Classification and Detection Considerations for Thermal Imaging

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SAVING LIVES – AUTONOMOUS DRIVING

Goal of autonomous driving: A vehicle is able to drive to a final destination without endangering its surroundings (ie. **pedestrians**) or its occupants.

Requirements for safe driving:
100% detection of the ego vehicle's surrounding vehicles, people, and animals coupled with appropriate driving responses to these surroundings

- Requires fusion of multiple sensors that supply a variety of information. Typical sensors include CCD cameras, radars, LIDARs, and ultrasonic

Avoidable recent accidents:

- 2018: Tesla vehicle (CCD camera, radar, and ultrasonic sensors) on auto-pilot strikes non-moving object on the road on five separate occasions (2x firetruck, police car, stalled car, and concrete lane divider)
- Mar 18, 2018: First recorded **pedestrian** death by an Uber self-driving Volvo (camera, radar, and LIDAR systems)
  - Death caused by limited visibility and the radar and LIDAR systems not properly classifying the crossing pedestrian in time

DESIGN CONSTRAINTS AND CAMERA CAPABILITIES

Raw images recorded using a **FLIR A65** thermal imaging (TI) camera.

Reaction time: Must be able to detect and respond to a visual stimulus faster than a human driver. The average human reaction time is approximately 0.25s. Aiming to achieve 0.1s detection time. Camera has a frame rate of 30 Hz.

Detection Range: 60m minimum range for detecting a pedestrian. Vehicle speed assumed to be 100 km/h with a braking distance of ~55m. Camera is capable of capturing a person from 4.5-150m. Detection range will be less depending on the algorithm.

Field of View (FOV): As living things, especially wildlife, will usually appear from the driver's peripherals, a wider FOV is desired. FLIR A65 offers a FOV of 45° x 37°, which offers full single lane detection at 3.6m. Masking this image further will improve algorithm speed (remove useless information like horizons and the hood of the car)

Resolution: Higher resolution costs more in terms of algorithm speed and money but allows for a wider FOV or larger detection range. Camera has a resolution of 640x512 pixels.

LEVERAGING THERMAL IMAGING (TI) FOR DETECTION

Advantages

- Warm bodied objects exhibit high contrast in cold environments, making them easily identifiable
- No dependence on visible light with better performance during nighttime applications
- Offers more detail on small, warm objects than LIDAR and radar
- No blooming effects from lights
- Minimal shadow effects

Disadvantages

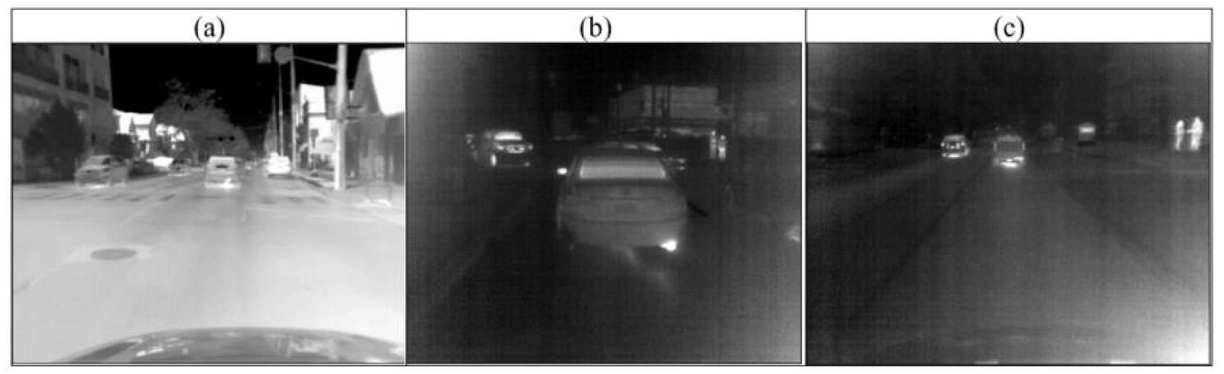
- Expensive (low economies of scale)
- Low levels of image detail
- Low image information content when no warm bodies are present in an image
- Image appearance (and therefore algorithm performance) is dependent on the weather conditions
- Atmosphere absorbs IR meaning measured temperature readings may not be accurate

APPEARANCE OF DIFFERENT OBJECTS – WHICH OBJECTS SHOULD TI DETECT?

