International Global Navigation Satellite Systems Association
IGNSS Conference 2016

Colombo Theatres, Kensington Campus, UNSW Australia
6 – 8 December 2016

Integrity Monitoring Methods for Co-operative Intelligent Transport Systems

***Elizabeth Smith*[1]**
UNSW Australia
Elizabeth.a.smith@student.unsw.edu.au
DST Group
Liz.smith@dsto.defence.gov.au

Joon Wayn Cheong
UNSW Australia
cjwayn@unsw.edu.au

Andrew Dempster
UNSW Australia
a.dempster@unsw.edu.au

ABSTRACT

Co-operative Intelligent Transport Systems (CITS) equip vehicles with the ability to communicate with each other and surrounding infrastructure wirelessly to enhance their positioning information determined by on-board sensors. CITS are designed to increase the accuracy and reliability of vehicle positioning leading to a safe, efficient environment for vehicles and their passengers. For positioning applications, the integrity monitoring process ensures that the data used to compute a position solution is accurate. If the integrity monitoring process fails to detect a fault in the data and the fault is not excluded, an incorrect position solution may result. Analysis of the published works available shows that each sensor utilised in CITS has its own independent integrity monitoring process. This paper will present the individual sensor error sources and related integrity monitoring techniques. Through this investigation, it can be concluded that not all fault detection methods are applicable to CITS and that further consideration on the integrity requirements is needed.

KEYWORDS: CITS, Cooperative Positioning, Integrity, Fault Detection

1. INTRODUCTION

Vehicles that can self-navigate are becoming more established, however navigation capabilities are not the only requirements for a safe network of autonomous vehicles. The

[1] This research is supported by the Defence Science and Technology Group

ability of cars to communicate navigation and hazard information between themselves and localised infrastructure is what sets Cooperative Intelligent Transport Systems (CITS) apart. The sensors in CITS can be used independently or together to increase accuracy, redundancy and integrity in the system. Fault sources are tied to the sensor of interest which requires its own unique method for detection and isolation. This paper will present a set of common sensors in CITS and their fault sources. For each sensor, methods of detecting and mitigating the faults will be presented. The aim of this paper is to give an overview of the current state of integrity monitoring in the sensors of CITS.

2. GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

Global Navigation Satellite Systems (GNSS) describes all the different satellite navigation systems developed or in development across the globe. These include the Global Positioning System (GPS) developed by the United States, the BeiDou, GLONASS and Galileo systems developed by China, Russia and Europe respectively along with many augmentation systems are also included under this title.

The GNSS position can be used by the vehicle to determine its location with respect to the roads in the area. If the vehicle and its neighbours possess a wireless communication link, the position solution can be transmitted to the other vehicles and vice versa to determine relative positions and speeds (Umit Ozguner *et al.*, 2011).

Accuracy	Position
<5 m	Which road
<1.5 m	Which lane
<1 m	Where in lane

Table 1: CITS accuracy requirements (Williams *et al.*, 2012).

The accuracies applicable to CITS vary depending on the requirement of the vehicular navigation system and are shown in Table 1. The accuracies for CITS need to be achieved despite the many errors that can plague the system.

2.1 GNSS Fault Sources

Timing errors are generated from incorrect frequency standards within the satellite (Kaplan, 2006). Time inaccuracies can lead to position errors of up to 1.5 m (1σ) (Misra & Enge, 2006; Umit Ozguner *et al.*, 2011). This scale of error is enough to make it difficult to determine where in the lane a vehicle is travelling. The time error itself can result in significant problems depending on how the GNSS time is integrated with other systems.

Incorrect ephemerides of the satellites can cause errors in the trilateration of the receiver (Blanch *et al.*, 2013). The length of time since the ephemeris predictions were generated directly impacts the size of the associated errors (Misra & Enge, 2006). The position error from incorrect ephemerides could be up to 2.5 m (1σ) (Umit Ozguner *et al.*, 2011). A position error of this scale would result in incorrect lane position of the vehicle.

The GNSS receiver can generate higher levels of noise when not working properly (Blanch *et al.*, 2013) leading to errors in position up to 0.7 m (Umit Ozguner *et al.*, 2011). Whilst this is not a large error in terms of vehicular navigation, it becomes significant when it is added to the other errors present in the position solution.

Delays in the signal propagation time can be caused by the Earth's atmosphere, resulting in incorrect pseudoranges. The ionosphere has a varying refractive index which affects the speed of the GNSS signal (Misra & Enge, 2006). This process is worse during periods of high solar activity as this directly impacts the composition of the ionosphere (Blanch *et al.*, 2013). Ionospheric delays can generate errors of up to 5 m (Umit Ozguner *et al.*, 2011). Tropospheric delays are caused by varying amounts of dry or moist air (Misra & Enge, 2006). The density of the air affects the propagation time of the GNSS signal which also causes incorrect positions (Blanch *et al.*, 2013). Tropospheric delays can generate errors of up to 0.7 m (Umit Ozguner *et al.*, 2011). These errors are less severe than ionospheric errors alone, however these two atmospheric effects disrupt the GNSS signal at the same time with the errors combining.

