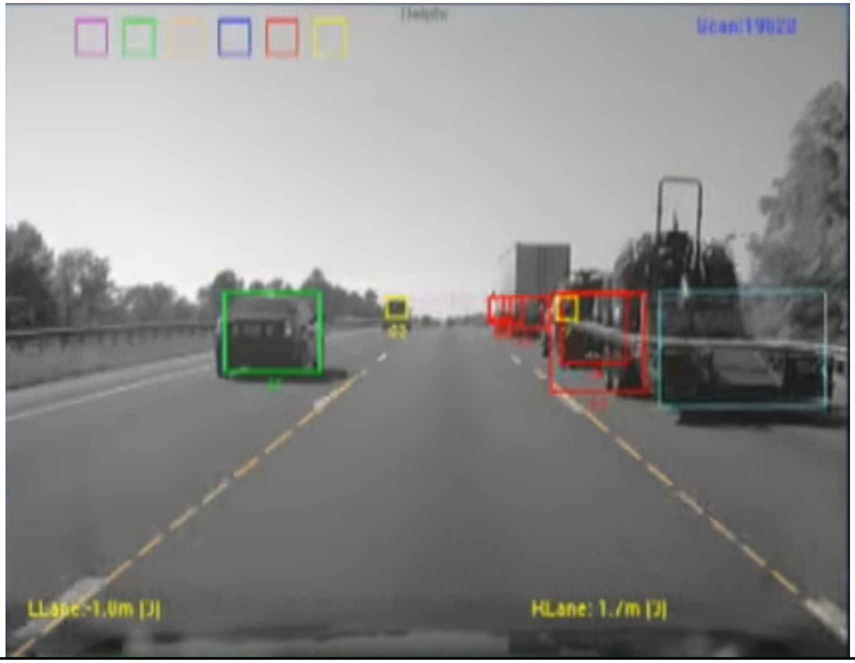


Use case (contd.):

- Thankfully, Prof. Nolan can use Team Aware's sensor system!
- <u>Low cost</u>, <u>full-range</u>, <u>easy to use and maintain</u> (LIDARs are expensive)
- Redundancy and cross-calibration allows for robustness



