

An Assistance System for Collision Avoidance Using Context-Sensitive Prediction

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Abstract: An alert and collision avoidance system is introduced. A new method has been used to calculate a closest point of approach, incorporating a context-sensitive prediction. Movement and routing information were used and an approach for taking evasive action is described. When a potential collision was detected, then an estimation was made of the direction of movement and an evasive manoeuvre was selected. A closest point of approach was calculated between the wheelchair and any object detected in its vicinity. A linear motion vector was calculated based on current speed, position and direction and that vector was compared with the object position.

1 INTRODUCTION

This paper presents a system to reduce human workload and misperceptions of driving situations. The system provides pro-active collision avoidance including methods for collision avoidance and predicting wheelchair behaviour. It is a new Traffic Alert and Collision Avoidance System, similar to those used with commercial aircraft (Holdsworth, 2003). Figure 1 illustrates system infrastructure and main functions. The system was created to reduce collisions and support drivers with a collision alarm. A closest point of approach was calculated by applying context sensitive behaviour prediction (Steidel, 2019). Additionally, an alarm helped with assessing potential hazards. Cooperative manoeuvre negotiation and critical situation resolution systems contributed to reducing potential collisions.

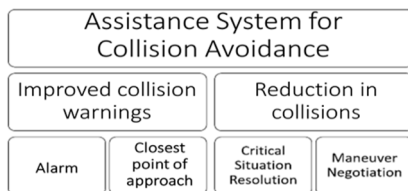


Figure 1: System principles and functionalities.

This paper gives an overview of the concepts of the system and discusses details of the system

presented in Figure 1, as well as describing the concept of Escalation States shown in figure 2, which depicts the likelihood of collisions.

Escalation States are used to assess how critical a potential collision is and to provide a weighted warning. The approach for predicting powered wheelchair behaviours and the introduction of alarms are developed. Following this, the concept of reducing misunderstandings during potential collisions is defined, focusing on evasive manoeuvres. The integration of the system into a powered wheelchair is briefed, followed by the description of the validation process.

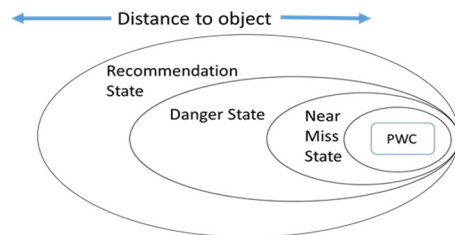


Figure 2: Escalation States.

2 DETECTING NEAR MISSES AND COLLISIONS

The system tracked the movement of a powered wheelchair and attempted to warn its user while

minimising the number of alarms. Using context-sensitive behaviour prediction, not only the number of collision warnings, but also the number of exaggerated and false alarms could be reduced.

Auto tracking with situation evaluation was introduced to improve collision avoidance and reduce the workload for wheelchair users. A concept of Escalation States for assessing collisions was developed in this work. This simplified situation evaluation used a series of Escalation States.

Kamijo detected traffic patterns in video images and was able to detect accidents (Kamijo *et al*, 2000). Using a hidden Markov Model, the system learnt various behaviour patterns. Xue presented a method for collision-free trajectory planning (Xue *et al*, 2009). The method had three-steps. For the powered wheelchair this would be: Identify target and powered wheelchair position; Detect potential collisions; and Control wheelchair. A three-degree of freedom model was used to generate a possible route.

Xue used the potential field method (Sanders, 1995; Sanders *et al*, 1991; 1992a; 1992b; 2010a; 2010b, 2011; 2015) for route finding, whilst Tam and Bucknall concentrated on close ranges and developed a method for assessing collision risk by determining encounter type (Tam, 2013). A method to evaluate the probability of a collision was presented by Montewka *et al* (2015). The shortest distance at which a collision could be avoided was calculated, namely, Minimum Distance to Collision. Youssef *et al* (2014) took work from (Montewka *et al*, 2015) to develop a probabilistic approach to select collision scenarios.

