Mensor : utilisation of the human sensor through inter-vehicle communication

MENSOR
UTILISATION OF
THE HUMAN SENSOR THROUGH
INTER-VEHICLE COMMUNICATION

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Abstract

The modern society's increasing mobility is placing a growing demand on traffic safety. An important way to meet this demand will be offered by on-board driver assistance systems. Introducing inter-vehicle communication allows these systems to use traffic data collected by other vehicles. This opens up the possibility to implement co-operative driving behaviour thereby improving the overall traffic safety. This idea is formalised in an advanced driver assistance concept called Mensor. In this concept the actions of multiple drivers are measured and combined into a 'safety state' indicating the 'level of traffic safety'. The safety state message is sent to other vehicles and communicated to their drivers allowing them to take preventive actions. Initial experiments with a small scale demonstrator consisting of three passenger cars show considerable prospects to improve traffic safety.

1 Introduction

Recent technological developments in the area of driver support systems, commonly known as Advanced Driver Assistance (ADA) systems, are very promising with respect to the enhancement of traffic safety. Automatic Cruise Control (ACC) for instance enables the driver to automatically keep a pre-set distance from the car in front. Although ACC primarily aims at the improvement of driving comfort, it clearly has the potential to increase traffic safety as well. A common characteristic of most ADA systems, whether they automate (part of) the driver's tasks or merely have an advisory role, is the inclusion of on-board sensors such as radar to scan the direct vicinity of the vehicle in order to determine the vehicle's headway. However, the range covered by these sensors, expressed in terms of number of preceding vehicles, is limited by nature. This range can significantly be extended using a communication link between vehicles. Such a link can be implemented either indirectly via road-side receivers and transmitters, or directly between neighbouring vehicles. Improvement of local traffic safety requires a communication range up to about 200 meters [1], [2]. Within this range a direct communication link between vehicles seems most effective. Moreover, a direct communication link offers the possibility of time-critical data exchange, which is a prerequisite for safety related applications. Summarising, inter-vehicle communication enables an ADA system to use data collected by other vehicles, thus largely extending the range and time span of relevant information. As a result pre-view information is gained, allowing the driver or an automated system to take anticipatory actions.

Based on the above considerations, a driver assistance concept featuring inter-vehicle communication has been developed within TNO Automotive. This concept, called Mensor, is presented in more detail in the next section. It appears that within this concept there are many different versions possible. Section 3 therefore specifically deals with a driver assistance application which is developed within the Mensor framework and which can be characterised as an early brake warning system. In order to experimentally verify the expected results, this application is implemented in a small scale demonstrator consisting of three ordinary passenger cars. The experimental set-up and the test results are discussed in section 4.

2 Conceptual design

The essence of Mensor is the transmission of safety related time-critical traffic data to upcoming or, more generally speaking, neighbouring vehicles in order to allow for anticipatory actions by the drivers. Within this concept a vehicle 'safety state' is introduced, i.e. a signal quantitatively indicating the level of traffic safety relevant to the vehicle. In fact, this state signal is the result of an algorithmic operation on measurement data such as vehicle acceleration and speed. The safety state can therefore be regarded as a compression of the various measurement data into one signal. The advantage of this approach is that the amount of data to be communicated between vehicles is largely reduced which allows for a relatively simple and robust communication system. Furthermore this approach leads to a certain flexibility with respect to the data to be measured as well as an implicitly simple communication standard.

In general there is a large variety of measurement data available in order to serve as a basis for the calculation of the vehicle safety state. We already mentioned speed and acceleration as standard measurement data. This can be extended with data generated by more sophisticated sensors such as headway sensors determining the distance to a preceding vehicle or other objects using either radar, vision systems, laser or a combination of those techniques, see e.g. [3]. Also the application of position data using Differential GPS techniques is developing in a way highly suitable for safety related driver assistance applications [4]. It was decided not to use these complex sensors in this stage of the development, but rather to make use of a relatively simple safety measure which can be obtained from the driver's driving behaviour, for instance by measuring braking actions, sudden steering actions, etc. Consequently, the driver is being used as a 'traffic safety sensor'. This specific feature is responsible for the name of the developed ADA system: 'Mensor' - man as a sensor. The vehicle safety state is then transmitted to neighbouring vehicles and communicated to the drivers. In turn, within these vehicles the same process takes place, where the safety state is calculated not only from the driver's own actions, but also from the safety states received from other vehicles. Drivers now receive preview information, allowing them to move to a state of increased alertness or even take preventive actions. Moreover, the safety state of a vehicle is the cumulative result of the actions of multiple drivers, thereby improving the degree of accuracy and reliability of the overall system.

