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Board 83: Sensor Fusion Algorithms and Tracking for Autonomous Systems

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Sensor Fusion Algorithms and Tracking for Autonomous Systems

Abstract

This paper discusses the results and experiences of an undergraduate senior project sponsored by an industry. The project focused on applying sensor fusion and localization algorithms to generate highly reliable and accurate sensor feedback for an autonomous ground vehicle. The main objectives of the project were to collect measurements and observations from a variety of sensors, extract the necessary information, and then combine or fuse the information in order to gain an enhanced understanding of the perceived or observed object or incident. Students utilized related algorithms and tools to design, simulate, test, and analyze systems that fused data from multiple sensors in order to maintain the vehicle's position, orientation, and situational awareness.

I.   Introduction

Senior projects are typically taken by students during their final year of undergraduate studies. The projects provide students with the opportunity to work in teams on a project in collaboration with a faculty advisor. Overall, senior projects are a valuable component of undergraduate education that helps students bridge the gap between theory and practice and prepare for their future careers. A senior project is an opportunity for students in the field of Electrical and Computer Engineering (ECE) to apply the knowledge and skills they have gained throughout their academic career to solve real-world problems. The objectives of a senior project are to provide students with a platform to demonstrate their creativity, critical thinking, and problem-solving abilities while enhancing their technical knowledge and practical skills. Additionally, senior projects motivate students to contribute to ECE education by exploring new technologies and developing innovative solutions that can benefit society. Through their senior projects, students can learn the importance of collaboration, project management, and communication skills, which are critical in the field of ECE. Our team, which has 9 students, in this project has a unique opportunity to work on sensor fusion algorithms and tracking for autonomous systems sponsored by industry and have some feedback from them.

Autonomous systems trust a set of sensors that provide data about the surrounding environment to feed the perception system. These sensor sets typically include LIDAR, cameras, ultrasound sensors, inertial measurement units (IMUs), and global positioning system (GPS) receivers. Combining different types of sensors usually yields a more comprehensive understanding of the object under observation. To develop a highly autonomous ground vehicle for difficult terrain, various sensors such as, LIDAR, camera, ultrasound sensors, and others, are used in conjunction with experimental algorithms to iteratively improve the object detection and maneuvering of the vehicle. During the trials, the following elements are considered: object detection, positional accuracy, estimation filters, motion models, and multi-object tracking. The safety and feasibility

of autonomous machines are determined by the performance of multiple integrated sensors. Sensor fusion is used to minimize or eliminate the weaknesses of individual sensors. Kalman filters are commonly used to fuse sensor readings. An example implementation is the 3D orientation of a machine, which uses a gyroscope, accelerometer, and magnetometer. The state estimate is eliminated from the algorithm, and the focus is placed on the error in the system. This allows the machine to know which way it is facing while reducing the computational power necessary to run the algorithm.

II.   A Brief Summary of Project with Highlights and Accomplishments

The project team has researched methods of sensor fusion and applied their knowledge to document the current developments in Sensor Fusion technology. They have implemented an adaptive cruise control with a basic sensor fusion algorithm using MATLAB Simulink and C/C++ on a game engine, which combines both camera and radar for adaptive cruise control. The safety and feasibility of autonomous machines are determined by the performance of multiple integrated sensors. Each sensor has its own limits and weaknesses, which can be minimized or eliminated through sensor fusion. Multiple implementations of sensor fusion have been used in this study, with each one utilizing a Kalman filter as the base to fuse the sensors. The first implementation was the 3D orientation of a machine using a gyroscope, accelerometer, and magnetometer, while the second implementation focused on fusing vision cameras and radar in order for a vehicle to observe its surroundings in a MATLAB simulation. The final execution opens up sensor fusion to future testing through an open-source simulation profile. To begin with, a basic autonomous vehicle using radar, LIDAR, and camera sensors is applied in a virtual design environment to test the functionality of sensor fusion.

The team recorded in multiple stages the current development:
- Low Levels
    - Create an alternative library for Sensor Fusion testing using a virtual physical environment.
    - Create a design document to move into the base implementation phase.
    - Study multiple implementations of sensor fusion
    - Create base sensors to test sensor fusion with Kalman Filter.
    - Researching and documenting all data collected to implement and add into the scope for the low-level design.

- Medium Level
    - Recreate current implementation for Sensor Fusion algorithms in MATLAB.
    - Analyzing Adaptive Cruise Control on MATLAB.
    - Implementing cruise control on MATLAB using a library written by the team.
    - Researching current implementations available online and reading courses on Sensor Fusion.
    - Kalman filter has been created to test multiple sensors on MATLAB.

- High Level
    - Apply Sensor Fusion to recreate autonomous vehicles and object tracking applications.