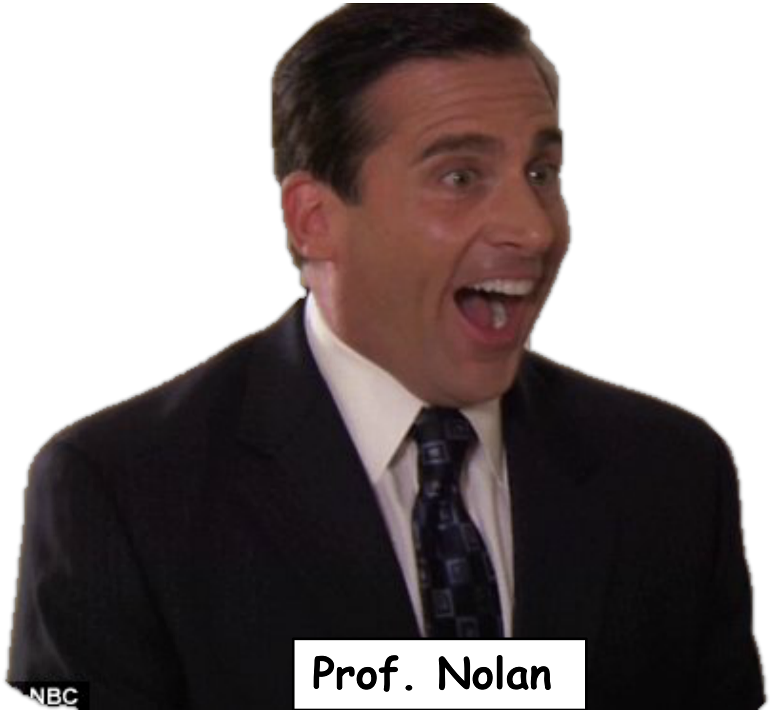
Radar unaffected by sunlight

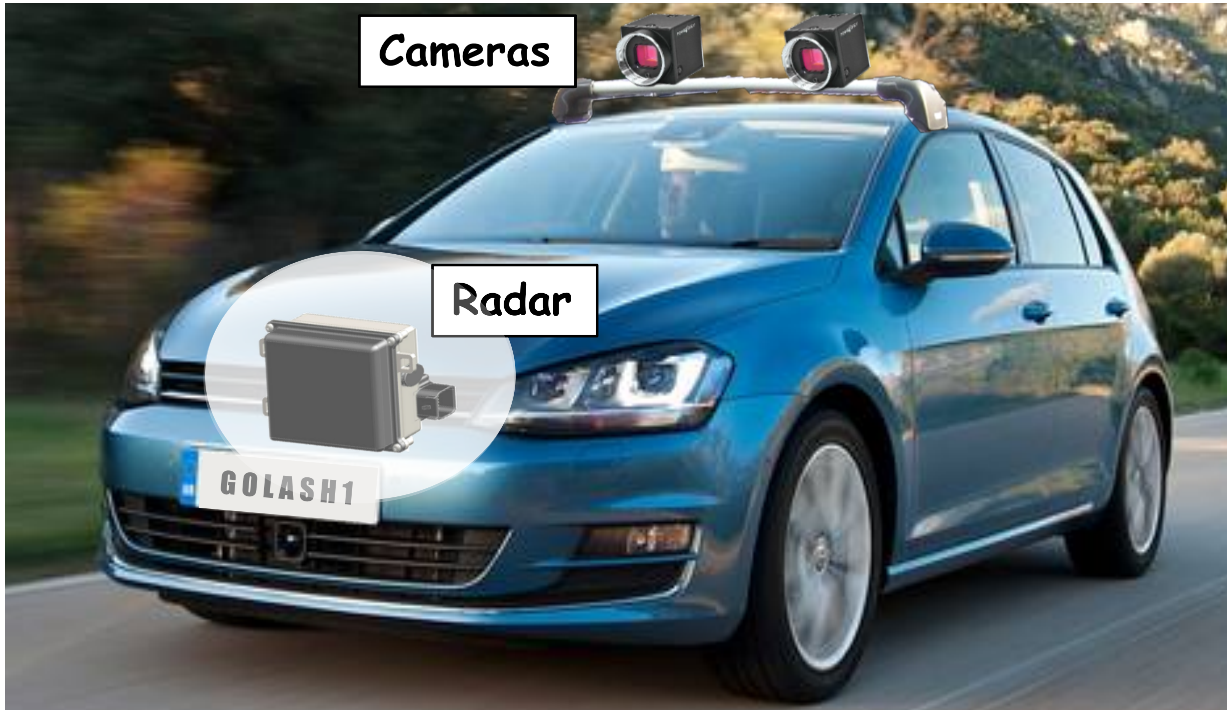


Objects detected by radar tracked by cameras

Use case (contd.):

- Weather-proof sensor system with no moving parts
- Overall cost is low since fewer sensors used
- Prof. Nolan and other entrepreneurs/users benefit directly!





Draft Functional Requirements

- Conduct full-range perception
- Perceive in real-time
- Use multiple sensors
- Detect and identify objects
- Classify objects (pedestrians and vehicles)
- Estimate external vehicle motion and egomotion
- Be self-contained

Mandatory Performance Requirements

The system will:

M.P1. Detect objects (pedestrians & vehicles)up to **150 m**

M.P2. Unify sensor data up to **50 m**

M.P3 Acquire sensor data at up to **20 Hz**

M.P4 Detect object size with an accuracy of up to **80%**

M.P5 Detect object distance with an accuracy of up to **95%**

M.P6 Detect object with an accuracy of up to **80%**

M.P7 Classify objects (pedestrians & vehicles)with an accuracy of up to **70%**

M.P8 Estimate vehicle motion with an accuracy of up to **90%**

Note: Mandatory (M) , Performance (P)

Non-functional Requirements

The system will:

