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FS - DV Assignment Report

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This report is submitted as the fulfillment of the task of drafting a document for the driverless system for the formula student competition.

Contents

1 System Design and Conceptualization

1.1 Driver-less System Requirements and Key Components

In a driverless electronic vehicle, the entire system functions as an autonomous robot. This robotic system achieves situational awareness through the integration of various sensors, processes the acquired data using an advanced control unit, and executes decisions via actuators. The primary components of the driverless system include:

1. **Sensors:** The vehicle employs an array of sensors to gather comprehensive environmental data. These sensors may include LiDAR, radar, cameras, ultrasonic sensors, and GPS, among others. Each type of sensor provides unique information that contributes to a detailed and accurate perception of the surroundings.

2. **Control Unit:** The sensor data is processed by a high-performance control unit. This unit typically comprises sophisticated hardware, such as multicore processors and GPUs, capable of handling complex algorithms and real-time data processing. The control unit executes various tasks, including sensor fusion, object detection, path planning, and decision-making, using advanced machine learning and artificial intelligence techniques.

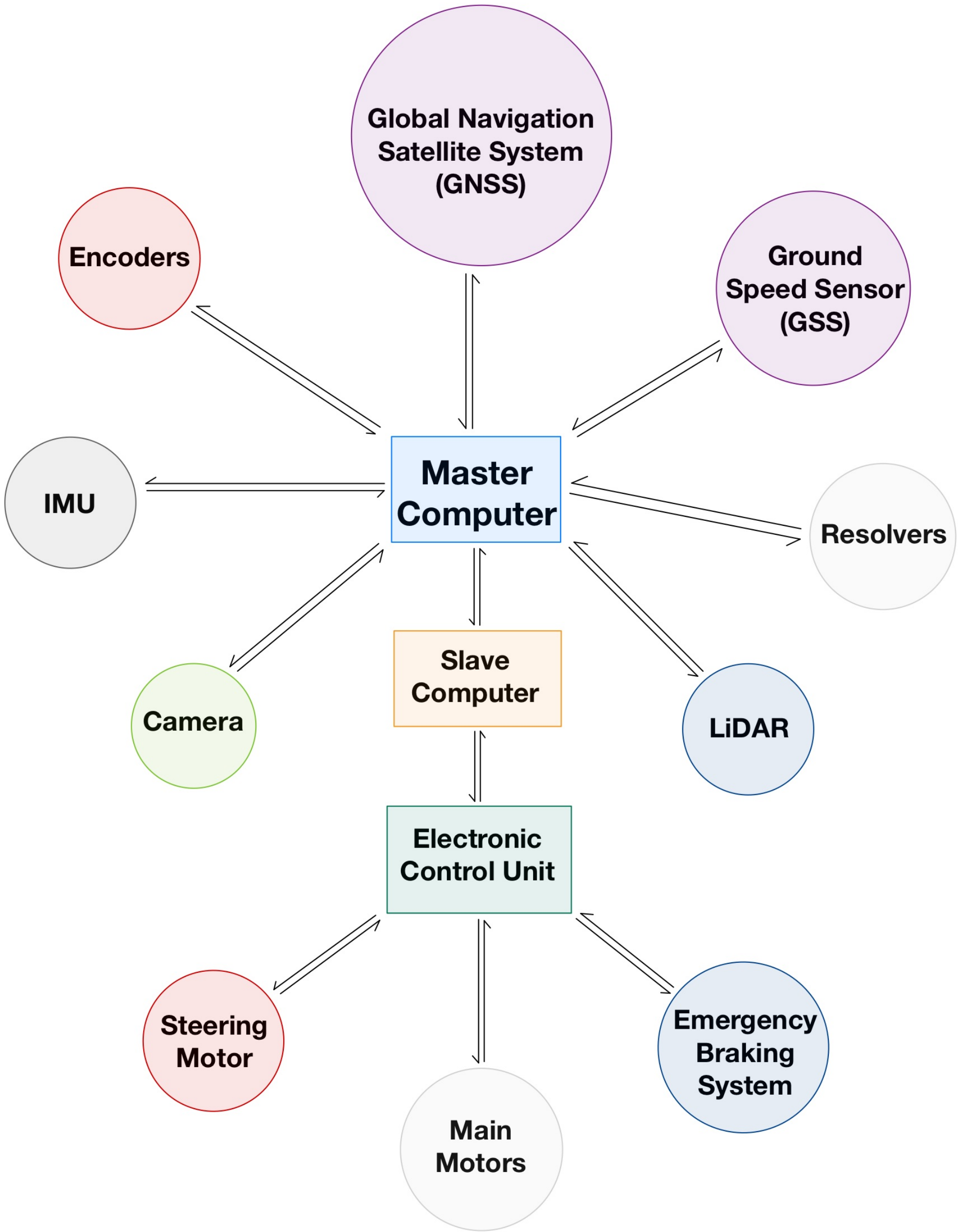
3. **Actuators:** The decisions made by the control unit are implemented through a system of actuators. These actuators control the vehicle's steering, throttle, brakes, and other critical functions. The control of the vehicle is often achieved using Ackermann steering geometry, which is specifically designed for the efficient maneuvering of wheeled vehicles.