- o   Research on high level applications on Sensor Fusion like autonomous vehicles, AR/VR headsets.

Some of the student's team activities are given as following:

a.   3D Orientation Design

The initial design of the project used an accelerometer and a gyroscope a magnetometer and use an Extended Kalman filter to increase the accuracy of the 3D orientation. The final design, which used a modified Extended Kalman filter to achieve 3D orientation. An Extended Kalman filter is composed of many parts, but one key part is the predicted state estimate. The predicted state estimate is the error in the system found by multiplying the state translation model and the updated state estimate. Normally, the Extended Kalman filter would track the orientation directly instead, the filter can track the error. By tracking the error, the state estimate is removed from the algorithm or made equal to 0. With the state error equal to zero, the state translation model can be considered zero also, as the translation model is made by the predicted state estimate time. With the predicted state estimation and the state translation model equal to 0, they can be removed from the algorithm internally. This should save computational power as it will reduce the amount of multiplication required in the algorithm.

The overall block design of the sensor fusion algorithm can be seen in Figure 1. The basis of the sensor fusion algorithm is the Extended Kalman filter. The other parts of the algorithm allow for the filter to run and account for different variables like magnetic jamming. The first step is to take estimations from the accelerometer and gyroscope seen in the pink box on the left in Figure 1. From the gyroscope, an estimate of orientation, gravity, and Earth's magnetic field are calculated. The accelerometer is also used to estimate gravity. The estimations are sent to the error model and the Extended Kalman filter. The error model finds the error between the gravity estimates and the magnetic fields. The Extended Kalman Filter takes in the estimates in order to begin processing the data. The error model and magnetic field correction go into the updated state estimate to account for magnetic jamming and update the data. The last block in the algorithm is the data correction block. This is where the updated state estimate is separated into the data for orientation, gyro offset, and linear acceleration. While orientation is the final output for the algorithm, the gyro offset, and linear acceleration are used to correct the estimates taken at the beginning of the algorithm.
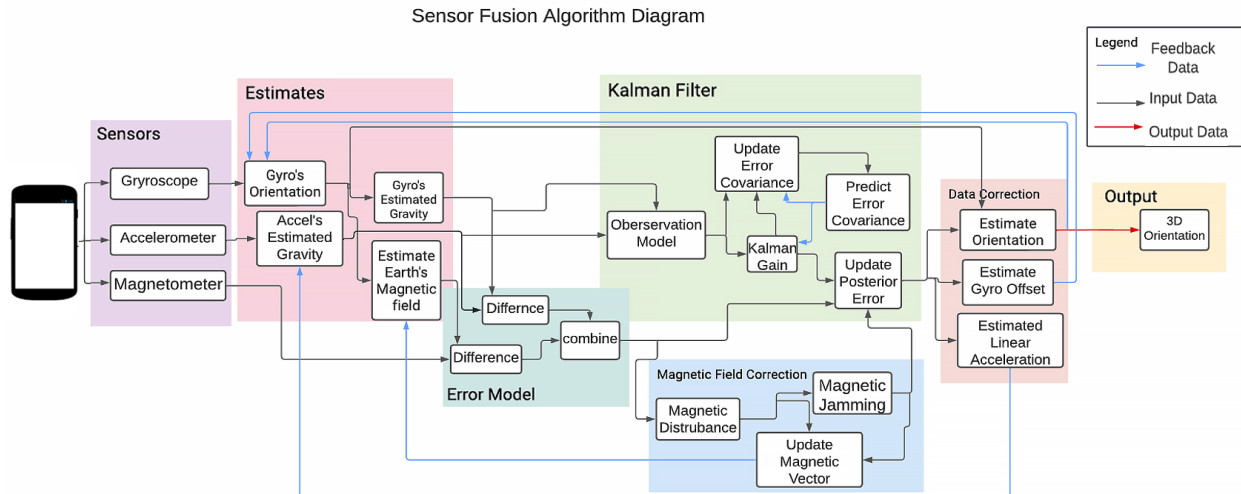
Figure 1: The Block Diagram of the Sensor Fusion Algorithm

b. LiDAR Sensor

The first implementation of a virtual sensor designed out of our research was LiDAR. In order to implement this, the team created a quick raycast script which creates a 2D mapping of depth in space. The implementation was quite simple; to create a simple LiDAR, a raycast needed to be made and the end distance recorded. A problem with this implementation is that the system was not able to support all angles; therefore, the team focused on only rendering the front of the vehicle. The LiDAR was then made to cast multiple raycasts in multiple directions, creating a 2D plane of the world and space.

