CISC 322

Assignment 3
Concrete Architecture of Apollo
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Abstract

This report analyses two different implementations of a feature enhancement called the "Enhanced Pedestrian Protection System". Our team developed this feature for Apollo to make it safer and efficient in a wider range of situations, such as during extreme weather events like fog, rain and snow. This enhancement works by adding software and hardware support for thermal cameras, in addition to the existing visible-light cameras, RADAR and LiDAR. We then performed a SAAM analysis of both approaches to identify the stakeholders, as well as discuss the advantages and disadvantages of the two implementations. We also discuss the Non-Functional Requirements of the feature to better understand its importance, and also how the feature would impact other modules and subsystems.

Enhancement Feature

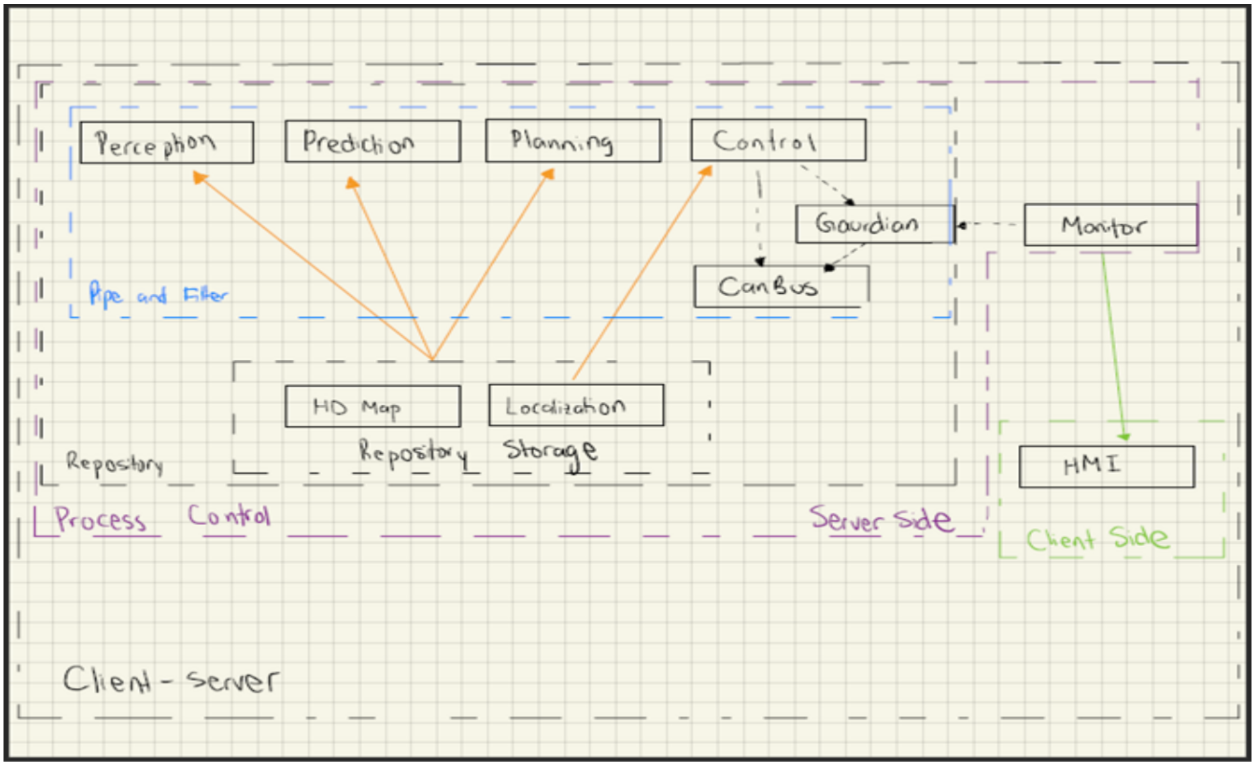
We have decided to implement the "Enhanced Pedestrian Protection System" to improve the functionality and effectiveness of Apollo's self-driving system. While the name implies an improvement only in pedestrian safety, the system would significantly improve the perception of living beings, which would include people and wildlife. It would also generally improve safety and self-driving capabilities at night and during unfavorable conditions.