Multipath is the name given to signals that have reflected off other surfaces before reaching the GNSS receiver. Tracking multipath signals rather than direct signals can be difficult for the receiver due to low signal to noise ratios as well as interference between the direct and reflected signal (Blanch *et al.*, 2013). The extra distance travelled by the signal results in a position error of up to 1.5 m (Umit Ozguner *et al.*, 2011). This is an error on the scale of 'which lane' navigation.

Signals that are on or around the GNSS signal frequencies can interfere with the calculation of position solutions. The interference can be unintentional from sources such as spurious emissions from mobile phone towers, or signals transmitted on nearby frequencies that saturate the RF front end of the GNSS receiver. The interference can also be intentional with the availability of illegal in-car GNSS jammers for purchase ("Radiocommunications Act," 1992).

2.2 GNSS Integrity Monitoring Methods

The errors generated from clock, navigation message or hardware malfunctions can be detected using Receiver Autonomous Integrity Monitoring (RAIM). RAIM was designed for use in the aviation industry to provide a higher level of integrity for precision navigation when using GPS (Kaplan, 2006). The algorithm requires a minimum of 5 satellites to detect an error and a minimum of 6 satellites to remove the faulty measurement from position computations (Kaplan, 2006).

The adaptations of the RAIM algorithm assume two approaches to gather measurements for integrity monitoring. (Brown, 1992), (Parkinson & Axelrad, 1988) and (Salgueiro et al., 2012) all apply the snapshot method, where only current measurement data is used in the RAIM algorithm. These three approaches use different methods to calculate the residual threshold, affecting the performance of the algorithm. None of these specific methods are adequate for CITS due to an inability to remove faulty satellites, no functionality to cope with multiple faults at once or not detecting faults fast enough. Speed, reliability and availability are the main factors contributing to an effective RAIM algorithm to be used in CITS.

The use of previous data is an alternative method to determine the faults in a system. The average over a time window of range residuals is used to detect smaller error margins also known as Slowly Growing Errors (SGE). (Tsai *et al.*, 2004) and (Yang *et al.*, 2001) utilise the moving average approach to RAIM to improve the fault detection capability. The moving

average approach results in faster fault detection, however these two methods make some assumptions about the fault probabilities which are not realistic in CITS.

The methods presented so far can be adapted and applied to multiple satellite constellations. (Dyke, 1995) used only the GPS and GLONASS constellations whereas (Hewitson & Wang, 2006) added Galileo. The extra constellations increase RAIM availability across the world and make small errors easier to detect. Fast selection of the satellites in a multi-constellation RAIM algorithm was evaluated by (Meng *et al.*, 2014) and (Walter *et al.*, 2014). The satellites selected need to be in an optimal geometry and processed in such a way as to minimise computational requirements.

Comparing these approaches to snapshot and moving average single constellation RAIM algorithms, it becomes apparent that multi-constellation positioning and RAIM needs to be incorporated into CITS. The availability of RAIM when there are multiple constellations is much higher than single constellation. A RAIM algorithm that can detect multiple faults across multiple constellations quickly and efficiently is also beneficial.

Ephemeris and atmospheric errors can be removed with the installation of two GNSS antennas on the vehicle. (Hwang & Speyer, 2009) used differencing between the signals detected by the multiple antennas to remove the common errors between them.

Multipath is a common source of error in GNSS with detection and mitigation techniques the focus of many research projects. (Pinana-Diaz *et al.*, 2011) have developed a process to determine if the signal detected has a direct LOS to the satellite using an elevation-enhanced digital map of buildings in the area. This is not applicable to CITS due to the high dynamics of the vehicle. The detection rate of multipath signals can be improved using a method developed by (Brodie, 2001) with the order of processing measurements within a Kalman Filter as the focus. If the process takes longer than it takes for a car to move past a building however, the method is ineffective in a city.

CITS will could utilise a combination of a multi-constellation moving average RAIM algorithm, two GNSS antennas, and a method to detect and mitigate multipath to improve its integrity.

3. INERTIAL NAVIGATION SYSTEMS

Inertial Navigation Systems (INS) contain a varying number of accelerometers and gyroscopes. Accelerometers detect changes in velocity by measuring inertial forces on a given axis specific to the system (Bevly & Cobb, 2010). The velocity is determined by integrating the acceleration measured and position is determined by integrating the velocity. Accelerometers produce a relative measurement and will give position with respect to a starting point, however a position within a global coordinate system is not given (Bevly & Cobb, 2010).

Accelerometers measure linear changes in motion whereas gyroscopes measure angular changes in motion. This means they can detect rotations around the axis specific to the system rather than along it as in the case of accelerometers. Gyroscopes use either lasers or vibration sensors to measure the angle of rotation of the vehicle (Bevly & Cobb, 2010).

3.1 INS Fault Sources

A bias in the position solution produced by an INS could be due to poor calibration of the instrument or a slow change due to drift which can result from changes in temperature (Umit Ozguner *et al.*, 2011). The size of the bias and the magnitude of its variation over time is a function of the quality of the system (Bevly & Cobb, 2010). The variability of the bias during a vehicle's navigation can be dangerous as the errors tend to increase with time.

Noise is present in all measurements and can be generated by thermal or vibrational variations in the data (Bevly & Cobb, 2010). High levels of noise will degrade the accuracy of the position solution and needs to be maintained at low levels.

