

Networked Environment Description for Advanced Driver Assistance Systems

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Abstract—An overview of our work is given which provides future driver assistance systems with an extended environment description. In detail, methods for low-delay video compression, attention selection, sensor data fusion, inter-vehicle communication, cooperative cognition of vehicles and the improvement of gear shift logic are presented. The algorithms were developed in the context of a joint project of the University of Ulm and the University of Karlsruhe. To evaluate the system in real traffic situations, we are equipped with two test vehicles.

I. INTRODUCTION

With the number of road users increasing, the reduction of traffic accidents and an efficient utilisation of the road capacity gain importance. A promising approach are active safety systems that incorporate knowledge about the vehicle's environment. They enable the detection of dangerous situations in order to prevent accidents or at least reduce their effects by adequate reactions.

The vehicle's environment is composed of the road as well as static and moving objects. It is detected by sensors installed in the vehicle itself. For safety applications all systems face high requirements concerning reliability and low time delay. To transfer video data efficiently, e.g. from a rear-view camera, algorithms for compressed transmission are developed based on common standards. The data interpretation of monocular greyscale video is accelerated by the proposed attention selection. The fusion of complementary sensor data from a laserscanner and a monocular camera system yields further improvements. Communication between vehicles extends the field of view by the measurement regions of neighbouring cars. Thus dangerous situations outside the own range of vision can be perceived. For the data transfer the usage of Wireless LAN is examined. The cooperative environment cognition is based upon a common time and global coordinate system for positioning. The data is not only used for safety reasons but may yield as well an improvement of the energy management in novel hybrid vehicles.

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Within the scope of a joint project, multiple departments of the University of Ulm and the University of Karlsruhe work together to equip two test vehicles with the necessary sensors. These vehicles are used to evaluate the algorithms for video compression, attention selection, data fusion, inter-vehicle communication, cooperative cognition and predictive vehicle control.

II. LOW-DELAY VIDEO COMPRESSION

In this project algorithms for compressed video transmission with very low latency are developed using common standards and platforms. Target applications include camera-based driver assistance systems as well as rear-view and night vision cameras. The additional delay introduced by encoder, transmission and decoder should be in the range of 50 to 100 ms at 25 Hz frame rate.

Video compression standards can be distinguished into frame-based standards (e.g. JPEG, JPEG2000, MPEG I-Frame only) and standards with temporal prediction (e.g. MPEG-1/2/4, H.264). Temporal prediction generally allows higher compression ratios at higher computational cost. All the standards mentioned above combine a two-dimensional transformation with frequency-dependent quantisation and a subsequent entropy encoder (Fig. 1). For the transformation either a discrete cosine transformation (JPEG, MPEG, H.264) or a wavelet transformation (JPEG2000) is used. As lossless compression of video data does not allow high compression ratios, a lossy quantisation step is introduced which results in more or less visible coding artifacts.

A. JPEG2000 latency issues

For the frame-based JPEG2000 encoder [1] the minimum latency is defined by the coding parameters, internal processing delay and stream buffers. For minimal latency the coding parameter progression style "PCRL" should be combined with a small tile size. A tile size of 128 pixels by 32 lines results a minimum capture latency of 2 ms. To achieve a constant data rate over time it is essential to average-out data rate variations caused by different complexity of image regions. Therefore, an output buffer for one field or frame is needed resulting in a latency of 20 or 40 ms.

B. MPEG latency issues

The MPEG video standards [2] allow temporal prediction for better compression of video. Simple IP-coding uses only forward prediction of consecutive frames. IPB-coding

allows bi-directional prediction of image regions from two surrounding reference frames. As bi-directional prediction requires frame-reordering prior to the encoding process the latency would be increased by 40 ms for one and 80 ms for two B-frames. The simple IP coding scheme does not require frame re-ordering and the minimum latency is defined by the size of the macroblocks. For a macroblock-based encoder the processing of a macroblock can start immediately when the last line is captured in the pixel buffer, so the minimum capture latency is about 1 ms (16 lines of video). All subsequent processing steps (prediction, transformation, quantisation, entropy encoding) can be performed on macroblock level as no information about the following image regions is required. For real-time performance a DSP-based encoder at D1 resolution (720×576 pixels) must process one macroblock within $25 \mu\text{s}$ (1620 macroblocks/frame * 25 frames/s), so the processing delay would be increased by 80 ms for one and 120 ms for two B-frames.