4. **Communication System:** Effective communication is essential for the seamless operation of the driver-less system.

   - The sensors continuously send data to the master computer through high-speed communication channels, such as CAN bus, Ethernet, or specialized automotive communication protocols.
   - The master computer processes this data and transmits control commands to the slave computer, which interfaces directly with the actuators.
   - A continuous communication among the master computer, slave computer, and the electronic control unit (ECU) to coordinate the vehicle's overall functioning.

The task is to navigate the electronic vehicle autonomously through a track constructed using blue and yellow cones. The vehicle must identify the cones, recognize their colors, and map their locations in a 2D plane to accurately traverse the track. The key objectives include localizing the vehicle and generating an optimal acceleration, velocity, and braking pattern to ensure the vehicle traverses the track in the shortest possible time.

In the next page we can see the block diagram of the conceptual design of the vehicle



For the communication purposes Ethernet or Can Bus protocol is utilized.

Figure 1: Block Diagram for the Conceptual Design of the Driver-Less Vehicle

2 Sensor Selection and Specification

Sensors play a major role in building the driver-less vehicle. The use of sensors can be divided into several sub-areas:

1. **Machine Vision:** Used to recognize the cones and their color.
2. **Locating the Position of the Cones:** Used to map the locations of the cones in the environment.
3. **Locating the Position of the Vehicle:** Used to localize the vehicle in the environment.

2.1 Machine Vision

2.1.1 Camera

1. **Range:** There is not a specific range which can be seen with the camera sensor. However, the observable distance of the sensor will be different based on the sensor specifications like the lens of the sensor and the resolution of the sensor.
2. **Resolution:** Camera sensors with different resolutions are available in the market and have the freedom to choose the sensor with the specific resolution for the purpose. Frame rate of the sensor is also a thing to consider.
3. **Field of View:** This also depends on the model of the sensor that is utilized. There are sensors with high and normal field of view and it also depends on the necessity.
4. **Cost:** Relatively the cost is cheaper compared with high-end LiDAR; one can also go with high-end camera sensors with the necessity.
5. **Environmental Robustness:** Variable light conditions and reflections on the objects are the main environmental challenges in utilizing the camera. Since the development of high-end algorithms, we can overcome these challenges and make the sensor robust.

Figure 2: Camera Sensor

- Pros:
  - Camera sensors can effectively detect objects within their field of view and accurately localize them within the frame.
  - hey are capable of distinguishing and recognizing colors, which is essential for tasks like identifying cones of different colors.

- These sensors leverage Convolutional Neural Networks (CNNs) and YOLO (You Only Look Once) models, which are well-established in computer vision. These models enhance detection and localization accuracy.
- Modern algorithms make camera sensors highly robust, capable of functioning effectively despite variable light conditions and reflections.

• Cons:

- Analyzing pixel data and running neural networks in real-time demands substantial processing power. This requirement increases significantly when multiple cameras are employed.
- Achieving real-time processing at high speeds can be challenging, especially with the computational load imposed by multiple cameras simultaneously.