The process of mathematically integrating the measurements from the accelerometer and gyroscope to determine the position solution will generate errors as well as compound and transfer errors from other sources within the INS (Bevly & Cobb, 2010). Detection of these errors early in the cycle is important, otherwise they will grow to become a detriment to the position solution calculated.

The equipment in INS can contain errors due to poor calibration or low quality. An example is measurements from a Ring Laser Gyroscope (RLG) contain errors which can affect the attitude reported (Mynbaev, 1994).

3.2 INS Integrity Monitoring Methods

The sensor bias or error drift in the INS along with noise and integration errors can be mitigated by fusion with GPS data. (Sukkarieh *et al.*, 1998) use a Kalman Filter to fuse GPS and INS in a loose integration setup to correct bias and integration errors. In this fusion process the GPS is used to determine the errors in the INS sensor, then correct it. As both GNSS and INS systems are most likely to be installed in all vehicles in CITS, the implementation of this method for fault detection and mitigation is logical.

The specific equipment within an INS can generate its own errors that can be characterised and compensated for. (Mynbaev, 1994) characterised the Ring Laser Gyroscope (RLG) by developing a set of error equations that links the angular rate of the RLG with the change required to achieve the ideal attitude. Whilst this is an important relationship to understand, the altitude of a vehicle in CITS is not that relevant for navigation and safety purposes.

Whilst the components that make up an INS affect the errors of the system, so too does the sensor geometry according to (Sturza, 1988). He determined that the sensor geometry within the skewed axis INS equipment directly affects the unit's ability to detect and mitigate faults. It does not appear that the same problem is applicable to the generic strap down INS equipment which is more common in vehicular navigation systems.

The integration of the INS with a GNSS system would be the best approach to improve its integrity within CITS.

4. RADAR

Radio Detection and Ranging (RADAR) uses RF transmissions to determine the range to an

object, its velocity, the direction and sometimes its size and shape depending on the waveform used and the distance to the object (Skolnik, 2008; Josef Wenger, 2005). The Doppler of the returned signal can also be used to distinguish between moving targets and stationary objects (Skolnik, 2008). An advantage to radar sensing is that it is not susceptible to low light levels, the weather or particulates in the air (Clark & Durrant-Whyte, 1998; Farkas *et al.*, 1997; Josef Wenger, 2005).

The radars used in CITS can be classified as short range or long range. Long range radars (LRR) have a large range of detection with a higher field of view and a higher resolution for reflections and detections and better accuracy (J. Wenger & Hahn, 2007). Automatic Cruise Control (ACC) is the main use for LRR which allows the car to determine safe distances between vehicles (J. Wenger & Hahn, 2007). Ultra-wide band (UWB) short range radars (SRR) have a range of up to 30 meters and are used for collision avoidance, parking assistance, and warnings during lane changes (J. Wenger & Hahn, 2007).

The combination of LRR and SRR makes cars safer and more reliable through a greater field of view. The signals from each radar are combined in the radar decision unit within the vehicle (J. Wenger & Hahn, 2007). The combination allows the strengths of each radar to overcome the limitations of the other to provide a more comprehensive picture.

4.1 Radar Fault Sources

Reflected signals from objects in the field of view that are not the target is known as clutter. This is the primary source of error for radar systems. If the dynamic range of the radar is not sufficient, the background signals can overload the radar and the target reflection is lost in the noise (Skolnik, 2008). Clutter can make target detection and tracking very difficult. Different objects and surfaces can generate different quantities and strengths of clutter to occlude the image of the target. Clutter will be present in all radar measurements, however the extent to which it overcomes the image is the primary issue.

4.2 Radar Integrity Monitoring Methods

The detection and mitigation of clutter in received radar signals is predominantly taken care of using Constant False Alarm Rate (CFAR) processes. There is not one specific CFAR process for radar signal processing, as the outcome can vary depending on the focus in the image. (Gandhi & Kassam, 1988) provide a good analysis of the different types of CFAR processes and their performance. Each method is chosen for a specific purpose, usually to detect or track a target, however there is often a compromise made in either processing time or false alarm rates.

(Himonas & Barkat, 1992) expand on the work presented by Gandhi & Kassam (1988), integrating a censored mean level detector (CMLD) with the CFAR process. This method can detect and exclude unwanted information which can contribute to false alarms. The amount of time required to analyse each cell in the image using these methods would be too large for a vehicular radar system.

(Nagle & Saniie, 1995) use a Linearly Combined Order Statistic (LCOS) method which is an extension of the order statistic (OS) CFAR detector described in Gandhi & Kassam (1988). This method requires a significant amount of a-priori knowledge of the background information. In a highly dynamic vehicular environment, a-priori knowledge of the images

taken is not possible so this method is not applicable to CITS.

In CITS, a radar with low false alarm rates and a fast processing time is imperative. None of the methods described in this section satisfy these requirements.

5. LIDAR

Light Detection and Ranging (LIDAR) is an electromagnetic signal in the visible spectrum (also known as a laser) that is transmitted towards the road. The time between transmission and receiving the reflected signal provides three dimensional range and reflectivity of an object (Bevly & Cobb, 2010). In lane detection, the echo width of the reflected signal from the painted lines on the road is different to the unpainted surface of the lane, which allows the lines to be detected and their range to be calculated (Bevly & Cobb, 2010). The quality of the LIDAR can determine its accuracy and resistance to weather, particulates and glass (Umit Ozguner *et al.*, 2011).