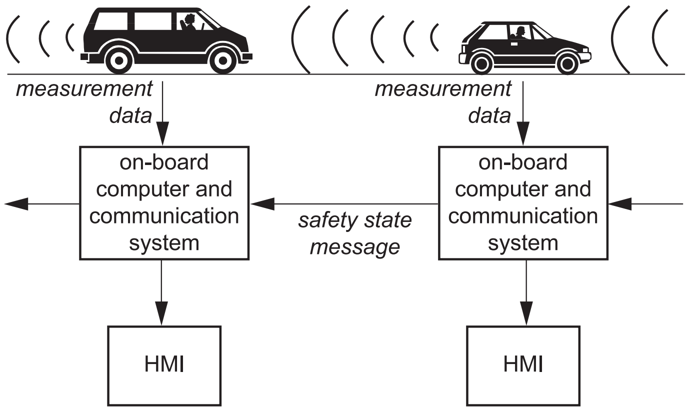

Figure 1 Elementary scheme of Mensor

Figure 1 shows an elementary scheme of Mensor in its longitudinal version. Note that it is assumed that the system has an advisory role only. Its output therefore, besides the safety state to be transmitted, is a human-machine-interface (HMI) displaying the safety state which is received from the vehicle in front. Depending on the reliability of the safety state signal, we could turn Mensor into an active system by adding automatic functions. As an example we mention automatic emergency braking initiated by a threshold crossing of the safety state.

3 Implementation: an early brake warning system

From the conceptual design we can distinguish three main aspects within Mensor: the safety state signal, the inter-vehicle communication and the HMI. In order to move to a concrete driver assistance application which can be tested using an experimental set-up, we need to specify these three aspects. This is carried out while aiming at an early brake warning functionality of Mensor because such a system is likely to be highly effective in reducing the number of traffic accidents [2], [5]. According to [2] the number of rear-end collisions would be reduced by about 50 % at time headways (headway distance divided by actual speed) ranging from 0.5 s to 1 s.

3.1 Safety State definition

Given our goal to develop an early brake warning system, it seems logical to define the vehicle safety state based on deceleration of the vehicle. This can be reached through various types of measurements. Among these are direct deceleration measurement using an acceleration sensor, indirect measurement using a speed sensor and differentiating the speed signal, measurement of brake pressure and/or measurement of the brake pedal position. From these, the brake pedal position signal is most likely to have the best signal-to-noise ratio. Moreover, the brake pedal position provides the most direct and early indication of the driver’s actions. Let us denote the measured brake pedal position by u_k where the index k refers to a specific vehicle. However, it is not the brake pedal position itself we are interested in: this position still needs to be converted to an estimated level of deceleration. This can be implemented using a vehicle specific function providing the relation between brake pedal position and deceleration. Figure 2 shows an example of this function for a Peugeot 806 and a Smart.