c. Sensor fusion with Adaptive Cruise Control

The project was set to a smaller scale in order to understand the concept of sensor fusion with adaptive cruise control using MATLAB Simulink. In this case, the scenario used an ego vehicle equipped with a radar and camera sensor to travel along a predetermined road at a variable speed alongside other vehicles, which are referred to as 'actors'. Figure 2 displays the blocks used in MATLAB Simulink to create a road [5]. The first block, titled "Vehicle and Environment", includes the data gathered from combinations of the radar and camera sensors in the process of sensor fusion. The block titled "ACC with Sensor Fusion" displays the scenario in MATLAB Simulink while controlling the acceleration of the vehicle depending on the data gathered in the first block. The final block, called "MIO Track", displays the squares and lines produced after running the scenario. The squares symbolize a nearby object as a hazard to the ego vehicle, while the lines demonstrate the path of the ego vehicle
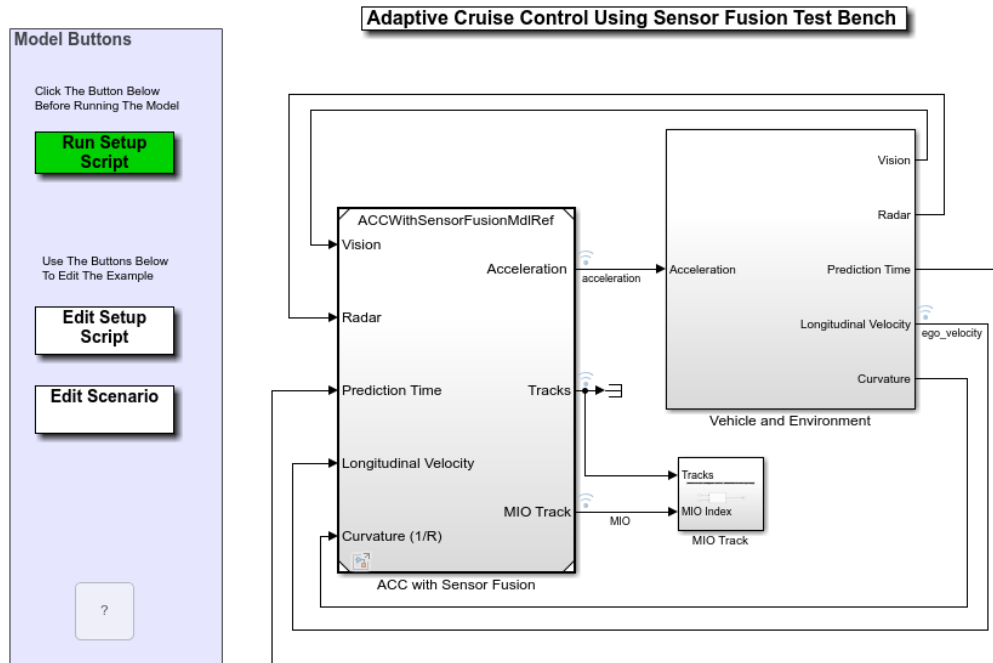
Figure 2: Adaptive cruise control using MATLAB Simulink blocks [5]

III.   **Impact of the Project on the Students**

The backgrounds of the students include basic knowledge about electronics, computers, and the supporting lab classes, which typically require virtual labs that don't involve motion. This project has challenged them to conduct research about an unfamiliar topic and understand the benefits of applying sensor fusion in the real world. The focus of the project encompasses the theories behind sensor fusion and the necessary algorithms used in the project, thus improving their research skills through constant learning of sensor fusion and how to create scenarios with sensor fusion using MATLAB. Furthermore, their skills in MATLAB and Simulink have been enhanced. The students have found the project to be helpful in applying sensor fusion to the world around them, making better connections through their research of VR, autonomous vehicles, and object tracking applications, which all use sensor fusion, than what a normal classroom would be able to provide.

IV.   **Some Feedbacks or Testimonials from Students**

This project has proven to be highly beneficial for the students as it provided them with an opportunity to communicate and collaborate with industrial engineers while working on a real-world project. By interacting with industry professionals, the students were exposed to the norms and expectations of the workplace, which will serve them well as they embark on their careers. Overall, the project has provided the students with a unique learning experience that goes beyond the classroom and prepares them for success in their future endeavors. At the second semester of the project, a survey was conducted to gather feedback from the students. Nine students took the survey. The survey includes open-ended questions. The following are some examples of

feedback we received.