The laser is usually a pulsed infrared signal (Umit Ozguner *et al.*, 2011) directed with the use of a mirror or prism (Lu & Tomizuka, 2006) allowing the signal to be sent in many directions in the horizontal and vertical planes (Bevly & Cobb, 2010). High quality sensors can scan at several elevations, leading to a semi 3D picture which helps distinguish between ground reflections and objects on the road (Umit Ozguner *et al.*, 2011).

LIDAR can also be used for Autonomous Vehicle Following (AVF) where a vehicle is in front of the automated vehicle and is used as a guide for the centre of the road (Lu & Tomizuka, 2006). A reflective target is placed on the back of the lead vehicle for the follower to track (Lu & Tomizuka, 2006). This setup is applicable to a convoy of vehicles travelling together.

5.1 LIDAR Fault Sources

High levels of clutter can interfere with the correct tracking of the target in a similar manner to radar (Lu & Tomizuka, 2006). The increased multi directional reflections make it hard to determine which reflection is from the desired target. The intensity of the returned signal is useful but not the only factor as a false detection could lead to false target tracking (Lu & Tomizuka, 2006).

5.2 LIDAR Integrity Monitoring Methods

The clutter in a LIDAR image can be reduced by using a laser mounted above the vehicle according to (U. Ozguner *et al.*, 2007). This is suggested because it can provide another angle of the situation and help mitigate variations from the movement of the car. This laser is used in conjunction with three other lasers for navigation. Whilst the setup is useful, it is limited by the current costs of LIDAR in vehicles.

A more cost effective method to reduce clutter is proposed by (Lu & Tomizuka, 2006). They reduce clutter and unwanted data by only using data that has a good probability of being the desired target measurement and feeding them into a Kalman Filter. The higher the probability for a given measurement, the greater the weight allocated within the filter. If a LIDAR system is already integrated into the vehicle's sensor network, then this method of reducing the

clutter would be a cost-effective approach.

CITS should incorporate the extra laser if costs allow however, the probability method described could also be used for clutter mitigation.

6. VISUAL

A visual navigation system can possess a single camera or two cameras working together to achieve stereo vision, enhancing depth perception and viewing angles (Bertozzi *et al.*, 2002). Vision based navigation has the capacity to read road signs, follow road lanes and visually identify hazards (Bertozzi *et al.*, 2002).

The cameras main purpose is to detect lines rather than give better viewing for the driver (Yenikaya *et al.*, 2013). The edges of the lane markings are detected using a number of image recognition algorithms (Bevly & Cobb, 2010). Visual tracking of lanes is used in Lane Departure Warning systems in vehicles for collision avoidance (U. Ozguner *et al.*, 2007). Visual systems can also be designed to work without defined lanes where the contrast between the colour of the road and the area beside the road is used (Bertozzi *et al.*, 2002).

Objects on or near the road are detected using pattern recognition and edge detection methods (Yenikaya *et al.*, 2013). Stereo cameras, pattern recognition and tracking can distinguish pedestrians from other objects in the area (Bertozzi *et al.*, 2002). The position of the cameras is important for accuracy and reliability and should be carefully considered when being installed in the vehicle (Yenikaya *et al.*, 2013).

Visual systems require the ability to change detection parameters depending on the environment, for example transitions between day and night, the appearance of fog or going under a bridge (Bertozzi *et al.*, 2002).

6.1 Visual Fault Sources

Unfavourable weather conditions and a large concentration of particulates in the area can make visual object detection difficult (Bertozzi *et al.*, 2002; Bevly & Cobb, 2010; Farkas *et al.*, 1997; Yenikaya *et al.*, 2013). Unfavourable weather and the transition to night time can cause low light levels which presents its own problems. Consistent light is also important and changes from day to night or passing through shadows can disrupt the pattern recognition process (Bertozzi *et al.*, 2002; Yenikaya *et al.*, 2013).

In contrast to this, the intensity of the sun's rays during dawn and dusk can saturate the camera resulting in no visibility of the road (Bertozzi *et al.*, 2002; Bevly & Cobb, 2010). This effect will not be limited to these times of day however, as other sources of intense light can result in the same effect.

Poor condition of lane lines in urban environments due to degradation or impedance by other vehicles can affect lane following processes (Bertozzi *et al.*, 2002; Bevly & Cobb, 2010; Yenikaya *et al.*, 2013). Multiple lanes on the road can make distinguishing a given lane difficult as the lane being followed will be ambiguous to the camera (Yenikaya *et al.*, 2013).

Incorrect calibration of the cameras including its position on the vehicle can offset any range

estimation calculations from the images (Bertozzi *et al.*, 2002). The vibrations in the vehicle due to travelling on various road surfaces will affect the calibration so it will need to be repeated to ensure accuracy.