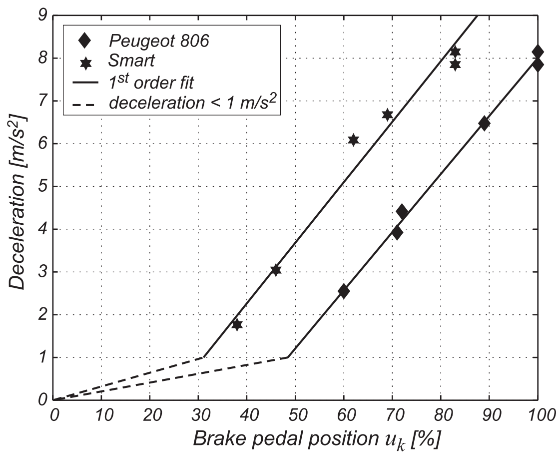

Figure 2 Measured relation between brake pedal position and deceleration

Let us denote this function, possibly implemented as a table look-up operation, by $f_k(u_k)$. Because our goal is to design an advisory system, we do not need the exact deceleration values. The vehicle specific function f_k therefore also includes a discretisation with respect to amplitude by dividing the entire deceleration range (from 0 m/s² to approximately 10 m/s²) into a limited number of intervals. As a result, $f_k(u_k)$ is an integer number being a discrete indication of the level of deceleration. Without loss of generality we assume $f_k(u_k)$ has six possible values: 0 - 5 where 0 indicates constant speed or acceleration and 5 indicates maximum deceleration, i.e. an emergency stop.

With the discrete level of deceleration $f_k(u_k)$, the vehicle safety state $x_{s,k}$ of vehicle k is calculated using the following recursive expression:

$$x_{s,k} = \begin{cases} f_k(u_k)\ , & k = 1 \\ \max\left(f_k(u_k), x_{s,k-1} - q\right), & k > 1 \end{cases} \qquad (1)$$

where $x_{s,k-1}$ is the safety state of the preceding vehicle. The constant q is an attenuation term. From (1) it follows that x_s has a discrete value in a range exactly matching the range of $f_k(u_k)$, in this case 0 - 5. Decreasing $x_{s,k-1}$ by q results in attenuation of the safety state. With $q = 1$, the safety state will be decreased to 0 after 5 vehicles, provided there is no intermediate braking. As a consequence the Mensor horizon consists of 5 vehicles in this particular case. Note that [2] indicates a horizon of 5 vehicles to be most effective and that very little or no benefit is obtained by utilising data from more than 5 vehicles ahead. Finally, expression (1) clearly shows that the state $x_{s,k}$ is the result of the incoming state $x_{s,k-1}$, modified by the driver's braking action $f_k(u_k)$.

Figure 3 shows a block scheme of this early brake warning assistance application. This scheme fits within the elementary scheme presented in figure 1.

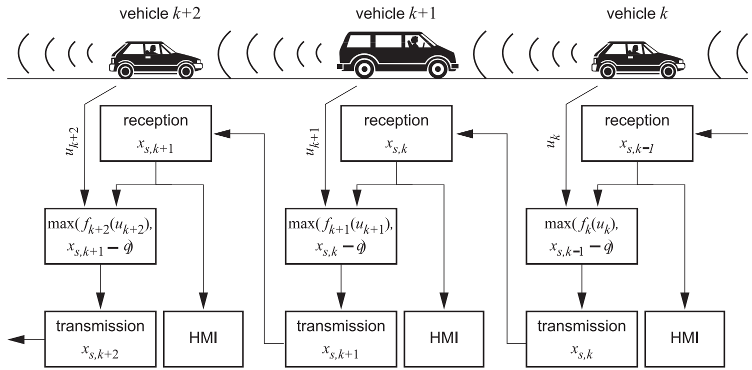

Figure 3 Block scheme of the Mensor early brake warning system

3.2 Inter-vehicle communication

With respect to the method of vehicle-to-vehicle communication, there are broadly speaking two essentially different methods, being broadcast versus line-of-sight [6]. Broadcast refers to communication in all directions using a radio frequency. Line-of-sight requires the transmitting and receiving vehicles to have ‘eye contact’. This can be implemented using infrared light. A line of sight method inherently guarantees that a communication link is set-up with relevant vehicles only, in our case the vehicle directly behind the transmitting vehicle. Broadcast requires much more calculation effort in order to determine the source of a received signal and whether the transmitting vehicle is relevant or not with respect to the safety of the receiving vehicle. For this reason a line-of-sight method has been chosen. It should be noted however that there are some serious disadvantages of line of sight communication, the most important being the inability to communicate in the presence of obstacles. This plays an important role in mixed traffic where not every vehicle would be equipped with a communication system.