The largest delays are however introduced by the stream buffers at the encoder and decoder. These buffers are usually required for averaging the varying size of intra and predicted frames to achieve a constant bitrate for transmission. Using standard parameters a typical latency of 500 ms (Main Profile@Main Level, D1-resolution, 4 Mbit/s) can be observed in realtime-systems. For achieving lower delays it is essential to average-out data rate variations within shorter time intervals which is only possible if no I-frames are present in the stream. A scheme for embedding intracoded image regions into predicted frames was described in [3]. In this project the feasibility and performance of improved algorithms are examined on a SIMD video DSP.

C. Evaluation of image quality

The simulations carried out with recordings from a 300 kpixels colour rear-view camera allow the conclusion that JPEG2000 and MPEG-2 can transmit this video at 2 Mbit/s data rate if the image is not too complex. For lower data rates the visual impression of MPEG-2 is slightly better as JPEG2000 introduces annoying blurred artifacts. For more detailed scenes (i. e. gravel, close bushes) about 4 Mbit/s data rate is needed to keep the coding artifacts acceptable. It is expected that more efficient standards like MPEG-4 or H.264 with IP-coding will achieve better compression than JPEG2000.

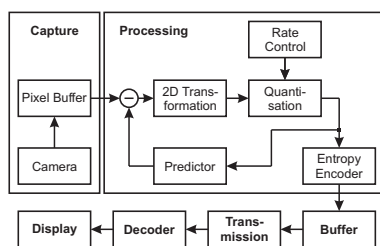


Fig. 1. Generalised video compression system. Frame-based encoders (JPEG2000) do not use temporal prediction.

III. ATTENTION SELECTION

In the automotive sector much research is devoted to the area of binocular vision. Our current work focuses on monocular greyscale visual information only and the analysis how reliable traffic-relevant data can be extracted from this simple data source. However, even this simple source delivers more data than can be handled, if trying to fully process every single data point. So there is a need to limit or focus computation on designated salient regions, which are significant for the actual task. The goal of visual attention selection is to allow an early focussing on these relevant regions to deploy further processing resources. Computational models that determine regions containing salient features of a scene have been proposed. These models however work on single input images and do not incorporate motion data. We focus on recovering salient locations from optical flow. In case of an arbitrarily moving observer – like a vehicle – salient regions can be divided into two categories: Independently moving objects (IMOs), e. g. other vehicles or pedestrians, and static obstacles that are blocking the observer’s pathway. For both categories, knowledge of the observer’s motion is required.

A. Independently moving objects

Within a rigid scene recovery of the observer’s ego motion for an arbitrarily moving observer is already a demanding task. IMOs within the scene further complicate ego motion recovery to a degree that it actually unveils to be a “chicken-and-egg” problem: The presence of IMOs biases the estimated ego motion, which on the other hand is needed to detect IMOs and exclude them from estimation. We followed the approach of Pauwels and van Hulle [4], which iteratively removes IMOs from optical flow by repeatedly estimating ego motion and suppressing outliers. In contrast to their approach we use subspace methods proposed by Heeger and Jepson [5] to estimate ego motion. The grade of fit of each flow vector to the estimated ego motion is determined by the angular error between the optical flow vector and the vector pointing from the estimated focus of expansion (FOE) to the location of the flow vector. By using this iterative approach we simultaneously obtain knowledge about the observer’s motion as well as knowledge about IMOs present in the current scene. We extend the approach of Pauwels and van Hulle that utilises single pairs of images by incorporating temporal coherence information from longer sequences. This on one hand allows us to eliminate outliers prior to ego motion estimation, which is achieved by calculating the “smoothness” of movement for each flow vector and removing vectors that are moving randomly over time. On the other hand, we can use knowledge from previous frames to remove flow vectors already known to belong to IMOs before utilising the iterative algorithm for FOE estimation. This temporal integration and consistency checking yields more stable results than operation on single pairs of frames.