A Conflict Ranking Operator was presented by Zhang (2015). Distance, speed and relative angle were considered; therefore, decisions could be made to avoid near-misses. Van Iperen (2015) introduced two ways to detect near-misses. One deploys the closest point of approach calculation while the other used domains. The author evaluated the main indicators for the level of safety in a specific area.

A review of work concerning collision avoidance revealed some factors that can lead to a collision. The biggest problems in collision avoidance are human factors. That means to prevent collisions, the uncertainty of the behaviour of other powered wheelchairs and other humans needs to be considered. Risk (and probability) of collision increases with higher uncertainty. Distance, speed and angle need to be considered in order to assess the risk of a collision (Haddad *et al*, 2020a; 2020b; 2020c; Sanders *et al*, 2020a; 2020b).

The closest point of approach calculation primarily considers distance. Manoeuvrability is also important in solving the uncertainty problem by

generating the possible set of potential states of the powered wheelchair. These findings were considered when creating system concepts.

3 COLLISION WARNINGS AND AVOIDANCE

Assistance systems have tended to generate collision warnings based on a comparison of linear movement vectors. However, a closest point of approach calculated in this way can be unrealistic and exaggerated, since external conditions and typical movement patterns are not included. In addition, alarms can be ignored by wheelchair users. The newly developed system in this work uses two concepts for generating improved collision warnings. The first is called Critical Pose, which is an extension of the traditional closest point of approach. In addition to this, the system predicts the most probable behaviour of a wheelchair. These concepts can avoid some unnecessary alarms. The system also evaluates the likelihood of collision using Escalation States. In the following sections the Escalation States, the closest point and behaviour prediction are described.

The system uses a concept of Escalation States to assess the likelihood of collisions. Figure 2 shows the concept. The further right an escalation state is plotted in figure 2, the more critical the state.

In order to determine the different states, the closest point must first be calculated. Next, the time and distance that a powered wheelchair will need to reach the calculated closest point is calculated. In this work, the thresholds for each Escalation State were obtained experimentally, which could be varied depending on the abilities of different drivers (Sanders *et al*, 2010). If the closest point was more than a pre-set range (for example one meter) the situation was labelled "Clear", i.e., no danger existed.

If the wheelchair continued to move towards an object and required less than a pre-set time (for example one second) to reach the closest point, the wheelchair was in a Recommendation State. In this state, the system triggered a warning. Behaviour prediction would be used. This prediction gave an estimation about how the powered wheelchair would travel based on the analysis of historic data.

The wheelchair moved into a Danger State when the time was less than a pre-set time (for example half a second) and the distance to the closest point was less than a set point (for example 0.5 meters). During this State, the system could help wheelchair users avoid a collision by applying a cooperative negotiation

algorithm that shared control of the wheelchair with the driver (Sanders 2017; 2018).

This was the last possible state to prevent collision. An Alarm was generated if the powered wheelchairs were less than a critical pre-set time or distance, such as 300 milliseconds or 0.2 meters from the closest point. The system performed an emergency manoeuvre to avoid collision by taking control of the wheelchair. If a manoeuvre was not carried out then a collision would become inevitable.

4 CRITICAL POSE

A way of assessing and identifying hazardous wheelchair encounters was to calculate the closest point of approach. A linear vector for a powered wheelchair was generated based on *position, speed* and *course*. These vectors were then compared to produce a closest point of approach (a geographical point). The closest point of approach was extended by the calculation of two additional values: *Distance to closest point of approach* (D_{close}) and *Time to closest point of approach* (T_{close}). Drivers received a warning if T_{close} and D_{close} fell below threshold values.