Line of sight communication can be established using different types of media. We mention the optical/non perceptible spectrum (infrared), optical/perceptible spectrum (e.g. modulating braking lights combined with CCD cameras), radio with dual-directional antennas or even microwave systems. From these, an infrared communication system is expected to provide a good compromise between robustness against weather conditions, hardware costs and a well controlled beam coverage. For this reason infrared communication is chosen to experimentally test the potential of the Mensor concept. Chart 1 below shows the main requirements for the infrared system.

Update rate .... 50 Hz
Transmission range .... 2 - 60 m
Directionality .... uni-directional
No. of transmitters per vehicle 3
No. of receivers per vehicle 1
Transmitter sight angle .... 30°
Receiver sight angle .... 8°
Transfer rate .... 1 kbyte/s
Main area of application .... highways, regional roads

Chart 1 Main requirements of the infrared communication system

The update rate of 50 Hz is chosen to be able to take vehicle dynamics up to 5 Hz into account. More importantly, using this update rate the delay time of 1/50 = 0.02 s is significantly smaller than the human reaction time of about 0.6 s. The transmission distance of 2 - 60 m is based on the relevance of a driver’s actions: within a headway of 2 m, a crash is likely to become unavoidable whereas above 60 m there is no immediate need to take any action, except at very high speeds. Furthermore, the early brake warning application only requires a uni-directional communication from the vehicle in front to the following vehicle. In order to allow for a certain lateral misalignment of two successive vehicles as well as to secure the required transmission range, 3 wide beam transmitters per vehicle have been applied. The combination with a receiver sight angle of 8° leads to an acceptable maximum misalignment error. Also the communication link will be maintained at curved highways and regional roads. In real traffic these characteristics will certainly lead to lateral interference, i.e. a vehicle receiving a signal from a vehicle in another driving lane, for headways above 20 m. As a consequence this system probably needs to be re-designed for real traffic applications which may include some sort of additional addressing [6]. This matter requires further research.

Figures 4 and 5 show the electrical schemes of the infrared transmitter and receiver respectively. From these schemes it can be seen that the infrared communication system uses the IrDA protocol which is the current standard for mobile equipment, i.e. laptops, mobile phones, etc.

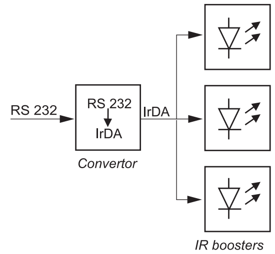

Figure 4 Electrical scheme of the transmitter

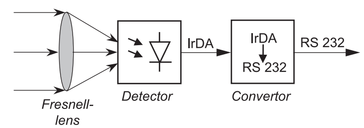

Figure 5 Electrical scheme of the receiver

Figure 6 depicts a close-up of a receiver unit mounted in the front panel of a Smart. Finally, figure 7 shows the transmitter units at the rear side of a Smart.

Figure 6 Infrared receiver unit

Figure 7 Infrared transmitter units

3.3 Human Machine Interface

Within this driver assistance application, the safety state received from the preceding vehicle must be communicated to the driver. Although the human machine interface design is not a major focal point in this stage of the development, it is nevertheless necessary to clearly communicate the safety state to the driver in order to be able to test the effectiveness of the system. Consider for this purpose a Mensor horizon of 5 vehicles, i.e. $f_k(u_k)$ lies in the range 0 - 5 and $q = 1$. In this case the safety state has a value ranging from 0 to 5 where 0 can be interpreted as "nothing happening" and 5 as "emergency stop". Due to this feature of the safety state, it can be communicated to the driver almost without any post processing. This has been implemented using an intuitively interpretable interface consisting of 5 rows of high intensity LEDs, together shaping a warning triangle. As a result, the HMI is self explaining, which contributes to a minimal distraction of the driver's attention. This interface, mounted on the dashboard of the test vehicles, is shown in figure 8. The rows of LEDs are activated from the lower left corner of the triangle (one LED only) up to the diagonal right row of 5 LEDs. The number of activated rows corresponds to the actual value of the safety state. In this way the warning triangle gets larger as the safety state value increases thereby intuitively indicating an increasingly dangerous situation.