B. Multimodal representation

During the presented computations a variety of different local image attributes need to be processed, e.g. position, optical flow and information about the greyscale structure. Due to the aperture problem as well as for reasons of computational costs, optical flow is calculated only at designated locations using the pyramidal Lucas-Kanade algorithm. These locations are determined according to the local image structure. In order to obtain a compact yet flexible representation of the features at these locations, we utilise a multimodal representation for these features similar to the approach proposed by Krüger et al. [6]. The resulting image representation builds upon symbolic tokens T that bind together the local feature attributes, $T = (\vec{x}, \vec{f}, \lambda_1, \lambda_2, \phi, \omega_i, c_i)$. On the lowest level the local feature attributes in our symbolic description consist of position \vec{x} , optical flow \vec{f} , intrinsic dimension calculated from structure tensor (λ_1, λ_2) and contrast orientation ϕ (where applicable) as well as values ω_i derived from temporal observation of these features. Beyond this, all of these properties are coupled by a confidence value c_i for each single property value. All subsequent computations operate on this compact data representation. The token-based representation is generalised to build dynamic hierarchical descriptions of the scene. For example, low-level spatio-temporal tokens are grouped by a simple clustering algorithm. Tokens are grouped, and therefore segmented from background, by combining similar flow directions that are spatially close (Fig. 2).

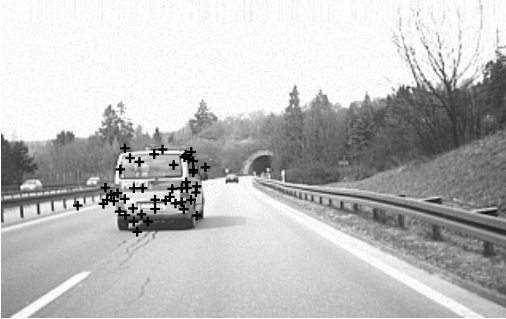


Fig. 2. A cluster of symbolic tokens grouped over an IMO. Grouping was based on spatial coherence and optical flow similarity. The plot shows only the spatial location of the tokens, not their other attributes.

Such a hierarchical representation may be utilised to feed a collision warning system that operates on token trajectories that are weighted dependent on the particular scene context (e.g. highways, street junctions, etc). However, this is beyond the scope of our current work and may be approached in future work.

IV. ENVIRONMENT PERCEPTION USING SENSOR FUSION

Environment perception using laserscanners for automotive safety and comfort applications has been presented in many publications [7], [8]. As a sensible additional sensor a monocular camera system is chosen, which provides mainly complementary data with respect to the laserscanners distance measurements [8].

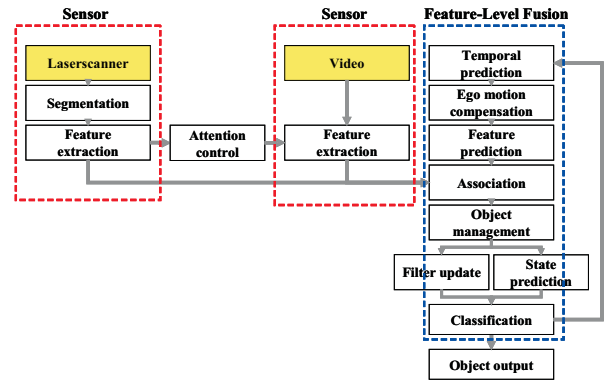


Fig. 3. System architecture of the feature-level fusion.