Conclusion: Cameras are the best choice in developing an Autonomous Vehicle

2.2 Locating the Position of the Cones

2.2.1 LiDAR

1. **Range:** LiDAR systems can detect objects up to 200 meters away with a full 360-degree view. The observable range depends on the specific model and settings of the LiDAR sensor.
2. **Resolution:** Typically offers high angular resolution, such as 0.2 degrees vertical and 2 degrees horizontal, though this can vary based on the model chosen.
3. **Field of View:** Available with flexible field of view options, including 90, 180, or 360 degrees, depending on the specific LiDAR model. 3D LiDARs provide both horizontal and vertical scanning capabilities.
4. **Cost:** LiDAR sensors are generally more expensive compared to other sensor types due to their advanced technology and capabilities. Higher-end LiDAR models are available for specific needs.
5. **Environmental Robustness:** LiDAR systems demonstrate high environmental robustness, performing effectively in various weather conditions and lighting environments.

Figure 3: LiDAR

• Pros:

- LiDAR systems can generate detailed 3D maps of the surrounding environment over a large range, enabling accurate object detection and mapping.

- They offer high robustness and accuracy in environmental perception, making them suitable for demanding applications.
- LiDAR technology facilitates precise localization and mapping of objects, supporting navigation and obstacle avoidance.

- Cons:
  - LiDAR sensors are generally more expensive compared to other sensor types, which can impact overall system cost.
  - They require significant computational power to process the large volumes of data generated, especially in real-time applications or when multiple LiDAR sensors are utilized simultaneously.

2.2.2 Ultrasonic Sensor

1. **Range:** Ultrasonic sensors typically have a range of a few centimeters to several meters, depending on the specific model and environmental conditions. The effective range can vary based on factors such as object size, surface reflectivity, and ambient noise levels.
2. **Resolution:** The resolution of ultrasonic sensors is generally low compared to LiDAR or camera sensors. They provide distance measurements with accuracy typically in the range of millimeters to centimeters.
3. **Field of View:** Ultrasonic sensors typically have a narrow beam angle, usually less than 30 degrees, which limits their field of view compared to other sensors like cameras or LiDAR.
4. **Cost:** Ultrasonic sensors are generally more cost-effective compared to LiDAR and some high-resolution camera systems, making them a practical choice for applications where moderate accuracy and lower cost are priorities.
5. **Environmental Robustness:** They are robust against environmental factors such as ambient light conditions and can operate effectively in various weather conditions without significant degradation in performance.

Figure 4: Ultrasonic Sensor

- Pros:
  - Ultrasonic sensors are effective for proximity sensing and obstacle detection within their operational range.
  - They provide reliable distance measurements, making them suitable for applications requiring precise object detection at close to moderate distances.
  - They are relatively simple to integrate and operate, requiring minimal computational resources compared to LiDAR or camera systems.

- Cons:
  - Limited range compared to LiDAR, which restricts their application to short to moderate distances.
  - Lower resolution compared to LiDAR and cameras, affecting the precision of object localization and mapping.
  - Ultrasonic sensors may struggle with accuracy in highly reflective or acoustically noisy environments, where echoes and interference can distort distance measurements.

Conclusion: LiDARs are the best choice for developing an Autonomous Vehicle.

2.3 Locating the Position of the Vehicle

2.3.1 Resolver

1. **Range:** Resolvers typically measure angular position within a specific range, often used in systems where precise rotational feedback is needed.
2. **Resolution:** Resolvers can provide high-resolution angular measurements, often in terms of electrical cycles per degree or radians.
3. **Field of View:** Resolvers operate within their mechanical design limits and do not have a traditional field of view like optical sensors.
4. **Cost:** Resolvers can vary in cost depending on their precision and application requirements, generally falling between lower-cost encoders and more expensive sensors like GNSS.
5. **Environmental Robustness:** Resolvers are robust against environmental factors such as temperature variations, electromagnetic interference, and mechanical shock.