M.N1 Works in real-time

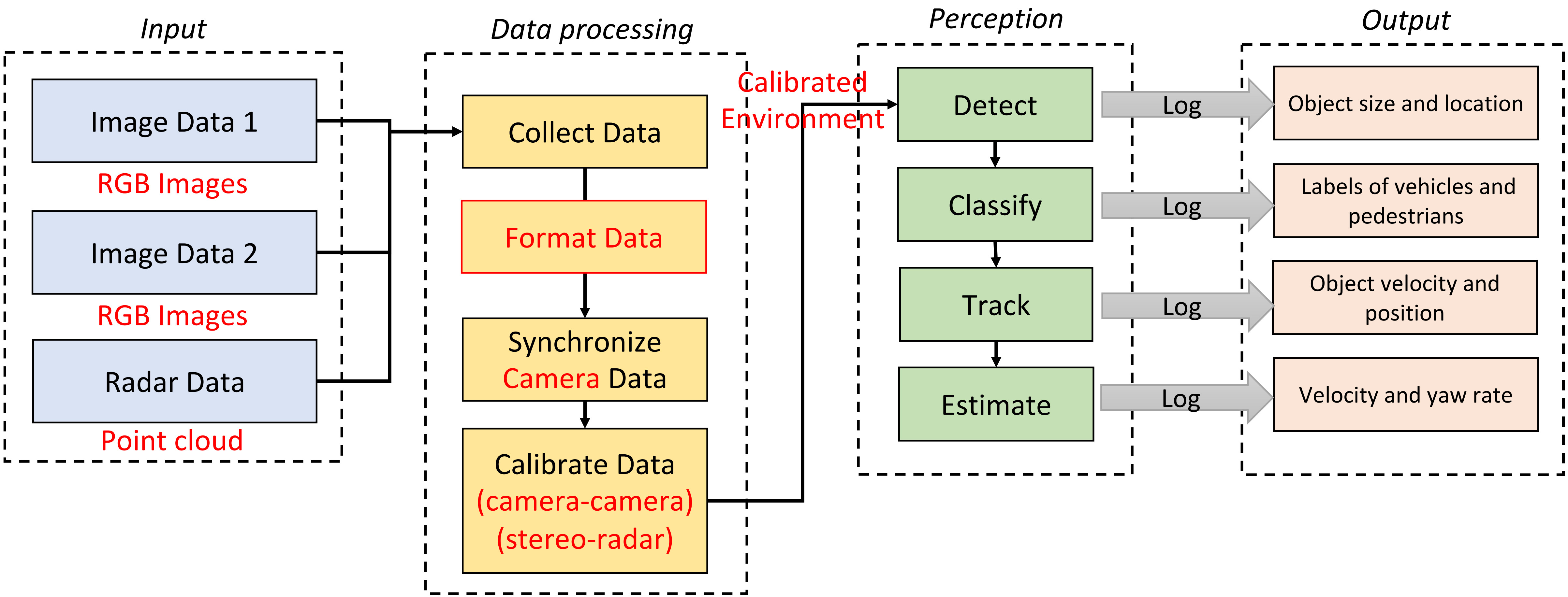
D.N1 Weather-proof

D.N2 Functions in sunlight conditions

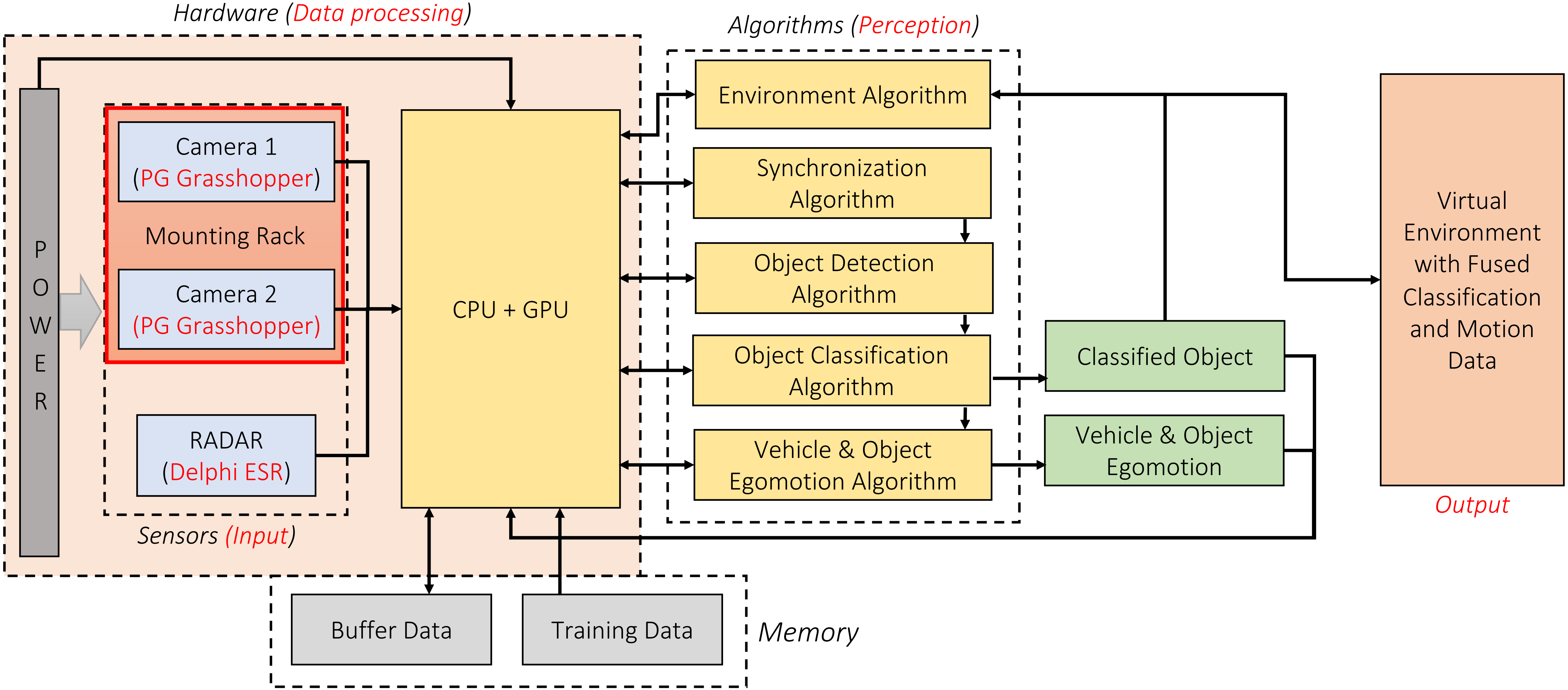
D.N3 Is compatible with vehicle display systems

Note: Mandatory (M) or Desirable (D), as well as Performance (P) and Non-functional (N).

