Contributions to Visual Autonomous Driving

A Review

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Part II: PROMETHEUS and the 2nd-generation System for Dynamic Vision (1987 ÷ 1996)

Abstract (Part II)**:** Cooperation with the Daimler-Benz AG in the PROMETHEUS project embedded in the Europe-wide EUREKA effort enlarged the base for scientific exchange and mutual instigation considerably. A fertile competition among the participants brought Europe in a leading position in the field of visual guidance of road vehicles within a decade. Contributions of UniBwM are discussed to some detail; a big step forward has been achieved through switching to transputers as new computing devices. General surveys are referenced. Finally, since the development of transputers stopped in the early 1990s, the switch to Power PC as main processors in the system developed is discussed.

II.1 Introduction

In Part I the basic approach and the development leading to the cooperation with the Daimler-Benz AG (DBAG) has been described. Though DBAG had contributed nothing to the basic approach, its openness for pushing the field was very valuable, and the effect on progress achieved in the timeframe till the mid-1990s was appreciable.

It is interesting to note that the hierarchically higher levels in the automotive industry for the first several years did not consider 'autonomous driving' as a goal of the PROMETHEUS project [Braess and Reichart 1995; Winner und Graupner 2015]. According to this source it took until 1991 that autonomous driving by machine vision was accepted as an official goal on the higher management levels also; this was due to the second Board Member Meeting 1991 in Torino with demonstrations of intermediate results achieved. None-the-less autonomous driving has been the dominant purpose in the sub-project Pro-Art, at least for one group as may be seen from the final report of UniBwM of the definition phase [Dickmanns et al. 1987, esp. page 6] (see Annex 1).

The progress achieved till 1991 has led to a structuring on the time scale. Both the vehicles for demonstration and the computer systems for machine vision became completely different. The rest of Part II is organized according to this aspect.

II.2 The general structure of the sub-project Pro-Art for UniBwM

All over Europe groups of automotive companies cooperating with specific research institutions were formed. They selected certain topics so that in total the entire range of interesting approaches with different sets and combinations of sensors and methods were covered. DBAG cooperated beside UniBwM also with the groups of Prof.s Nagel and von Seelen; only the contributions of UniBwM will be discussed in the sequel.

II.2.1 Goal of DBAG/UniBwM till 1991

According to the geometrical size of both the cameras and the computers needed, in the late 1980s large vans were required as basic vehicles. For easy adaptation to new developments, the voltage level in the test vehicles was selected to be 220 Volt. An electric power generator in the rear part of the van was capable of providing up to almost ten kilo-Watt. All electronic devices including computers and monitors were to be mounted in industry-standard 19-inch racks. In VaMoRs the latest versions of microprocessors Intel 80x86 (x up to 3 for number crunching on the higher control levels) have been introduced; for feature extraction in the BVV2 the 8086 with highest clock rate predominated [Mysliwetz 1990].

Figure II.1: Daimler-Benz test vehicle VITA for the Torino-demo of Prometheus 1991, equipped with UniBwM vision system.

For the intermediate demo of Prometheus 1991 in Torino, the 7-ton van of DBAG dubbed "**VI**sion **T**echnology **A**pplication" (initially 'VITA', later on 'VITA1', see Fig. II.1) was equipped with a similar bifocal set of cameras as used in VaMoRs (Fig. II.2). For image sequence interpretation a copy of the improved vision system BVV2 [Graefe 1989] has been industrially built; the complete set of higher-level software for dynamic vision has been transferred by UniBwM. No radar or Laser Range Finder (LRF or lidar) sensors have been used; monocular motion stereo through the 4-D approach has been demonstrated for the first time. On the test site of FIAT near Torino both autonomous lane keeping and convoy-driving behind another car at a speed-dependent distance in the speed-range up to 60 km/h has been shown. When the leading vehicle decelerated and stopped, VITA did the same and always kept a safe distance; all of this had been developed experimentally and tested previously with VaMoRs on the test tracks of UniBwM. Video clips of these maneuvers may be found under www.dyna-vision.de, Section 3.

Figure II.2: Bifocal camera set mounted on a two-axes pitch-and-yaw platform.

These results and those demonstrated by several other European integrated groups from research and industry using additional radar and laser sensors led to a revision of the skeptical judgments by the higher management levels of the automotive industry. In the meantime, computer performance had increased by more than an order of magnitude in general, and a European company had brought micro-processors with four direct communication links to its neighbors on the market, the "Transputers". These links allowed transferring entire (small) images between units, which for the first time allowed getting rid of the window-concept for storing image data. Adaptation of the architecture is discussed in the next section.