Figure 5: Resolver

- Pros:
  - Provide accurate and reliable angular position feedback, crucial for applications requiring precise rotational measurement.
  - High durability and reliability in harsh environments, suitable for industrial and automotive applications.
- Cons:
  - Limited to measuring rotational position and velocity, not suitable for applications requiring linear motion or detailed spatial awareness.
  - Higher cost compared to simpler sensors like encoders, particularly for high-precision models.

2.3.2 IMU (Inertial Measurement Unit)

1. **Range:** IMUs measure accelerations and angular rates across three axes (X, Y, Z), providing dynamic information rather than specific range measurements.

2. **Resolution:** IMUs provide high-resolution measurements of accelerations and angular rates, typically in units like meters per second squared (m/s^2) and degrees per second ($^\circ/s$).

3. **Field of View:** IMUs capture data from all directions around their mounting orientation, providing a spherical view of dynamic motion.

4. **Cost:** IMUs vary widely in cost based on their precision, output rates, and integration complexity, ranging from consumer-grade to high-precision models used in aerospace.

5. **Environmental Robustness:** IMUs are sensitive to environmental factors like vibration and temperature variations but can be housed in ruggedized enclosures for improved robustness.

Figure 6: IMU

- Pros:
  - Provide real-time data on acceleration and angular rate changes, essential for motion tracking, navigation, and stabilization applications.
  - Compact and lightweight, suitable for integration into mobile platforms and wearable devices.
- Cons:
  - Susceptible to drift over time without external reference updates (like GNSS corrections), impacting long-term accuracy.
  - Higher-end models can be expensive and require sophisticated calibration and processing algorithms for optimal performance.

2.3.3 Encoder (For measuring the steering wheel rotation angle

1. **Range:** Encoders measure angular displacement typically up to 360 degrees, providing precise feedback on steering wheel rotation. Absolute encoders are best suitable for this purpose.

2. **Resolution:** Encoders offer high-resolution angular measurements, often in units of degrees or encoder counts per revolution.

3. **Field of View:** Encoders have a narrow field of view limited to the rotation range of the steering wheel.

4. **Cost:** Encoders are relatively affordable compared to other position sensing technologies, making them cost-effective for automotive applications.

5. **Environmental Robustness:** Encoders are robust in automotive environments, enduring temperature variations and mechanical vibrations.

Figure 7: Encoder

- Pros:
  - Provide accurate feedback on steering wheel position, essential for vehicle control and navigation systems.
  - Reliable performance over long periods with minimal maintenance requirements.
- Cons:
  - Limited to measuring angular position, not suitable for tracking linear motion or providing detailed spatial awareness.
  - Mechanical wear and tear can affect long-term accuracy, requiring periodic calibration and maintenance.

2.3.4 GSS (Ground Speed Sensor)

1. **Range:** GSS measures the speed of a vehicle relative to the ground surface, typically covering a range relevant to vehicle speed.
2. **Resolution:** GSS provides high-resolution speed measurements, often in units like meters per second (m/s) or kilometers per hour (km/h).
3. **Field of View:** GSS typically measures speed along a single axis (forward direction), focusing on ground-relative velocity.
4. **Cost:** GSS cost varies based on accuracy requirements and integration complexity, generally more affordable than GNSS systems.
5. **Environmental Robustness:** GSS is robust against environmental factors such as temperature variations and mechanical vibrations, common in automotive applications.

Figure 8: Ground Speed Sensor

- Pros:
  - Provides accurate real-time ground speed information, crucial for vehicle dynamics, navigation, and control.
- Cons:
  - Limited to measuring ground speed along a single axis, not providing detailed position or heading information.
  - Requires integration with other sensors like GNSS for comprehensive navigation and localization tasks.

2.3.5 GNSS (Global Navigation Satellite System)

1. **Range:** GNSS provides global positioning information, covering the entire Earth's surface with signals from multiple satellite constellations.
2. **Resolution:** GNSS offers high-resolution position and velocity measurements, typically in units of latitude, longitude, and altitude.
3. **Field of View:** GNSS operates globally with a wide field of view, receiving signals from satellites across the sky.
4. **Cost:** GNSS receivers vary in cost depending on their accuracy, update rate, and integration capabilities, generally more expensive than local positioning sensors.
5. **Environmental Robustness:** GNSS performance can be affected by signal blockage (e.g., in urban canyons) and atmospheric conditions but remains robust in open sky environments.