Draft Functional Architecture



Draft Cyber-physical Architecture



System/Subsystem descriptions

- Mounting Rack
- Power Source
- Sensors
- Processing Unit
- Perception Algorithms
  - Synchronization
  - Object Detection
  - Object Classification
  - Motion Estimation
  - Environment Modelling

Mounting Rack

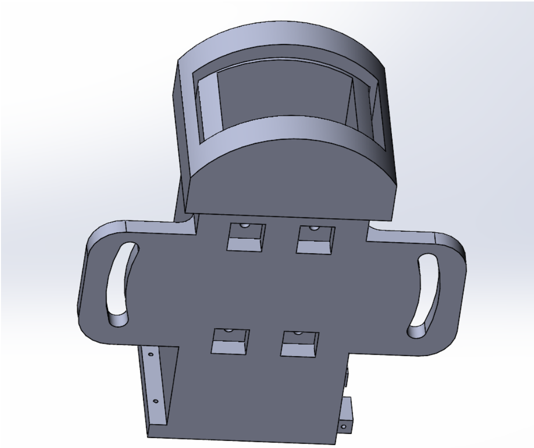
- Mounting rack to hold the 2 cameras
- Mounting rack to hold the RADAR
- No modifications to the vehicle
- Weatherproof housing for the cameras
- Basic heat sink characteristics
- Unblocked view of the road

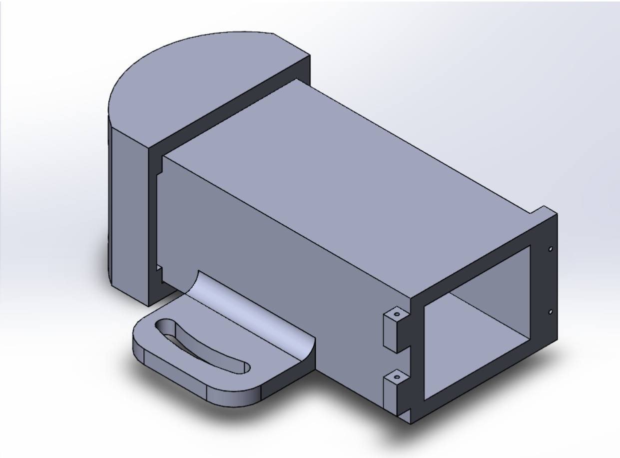
Mounting Structure
Stereo Vision Subsystem
Radar

Mounting Rack – Current Status

- 3-D printed prototype for cameras in place
- Aluminum components ordered
- Final prototype will be CNC
- Base rack is a Thule 53” Aeroblade (car-independent)

- Radar mounting rack – in progress
- Weatherproofing testing – in progress

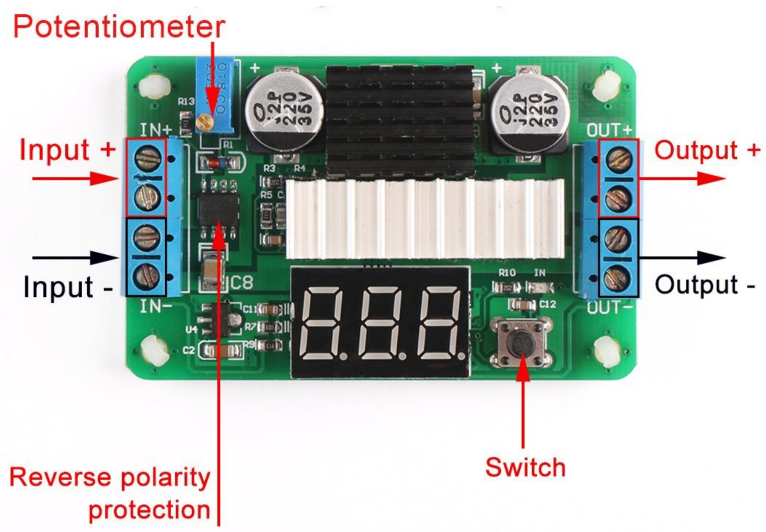




Power Source

- Unified source for all components of the system
- Portable source, usable in a car
- Cameras needs 8-24V with max power draw of 4.5W
- Radar needs 24V with max power draw of 5W
- CPU will need 500-1000W

Power Source– Current Status



- Voltage step-up circuit from 12V to 24V
- Separate PCB in development through the class

- Currently using a mini-inverter for testing
- Eventually, maybe use the power supply for the CPU to power everything

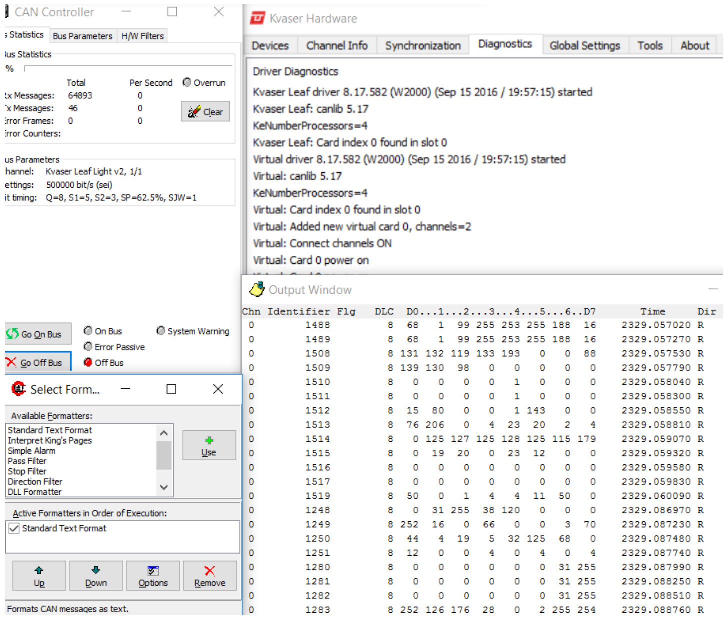
Sensors

- 2 Grasshopper3 3.2 MP USB3 Vision by PointGrey Research
- 2 Tamron 8 mm 1/1.8” C-mount lenses by PointGrey Research
- ESR 2.5 Radar by Delphi Automotive