6.2 Visual Integrity Monitoring Methods

The effects of weather on visual navigation systems require real time management to ensure the safety of the vehicle. (Nayar & Narasimhan, 1999) have developed a technique that uses two images of the same location experiencing different bad weather effects for distance calculations. This does not appear to be done in real time, however it is an interesting approach. The colour of the image is also used to determine structures and their depth. (Narasimhan & Nayar, 2003) build on the technique presented by Nayar & Narasimhan (1999) to remove the effects of bad weather from an image, then produce a method to restore the contrast to the image for depth perception. Both of these methods are not real time, require two images to be effective, and are not applicable to the CITS environment.

The effects of shadows on lane lines is reviewed by (Bertozzi *et al.*, 2002) who suggest solutions including the use of better filters in the processing of the data, pattern and edge detection of the lines as well as the use of colour to detect the line on the road background. They also show how occlusion of the lines from other vehicles can be mitigated by doing a small local image tracking of the lines. This would be beneficial to have in vehicles that travel in dense urban environments with many cars as well as on highways.

A further approach to dealing with inadequate light levels is to use a night vision mode to help the driver in low light areas. (U. Ozguner *et al.*, 2007) list several car manufacturers that have employed night vision cameras in their vehicles as an aide. This would be a beneficial addition to CITS as an assistance to regular visual driving.

The saturation of the camera due to intense light can be overcome using integration with the vehicles other sensors. A Kalman Filter fusing all sensor information in the vehicle is used by (Karam *et al.*, 2010) whereas (Vermeulen, 2014) install a thermal camera to be used in conjunction with the regular visual system. Both methods are adequate to overcome light saturation however for CITS, a combination of both would be the best approach. If the thermal camera could be integrated with all vehicular sensors, then it would be an asset.

The calibration of the camera is just as important for error correction as the fault detection methods described so far. (Clarke & Fryer, 1998) highlight that the correct lens distortion algorithms are necessary for accurate calibration. A smaller pixel size will also help achieve higher resolution and accuracy in the calibration process. This helps determine if the camera is tilted away from the centre point. Determining adequate calibration methods would go a long way to ensuring accurate information from the camera.

Any visual system in CITS will need to operate in real time with a series of inbuilt models for line tracking and object tracking. The use of night or thermal should be integrated and the cameras need to be calibrated correctly and frequently.

7. VEHICLE TO VEHICLE/INFRASTRUCTURE (V2X) COMMUNICATION

Communication in CITS occurs between vehicles and with localised infrastructure allowing

messages relevant to a local area to be distributed equally. This could include intersection layouts, traffic light status, local hazards as well as traffic congestion information (Kenney, 2011). There are multiple methods of communication between entities in Vehicle Ad-hoc Networks (VANETS), such as Dedicated Short Range Communication (DSRC) (Kenney, 2011), Dedicated Omni-purpose inter-vehicle communication Linkage Protocol for HIghway Navigation (DOLPHIN) (Tokuda *et al.*, 2000), Ultra-Wide Band (UWB) communication (Mahfouz *et al.*, 2009) and more.

DSRC uses a modified version of IEEE 802.11a called IEEE 802.11p and Wireless Access for Vehicular Environments (WAVE-IEEE 1609) protocol standards. The messages communicated through DSRC can range from hazard and collision warnings for safety applications to traffic and weather updates (Umit Ozguner *et al.*, 2011; Xu *et al.*, 2004). The relative position of nearby vehicles can be determined through radio ranging (Parker & Valaee, 2006) and the Doppler shift of the DSRC message (Alam, 2012). DOLPHIN is an Inter Vehicle Communication (IVC) protocol that uses carrier sensing multiple access (CSMA) which monitors the channel to determine the optimum time to transmit a message to minimise collisions (Tokuda *et al.*, 2000).

7.1 Vehicle to Vehicle/Infrastructure (V2X) Communication Fault Sources

The most common source of error for V2X communication is packet loss. This occurs when the messages transmitted from one vehicle do not reach the surrounding vehicles. The cause of the packet loss can be from large velocities of the vehicles leading to a spread in the Doppler of the signal on OFDM (Ma *et al.*, 2009) or simply messages arriving at the same time and interfering (Tokuda *et al.*, 2000). Vehicles passing out of range also results in lost packets (Fan & Krishnan, 2006).

The relative positioning measurements using DSRC can become noisy due to multipath and non-line of sight signals (Parker & Valaee, 2006). Multipath is a high concern in urban environments where CITS is most likely to be implemented.

An error source similar to packet loss is Hidden terminals. Hidden terminals occur when two cars are out of each other’s message range but there are many vehicles between them that can see both (Ma *et al.*, 2009). Hidden terminals will affect the communication network by transmitting at the same time as vehicles in the known network, causing interference.

Noise in the DSRC signal increases with vehicular dynamics (Parker & Valaee, 2006). Urban environments will have many vehicles transmitting, all travelling at various speeds, all of which can contribute to the noise levels in the communication link.

Errors can arise within the software of the system. Memory corruption and logic errors within the processing of the signals can result in the system becoming unusable (Worrall *et al.*, 2014). The consequence of these errors could range from errors in signal transmissions to complete inability of the program to function.