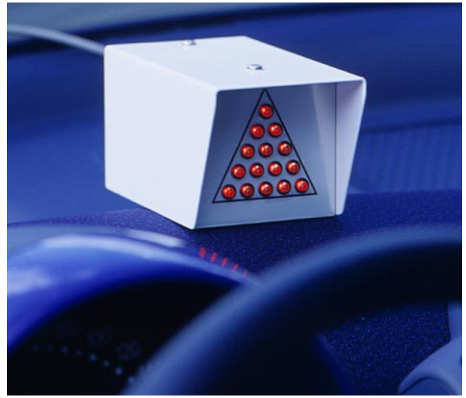

Figure 8 Human machine interface

4 Experimental results

4.1 Experiment design

The main effect of this early brake warning application that is envisaged is the compensation of the driver's reaction times. Consider for instance a 'platoon' of vehicles driving on a highway. When a vehicle suddenly slows down for some reason, a following vehicle will slow down after the driver has detected the braking lights of the preceding vehicle. For all vehicles in this row, the moment of braking is therefore determined by the propagation of braking lights along the row, which in turn is determined by the reaction times of the drivers (about 0.7 to 1.1 s) and a small time lag of about 0.1 s of the brake system [1]. Application of the Mensor system effectively compensates for these reaction times because the propagation of braking lights has been replaced by the propagation of the safety state message which is determined by the computer update rate of 0.02 s. This is experimentally verified using three ordinary passenger cars in a row, with the middle car being relatively large (Peugeot 806) compared to the other cars (Smarts) in order to block the view of the driver in the last car at the braking lights of the first car. While driving in a steady state situation at a speed of 50 *km/hr*, the first car in this vehicle platoon suddenly and without any announcement makes an emergency stop. The effectiveness of the application can now be quantified by measuring the reaction times of the last two cars. The same test has been carried out at 80 *km/hr*. Note that these tests evaluate the effectiveness of the system at emergency situations only, i.e. a safety state value of either 0 or 5. The effect of intermediate safety state values has only qualitatively been evaluated based on the test drivers experiences. Also the optimal Mensor horizon could not be tested in this small scale demonstrator.

With respect to the line of sight communication system, a number of simple tests have been carried out to determine the minimum and maximum transmission ranges and to evaluate the robustness of the communication link under several environmental and road conditions.

4.2 Measurement results

During the above mentioned tests the deceleration is measured of all three test cars using acceleration sensors. Figure 9 shows a typical deceleration measurement. This figure also indicates the time period between pressing the brake pedal in the first car, i.e. the moment an increased safety state will be send in upstream direction, and the initial moment of deceleration. In case the Mensor system is running, the third car responds to the emergency stop 0.51 s earlier, corresponding to a 7.1 *m* headway profit at 50 *km/hr*. We can also see a slightly lower deceleration level, which can be interpreted as an increased level of comfort. As expected, the second car does not benefit from the system because the driver detects the preceding car's braking lights just as fast. Nevertheless, the evaluation of Mensor under normal traffic conditions indicates an increase of comfort and improves judging of the actual traffic situation due to the differentiation into 5 levels of braking actions by the HMI. With respect to this theme, even the second vehicle benefits from Mensor.

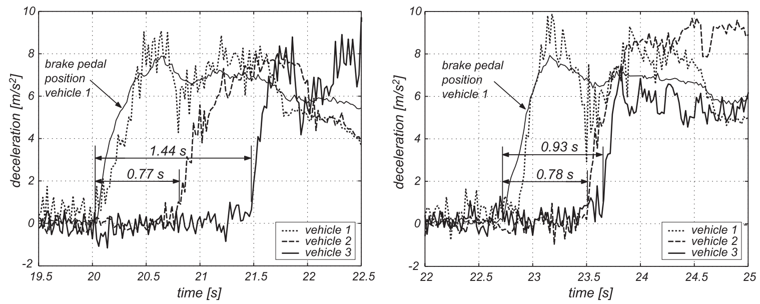

Figure 9 Measured deceleration without (left) and with Mensor (right)