II.2.2 Transition to transputers (1991 ÷ 1994)

Since the geometrical size of both cameras and microprocessors had become much smaller in the early 1990s, and since also the power requirement for the overall vision system was lowered to less than 2 kW, the decision was to switch to standard passenger cars as test vehicles for the final demonstration of 'PROMETHEUS' in the fall of 1994. In addition, the requirement of DBAG was to allow guests as passengers in the vehicles during demonstration drives. For these reasons two sedans 'Mercedes SEL-500' have been selected, one for DBAG (VITA2) and one for UniBw Munich (VaMP). Both groups had to purchase these second-hand from the general market. They have been equipped with a (second-generation) dynamic vision system based on the European microprocessor system 'transputer' that was conceived as network processor with four direct links for communication to neighboring units (see Fig. 4, lower part).

The software for communication and for the application to vision in a network of up to 60 transputers has been developed by UniBwM [Dickmanns et al. 1993; 1994], while the equipment of both vehicles with hardware for measurement and control was done by DBAG. However, the two bifocal arrangements of 'finger-cameras', (the 'vehicle-eye' with one *d.o.f.* in yaw) for both the front and the rear hemisphere were designed and built by UniBwM (see Fig. 3). In the lower left corner the figure shows the optical properties of the system: L_5 is the distance in meters at which one pixel covers 5 cm orthonormal to the viewing direction. Since standard lane markings are 12 cm wide, in general, L_5 may be interpreted as the distance up to which visual lane recognition should work reliably.

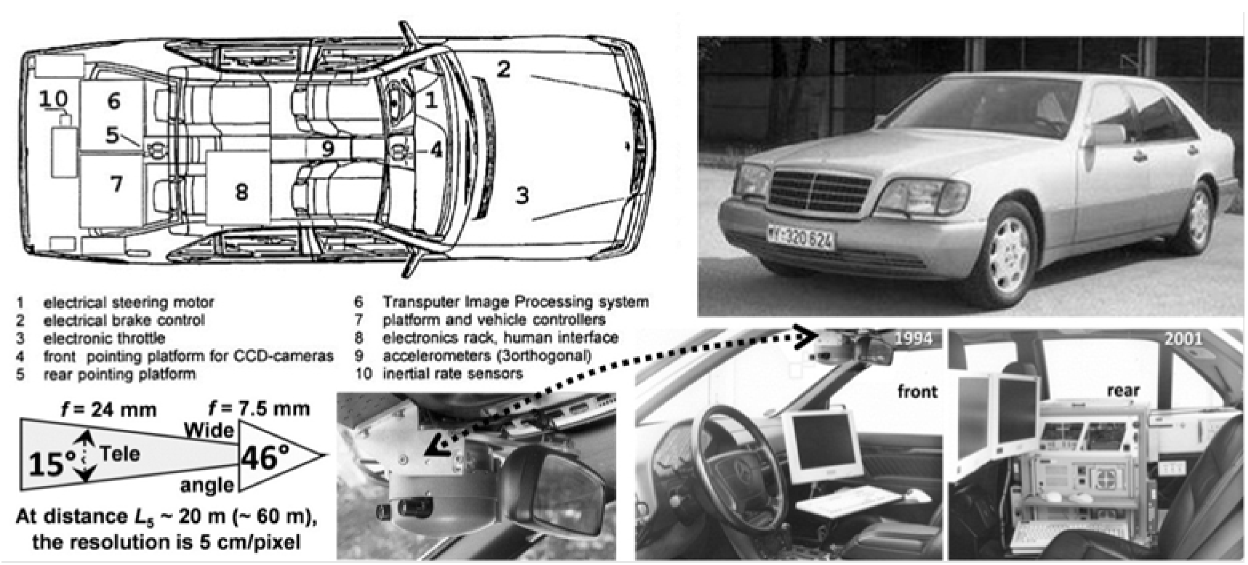

Figure II.3: VaMP 1994: (top left) components for autonomous driving; (right) VaMP and view into the passenger cabin (bottom); (lower left) bifocal camera arrangement (front) on yaw platform.

