EUROPEAN SPACE AGENCY CONTRACT REPORT

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Nottingham Scientific Limited (NSL)

INTEGRITY MONITORING AND PREDICTION CONCEPT FOR AUTONOMOUS CAR RESILIENCE AND SAFETY (IMPACARS)

Executive Summary Report

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Executive Summary

The emerging industry of autonomous cars has been progressing with cutting-edge technology to make driverless cars a reality for road users. In the last decade, road users and/or human drivers have experienced a significant innovation in terms of automation within the automobile sector. This ranges, but not limited to, from simple, parking assisted technology to lane assisted and cooperative cruise control system which is not only made for the comfort of the users' road journey but also for their safety. Despite the ambitious vision and race about getting the fully autonomous vehicle on the road, the standard agencies and scientific organisations are not willing to compromise the safety and integrity of autonomous vehicles. Thus, a benchmark has been set by standard agencies for autonomous vehicles, particularly for integrity prediction systems. The Society of Automotive Engineers (SAE), USA; ETSI-ITS for European region and ISO 26262 ASIL (Autonomous Safety Integrity Level) standardised certification to make sure the highest level of safety norms is followed. However, the integrity monitoring concept of SAE defined level-4 and level-5 APV (Autonomous Passenger Vehicle's, no driver) is not yet defined. Likewise, the integrity standard for aviation is critical to have an integrity monitoring concept for the APV-4 and APV-5. This is crucial to the success of autonomous vehicles and it is described as the concept of integrity. Through this concept, the estimated position of an autonomous vehicle can be monitored accurately and within a defined safety boundary called the alert level. Considering the safety criticality of the ambitious APV-4 and APV-5 levels, ESA sponsored project called Integrity Monitoring and Prediction Concept for Autonomous Cars Resilience and Safety (IMPACARS) was announced in early 2019. This is the core focus of the project IMPACARS, funded as part of the ESA NAVISP Element 1 research and development program. The scope of the IMPACARS project has allowed the expertise coming from modelling, simulation, and implementation background under the leadership of NSL to present an innovative approach to integrity monitoring for potential level-4 and level-5 Autonomous Passenger Vehicles (APVs).

The project has several stages of research and development before the system can be tested in a controlled and safe road traffic test environment provided by HORIBA MIRA. The first stage of research describes the concept of APVs and the level of integrity required in a fully autonomous vehicle. IMPACARS follows the SAE levels for autonomous vehicles defined in the SAE J3016 standard [1]. These levels start at level 0, which has no autonomous capabilities, to level 5, which is a fully autonomous system. The scope of the IMPACARS project is to verify whether a level of integrity can be achieved that will be suitable for a level 5 autonomous vehicle.

The fundamentals of different sensors that are required to safely provide integrity for an autonomous vehicle are also introduced at this stage. In general, list of sensors include: two Septentrio GNSS receivers, a tactical grade XSens IMU and a 3D 360° LiDAR. These sensors are fused together through an extended sensor fusion technique, this solution is then compared to a high-grade SPAN INS during testing to determine the accuracy and resulting integrity of the system. These sensors are fitted into a van for the testing phase of the project.

The next stage of research is to determine the best method for fusing the above sensors and introduces the concept of integrity to the system. This includes the mechanisation of each sensor and the mathematical models suitable for fusing the sensors and how integrity can be parametrised from this result. An innovative integrity model was derived to use three safety ellipses based on the measurements from the onboard sensors. The integrity of a given system for a given epoch, t, is defined as the confidence interval of the measurements observed by the sensors used for that given epoch. A threshold of C_x to $-C_x$ can be applied to the data, this is considered as the protection level for the measurements and represents the integrity risk to the system. The highlighted region is the complementary confidence region. When E_x is monitored in this confidence region the estimate is considered as a risk to the integrity of the system and is therefore unreliable.

The first stage of testing involved simulation testing to validate the sensor fusion integrity model using a trolley and some equivalent but low-cost sensors. The sensors used were a: Septentrio GNSS receiver, low grade XSENS IMU and 2D LiDAR. This equipment was tested for three different dynamic scenarios: open sky, narrow view and tree cover.