This procedure did have drawbacks. It was based on the abstraction of wheelchair motion to linear motion and the system lacked context information. All sensors used for measuring course, speed and position as well as those for detecting obstacles had inaccuracies. A snapshot could combine these errors and yield an imprecise closest point of approach. To avoid this, the idea of a context-sensitive closest point of approach was introduced. The calculation was combined with a consideration of sensor inaccuracies. A term for describing the result was introduced “Critical Wheelchair Pose (closest point)”. In contrast to the closest point of approach, the closest point was defined by two values: **position** at which the wheelchair had the shortest distance to an object and the **pose** of the wheelchair at this position. Figure 3 illustrates the closest point concept and figure 4 represents the Evasive Manoeuvre Negotiation.

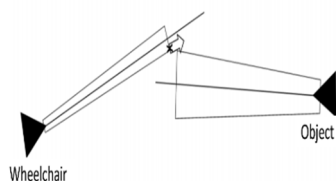


Figure 3: Calculation of Closest Point of Approach.

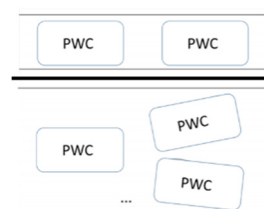


Figure 4: Above: Single object (assumed to be another wheelchair). Below: Multiple objects (assumed to be other wheelchairs).

A wheelchair is depicted on the left side of figure 3. The straight line running from the wheelchair in the direction of travel is the current course. The straight line running from the object on the right side of figure 3 shows the dangerous path that might cause collision. Sensor inaccuracies and possible changes are represented by the two funnels. The funnel describes the probability of the wheelchair's and object's position in the future, taking sensor errors and possible change into account.

The funnel for the wheelchair was smaller than for the object, because the wheelchair and wheelchair sensor inaccuracy can be determined whilst the object is usually unknown. Thus position, speed and course of the wheelchair can be determined with a higher accuracy so that future positions of the wheelchair can be predicted more precisely. To calculate the closest point, the two funnels are compared. Due to the inaccuracies, the wheelchairs may be located at any positions within their respective funnels. For the closest point, the minimum distance between the funnels was considered. This pessimistic assumption helped better clarify the criticality of the situation. The problem was addressed using path planning algorithms (Sanders, 1995; Sanders *et al*, 1991) during the calculation and introducing No-Go-Areas and routing information. The outcome for the calculation was that a wheelchair would not pass through a No-Go-Area. Thus, a calculated closest point should not be within a No-Go-Area. The system used this extra information to calculate a closest point using the current route for the wheelchair. The advantages of using this method over conventional methods was that unnecessary and exaggerated alarms based on a linear closest point of approach were avoided. This reduced stress and workload for the wheelchair user.

When powered wheelchairs were in the Recommendation State, the system predicted the most probable behaviour of the powered wheelchair using a rule-based approach (Sanders *et al*, 2011). The approach had two levels. On the first level, a prediction about the most probable behaviour of the

powered wheelchair was made. A possible influence of obstacles in the proximity were ignored. This resulted in the most probable situation in the proximity of a wheelchair, which was then used to estimate potential collision risks. In order to support the wheelchair users to assess and avoid potential collisions, situations were classified as Head-On, Overtaking or Crossing (Steidel, 2019). This classification was made in a second level. Following this, the most probable resolution was predicted. Mean values for course and speed of matching historic movements were considered as a future value for prediction. The most probable behaviour of the wheelchair was predicted using an Artificial Neural Network. Predicted behaviour was modelled using a process similar to the one used by Ornstein-Uhlenbeck to model uncertainty for.

Typical tracks were generated based on historic data. Rule-based prediction was based on an association between historic tracks and the current track. The whole track was not predicted, but instead the next likely powered wheelchair position was produced a set time ahead (one second). Hence typical behaviour was used as a prediction. Behaviour of a powered wheelchair was modelled using Kernel Density Estimation and predicted for a set time span. In order to extract and learn patterns, the working area was divided into different regions, i.e. a grid. Typical patterns in a region could then be learned. This enabled an extended possibility to predict behaviour ahead of a certain time frame. As a result, future positions in a grid were predicted. By applying Neural Associative Learning, future behaviour was predicted based on the patterns.