7.2 Vehicle to Vehicle/Infrastructure (V2X) Communication Integrity Monitoring Methods

The main source of packet loss in V2X communication is messages colliding and interfering with each other. The best way to reduce the likelihood of message collision is to reduce the

number of messages transmitted. (Tatchikou et al., 2005) uses a packet forwarding protocol to transmit messages only in certain directions depending on the Direction of Arrival (DOA) of the message. This requires the installation of a phased array antenna on all vehicles in CITS to be a practical solution. (Ma et al., 2009) present a method that does not require extra equipment to be implemented where messages are sent in accordance with a priority system. The timing of the message transmission is determined by carrier sensing of the channel. The method of carrier sensing is investigated by (Tokuda et al., 2000) who determined that there is an optimal time to wait for transmission opportunities. Carrier sensing and message prioritisation are the most applicable mitigation strategies to implement in CITS.

The detection of packet loss can be done in two ways; monitoring the packet numbers received for missing entries, and timing message reception delays to indicate a missed packet delivery. (Fan & Krishnan, 2006) have developed the packet delivery ratio which deems the system unreliable when messages are not received in sequence. (Cambruzzi et al., 2010) developed a connectivity detector that determines if the packet loss is due to a fault or the vehicle moving out of range. The combination of these two methods for packet loss detection would be beneficial to CITS.

The message received by a vehicle could be a reflected signal which can affect the direction of arrival in packet forwarding protocols as well as the time of flight for relative positioning applications. (Schroeder et al., 2007) propose that a sudden change in the signal to noise ratio, indicating a signal that is affected by multipath can be detected using a running variance. Conversely, (Güvenç et al., 2007) propose an algorithm that uses amplitude and delay statistics of the signal as well as the assumed path of the original signal to detect the NLOS path. If the time of flight or DOA of a signal is used within the vehicle, then some form of multipath detection such as the two presented here will be required.

Quality equipment is needed in CITS to reduce noise. (Choi *et al.*, 2011) designed a RF front end for a DSRC receiver that reduces the noise factor significantly. This is a hardware specific solution, whereas (Cheng *et al.*, 2007) use a narrow bandwidth in the sampling of the signal and work in the frequency domain which allows the signal and the noise to be estimated separately.

Runtime and memory errors in the hardware are also a risk. (Shende *et al.*, 2012) developed a fault detection system that will detect and report runtime or memory errors in a software program and aid in debugging the fault. Whilst beneficial to the system, it is not something that can be implemented in real time. It should be implemented in all vehicles however to ensure that there is adequate monitoring of all aspects of the navigation system.

Whilst deliberate system attacks aren't quite an error source, they can completely disrupt the communication network. (Raya *et al.*, 2007) describe the Misbehaviour Detection System (MDS) and Local Eviction of Attackers by Voting Evaluators (LEAVE) that deal with the situation of an attacker who generates false information into the communication network. Some level of monitoring for deliberate attack should be incorporated in all vehicles and infrastructure in CITS.

A vehicle in CITS would require at least one method to reduce packet loss, and one method to detect it present within the system. A methodology to deal with multipath affecting the lines of communications, software faults and deliberate attacks on the network should be integrated into all vehicles in CITS.

8. CONCLUSIONS

This paper reviews the literature around the sensors involved in CITS, their most common fault sources, and fault detection methods to mitigate the effects of such faults. This review is not a complete study of all the fault detection methods available, however the evidence is available that the strengths of one sensor would overcome the weaknesses of another. The integration of these sensors would provide a more robust fault detection and exclusion environment.

This review also shows that not all FDE methods can be implemented in CITS. The requirements for real time application and the ability to handle highly dynamic situations limit many of these methods beyond use in CITS. Future work would involve a continued study into the integration of the sensors to varying degrees, analysing how the sources of error behave and if there are fault detection methods that can address them.

REFERENCES

Alam N. (2012). Vehicular Positioning Enhancement using DSRC. University New South Wales.

Bertozzi M, Broggi A, Cellario M, Fascioli A, Lombardi P, Porta M. (2002). Artificial vision in road vehicles. Proceedings of the IEEE*,* 90, 1258-1271. doi: 10.1109/JPROC.2002.801444.

Bevly DM, Cobb S. (2010). GNSS for Vehicle Control. Artech House, Norwood, MA.

Blanch J, Walter T, Enge P. (2013). Advanced RAIM System Architecture with a Long Latency Integrity Support Message. In: 26th International Technical Meeting of the ION Satellite Division, INO GNSS+, Nashville, Tennessee, pp. 2605-2613.

Brodie K. (2001). Improved Chi-Square Fault Detection for GPS Navigation. In: ION National Technical Meeting, Long Beach, CA, pp. 438-446.

Brown RG. (1992). A Baseline GPS RAIM Scheme and a Note on the Equivalence of Three RAIM Methods. Navigation*,* 39, 301-316. doi: 10.1002/j.2161-4296.1992.tb02278.x.

Cambruzzi E, Farines JM, Macedo RJ, Kraus W. (2010). An adaptive failure detection system for Vehicular Ad-hoc Networks. In: Intelligent Vehicles Symposium (IV), 2010 IEEE, pp. 603-608.

Cheng L, Henty BE, Stancil DD, Bai F, Mudalige P. (2007). Mobile Vehicle-to-Vehicle Narrow-Band Channel Measurement and Characterization of the 5.9 GHz Dedicated Short Range Communication (DSRC) Frequency Band. IEEE Journal on Selected Areas in Communications*,* 25, 1501-1516. doi: 10.1109/JSAC.2007.071002.