For the open sky scenario, the GNSS solution was highly accurate at 72.3% availability and an average error of 1.15m, by using the sensor fusion integrity model the availability became 100% and an average error of 0.76m. The narrow view scenario saw a huge degradation in the GNSS solution, with and availability of 28.6% and an average error of 5.01m, this error is cause by multipath from the surrounding tall buildings and greatly degrades the GNSS signal quality. The availability and accuracy of the PNT trajectory resulting from the sensor fusion model was greatly improved, with a trajectory availability of 93.5% and an average error of 0.75m. The final test scenario was a tree cover scenario, a degradation in the GNSS solution was present due to the trees, with an availability of 17.6% and an average error of 1.59m. The sensor fusion integrity model improved the solution, with an availability of 74.1% and an average error of 0.64m. It is clear from each scenario that the sensor fusion integrity model improved the availability of the system by making the accuracy solution more available.

After the validation of the sensor fusion integrity model, different test scenarios for the final phase of testing at the HORIBA MIRA test track were decided. With a finalised test platform, a preliminary test was conducted around Nottingham to test the platform and further validate the sensor fusion integrity approach with the new equipment before entering the final phase of testing. This preliminary test involved multiple dynamic environments, including city environments with high-rise buildings that will cause multipath to the GNSS signal and under large bridges where the GNSS signal is unavailable and the system must rely on the non-GNSS onboard sensors for navigation. For analysis purposes, this test and the final tests are divided into six different grades based on the velocity of the vehicle. These grades are in 10 mph intervals, starting at 20 mph and finishing at 70 mph. The effective range of the LiDAR and V2X module needed to be within the maximum stopping distance of the vehicle, the stopping distance and width of road which does depend on speed, are consider a baseline to define what road and where-in-road (lane). This is mainly to take advantage of ETSI time to alert for collision and stopping distance based on department of transport safety standards. Furthermore, it was used instead of the braking distance to give the system an extra layer of safety, even though the system should react instantaneously to a threat it was decided that the extra distance from the average thinking distance gave more than enough distance for the system to detect, react and come to a complete stop while maintaining the safety of the passengers.

The final phase of testing was done over two days at the HORIBA MIRA test track. Along with the test equipment used for the sensor fusion integrity solution a V2X receiver was also fitted to the vehicle. This receiver module allowed the vehicle to detect and monitor another vehicle with a transmitter module, this allows the vehicle to determine where this other vehicle is even when the LiDAR can't detect it. The V2X receiver module also detects messages from the traffic light systems installed at the HORIBA MIRA city circuit, these messages transmit the sequence of the traffic lights and the congestion of the lanes in the network. A double difference approach was used to improve the range and phase measurements received by the GNSS receivers. This required range and phase measurements from the base station at the top of the HORIBA MIRA control building. The accuracy of the final GNSS measurements used in the sensor fusion model greatly improved by including the range and phase measurements from the base station alongside the measurements from the onboard GNSS receiver. The first day consisted of four test scenarios covering multipath, GNSS denied and real traffic roundabout environments. For the multipath and GNSS denied environments the availability of the system was 73.8% with an average error of around 1.1m. There were two large position deviations in these tests which were caused when the vehicle travelled under a bridge and the GNSS signal was temporarily denied. The remaining data are Misleading Information (MI's) and present due to the presence of the bridge and multipath from the control building.

The second day of testing was focused on high speed navigation and cooperative city navigation involving traffic light and roundabout situations. Despite most of the scenarios being in open sky environments the integrity of the system was not 100% reliable for all of the tests. The data from the scenarios are merged into hourly files, this is so that the software has time to converge.

The first hour was concentrated on high-speed, multi-lane navigation in an open sky environment. The results from this hour show that the system was greater than 99.9% available and safe and the few MI's detected were due to system convergence.

The second hour involved a real-traffic motorway scenario that involved a twenty minutes' drive up and down a public, multi-lane motorway. Upon initial analysis the integrity results for this hour were not very good, with only 34.4% availability. This was believed to be caused by overhead trees, bridges and sever weather conditions. Upon further analysis, the availability of the solution was improved to 89% available (upon modification of the data filtering before sensor fusion) and the remaining 11% of the data is categorised as unavailable instead of as MI's. This results in a better Integrity, at the expense of a lower availability. This is still far from ideal but a much better solution.