- Cameras used for stereo vision
- Radar to augment the stereo vision

Sensors – Current Status

- Acquiring images using code from the cameras over USB
- Triggering both cameras with GPIO pulse input
- Lenses tuned for optimal focus and clarity
- Radar is working over CAN connection
- Yet to acquire sensible data from the Radar

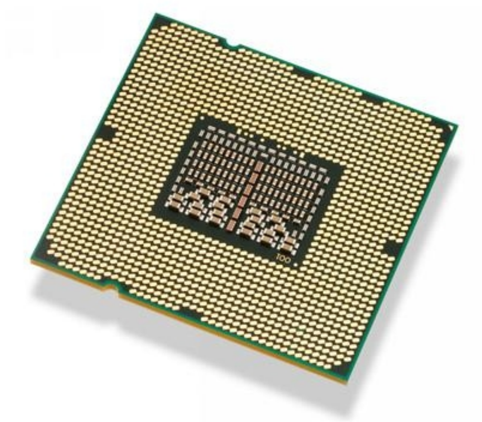


Processing Unit

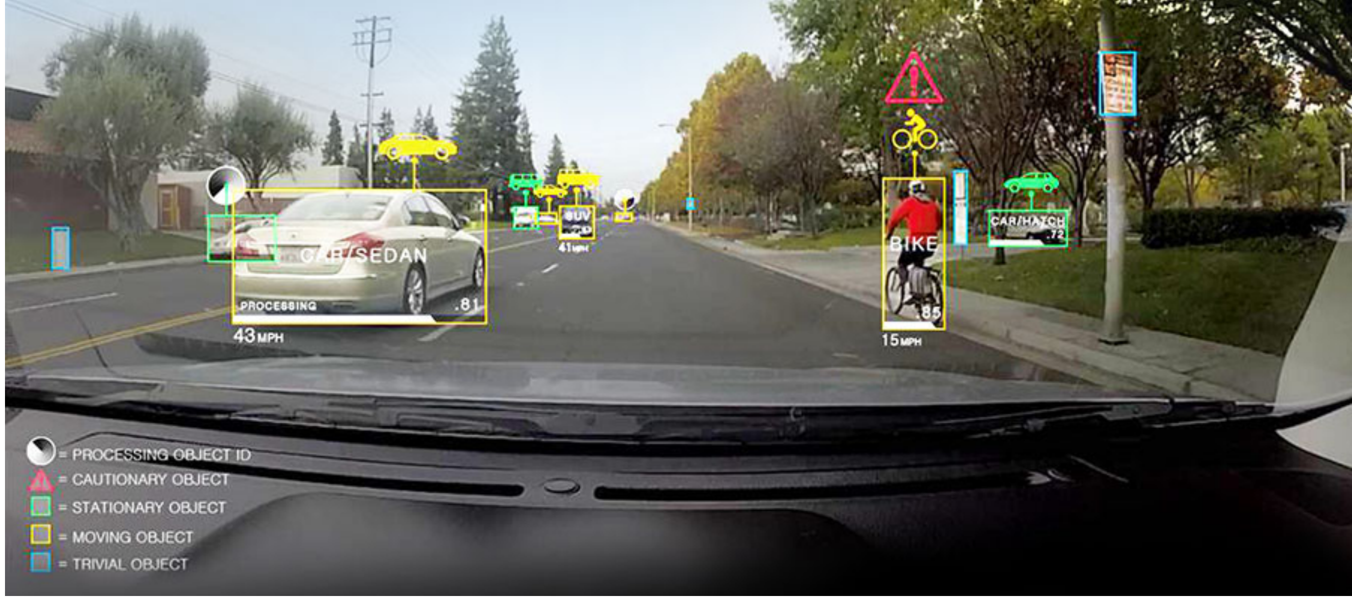
- High levels of single and multi core processing power
- Multiple threading for parallelization
- High power GPU for parallel computation
- Big and fast storage for real time read/write speeds

Processing Unit – Current Status

- A lot of other tasks to be performed before deciding specifications
- Although, quite certain that will need top of the line components



Perception



- Synchronization Algorithm
- Object Detection Algorithm
- Object Classification Algorithm
- Motion Estimation Algorithm
- Environment Modelling Algorithm

Perception – Current Status

- At current stage, no tangible work. Only research about algorithms
- Faster-CNN for object detection and classification (possibly)

Draft Work Breakdown Structure (deliverables)