The feature adds full support for thermal cameras to the software, as well as the necessary hardware. Currently, Apollo relies on visible-light cameras, RADAR and LiDAR. This limits Apollo to driving in good weather conditions, since neither of these technologies can perceive accurate data in bad weather conditions like rain, snow and fog. RADAR in general has poor vision capabilities and LiDAR doesn't work well in bad weather. Far Infrared thermal cameras do not suffer from these issues. It is also the only technology that can reliably "see" the things Autonomous Vehicles want to hit the least - people and animals.

Adding thermal camera support to the software will bring the system much closer to full autonomy, allowing the driver to safely give up control in a wider range of situations like driving during bad weather or in rural areas.

Fig. Images from a thermal camera on left vs visible light camera on the right

Recap of Conceptual Architecture



We based our conceptual architecture on our initial A1 report on Apollo's architecture as well as the same report from Group 6: Dash. Our final conceptual architecture combined elements from the pipe-filter, repository, process control, and client-server architectures to represent the Apollo system.

The primary style is pipe-and-filter, used to handle control flow between the Perception, Prediction, Planning and Control modules. The repository style encompasses those modules and allows them to access the map engine and localization data repository. The Monitor and Guardian modules interact with this system using a process control style, and a client-server style is also used to display relevant data to the user via the HMI client. The pub-sub style is also used throughout to ensure minimal performance degradation, and provide scalability and flexibility.

Non-Functional Requirements

Thermal scanning and vision requires three Non-Functional Requirements regarding quality.

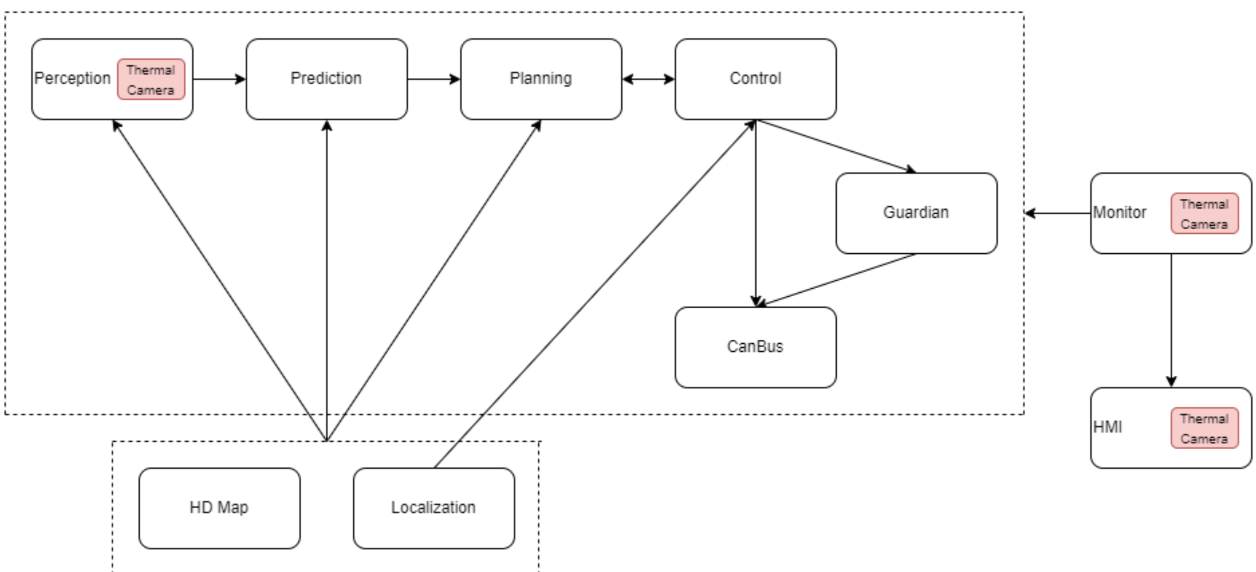
- Performance
- Maintainability
- Availability

The performance is one of the most important NFRs as it should get data quickly so that the car can process it, detect hazards, and send that data to monitor and HMI for safety. Any unnecessary latency between detection and reaction could have catastrophic consequences, especially because the situations in which thermal scanning would be most useful are in reduced-visibility situations, where driver vision is limited.

Maintaining the thermal camera feature is another key point. The thermal camera enhances the safety of autonomous driving, so it should be ensured that the thermal camera is working without errors since that could potentially lead to an accident if the camera data is inaccurate. The thermal camera hardware and software components should be checked regularly for faulty data or transmission problems.