5 PREDICTION

The prediction algorithm in the first level required the most common behaviour as a basis to predict the most probable powered wheelchair behaviour.

5.1 Most Probable Behaviour

A rule-based system was used to make-a-decision based on previous knowledge. Required knowledge was obtained by analysing historic data to extract patterns and rules for predicting behaviour in a similar way to Oltmann and Pallotta (is there a reference here?). Extracted behavioural patterns were modelled as a graph. The graph contained two types of nodes: one representing geographical points where objects were in the vicinity; the other represented usual (historical) behaviour, that is points (targets) the

wheelchair was expected to move towards. For each of those target nodes, a frequency distribution was calculated which described recorded wheelchair behaviours. The first-level prediction algorithm used this information to decide where a powered wheelchair would head. The rule-based approach for predicting powered wheelchair behaviour on the first-level was divided into two parts. The first aimed to predict the most probable target. The node with the highest accordance was selected as a potential destination so that a possible path through the graph from the current position to the predicted target could be generated.

5.2 Prediction of Evasive Manoeuvres

This required predicted behaviour as an input. Potential hazardous collisions were estimated. The closest points on the predicted object track and wheelchair route were predicted. If distance between them at the closest point fell below a threshold, this encounter was examined. The encounter was labelled Head-On, Overtaking or Crossing. In the data analysis phase, encounters for each of these situations were extracted. A rule for evasive manoeuvres was statistically extracted and applied to the identified encounter based on the first-level prediction. As a result, an evasive manoeuvre could be performed / executed.

5.3 Evaluation

Prediction algorithms were applied using historical data collected over three months of testing by two interdisciplinary MEng Project Groups at the University of Portsmouth. The testing region consisted of two downstairs rooms and a section of connecting corridor at the University. For evaluation purpose, the related data was grouped as tracks. racks and positions were selected randomly. Based on positions, a potential destination and corresponding tracks were predicted. Afterwards, the distance between the historic and predicted track was calculated. To evaluate the prediction algorithm for the second-level, a route for a wheelchair was generated. Several encounters with predefined evasive manoeuvres were created. Starting from a point on the track, the second algorithm yielded an evasive manoeuvre. The predicted manoeuvre was compared to the real evasive manoeuvre.

The algorithm for predicting Give-Way performed better than the prediction of the destination as shown in Table 1. For determining the distance between the predicted track and the historic track, the

median of the distance between these two tracks was used. This yielded an average distance of 20 centimetres.

Table 1. Prediction results.

Predicted	Destination	Give-Way
Correct	65%	76%
Incorrect	35%	24%

6 REDUCING MISUNDERSTANDINGS

Before taking over the control from the wheelchair user and performing an evasive manoeuvre it was important that a consistent operational picture was to be maintained. Misunderstandings could lead to erroneous actions, which would result in collisions even though the wheelchair user might be trying to avoid it. To address this problem, the system included an algorithm to negotiate evasive manoeuvres.

If a driver entered a Danger State, an evasive manoeuvre would be applied. The calculation of the evasive manoeuvre and the negotiation principles aimed to assist a wheelchair driver but not to take over control. A near miss or collision was classified as Head-On, Crossing or Overtaking. This was a parameter for the negotiation algorithm since different kinds of evasive manoeuvres were recommended depending on the classification. In addition, it is necessary to have a list of assumptions as:

- Objects were another wheelchair or person;
- Other wheelchairs and people would tend to want to avoid collision; and
- Any other powered wheelchairs were equipped with sensor systems.

Two cases were examined and analysed (Figure 4). For the single object shown at the top part in Figure 4, the negotiation algorithm generated a manoeuvre based on a wheelchair-to-wheelchair encounter. Negotiation started with the evasive manoeuvre. The proposed moves were then stored until the situation turned into a potential near miss or collision. The system monitored the development of the situation and would raise an alarm if a dangerous situation (potential collision) was detected.