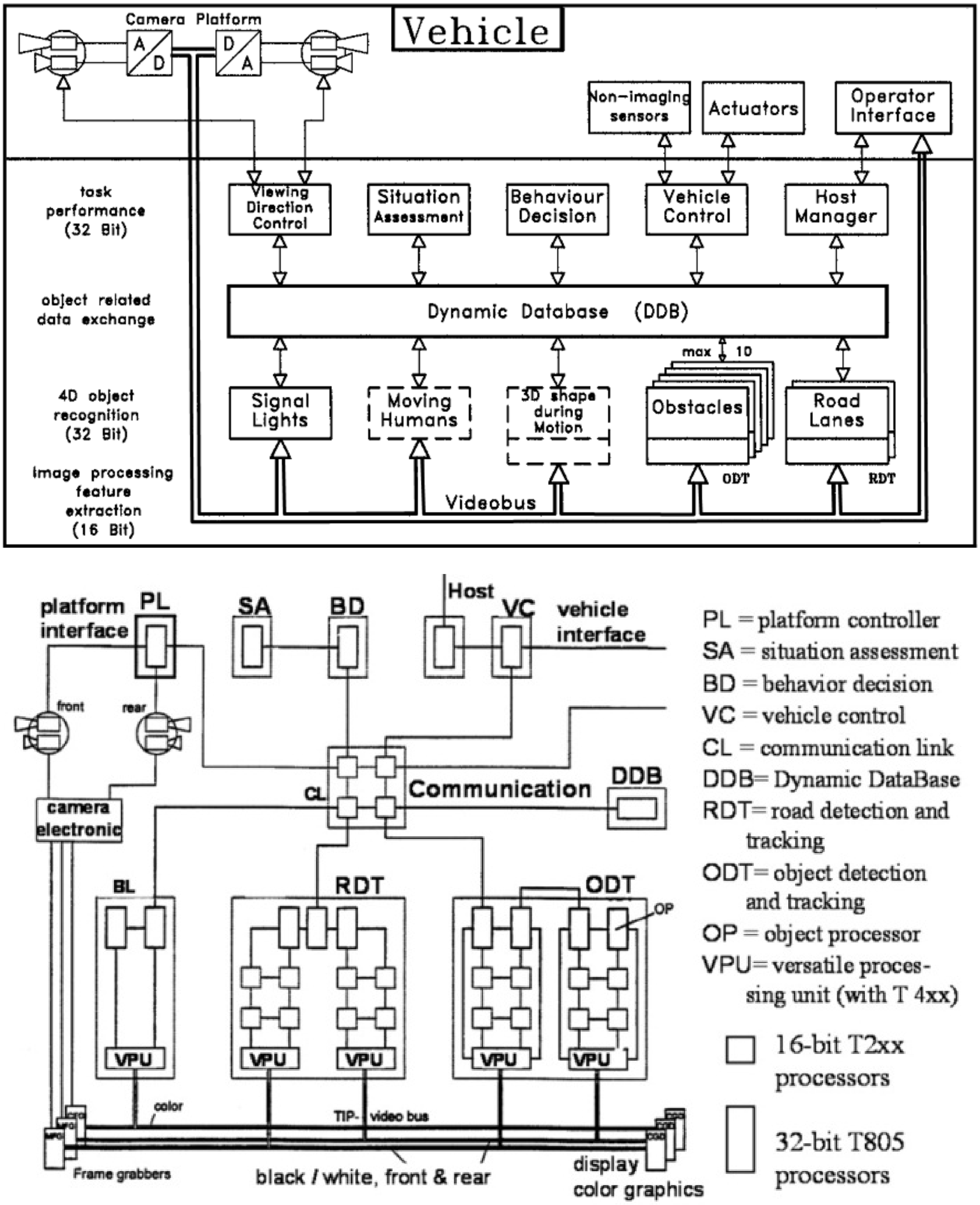

Figure II.4: Overall system architecture of the second-generation dynamic vision system based on transputers (about 60 in total) in VaMP; (top) functional structure with feature-, object-, and situation level, (bottom) structural arrangement of the transputer elements. (For more details see **www.dyna-vision.de**).

In the top part of Fig. II.4, the structuring of the system is shown in terms of objects and actions performed: The lowest level is image distribution to groups of specialist-processors for feature extraction (16 bit, squares in lower part) and the generation of hypotheses for real-world objects (32 bit, rectangles). New object hypotheses are checked internally over a few image cycles until they are published to the rest of the system in the dynamic data base (DDB) including the best estimates for shape parameters and object states. The reduction in volume for data (from pixels / features to object representations) is two to three orders of magnitude. This allows the processes for situation assessment, behavior decision and control output on the next higher system level (above the long horizontal rectangular bar in the upper part of Fig. 4) to handle even complex situations with several lanes and other vehicles. The processes shown in dashed lines below the DDB for 'moving humans' and '3D shape during motion' have been tackled by PhD-students [Kinzel 1994; Schick 1992], but computer performance was not yet sufficient for running the algorithms in real-time.