- The sensor fusion project was definitely the hardest project I did in at the university, but it was also the one that I learned the most from. A lot of the topics in sensor fusion were new to me, so I had a large learning curve before I could begin making progress on an algorithm. I did enjoy learning about this topic as I see so many uses for it today. Overall, the project was fun, and I think it made me better in long run.
- The problem is that half of our project was remote so it was really hard to synchronize. Likewise, we are the first group for a research project. Maybe getting a pipeline for sharing resources and info would be. Overall, I had a pretty good experience.
- The Project has left a big impact on me because it was very interesting talking to the engineers from the company back in January. It also left a big impact on me personally because it allowed me to land a job at the NSWC in CA.
- This project has exposed me to the sensor technology used in unmanned ground vehicles (UGVs) and this hands-on experience can be transferable to other sensor feedback systems. I learned about the limitations of sensors and other equipment first-hand and the difficulties of getting a system running. A principal engineer is not only skilled in their field but can understand the overall system and be able to communicate clearly to the whole team and give them guidance.
- The Project taught me how difficult and crucial organization and communication are to keeping a large group project group cohesive. Unlike how labs are organized for on-campus classes, a free-reign project is both convenient yet stressful. Communication throughout each step forwards or backwards in progress has a domino-effect on the entire group's efficiency. Throughout the project, I learned how difficult was to build the base of understanding before beginning to work with single sensors.

V.   Discussion and Conclusions

The results of the implementation demonstrate that sensor fusion is an effective way to increase accuracy in autonomous machines. The fusion of multiple sensors allows for more accurate measurements to be taken. The fusion of vision cameras and radar together is necessary for autonomous vehicles to be able to recognize their surroundings. The study also shows that sensor fusion is able to reduce computational power, allowing for simpler, faster implementations.

In conclusion, this study has demonstrated that sensor fusion is an effective way for autonomous machines to increase accuracy. The implementations in this project demonstrate the advantages of sensor fusion in autonomous vehicles. The results of this study provide an effective platform for future development of sensor fusion technology.

The students have also been able to develop their problem-solving skills while working on the project. The students had to learn how to use MATLAB and Simulink, and then develop a solution for their project. This involved learning how to build and troubleshoot their own algorithms for the project, as well as how to interpret data and make sense of it. This has allowed the students to learn how to think critically about their own solutions and the data they were working with.

Finally, the project has been beneficial for the students in terms of developing their communication skills. Working on the project has required them to communicate with each other, their instructor, and engineers from the industry to discuss their progress, ask questions, and receive feedback. This has helped the students build their communication skills by allowing them to practice their communication in a safe environment.

Overall, the project has been extremely beneficial for the students. It has provided them with a unique opportunity to learn about sensor fusion and its applications, develop their problem-solving skills, and practice their communication skills. As a result, the students have been able to gain invaluable knowledge that they can apply in their future endeavors.

Acknowledgment

References

[1] M. Silverio, "How to make a vehicle, autonomous.," *Medium*, Dec. 27, 2019. https://towardsdatascience.com/how-to-make-a-vehicle-autonomous-16edf164c30f

[2] P. Narkhede, S. Poddar, R. Walambe, G. Ghinea, and K. Kotecha, "Cascaded Complementary Filter Architecture for Sensor Fusion in Attitude Estimation," *Sensors*, vol. 21, no. 6, p. 1937, Mar. 2021, doi: 10.3390/s21061937.

[3] M. Nazarahari and H. Rouhani, "Full-State Robust Extended Kalman Filter for Orientation Tracking During Long-Duration Dynamic Tasks Using Magnetic and Inertial Measurement Units," Jun. 28, 2021.

[4] https://www.researchgate.net/publication/352811149_A_Full-State_Robust_Extended_Kalman_Filter_for_Orientation_Tracking_During_Long-Duration_Dynamic_Tasks_Using_Magnetic_and_Inertial_Measurement_Units

[5] "Adaptive Cruise Control with Sensor Fusion." *MATLAB & Simulink*, www.mathworks.com/help/driving/ug/adaptive-cruise-control-with-sensor-fusion.html.

[6] Stahl, Tim, and Johannes Betz. "An Open-Source Scenario Architect for Autonomous Vehicles." *2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, 2020, doi:10.1109/ever48776.2020.9243029.

[7] Steinbaeck, J., et al. "Next Generation Radar Sensors in Automotive Sensor Fusion Systems." *IEEE Xplore*, 2017, ieeexplore.ieee.org/document/8126389.

[8] Yeong, De Jong, et al. "Sensor and Sensor Fusion Technology in Autonomous Vehicles: A Review." *Sensors*, vol. 21, no. 6, 2021, p. 2140., doi:10.3390/s21062140.

[9] Zhaohua, Liu, and Gao Bochao. "Radar Sensors in Automatic Driving Cars." *2020 5th International Conference on Electromechanical Control Technology and Transportation (ICECTT)*, 2020, doi:10.1109/icectt50890.2020.00061.