- 1.0 Stereo vision and radar system
  - 1.1 Cameras
    - 1.1.1 Synchronize both cameras
    - 1.1.2 Acquire data
    - 1.1.3 Test in various conditions
    - 1.1.4 Reliable stereo vision
  - 1.2 Radar
    - 1.2.1 Synchronize with cameras
    - 1.2.2 Acquire data
    - 1.2.3 Test in various conditions
    - 1.2.4 Reliable sensor fusion
  - 1.3 Rack system
    - 1.3.1 Design
    - 1.3.2 Manufacture
    - 1.3.3 Test in various conditions
    - 1.3.4 Mount sensors on car
  - 1.4 Power supply
    - 1.4.1 Design
    - 1.4.2 Manufacture
    - 1.4.3 Test
    - 1.4.4 Install in car
  - 1.5 Computing
    - 1.5.1 Receive sensor data
    - 1.5.2 Object detection
    - 1.5.3 Object tracking
    - 1.5.4 Perception system
  - 1.6 Project Management
    - 1.6.1 Manage work
    - 1.6.2 Manage finances
    - 1.6.3 Manage schedule
    - 1.6.4 Manage risk

Draft Schedule until CDR: Milestones

- 10/27 (PR# 2)
  - Trigger both cameras using a pulse – Complete
  - Finalize rack solution – Complete
- 11/10 (PR #3)
  - Visualize radar data – In progress
  - Manufacture all final sensor mounts / housings – In progress
- 11/22 (PR #4)
  - Finalize power supply (PCB) – In progress
  - Working / calibrated stereo vision and radar – In progress

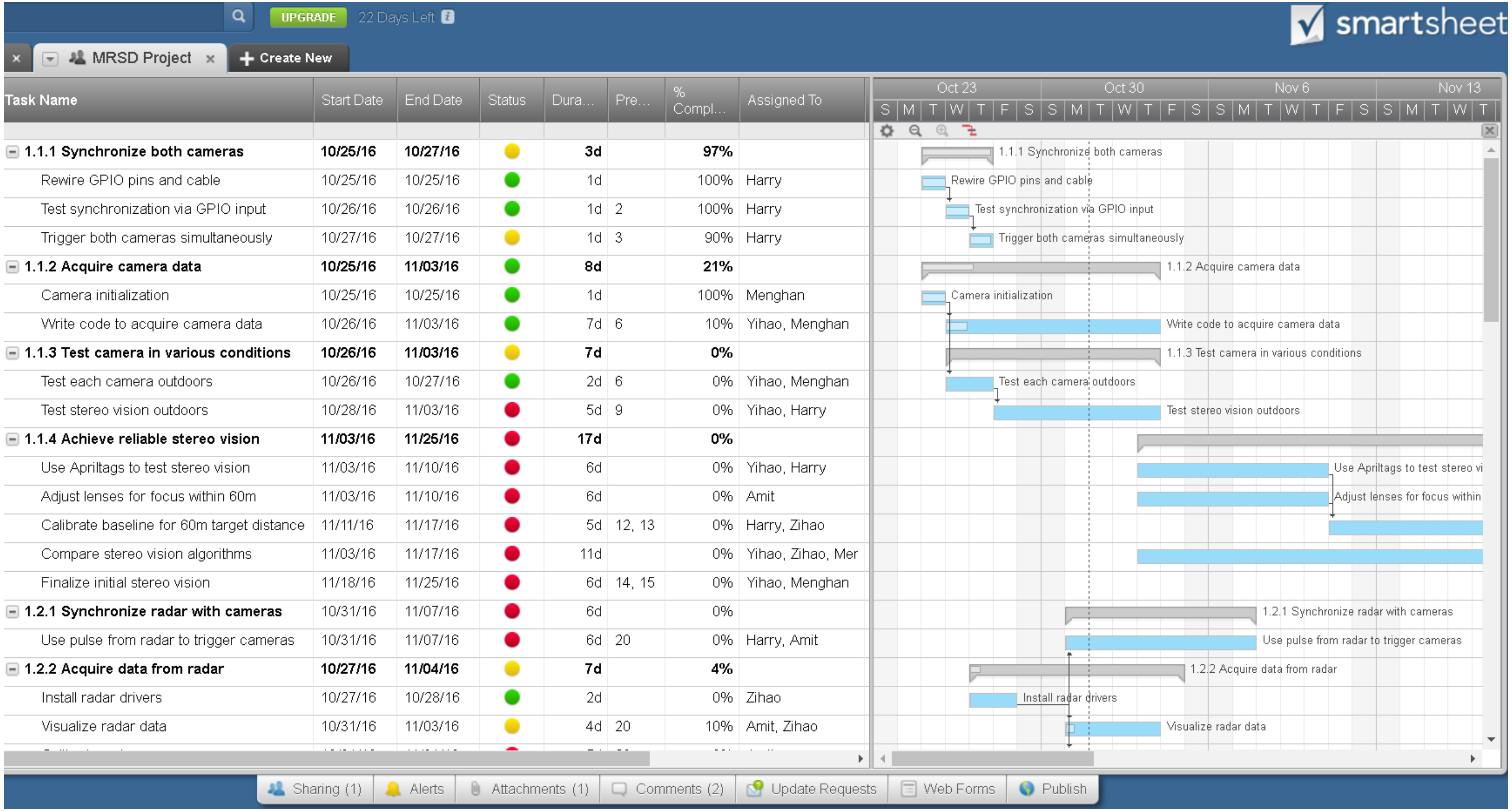
Draft Schedule until CDR: Milestones (contd.)