Both sensors are combined in a sensor fusion architecture which aims at a maximisation of the synergetic effects (Fig. 3). Object features, such as position, orientation, width and length, are extracted from the segmented and pre-processed laserscanner data. The features, transformed into the image domain, control the feature extraction of the image processing. This attention control of the image processing by the laserscanner has the advantage of superseding the time consuming and unreliable single image object detection. The gained computation time is therefore used for a precise localisation of the objects in the image domain. This low-level fusion approach requires a spatio-temporal sensor alignment, which is realised by calibration and hardware sensor synchronisation.

The fusion associates the features of both sensors with already existing objects of the environment description. The objects are tracked based on Kalman filters. The object tracking up to a distance of 50 m is based mainly on the laserscanner data, covering a horizontal field of view of up to 180° in front of the ego-vehicle (140° if integrated into the vehicle) as shown in Fig. 4.

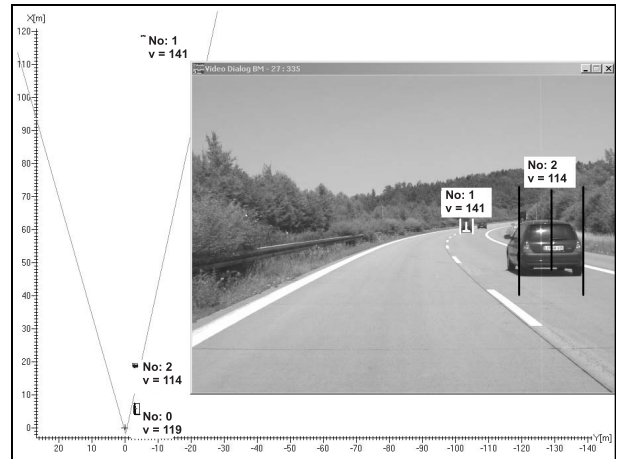


Fig. 4. Left: vehicles detected by the laserscanner. Object number and velocity (in km/h) are provided. Object 0 is only in the FOV of the laserscanner. Right: the fused result in the image domain. The state estimation of the vehicles 0 and 2 is based on laserscanner measurements. The vehicle in the far range is localised by both sensor systems.

Due to the good angular accuracy of 0.5° at 20Hz of the IBEO AS multi-layer laserscanner, the achieved precision in position, width and velocity estimation is in these distances sufficient for many advanced driver assistance systems. The image processing determines the width and the position of cars and trucks in the image at far ranges, thus enhancing the localisation estimation. Optical flow measurements enable an improvement of the overall velocity estimate of cars and trucks.

V. INTER-VEHICLE COMMUNICATION

Providing vehicles with various kinds of sensors helps to recognise dangerous situations in advance. Nevertheless, these systems also have a limited field of view. Of course, there are objects located outside the range of a certain sensor or hidden by other vehicles. The not detected sudden stop of one car may be dangerous due to the more and more delayed reaction of following drivers. The reaction time can be minimised by introducing inter-vehicle communication to forward information, gained by a sensor system, to neighbouring vehicles. Thus, an intelligent driver assistance system will recognise dangers in advance, even if they cannot be detected by its own sensors.

A. Requirements

In order to transmit information about detected objects, special requirements have to be fulfilled by the communication system. The most crucial one is the delay caused by the transmission. As traffic is a highly dynamic system, data becomes obsolete very fast. Therefore, a communication protocol, which provides QoS (Quality of Service) mechanisms is necessary. In addition an information management strategy is required to handle the large amount of data in an efficient way. This means that rules have to be defined regarding how far the generated object data should be forwarded and how general information can be extracted. For instance traffic jams or weather hazards are interesting for a larger area.