For the electric power needed in addition to the 12-Volt basic system, a 24-Volt power generator had been installed in both vehicles. In VaMP part of the electronics and transputer system was installed in the rear back seat for more easy access during development testing, so that only the front right seat was available for one guest; in VITA2 all electronic equipment was buried in the trunk so that three guests could be afforded on board for demo drives. For this reason, several of the transputers in VaMP were replaced by more powerful processors. In addition, VITA2 had additional cameras mounted directly on the vehicle body and looking to the side for checking objects directly at the side of the vehicle. The signals of these cameras were not used in the situation assessment software developed by UniBwM.

II.3 The final demonstration in Oct.1994 near Paris

In the framework of the Prometheus project, work on computer vision for road vehicle guidance has been picked up by several automotive companies and became more stable in cooperation with groups from a variety of university-institutes all over Europe. They all worked hard for the final demonstration with their test vehicles in the fall of 1994 near Paris. Intermediate exchanges and internal Pro-Art conferences showed that the group Daimler-Benz / UniBw Munich clearly led the way. In 1992 the test vehicle **VaMoRs** of UniBw Munich was the first road vehicle worldwide allowed to do test driving on any kind of public roads in standard public traffic. This was possible only because this vehicle had a 'military' license plate (Y-...) and did not need any permit from civil institutions; the officer responsible for safety aspects and for licensing of military vehicles had observed the progress made in autonomous visual guidance over six years until he agreed to test the autonomous system in public German road traffic. He had appreciated the care of the safety crew always on board; a single person was not allowed to do this type of testing. Early in the year 1994 also **VaMP** was allowed to drive autonomously on public roads.

Both vehicles together, **VITA2** and **VaMP**, formed the 'Common European Demonstrators' CED 302 and CED 303 of DBAG. These were the only vehicles of all 'PROMETHEUS'-participants capable of driving autonomously by machine vision in three-lane public traffic. The following capabilities have been demonstrated in standard traffic on Autoroute_1 near the airport Charles-De-Gaulles (CDG) in Paris in September / October 1994 (in conjunction with IV'94) with guests on board [Dickmanns et al. 1994; Dickmanns 2007, Chap.11]:

- Road and lane recognition including curvature-parameters and lane widths [Behringer 1996];
- detection and tracking of vehicles ahead, both in the own and in the immediately neighboring lanes to the left and right; recursive (vision-only) relative state estimation to up to five other

vehicles has been achieved (monocular motion stereo, see Fig. II.5, [Thomanek et al. 1994; Thomanek 1996]).

- Road (lane) running at speeds up to 130 km/h, the maximum speed allowed in France.
- Convoy driving behind another vehicle at a speed-dependent distance, including full stop [Brüdigam 1994].
- Recognition of the traffic situation in the front and the rear hemisphere for lane changes, thereby keeping track of overtaking vehicles until they re-appeared in the front field of view.
- Performing lane changes autonomously after the safety pilot - by setting the blink light - had agreed to the decision for lane change that was then performed autonomously [Brüdigam 1994; www.dyna-vision.de , section 3.1.3.4].

Figure II.5: Five objects tracked in parallel by VaMP 1994

Roads with lane markings could be tracked at 12.5 Hz (80 ms cycle time) with four cameras on two yaw platforms (top left in upper part of Fig. II.4). Blinking lights (BL) on vehicles tracked could be detected with the subsystem in the lower left of Fig. II.4 bottom. In total, far beyond 1000 km of autonomous driving by machine vision have been performed on the Autoroutes around Paris in this effort. The International Symposium on Intelligent Vehicles (IV'94) allowed a direct comparison with other activities in the USA and in Asia; it showed that the European effort and the 4-D approach to visual guidance of road vehicles had resulted in a leading position in the field.

A survey of the functionality of the 4-D approach allowing this level of performance is shown in Fig. II.6. The feedback of prediction errors allows much more efficient feature extraction. Early jumps to object hypotheses (maybe several alternatives in parallel) allows search for additional features in certain image regions and pruning of alternatives if these features are not detected in several consecutive images. It was this 4-D approach − requiring no storage of previous images and taking advantage of early jumps to hypotheses on real-world objects (stationary or moving) which could not be falsified in the sequel – that made the difference to all other approaches investigated during the project.