The thermal camera is not only needed for autonomous driving, but also in extreme weather situations. The thermal camera would be a key safety feature in those scenarios. As a result, it should be available at all times during vehicle operation.

Implementation 1



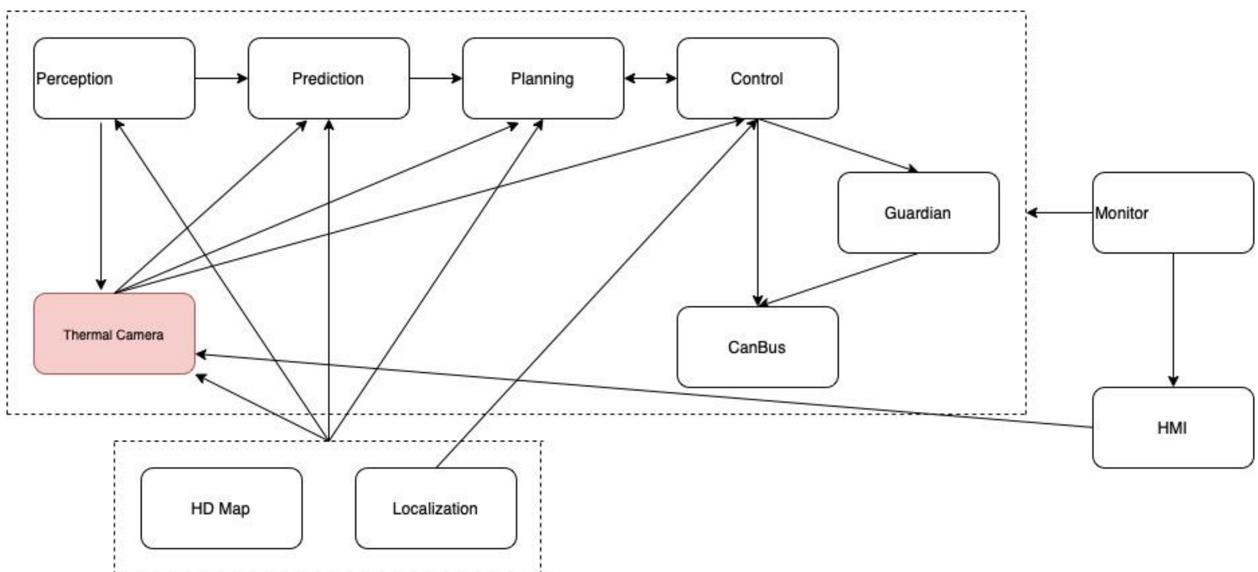
The first approach for implementing our new feature is by adding submodules to existing architecture, taking advantage of the modular and extensible architecture design of Apollo and all its components.

The most important component would be to add a “Thermal Camera Manager” submodule to the perception module. Its job would be to take in raw data from the associated hardware and process it. The processed data can then be used by other submodules to combine it with other perception data which can be used by other modules like Prediction.

Monitor would also need an upgrade, since its job is to monitor hardware and software systems. A new submodule can be added which is responsible for monitoring the sensors and software systems needed for the enhancement, and it can make sure everything is running smoothly.

Finally, we would add an additional component to the HMI module, so the users can directly get information from the thermal cameras. Looking at the direct video feed can be helpful to the users so passengers can also see what the car is seeing when the weather is bad and visibility is low.

Implementation 2



Another approach to the implementation of the Thermal Cameras to the existing architecture of Apollo would be to include it as a separate module. This would further increase the dependencies of each of the existing sub-systems in the architecture, thus building a robust architecture.

This new module would take, as input, data from the Localization, Perception and HMI modules. Its output would then be used by the Prediction, Planning and Control modules, in order to improve on the existing trajectories during low-vision conditions such as fog, snow, low-light, etc. In order to optimize its performance, it can also take in useful data from the

RADAR and LiDAR wherever appropriate to do so, thus improving its accuracy in terms of image capturing.

The output of this module can also be shown to the users, making them aware of any possible obstructions to the vehicle ahead. This approach to the implementation will help in the understanding of the architecture, as all the tasks related to the Thermal Camera can be easily viewed in just this module.