B. Network characteristics

In inter-vehicle communication the network which has to be considered is a highly dynamic ad-hoc network where the nodes are the single vehicles of the traffic system. Due to the high relative velocities between single vehicles, the times for data transfer are very short and connections break down frequently. Thus a technology has to be used, which is able to set up connections fast and which is able to cope with the physical effects due to the mobility of the network. Looking at the common network protocols shows that current technologies used for mobile phones, like GSM and UMTS, are designed for the usage with high relative velocities. But as they are built as cellular networks with central stations, the delay times in this kind of networks are expected to be much higher than in an ad-hoc network, where nodes can communicate directly. On the other hand, networks suitable as ad-hoc networks, like Bluetooth or Wireless LAN (Local Area Network), are not especially designed for the usage in such a highly dynamic network environment. In the case of Bluetooth, the long inquiry process creates serious

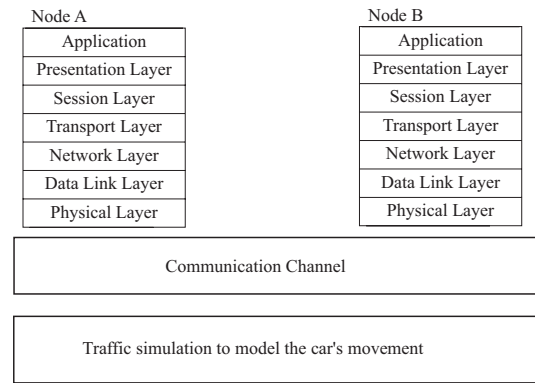


Fig. 5. Architecture of the simulation environment [10].

problems when using it in a highly dynamic environment, as it can take seconds to find possible communication partners. For Wireless LAN the main problem is the channel access mechanism. A shared channel with the access mechanism CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) is used. This causes a lot of collisions due to the unsolved hidden station problem.

C. Simulation architecture

To develop improved channel access mechanisms, which can overcome these problems, it is necessary to simulate the communication network using a realistic model for the nodes movement. Fig. 5 shows the architecture for such a simulation model. The basis of this tool is a traffic simulation, which is able to model the movement of the vehicles in a street network based on the cellular automaton model of Nagel and Schreckenberg [9]. Additionally a routing process for the vehicles is implemented, so that larger networks like whole cities can be simulated. This traffic simulation provides a means of identifying the parameters of an inter-vehicular network based on a realistic behaviour of the vehicles. Interesting parameters here are possible connection times and also the size of the network and the number of communication partners.

Based on the modelling of the behaviour of the vehicles a simulation of the communication is built. It consists of a channel model and the various layers implemented in the single communication nodes. The aim of the channel is to deliver the packets sent by the nodes to all other nodes within the communication range, taking into account the effects caused by the physical layer, like bit errors, delay or packet loss due to collisions. The OSI layers in Fig. 5 symbolise the communication nodes, in which some of these layers can be implemented, depending on the focus of the simulation.

VI. COOPERATIVE COGNITION OF VEHICLES

An inter-coordinated cognition of traffic situations provides the basis for cooperative driving decisions [11]. In addition to the communication between networked vehicles the processing of transmitted data has to be considered. Several forms of networking can be distinguished, beginning with the transmission of general information or warnings,

e. g. about road conditions. In this case information may be send from a superior station and is uncritical regarding exact localisation and time delay. The next level is the sending of data about the own vehicle state to neighbouring vehicles, which has to be combined with positioning and time. To obtain the completed description of a complex vehicle environment, an additional exchange of environment information is proposed. Therefore, remote object data from other vehicles is added to the object data measured by own sensors taking into account time, positions and orientations. This architecture allows a detection of vehicles that are not connected in the network and a comprehensive harmonised description of traffic situations.

A. Alignment of position and time

An inter-vehicle information fusion supposes cooperating vehicles to be provided with identical spatiotemporal systems to match the objects found by different vehicles. Here various systems are possible as discussed in [12]. In our test vehicles D-GPS (Differential Global Positioning System) serves as a shareable basis of time and position information. The geographical world coordinates of GPS position are transformed to earth-fixed Cartesian coordinates. With the vehicle's orientation the vehicle coordinate system is mapped to the Cartesian coordinates.