In the second case, n powered wheelchairs are present (where $n > 1$). The processing procedure was similar to that for a single object. The difference was that manoeuvres depended on the projected

movements of multiple wheelchairs rather than a single one. If one of the powered wheelchairs continued to get closer, then negotiation was cancelled, and the system took control to avoid collision. The use of a pseudo-collaborative approach to negotiating evasive manoeuvres brought some benefits. The negotiation algorithm classified potential collisions as wheelchair-to-wheelchair encounters. Within the system an exchange of the result from calculations for both wheelchairs was carried out. This prevented possible misunderstandings in the assessment of wheelchair-to-wheelchair encounters. That also enabled a distinct classification into "Continue" or "Avoid". As the wheelchair kept moving forward, it became clear whether each powered wheelchair should take a proposed manoeuvre. This prevented misunderstandings, human errors and reduced the workload of the wheelchair user.

The system was tested in a number of simulations and representative scenarios were generated to cover different wheelchair-to-wheelchair, wheelchair-to-person, and wheelchair-to-static-object encounters. In addition, scenarios were extracted from real wheelchair collision incidents during real world testing. Iterative testing and development enabled faster integration and validation. Besides testing in simulation, a Bobcat II wheelchair was used to perform practical tests. In a total of three tests, the system was tested at different stages of development. The general functionality of the features described above was successfully tested and validated.

7 DISCUSSION AND CONCLUSION

Concepts were created to support wheelchair users in situations where a collision might occur. An intelligent hazard assessment considered external information such as No-Go areas, route information and sensor inaccuracies. The intelligent prediction of wheelchair behaviours enabled drivers to be warned of potential collisions at an early stage. A function for the evaluation of wheelchair encounters and the cooperative negotiation of evasive manoeuvres allowed intelligent collision avoidance. Concepts were successfully tested and evaluated through simulations, as well as practically with two wheelchairs. Future work will consider more affecting factors, especially reaction times and the

delays, as well as ways of improving assisted driving and modelling.