Figure 9: Global Navigation Satellite System Unit

- Pros:
  - Provides accurate global positioning and velocity data, essential for navigation, mapping, and precise timing applications.
- Cons:
  - Susceptible to signal blockage and multipath errors in urban canyons, affecting accuracy and reliability.
  - Higher cost compared to local positioning sensors like encoders or IMUs, requiring integration with other sensors for robust navigation solutions.

Conclusion: No single sensor can be selected over the other we need to apply Sensor Fusion to get the best out of the sensors.

3 Safety and Redundancy Planning

1. Sensor Redundancy:
   - **Multiple Sensors:** The systems often use multiple sensors for critical measurements, such as LiDAR, cameras, and GNSS, to ensure redundancy. This helps in maintaining functionality even if one sensor fails
2. Control System Redundancy:
   - **Dual Control Units:** Some systems implement dual control units to provide a backup in case the primary unit fails. This can involve running two parallel processors that can take over control if one fails
   - **Fail-Safe Mechanisms:** These include mechanisms that automatically engage in case of critical system failures, such as reducing speed or safely stopping the vehicle
3. Communication Redundancy:
   - **Multiple Communication Channels:** To ensure robust communication, systems often use multiple communication protocols and channels, such as CAN bus and Ethernet, to maintain data flow between various vehicle components even if one channel fails .
4. Software Redundancy:
   - **Redundant Algorithms:** The control software includes redundant algorithms that can take over if the primary algorithm encounters an error. This can include different methods for sensor fusion and state estimation
   - **Real-Time Monitoring:** Continuous real-time monitoring of software health and performance, with the ability to switch to backup software routines if anomalies are detected

4 Technical Questions

1. What is the maximum allowable latency for sensor data processing in the driverless system according to the Formula Student rule book?

   Though the document do not specify a numerical value it mentions the importance of processing real-time data processing to ensure safe and efficient operation.

2. Describe the key differences between LiDAR and camera sensors in terms of range, resolution, and field of view.

   (a) Range

   - LiDAR: Can detect objects up to 200 meters away.
   - Camera: The observable distance depends on the lens and resolution, but it is typically less than that of LiDAR.

   (b) Resolution

   - LiDAR: Typically high angular resolution (e.g., 0.2 degrees vertical, 2 degrees horizontal).
   - Camera: Resolution varies widely with models, from low to high resolution, depending on the sensor specifications.

   (c) Field of View

   - LiDAR: Can offer 90, 180, or 360 degrees, depending on the model.
   - Camera: Field of view depends on the lens; can be wide or narrow, but generally does not cover 360 degrees.

3. What are the minimum safety requirements for autonomous vehicles as specified in the rule book?

   - Systems must have redundant components to handle failures without compromising safety.
   - Autonomous vehicles must have fail-safe mechanisms to safely stop the vehicle in case of system failures.
   - There must be a clearly defined and accessible emergency stop function.
   - All sensor and control data must be logged for post-run analysis and debugging.
   - Thorough testing and validation of the autonomous system to ensure reliability and safety.

4. How often should the driverless system's control algorithms be updated to ensure real-time processing?

   Though the document hasn't explicitly mentioned an update frequency for the control algorithms, it mentions the need for continuous and real-time processing to handle driving conditions effectively.

5. What are the advantages of using ROS and Gazebo for simulating driverless vehicle systems?

   Using ROS (Robot Operating System), we can develop code in multiple programming languages and seamlessly integrate them into a unified system. One of the key advantages of ROS is the ability to simulate the entire driverless vehicle in a Gazebo environment. This allows us to create and test different racing tracks using datasets available in ROS bags, such as those published by teams like AMZ Racing on GitHub.

   Before deploying real hardware and sensors in the vehicle, we can test our simulations and algorithms extensively. This approach not only reduces costs but also enhances our testing capabilities. Furthermore, with ROS, there is no need to modify the code when changing hardware components. We can directly implement the same code in the vehicle, ensuring a smooth transition from simulation to real-world application.

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