GPS is also appropriate as time server to synchronise the clocks of all networked vehicles. All measurement data are labelled with the associated time stamp in the moment of reception. By time stamp, related global position and orientation of the sensor, it is possible to map the object detections from vehicle *B* to the coordinate system of vehicle *A* and align them to the local measurement data.

B. Tracking of object detections

The tracking of detected objects consists of multiple parts [13]. The local measurements are processed with a multiple object tracking that uses Kalman filtering and cheap Joint Probabilistic Data Association. With the same algorithms remote object data are integrated in the environment model of the vehicle. To adjust the delayed remote data to the internal measurement timing, they are extrapolated to the next internal time step assuming constant velocity. Their tracking is performed in spite of a higher covariance due to inaccuracies in global positioning and vehicle orientations. The result of the object tracking is shown in Fig. 6. Objects detected by vehicle *B* are mapped to the coordinate system of vehicle *A*. Therefore, the measurement area of *A* is broadened by the sensors of *B* to regions inaccessible before. The measurements depend on the road course, e. g. curvatures may be seen from the detected object positions in larger distances.

The case of overlapping measurement fields yields redundant object data. Therefore, measurements in the overlapping area are compared by Mahalanobis distance if they belong to the same object. By fusion, plausibility and quality of detections will increase. Furthermore, specific overlapping constellations enable the verification of the transformation process between the vehicle coordinate systems.

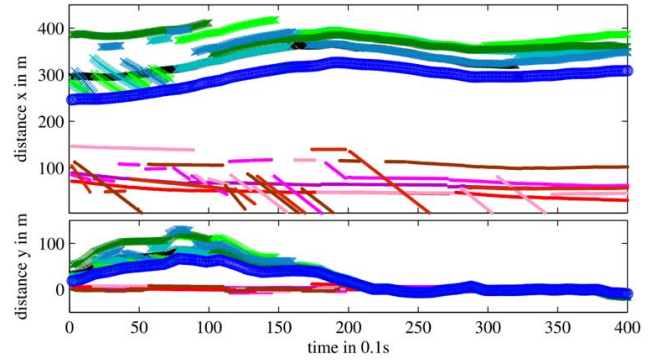


Fig. 6. Tracking of object positions in driving direction *x* and lateral direction *y* of vehicle *A*. The dark bold line shows continuously the state of vehicle *B* in front of *A*. Objects detected by *A* are indicated by fine lines, remote object data measured by *B* as bold lines in larger distance.

VII. IMPROVEMENT OF GEAR SHIFT LOGIC

New sensor technology is not only used to make driving safer. As a synergy effect sensor data improve the gear shift logic of an automatic gear box, for instance. In novel parallel- or mild-hybrid vehicles the energy management is inseparably connected to the gear shift logic. But the gear changes optimised for the best fuel efficiency are sometimes adversarial for the driving comfort. The distance to the car in front may provide necessary information to maintain driving comfort.

Fig. 7 shows the costs of the best operating points for the combustion engine and electrical engine combination with every possible gear ratio. The gear with the lowest cost is chosen. The difference between the cost curves is normally big enough to avoid gear hunting (Fig. 8). But in the display detail a driving situation emerge with changes from fifth to third gear and back in less than two seconds. For such cases a hysteresis is introduced to inhibit unnecessary gear shifts. This means that the difference in costs between the actual gear and a new gear must exceed a specific value. If the new gear is cheaper by this amount it could be chosen. With a static hysteresis the energy saving potential of a hybrid car is strongly decreased. Therefore, the hysteresis is adapted depending on the changing of the power demand of the drive train. A massive change in power leads to an

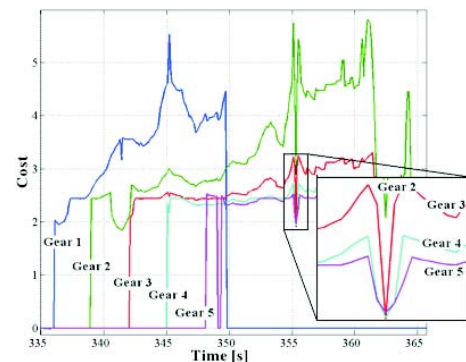


Fig. 7. Lowest costs for all possible gear ratios.