Additionally, we can also add a sub-module in the Control module that assesses the visibility conditions outside the car so that the system can automatically switch to the Thermal Camera when visibility is low/going down.

SAAM Analysis

To evaluate the architecture, let’s develop some scenarios that might challenge the current implementation of the architecture.

Scenario 1: The surroundings are quite foggy, so the system changes the primary source of external stimuli data to the Thermal Camera rather than the RADAR and LiDAR. What would be the changes that the system would undergo? First, a visibility test will be conducted in the Control module, which facilitates the change of the primary source of information to and from the Thermal Camera and the RADAR and LiDAR. Next, the outputs of the Localization module would get redirected to the Thermal Camera module in order to produce more accurate images for the Perception and Planning modules. Based on the outputs of these modules, the Prediction module will compute the appropriate trajectory for the car to pass safely and smoothly.

Scenario 2: There is a deer fast approaching the highway, where the car is being driven. What sub-systems respond to this and what are the actions that happen? With the Thermal Camera module in use, the presence of an animal will be sensed and this data will be sent to the Perception and Planning modules, which will test the animal’s trajectory and speed to calculate whether or not the vehicle will be close to the animal. If these trajectories meet, then the planning module will take this into consideration and hence, reduce the speed so that the animal can cross safely. This wouldn’t be possible without the Thermal Camera, as it would be very difficult to perceive an animal running through bushes and shrubs at speed.

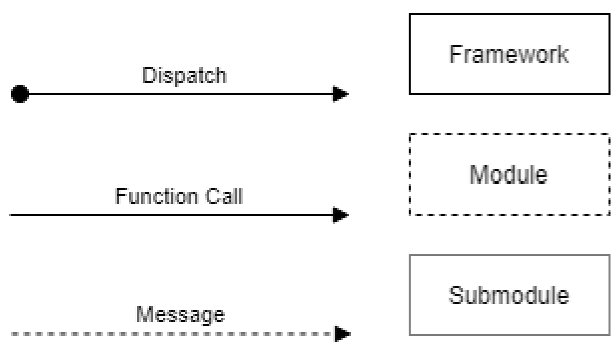
Impacted Subsystems

The most heavily impacted subsystem would be the Perception module, and modules which receive data from it. The thermal camera data would need to be combined with the existing perception data in a way that does not impact the normal functioning of the system, but serves as a secondary check for hazards which are more difficult for other sensors to detect.

The Monitor and Guardian modules would need modification to work with the new hardware and software related to the thermal camera components, and the HMI module would need modification in order to receive thermal camera output, as well as processed thermal imaging showing detected obstacles. This is particularly useful as a driving aid in low-visibility conditions, where the driver can use the thermal camera feed to see obstacles which may be difficult to make out otherwise.