Choi J-Y, Seo S-H, Moon H-W, Nam I-K. (2011). A Low Noise and Low Power RF Front-End for 5.8-GHz DSRC Receiver in 0.13㎛ CMOS. JSTS: Journal of Semiconductor Technology and Science*,* 11, 59-64.

Clark S, Durrant-Whyte H. (1998). Autonomous land vehicle navigation using millimeter wave radar. In: Robotics and Automation, 1998. Proceedings. 1998 IEEE International Conference on. IEEE, pp. 3697-3702.

Clarke TA, Fryer JG. (1998). The Development of Camera Calibration Methods and Models. The Photogrammetric Record*,* 16, 51-66. doi: 10.1111/0031-868X.00113.

Dyke KL. (1995). Fault Detection and Exclusion Performance Using GPS and GLONASS. Navigation, 42, 581-594. doi: 10.1002/j.2161-4296.1995.tb01907.x.

Fan B, Krishnan H. (2006). Reliability Analysis of DSRC Wireless Communication for Vehicle Safety Applications. In: 2006 IEEE Intelligent Transportation Systems Conference, pp. 355-362.

Farkas D, Young J, Baertlein B, Ozguner U. (1997). Forward-looking radar navigation system for 1997 AHS demonstration. In: Intelligent Transportation System, 1997. ITSC '97., IEEE Conference on, pp. 672-675.

Gandhi PP, Kassam SA. (1988). Analysis of CFAR processors in homogeneous background. IEEE Transactions on Aerospace and Electronic Systems, 24, 427-445. doi: 10.1109/7.7185.

Güvenç I, Chong C-C, Watanabe F, Inamura H. (2007). NLOS identification and weighted least-squares localization for UWB systems using multipath channel statistics. EURASIP Journal on Advances in Signal Processing, 2008, 1-14.

Hewitson S, Wang J. (2006). GNSS receiver autonomous integrity monitoring (RAIM) performance analysis. GPS Solutions, 10, 155-170. doi: 10.1007/s10291-005-0016-2.

Himonas SD, Barkat M. (1992). Automatic censored CFAR detection for nonhomogeneous environments. IEEE Transactions on Aerospace and Electronic Systems, 28, 286-304. doi: 10.1109/7.135454.

Hwang SS, Speyer JL. (2009). Collision Detection System Based on Differential Carrier-Phase Global Positioning System Broadcasts. Journal of Aircraft, 46, 2077-2089. doi: 10.2514/1.43517.

Kaplan ED. (2006). Understanding GPS Principles and Applications. Artech House, Inc, Norwood MA.

Karam N, Hadj-Abdelkader H, Deymier C, Ramadasan D. (2010). Improved visual localization and navigation using proprioceptive sensors. In: Intelligent Robots and Systems (IROS), 2010 IEEE/RSJ International Conference on, pp. 4155-4160.

Kenney JB. (2011). Dedicated Short-Range Communications (DSRC) Standards in the United States. Proceedings of the IEEE, 99, 1162-1182. doi: 10.1109/JPROC.2011.2132790.

Lu G, Tomizuka M. (2006). LIDAR Sensing for Vehicle Lateral Guidance: Algorithm and Experimental Study. IEEE/ASME Transactions on Mechatronics, 11, 653-660. doi: 10.1109/TMECH.2006.886192.

Ma X, Chen X, Refai H. (2009). Performance and reliability of DSRC vehicular safety communication: a formal analysis. EURASIP Journal on Wireless Communications and Networking, 2009, 1-13.

Mahfouz MR, Fathy AE, Kuhn MJ, Wang Y. (2009). Recent trends and advances in UWB positioning. In: Wireless Sensing, Local Positioning, and RFID, 2009. IMWS 2009. IEEE MTT-S International Microwave Workshop on, pp. 1-4.

Meng FC, Wang S, Zhu BC. (2014). Satellite Selection and RAIM for GNSS Reliability Enhancement in Multi-Constellation. In: International Technical Meeting of The Institute of Navigation, San Diego, California, pp. 78-88.

Misra P, Enge P. (2006). Global Positioning System: Signals, Measurements and Performance Second

Edition. Lincoln, MA: Ganga-Jamuna Press.

Mynbaev DK. (1994). Errors of an inertial navigation unit caused by ring laser gyros errors. In: Position Location and Navigation Symposium, 1994., IEEE, pp. 833-838.

Nagle DT, Saniie J. (1995). Performance analysis of linearly combined order statistic CFAR detectors. IEEE Transactions on Aerospace and Electronic Systems, 31, 522-533. doi: 10.1109/7.381903.

Narasimhan SG, Nayar SK. (2003). Contrast restoration of weather degraded images. IEEE Transactions on Pattern Analysis and Machine Intelligence, 25, 713-724. doi: 10.1109/TPAMI.2003.1201821.

Nayar SK, Narasimhan SG. (1999). Vision in bad weather. In: Computer Vision, 1999. The Proceedings of the Seventh IEEE International Conference on, pp. 820-827 vol.822.

Ozguner U, Acarman T, Redmill K. (2011). Autonomous Ground Vehicles. Artech House, Norwood, MA.