- 12/01 (PR #5)
  - Object detection and tracking methods research and design – In progress
  - Testing on car – Not started

- 12/12 (CDR)
  - Basic perception system and 3D reconstruction – Not started

    (Object detection and tracking will need tuning in next semester)

Draft Schedule until CDR: Screenshot



Task Name	Start Date	End Date	Status	Dura...	Pre...	% Compl...	Assigned To
1.1.1 Synchronize both cameras	**10/25/16**	**10/27/16**	Yellow	**3d**		**97%**	
Rewire GPIO pins and cable	10/25/16	10/25/16	Green	1d		100%	Harry
Test synchronization via GPIO input	10/26/16	10/26/16	Green	1d	2	100%	Harry
Trigger both cameras simultaneously	10/27/16	10/27/16	Yellow	1d	3	90%	Harry
1.1.2 Acquire camera data	**10/25/16**	**11/03/16**	Green	**8d**		**21%**	
Camera initialization	10/25/16	10/25/16	Green	1d		100%	Menghan
Write code to acquire camera data	10/26/16	11/03/16	Green	7d	6	10%	Yihao, Menghan
1.1.3 Test camera in various conditions	**10/26/16**	**11/03/16**	Yellow	**7d**		**0%**	
Test each camera outdoors	10/26/16	10/27/16	Green	2d	6	0%	Yihao, Menghan
Test stereo vision outdoors	10/28/16	11/03/16	Red	5d	9	0%	Yihao, Harry
1.1.4 Achieve reliable stereo vision	**11/03/16**	**11/25/16**	Red	**17d**		**0%**	
Use Apriltags to test stereo vision	11/03/16	11/10/16	Red	6d		0%	Yihao, Harry
Adjust lenses for focus within 60m	11/03/16	11/10/16	Red	6d		0%	Amit
Calibrate baseline for 60m target distance	11/11/16	11/17/16	Red	5d	12, 13	0%	Harry, Zihao
Compare stereo vision algorithms	11/03/16	11/17/16	Red	11d		0%	Yihao, Zihao, Mer
Finalize initial stereo vision	11/18/16	11/25/16	Red	6d	14, 15	0%	Yihao, Menghan
1.2.1 Synchronize radar with cameras	**10/31/16**	**11/07/16**	Red	**6d**		**0%**	
Use pulse from radar to trigger cameras	10/31/16	11/07/16	Red	6d	20	0%	Harry, Amit
1.2.2 Acquire data from radar	**10/27/16**	**11/04/16**	Yellow	**7d**		**4%**	
Install radar drivers	10/27/16	10/28/16	Green	2d		0%	Zihao
Visualize radar data	10/31/16	11/03/16	Yellow	4d	20	10%	Amit, Zihao

High-Level Test Plan

Name	Deliverable Functionality	Method to Test
Progress Review 3	Camera synchronization	Use Pointgrey SDK to show and capture image
Progress Review 4	Achieve Stereo Vision	Get Stereo vision data and image
Progress Review 5-6	Reliable Sensor Fusion Hardware finalization	Get point cloud data from radar and stereo vision of camera and fuse them together
Spring PR1	Object detection	Can detect all the object captured by sensors
Spring PR2	Object identification	Identify objects in the pictures
Spring PR3	Object classification	Give the labels of the objects detected by the sensors
Spring PR4	Vehicle motion estimation	Can estimate own and others velocity and position

Fall Validation Experiments

Location	Roads around school
Equipment	Car, mounting rack, cameras, radar
Environment	Sunny day with fine light

Table 1 :Hardware Validation steps

Steps	Fix the rack on the car and measure the relative position of the sensors
	Drive around the school for about 20 minutes
	Measure the relative position of the radar and camera again
Performance	The sensors should be fixed and the relative position should be the same (less than 1 cm change) in any conditions including, but not limited to sudden braking, bad weather, rash driving.

Table 2. Sensor Synchronization steps

Steps	Fix the sensors on the mounting rack and put them on the car
	Drive around the school for about 15 minutes
	Monitor the data collected by the stereo camera and radar and make the comparison of data’s timeline
Performance	Data from stereo camera and radar should be synchronized and show in real-time (less than 100ms delay)

Spring Validation Experiments

Location	Roads around school
Equipment	Car, mounting rack, cameras, radar, GPU/CPU
Environment	More than 15m wide road with more than 30 min traffic flow in any conditions

Table 3. Object Detection steps

Steps	Fix the sensors on the car and drive at 20mph around the school
	Get the synchronized data from cameras and radar
	Detect the objects on the road and return the size, color, shape information
Performance	Take the data from Delphi's LIDAR as ground truth. Detect object size with an accuracy of 80%, distance with an accuracy of 95%, velocity with an accuracy of 80%