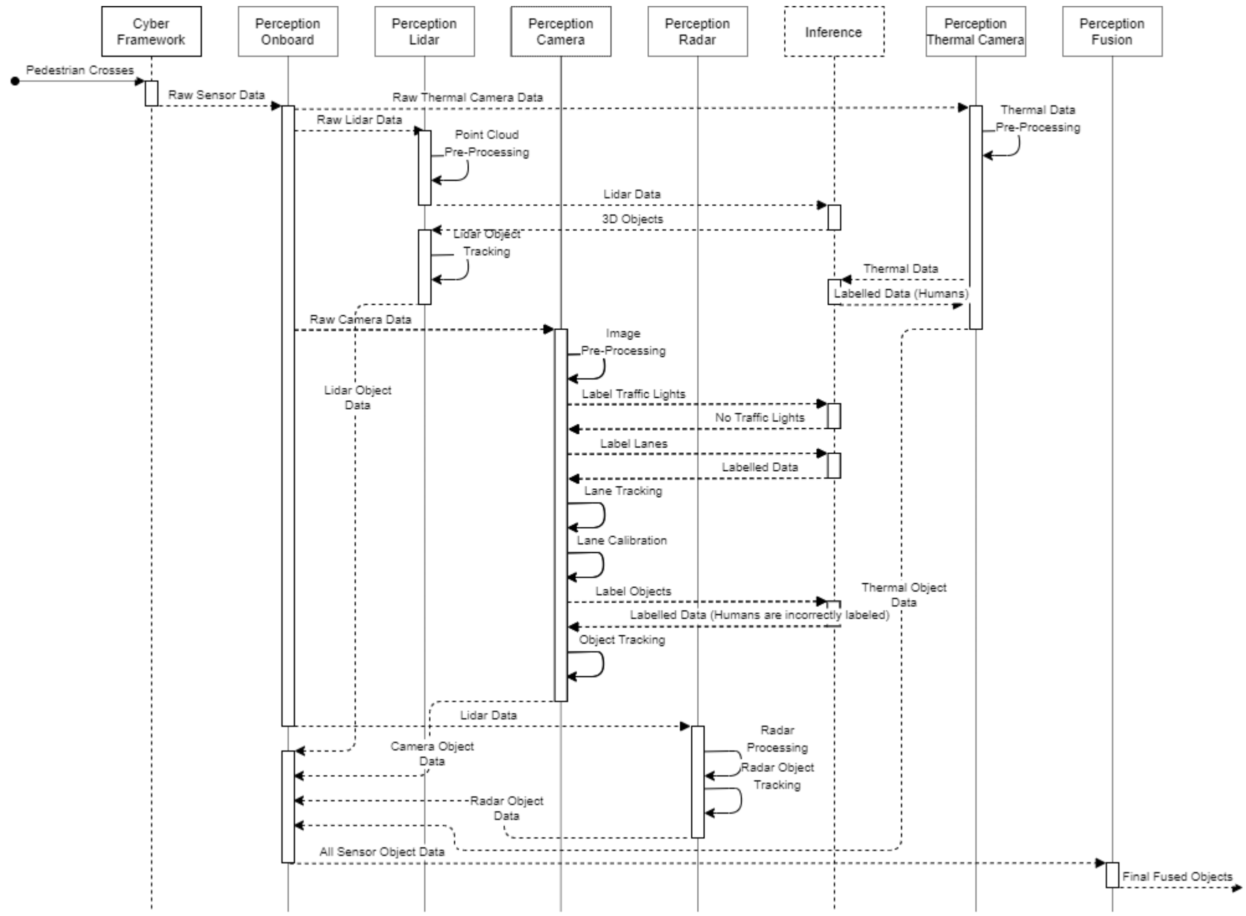
Depending on implementation, the Prediction, Planning, and Control modules may also be modified to use the thermal data as a secondary check to ensure the planned route is free of obstacles detected by the thermal camera. The thermal imaging would only be used in low-visibility situations, thus having minimal effect on the normal operation of the system.

Use Cases



Legend

Use Case 1 - Pedestrian Crosses (and is mislabeled by deep net)



When a pedestrian crosses in front of the vehicle, the raw data from the Apollo-Equipped Car's sensors is sent to the Perception module's Onboard submodule. The Onboard submodule then sends each sensor's raw data to its respective Perception submodule for processing.

When the Perception Lidar submodule receives the raw data, it first performs point cloud pre-processing and sends the data to the Inference module. The Inference module then returns the 3D Objects from the point cloud data, the objects are then tracked by the Lidar submodule and finally returns it to the Onboard submodule.