Common objects on the road that can be identified using thermal imaging:

- Different types of vehicles (cars, SUVs, busses, trams, etc.)
- Pedestrians and similar (with & without coats, groups, cyclists)
- Animals (dogs, cats, raccoons, deer, turtles)
- Other heat-radiating objects (sewers, transformers, lights)

If an object is easily detected by other sensory systems like LIDAR or radar, then using TI to detect these objects is redundant. It can also be detrimental if its true positive detection rate is low. For this reason, TI should not be used to detect objects like vehicles. Objects that have no impact on driving decisions (like sewers) should not be detected either. Some objects exhibit a wide range of appearance based on several factors. Cars, for example, can appear cold at start-up and hot later. Their tires also gain heat from road friction and braking as the vehicle is operated.



Vehicles in different conditions: a) 21°C – mainly sunny; temp scale of 23.3°C to 37.0°C; b) -1°C – snowy; temp scale of -3.7°C to 0.6°C; c) 15°C – overcast/misty; temp scale of 17.7°C to 20.9°C.

LABELLING OBJECTS

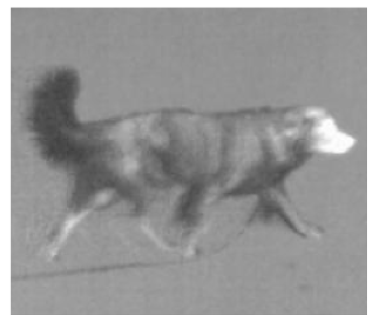
Due to the impact of the time-of-day and types of weather on image appearance, many driving conditions must be considered when labelling data. In order to collect representative data, thermal videos were captured and labelled on seven different days in different driving scenarios. Approximately 21,500 objects were labelled over 7900 frames. As objects can appear differently across these conditions, the following object classes will be used to ensure relatively consistent object appearances across images:

Pedestrian wearing a coat

Uniform temp. pedestrian

Group of pedestrians

Cyclist



Long-haired dog

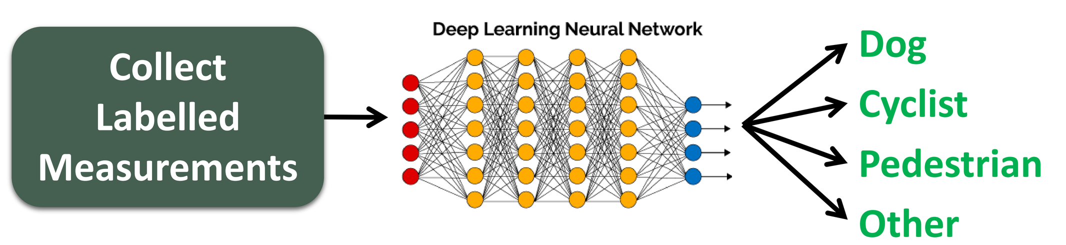
Short-haired dog

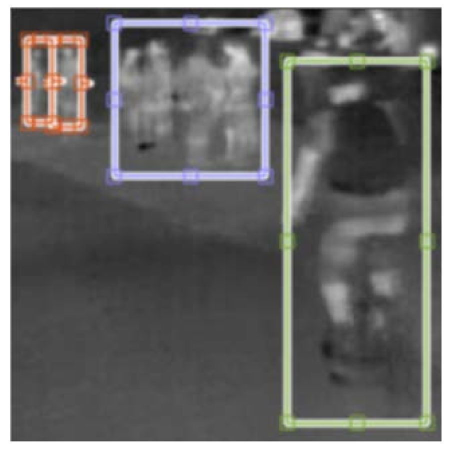
Note: There is also a class for pedestrians in unusual positions (sitting, squatting). Other animal classes would be beneficial but there was not sufficient data captured for these

HOW TO DETECT AND CLASSIFY

Convolutional Neural Networks: Since 2012, there has been a strong trend toward deep convolutional neural networks (DCNNs) for object localization and detection in images. CNNs take an image as an input and output the classification and location of an object in that image. They function using alternating convolution and pooling layers of different sizes. These algorithms rely on weighted nodes which are trained through linear regression.

Basic Research: In order to avoid the expensive process of training an entire network from scratch (a network can contain millions of nodes which require training), **transfer learning** can be used. Applying transfer learning means that only the nodes of the last couple of layers of an existing "pre-trained" network are re-weighted to adapt to new training data. This allows the network to be trained with less data while still maintaining robust functionality. Transfer learning with TI for driving scenarios has not been widely developed.





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