Ozguner U, Stiller C, Redmill K. (2007). Systems for Safety and Autonomous Behavior in Cars: The DARPA Grand Challenge Experience. Proceedings of the IEEE, 95, 397-412. doi: 10.1109/JPROC.2006.888394.

Parker R, Valaee S. (2006). Robust min-max localization algorithm. In: 2006 IEEE Intelligent Transportation Systems Conference, pp. 1000-1005.

Parkinson BW, Axelrad P. (1988). Autonomous GPS Integrity Monitoring Using the Pseudorange Residual. Navigation, 35, 255-274. doi: 10.1002/j.2161-4296.1988.tb00955.x.

Pinana-Diaz C, Toledo-Moreo R, Betaille D, Gomez-Skarmeta AF. (2011). GPS multipath detection and exclusion with elevation-enhanced maps. In: 2011 14th International IEEE Conference on Intelligent Transportation Systems (ITSC). IEEE, pp. 19-24.

. Radiocommunications Act. In. (1992)Department A-Gs (ed). Office of Legislative Drafting and Publishing, Canberra.

Raya M, Papadimitratos P, Aad I, Jungels D, Hubaux Jp. (2007). Eviction of Misbehaving and Faulty Nodes in Vehicular Networks. IEEE Journal on Selected Areas in Communications, 25, 1557-1568. doi: 10.1109/JSAC.2007.071006.

Salgueiro F, Sanguino J, Rodrigues A, Hernandez FA. (2012). Weighted total least squares RAIM algorithm using carrier phase measurements. In: Satellite Navigation Technologies and European Workshop on GNSS Signals and Signal Processing, (NAVITEC), 2012 6th ESA Workshop on, pp. 1-6.

Schroeder J, Galler S, Kyamakya K, Jobmann K. (2007). NLOS detection algorithms for Ultra-Wideband localization. In: 2007 4th Workshop on Positioning, Navigation and Communication, pp. 159-166.

Shende S, Malony A, Linford J, Wissink A, Adamec S. (2012). Isolating runtime faults with callstack debugging using TAU. In: Proc. HPEC 2012 Conference.

Skolnik M. (2008). Radar Handbook. McGraw-Hill, United States.

Sturza MA. (1988). Skewed axis inertial sensor geometry for optimal performance. In: 8th AIAA/IEEE Digital Avionics Systems Conference, pp. 128-135.

Sukkarieh S, Nebot EM, Durrant-Whyte HF. (1998). Achieving Integrity in an INS/GPS Navigation Loop for Autonomous Land Vehicle Applications. Proceedings of the 1998 IEEE International Conference on Robotics & Autonomation, 3437-3442.

Tatchikou R, Biswas S, Dion F. (2005). Cooperative vehicle collision avoidance using inter-vehicle packet forwarding. In: GLOBECOM '05. IEEE Global Telecommunications Conference, 2005., pp. 5 pp.-2766.

Tokuda K, Akiyama M, Fujii H. (2000). DOLPHIN for inter-vehicle communications system. In: Intelligent Vehicles Symposium, 2000. IV 2000. Proceedings of the IEEE, pp. 504-509.

Tsai YH, Chang FR, Yang WC. (2004). GPS fault detection and exclusion using moving average filters. IEE Proceedings - Radar, Sonar and Navigation, 151, 240-247. doi: 10.1049/ip-rsn:20040728.

Vermeulen E. (2014). Automatic incident detection (AID) with thermal cameras. In: Road Transport Information and Control Conference 2014 (RTIC 2014), pp. 1-5.

Walter T, Blanch J, Enge P. (2014). Reduced Subset Analysis for Multi-Constellation ARAIM. In: 2014 International Technical Meeting of The Institute of Navigation, San Diego, CAlifornia, pp. 89-98.

Wenger J. (2005). Automotive radar-status and perspectives. In: IEEE Compound Semiconductor Integrated Circuit Symposium, 2005. CSIC'05. IEEE, pp. 4 pp.

Wenger J, Hahn S. (2007). Long Range and Ultra-Wideband Short Range Automotive Radar. In: 2007 IEEE International Conference on Ultra-Wideband, pp. 518-522.

Williams T, Alves P, Lachapelle G, Basnayake C. (2012). Evaluation of GPS-based methods of relative positioning for automotive safety applications. Transportation Research Part C: Emerging Technologies, 23, 98-108. doi: http://dx.doi.org/10.1016/j.trc.2011.08.011.

Worrall S, Agamennoni G, Ward J, Nebot E. (2014). Fault Detection for Vehicular Ad Hoc Wireless Networks. IEEE Intelligent Transportation Systems Magazine, 6, 34-44. doi: 10.1109/MITS.2014.2304974.

Xu Q, Mak T, Ko J, Sengupta R. (2004). Vehicle-to-vehicle safety messaging in DSRC. In: Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks. ACM, Philadelphia, PA, USA, pp. 19-28.

Yang WC, Chang RR, Fan CH, Wang HS. (2001). RAIM Filter for Fast Failure Detection. In: ION National Technical Meeting, Long Beach, CA, pp. 144-150.

Yenikaya S, #246, Yenikaya k, D E, #252, ven. (2013). Keeping the vehicle on the road: A survey on on-road lane detection systems. ACM Comput. Surv., 46, 1-43. doi: 10.1145/2522968.2522970.