The final hour involved various roundabout and traffic light junction manoeuvres in a controlled environment. However, despite being an open sky environment the data was not as reliable as in the first test hour. The availability of the data for this hour is 88.53% with the remaining data being MI's.

After the analysing the achieved results it has been determined that at present the IMPACARS integrity model shows that APV level 4 is currently achievable, however not surprisingly, APV level 5 is still unachievable at this time. Several improvements have been identified as future work to meet APV level 5, including the use of HD maps, additional sensors and MI prediction through machine learning to more accurately predict the vehicular integrity.

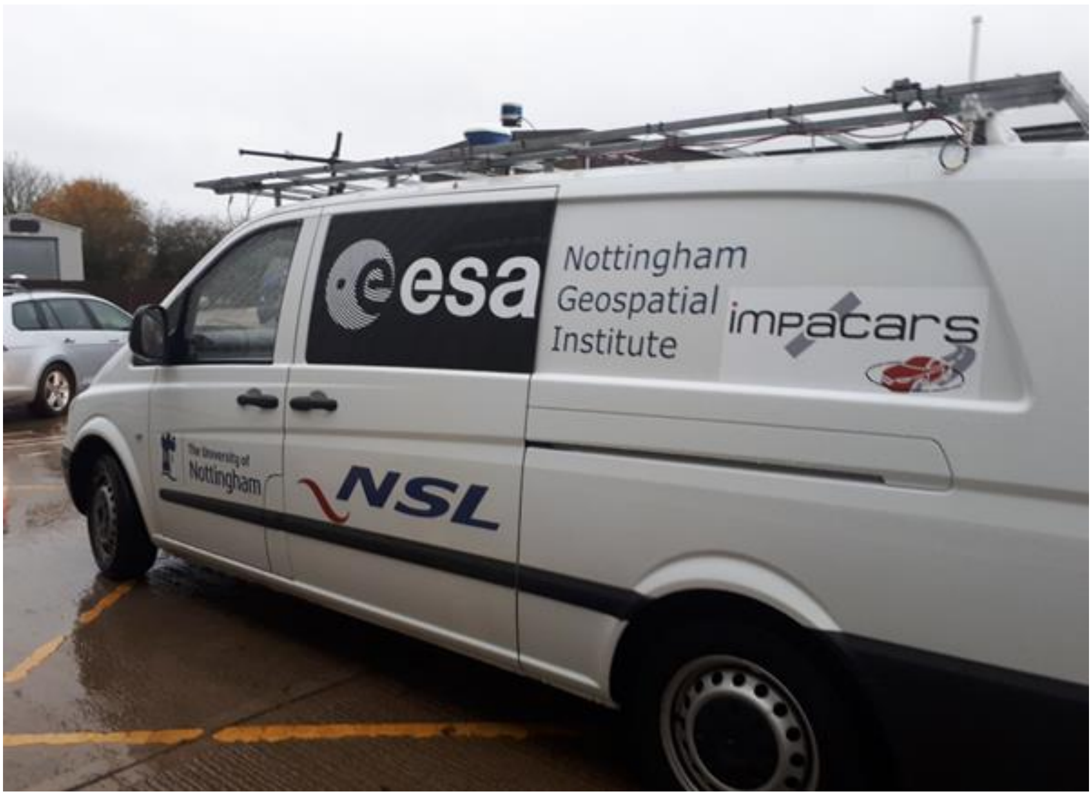

Figure 1: IMPACARS test vehicle.

References

[1] Society of Autonomous Engineers, "Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles", June 2018.

Appendix: Dissemination

Below is a list of dissemination from the IMPACARS project, including the project website and two technical papers:

1. IMPACARS website: https://www.impacars.com/
2. R. Tiwari, T. Stacey, F. Toran (2020), "Integrity Monitoring and Prediction Concept and Prototype for Fully Autonomous Vehicle Resilience and Safety", Institute of Navigation, International Technical Meeting (ITM), January 2020.
3. R. Tiwari, T. Stacey, F. Toran (2020), "Multi Sensor Fusion and Integration Approach for Safe and Secure Navigation for Fully Autonomous Vehicle", European Navigation Conference (ENC) 22-25 November 2020, (accepted).