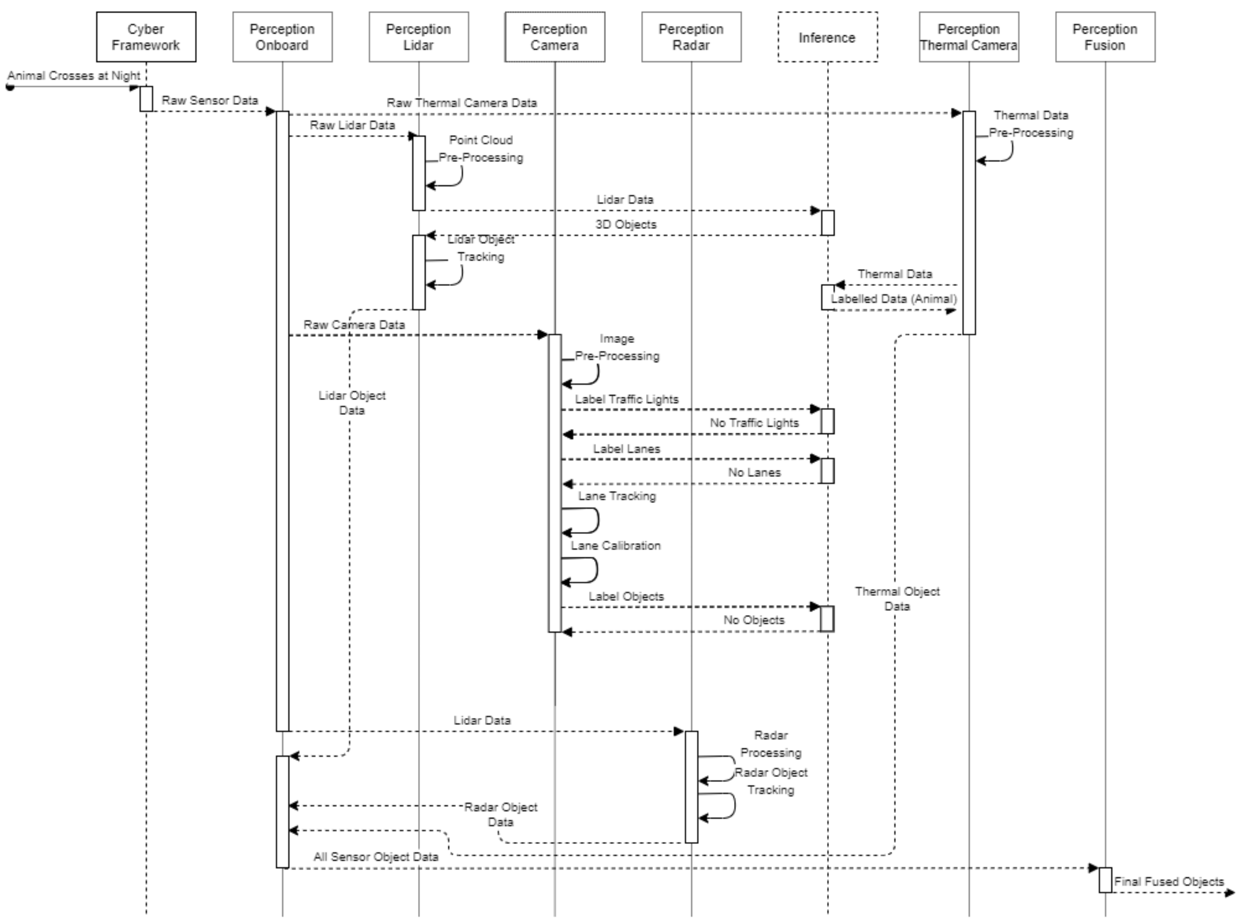
When the Perception Camera submodule receives the raw image it first pre-processes the image and then sends the data to the Inference module. The Inference module then labels the data. The data is returned to the Camera submodule, where the submodule learns that the image has no traffic lights. The Camera submodule then sends the data to the Inference module for lane labeling, after receiving the labeled data it then tracks and calibrates lanes. The Camera submodule once again sends the data to the Inference module to label objects. However, the labeller can potentially incorrectly label objects (in extremely rare cases) and in this case labels the human as a traffic cone. Finally, the Camera submodule sends the data to the Onboard submodule.

When the Perception Radar submodule receives the raw data it first processes the data. It then tracks the objects found in the data and returns them to the Onboard submodule.

When the Perception Thermal Camera submodule receives the raw data it first processes the data. It then sends the data to the Inference module. The Inference module uses machine learning models that look for clusters of heat activity that could potentially be a living thing(s). In this case, a human-being is detected and labeled. This data is retureded, and the Thermal Camera submodule sends the data to the Onboard submodule.

After the Perception Onboard submodule receives all the object data, it then sends it to the Perception Fusion submodule to fuse the data to create the obstacle data with positions, velocities, accelerations, and more. Without the Thermal Camera, the final data would not contain the accurate labeling of a human. While this error would most likely be corrected in subsequent sensor reads, the few seconds between the next data capture could be vital. Thankfully, due to the inclusion of thermal data, after fusion the human-being was correctly labeled.

Use Case 2 - Animal Crosses Car on Rural Road at Night



When the Perception Lidar submodule receives the raw data, it first performs point cloud pre-processing and sends the data to the Inference module. The Inference module then returns the 3D Objects from the point cloud data, the objects are then tracked by the Lidar submodule and finally returns it to the Onboard submodule.