REFERENCES

- Haddad, M., Sanders, D., 2020a Deep Learning architecture to assist with steering a powered wheelchair, *IEEE Trans. Neur. Sys. Reh.* 28 12 pp 2987-2994.
- Haddad, M., Sanders, D., Ikwan, F., Thabet, M., Langner, M., Gegov, A., 2020b Intelligent HMI and control for steering a powered wheelchair using a Raspberry Pi microcomputer, *Proc. 2020 IEEE 10th International Conference on Intelligent Systems-IS (Varna)* pp 223-228.
- Haddad, M., Sanders, D., Langner, M., Ikwan, F., Tewkesbury, G., Gegov, A., 2020c Steering direction for a powered-wheelchair using the Analytical Hierarchy Process, *Proc. IEEE 10th International Conference on Intelligent Systems (Varna)* pp 229-234.
- Holdsworth, R., 2003 *Autonomous In-Flight Planning to replace pure Collision Avoidance for Free Flight Aircraft using Automatic Dependent Surveillance Broadcast*, Swinburne University IMO (1996), Resolution MSC.64 67 Adoption of New and Amended Performance Standards, Int. Maritime Org.
- Kamijo, S., Matsushita, Y., Ikeuchi, K., Sakauchi, M., 2000 Traffic monitoring and accident detection at intersections. *IEEE Trans. Intell Transp Syst* 1 2 pp108-118.
- Montewka, J., Goerlandt, F., Kujala, P., 2012 Determination of collision criteria and causation factors appropriate to a model for estimating the probability of maritime accidents, *Ocean Eng.* 40 pp 50-61.
- Sanders, D., Moore, A., Luk, B., 1991 A joint space technique for real time robot path planning *Proc. Fifth Int' Conf on Advanced Robotics, 1991. 'Robots in Unstructured Environments'*, IEEE, pp 1683 - 1689.
- Sanders, D., Jaques, M., Clothier, H., 1992a Geometric modelling for real time flight simulator applications *Proc. IEE Colloquium on Advanced Flight Simulation. IET Conference Publications*, pp 4/1 - 4/6.
- Sanders, D., Harris, P., Mazharsolook, E., 1992b Image modelling in real time using spheres and simple polyhedral *Proc. H Schroder (ed.), International Conference on Image Processing and its Applications IET Conference Publications*, pp 433 - 436.
- Sanders, D., 1995 The modification of pre-planned manipulator paths to improve the gross motions associated with the pick and place task. *Robotica* 13 1 pp 77-85.
- Sanders, D., Graham-Jones, J., Gegov, A., 2010a Improving ability of tele-operators to complete progressively more difficult mobile robot paths using simple expert systems and ultrasonic sensors. *Industrial Robot: An International Journal* 37 5 pp 431-440.
- Sanders, D., Lambert, G., Graham-Jones, J., Tewkesbury, G., Onuh, S., Ndzi, D., Ross, C., 2010b A robotic welding system using image processing techniques and a CAD model to provide information to a multi-intelligent decision module, *Assembly Autom* 30 4 pp 323-332.
- Sanders, D., Tewkesbury, G., Graham-Jones, J., 2011 Simple rules to modify pre-planned paths and improve gross robot motions associated with pick & place assembly tasks. *Assembly Autom*, 31 1 pp 69-78.
- Sanders, D., Tewkesbury, G., Gegov, A 2015 Fast transformations to provide simple geometric models of moving objects. *Intelligent robotics and applications, "Lecture notes in computer science 9244* Springer pp 604-617.
- Sanders, D., 2017 Using self-reliance factors to decide how to share control between human powered wheelchair drivers and ultrasonic sensors, *IEEE Trans Neur Sys Rehab* 25 8 pp 1221-1229.
- Sanders, D., 2018 Non-model-based control of a wheeled vehicle pulling two trailers to provide early powered mobility and driving experiences, *IEEE Trans Neur Sys Rehab* 26 1 pp 96-104.
- Sanders, D., Haddad M., Tewkesbury, G., Thabet, G., Omoarebun, P., Barker, T., 2020a Simple expert system for intelligent control and HCI for a wheelchair fitted with ultrasonic sensors, *Proc. of the 2020 IEEE 10th International Conference on Intelligent Systems (Varna)* pp 211-216.
- Sanders, D., Haddad, M., Langner, M., Omoarebun, P., Chiverton, J., Hassan, M., Zhou, S., Vatchova, B., 2020b Introducing time-delays to analyze driver reaction times when using a powered wheelchair, *Proc. of SAI Intelligent Systems Conf (Amst)* pp 559-570.
- Steidel, M., 2019 Axel Hahn system - An Assistance System for Collision Avoidance at Sea," *Proc. 18 th International Conference on Computer and IT Applications in the Maritime Industries Technische Universität (Hamburg)* pp 261-273.
- Tam, C., Bucknall, R., 2010 Collision risk assessment for ships. *J. Marine Science and Technology* 15 3 pp257-273.
- Van Iperen, E., 2015 Classifying Ship Encounters to Monitor Traffic Safety on the North Sea from AIS Data, *TransNav. Int. J. Marine Navigation and Safety of Sea Transportation* 9 1 pp 51-58.
- Xue, Y., Lee, B., Han, D., 2009 Automatic collision avoidance of ships *J. Eng. for the Maritime Environment* 223 1 pp 33-46.
- Youssef, S., Kim, Y., Paik, J., Cheng, F., Kim, M., 2014 Hazard identification and probabilistic scenario selection for ship-ship collision accidents, *Int. J. Maritime Eng* 156 A1 pp 61-80.
- Zhang, W., Goerlandt, F., Montewka, J., Kujala, P., 2015 A method for detecting possible near miss ship collisions from AIS data, *Ocean Eng* 107 pp 60-69.