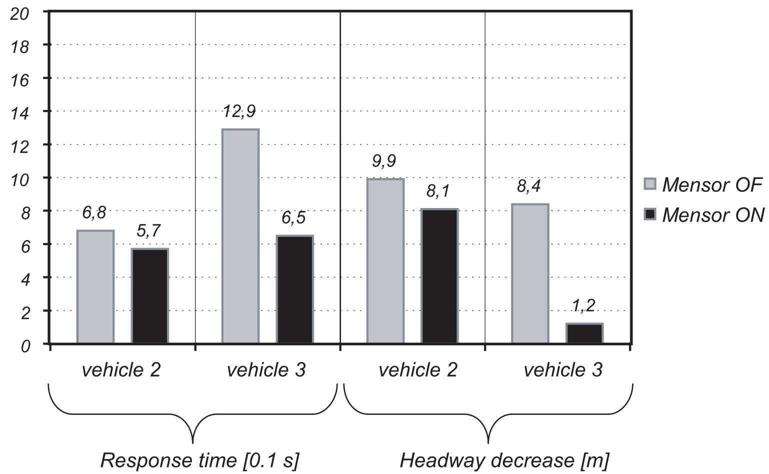

Figure 10 Test results without and with Mensor

More than 20 tests have been carried out at speeds of 50 and 80 *km/hr*, the results of which are summarised in figure 10. This figure shows the mean driver response time for vehicle 2 and 3 without and with Mensor. Also the headway decrease, measured using global positioning systems, is shown. Here, headway decrease is defined as the difference between the headway just before the emergency stop and the final headway at standstill. These results clearly indicate a significant improvement in response time for the third vehicle and a much smaller decrease in headway as a result.

The infrared communication system appears to be able to set up a communication link in a range of 0.35 to 300 *m* (at optimal weather conditions). Rain does not significantly influence the communication link. Unfortunately the system has not yet been tested in misty weather. The transmission range under optimal conditions however indicates that the minimum required transmission distance of 60 m should be reached under most weather conditions. The communication link appears to be sensitive to sudden changes in the light intensity, e.g. sudden sunlight shining directly into a receiver. Existing communication links will not be lost under these circumstances but new contacts are not so easily picked up. Although the communication system includes a high pass filter in order to eliminate for a varying environmental light intensity, adjustment of the speed of adaptation of this filter might solve this problem up to a certain extend. At sharp bends which regularly occur in urban areas, the communication link is usually lost, indicated by a blinking lower left LED of the HMI. Contact is easily recovered however. At highways and regional roads the communication link appears to be reliable.

Conclusions

Mensor is a generic advanced driver assistance concept aiming at the improvement of traffic safety, characterised by the application of inter-vehicle communication and the type of message, the so called ‘safety state’, to be communicated. Within the Mensor framework a specific early brake warning application has been developed. Experiments show a significant shorter brake response time in case of an emergency stop, indicating the potential to improve traffic safety. Under normal traffic conditions, the differentiation into five braking levels by the HMI, as opposed to the on/off mode of standard braking lights, leads to an increased level of comfort and improves judgement of the actual traffic situation with respect to safety.

The inter-vehicle communication, probably being the most critical aspect, has been implemented using a line of sight communication method based on infrared light. This low cost communication system appears to be quite reliable in a small scale experimental set-up comprising three passenger cars. Transmission ranges of more than 100 m, i.e. well above specification, did not pose any problem. Further research is directed towards the performance of this communication system in a less controlled environment, i.e. multi-lane traffic including split and merge manoeuvres. The challenge here is to find a satisfactory compromise between conflicting requirements, being maximisation of the allowable road curvature on one hand and maximisation of the distance above which lateral interference will occur on the other hand.

Another important issue is the effectiveness of this driver assistance application in the presence of vehicles which are not equipped. In order to determine the relation between effectiveness and degree of penetration, simulation studies and maybe even a large scale experimental set-up are required. Again, the type of communication system plays an important role as results will strongly differ for line of sight communication or broadcast.

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