When the Perception Camera submodule receives the raw image it first pre-processes the image and then sends the data to the Inference module. The Inference module cannot label the data due to it being too dark. The unlabelled data is returned to the Camera submodule. The Camera submodule then sends the data to the Inference module for lane labeling, receiving unlabeled data. The Camera submodule once again sends the data to the Inference module to label objects. The Inference module once again fails to label. Finally, the Camera submodule does not send the data to the Onboard submodule as it has no labeled data to send.

When the Perception Radar submodule receives the raw data it first processes the data. It then tracks the objects found in the data and returns them to the Onboard submodule.

When the Perception Thermal Camera submodule receives the raw data it first processes the data. It then sends the data to the Inference module. The Inference module uses machine learning models that look for clusters of heat activity that could potentially be a living thing(s). In this case, an animal is detected and labeled. This data is retureded, and the Thermal Camera submodule sends the data to the Onboard submodule.

After the Perception Onboard submodule receives all the object data, it then sends it to the Perception Fusion submodule to fuse the data to create the obstacle data with positions, velocities, accelerations, and more. Without the Thermal Camera, the final data would not contain the accurate labeling of an animal due to it being too dark for the camera to capture an image. Thankfully, due to the inclusion of thermal data, after fusion the animal was correctly labeled.

Testing plans

Short and convincing verification tests are required for focused sensor development. The purpose of developing new verification techniques is to mitigate or decrease superfluous testing, as well as to create tests that ensure that the presumed failure will not occur in practice. Product development efficiency must continue to improve in today's world. The demand for innovative sensors and functionality is critical, particularly in the automobile sector.

The first stage is to define the robustness requirements for the product, i.e., the conditions that the product must be able to bear while keeping full operation. The suggested technique converts use case situations into accurate physical events and then into measurable physical quantities that may be used as test loads to enable product verification (either Design Verification or Production Verification).

The development time is critical in the product development process, and achieving an acceptable degree of robustness in the lowest possible period is vital. This strategy allows you to concentrate on the most important robustness goals and assist you in achieving either the targeted robust product or a proven risk-based compromise. The technique has the advantage that even if the product fails one or more tests, the resultant robustness is still subject to interpretation and will be a number between 0 and 100 percent.

Risks and Limitations

Let us discuss the various risks that can occur in case precautions are not taken while integrating thermal sensors. Firstly, the temperature sensor is turned on by default for safety-related equipment, and the uncalibrated threshold may fall inside the working temperature range, thus not allowing the chip to boot and execute the program.

Secondly, when the calibration data changes, the temperature sensor is activated. Hence, the status cannot be assured at that period.

Lastly, the temperature sensor isn't working properly. In the event that the temperature sensor stops working fully (false indication or no indication). The situation can be deadly since the chip may be turned off needlessly or continue to operate in an unstable manner.

Although thermal sensors are the future and have a big list of advantages, there does exist a few limitations. The materials used to make thermocouple wires are not inert, and the thermoelectric voltage created throughout the length of the wire can be affected by corrosion and other factors. Lastly, in a certain temperature range, thermo-sensors are not as precise as RTDs and are prone to drifting over time. Finally, non-linearity, least stability, least sensitivity, and low voltage are limitations that can very easily occur if precautions are not taken.

Conclusion

The enhancement feature we will implement is the use of Thermal Imaging, which will act as a 'Enhanced Pedestrian Protection System'. However, its features will help not only pedestrians, but also other living beings that can obstruct the passage of the vehicle. This feature will be enabled during the night and when surrounding conditions are unfavorable. The current architecture limits Apollo only to good driving conditions, which can change very rapidly.

Thermal imaging, like all other automobile sensory systems, has a straightforward goal: to provide drivers with data about their environment and to assist them in reacting quickly—and sometimes automatically—to possible threats. It joins other advanced systems, such as medium and long radar, in providing a comprehensive set of safety measures.

Thermal imaging will play a critical role in getting self-driving cars on the road as soon as feasible. Perception that is human-equivalent (or superior) can only be obtained if numerous sensors function in tandem redundantly. When these sensors are combined with thermal imaging's expanded vision, an autonomous car may more correctly recognize the barrier ahead of it and activate the brake system. With these qualities, autonomous vehicles can drive as safely as people, if not safer.

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