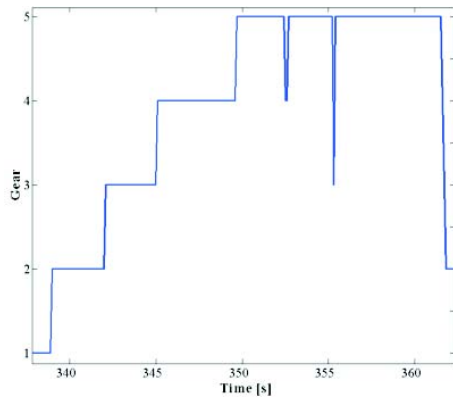


Fig. 8. Gear shifts for the driving situation of Fig. 7.

extended hysteresis, because cost function crossing normally arises with strong changes in power. For small changes in power the cost function crossing is not a problem. This method avoids gear hunting due to the economical character of the gear shifting decision. But even with this improvement the gear shifting algorithm cannot choose the gear in a predictive manner like a human driver would do. Predictive gear shift systems need more information about the vehicles environment from maps or sensors. For instance the road inclination or the curve radius could influence the gear shifting algorithm. The information about the distance to the car in front will improve the gear shifting strategy as well.

Figure 9 shows the speed of two cars driving one after another in a city traffic situation. The vehicle in front is measured by the car behind. The speed is calculated by using the distance measurement and the speed of the ego-vehicle (Ego). The results show, that the driver in the ego-vehicle follows the driving behaviour in front (Front) with a delay of about two to three seconds. The change of distance between the cars is a suitable information to improve the gear shifting algorithm. If the distance decreases the deceleration possibility of the subsequent vehicle is high. With the known behaviour of cost functions for slow deceleration – low- to medium-negative power demand – the hysteresis may be adjusted before the power already changes. Thus, unnecessary gear shifts are disabled by the distance information. Furthermore, a specific gear can be preferred by the cost function energy management that allows to

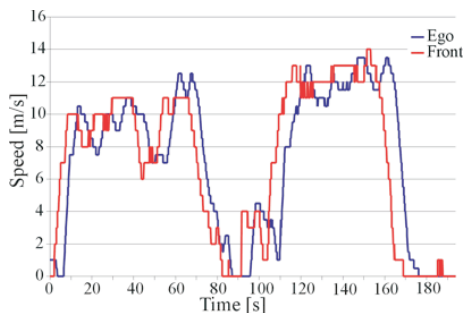


Fig. 9. Speed of two cars in city traffic situation.

introduce weighting values for each gear. An additional logic may influence the gear choosing algorithm to prioritise a specific gear which fits the expected future driving condition. Thereby, this gear is chosen instead of the most economic gear. By a predictive dynamic hysteresis and a predictive gear favouritism the fuel efficiency is slightly reduced, but the driving comfort and therefore the acceptance of the automatic gear shift logic by the driver is notably increased.

VIII. CONCLUSIONS

The algorithms developed within the joint project of departments of the University of Ulm and the University of Karlsruhe include new approaches for low-delay video compression and attention selection by detection of independently moving objects in monocular visual input. The fusion of laserscanner and video data provides the necessary environment information for an anticipatory gear shift logic. The inter-vehicle communication with Wireless LAN enables the generation of a cooperative environment description fusing information of multiple vehicles. Actual workings aim at the evaluation of the developed systems integrated in our test vehicles.

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