Table 11. Object Classification and Estimation steps

Steps	Following the above steps of object detection
	Use the data collected before and give the classification of the pedestrians and vehicles with labels on them
	Estimate the ego motion and give the information of velocity, position and orientation of the car
Performance	Classify objects with an accuracy of 70% and estimate vehicle motion with an accuracy of 90%

Budget

- Total budget left: $5000 - $1097 = $3903
- Sponsored items

Grasshopper3 3.2 MP Color USB3 Vision (GS3-U3-32S4C-C)	$975
Delphi ESR 2.5 24V Radar	$3300
Tamron M118FM08, 8mm, 1/1.8", C mount Lens	$210

- Total spent to date: $1097

Thule 53” Aeroblade	$570
UINSTONE 150W Power Inverter	$16
Belkin 6-Outlet Surge Protector	$10
Step-Up Circuit PCB (12V to 24V)	$15
Electromagnets and chargers	$25
Kvaser CAN connecter and adapter	$380
Mounting Rack Material (McMaster-Carr)	$81

Risk Management

Risk title:	Risk owner:	Date submitted:	Date updated:
Dynamic Range of Camera	Amit Agarwal	October 20, 2016	October 25, 2016

Description of risk:

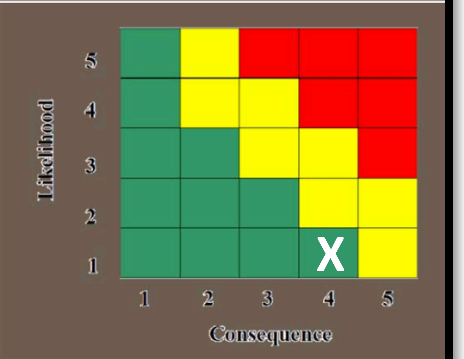
The Dynamic Range of the camera may not be sufficient for the camera to work in all lighting conditions.

Consequences if risk is realized:

A new and better camera with higher dynamic range will be needed. This will halt development on most activities related to stereo vision which will lead to schedule problems as well.

Risk type

- X Technical
- X Schedule
- X Cost
- ☐ Programmatic



Risk Reduction Plan Summary

Action/milestone	Date	Success Criteria	Risk Level	Comments
1. Test in Afternoon & Night	Nov 3, 2016	Produces reasonably detailed images		Next Week
2.				
3.				

Risk Management

Risk title:	Risk owner:	Date submitted:	Date updated:
RADAR Driver	Amit Agarwal	October 17, 2016	October 25, 2016

Description of risk:

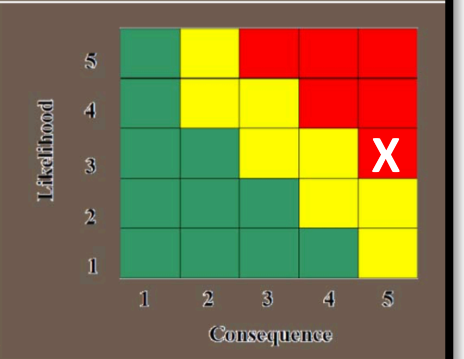
The Delphi RADAR provided does not come with a driver or an instruction manual. A driver is essential to use the RADAR.

Consequences if risk is realized:

A driver for the RADAR is absolutely necessary. The lack of a driver halts all activity dependent on the RADAR. This causes changes in schedule and costs. In addition, it calls for more technical knowledge and more research study.

Risk type

- X Technical
- X Schedule
- X Cost
- ☐ Programmatic



Risk Reduction Plan Summary

Action/milestone	Date	Success Criteria	Risk Level	Comments
1. Ask Delphi for help	Oct 21, 2016	Driver/help is provided	70%	Documentation provided
2. Get quote from 3rd party	Nov 3, 2016	Driver can be bought		Next Week
3.				

Risk Management

Risk title:	Risk owner:	Date submitted:	Date updated:
Teammate Inability/Incompetence	Amit Agarwal	October 24, 2016	October 25, 2016

Description of risk:

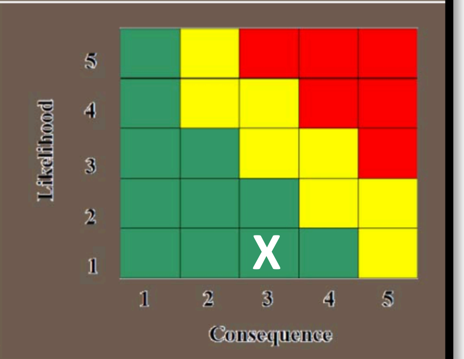
If a teammate is not willing to work on the tasks assigned or is acting in an extremely tardy manner.

Consequences if risk is realized:

The tasks dependent on the team-member are left incomplete, which leads to delays in the rest of the team's tasks. This also impacts the team's grade in the course.

Risk type

- X Technical
- X Schedule
- ☐ Cost
- X Programmatic



Risk Reduction Plan Summary

Action/milestone	Date	Success Criteria	Risk Level	Comments
1. Discuss strategy within team	Oct 24, 2016	New strategy	50%	Primary + Secondary lead of each task
2. Discuss with Prof Dolan	TBA (if needed)			
3.				

Questions?