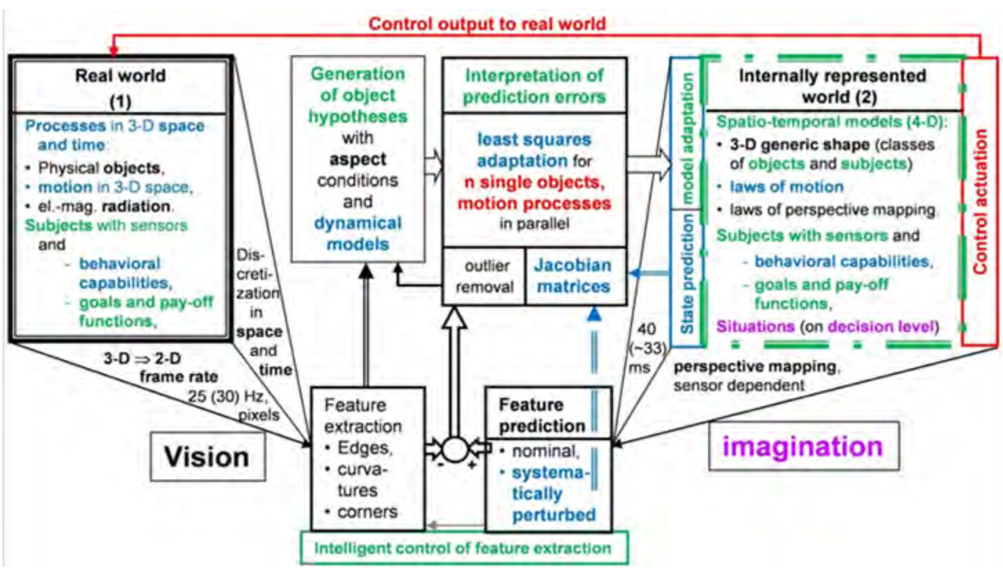

Figure II.6: Functional scheme of the 4-D approach developed by UniBwM allowing autonomous driving on public roads since 1992 [for details see www.dyna-vision.de].

Even a complex maneuver like a '**two-fold lane change**' on a busy three-lane Autoroute has been performed autonomously as documented in the video clip Nr.18 in www.dyna-vision.de. VaMP drives in convoy mode behind a bus in the rightmost lane. When the neighboring lane to the left is detected as free in the rear hemisphere, VaMP asks for the allowance to make a lane change. The safety driver then checks the scene and sets the left blinker as sign of his agreement to the maneuver. VaMP starts the lane change maneuver and accelerates. Suddenly it notices the bus in front doing the same: It also starts changing lane to the left! VaMP continues performing the lane change but takes back the throttle to do convoy driving in the center lane. Since there is another lane to the left, it starts checking the rear hemisphere whether the lane is free. Since it is detected as free, VaMP asks for the allowance to do a second lane change which is performed after it notices the blinking light set by the safety driver. This time the new lane remains free and VaMP accelerates for passing the bus. When it discovers the bus in the rear hemisphere at a sufficiently large distance backward it asks for a lane change to the right, which is performed after the same procedure in opposite direction.

It has to be kept in mind that these maneuvers could only be performed under favorable environmental and lighting conditions. Only edge features and adjacent average gray values have been used. The dark area underneath the vehicles has turned out to be the most distinctive feature. The capability of detecting and tracking homogeneous regions has been found to be the next most promising feature for object recognition. However, the capability of performing most basic maneuvers for guiding road vehicles autonomously by machine vision on special roads has been proven by VaMP and VaMoRs.

The costs of the experimental vision system were still higher than those of the basic vehicle. So the next step in developing vision systems for practical applications would be to integrate the results onto more powerful new processors with all optional behaviors accessible on demand by software control.

II.4 The European follow-on project 'CLEOPATRA' (1995 ÷ 1996)

When the second-generation of European transputer systems failed to appear in the mid-1990s, the commercial-off-the-shelf (COTS) US Power-PC by Motorola (MPC) with tenfold the computing power of the early transputers allowed switching from half to full video frame rate (of 25 Hz, 40 ms cycle time, 320 x 256 pixels). At the same time the number of processors needed in the UniBwM vision system could be reduced by a factor of five for the same level of performance. A first step in this direction has been achieved in the follow-on EC-project CLEOPATRA together with Daimler-Benz in the years 1995/96. While road detection and tracking (RDT) remained on transputers (center of Fig. II.7), object detection and tracking (ODT) was shifted onto the MPC (lower right corner) [Thomanek and D.Dickmanns 1992].

The new system, containing 4 MPC (instead of transputers 4 x T805 + 8 x T222), not only ran at half the cycle time (40 ms) but also allowed an additional process for object recognition running in parallel. As the two segmentation algorithms used different ideas for the detection of obstacles, this has led to high robustness by redundancy. In two video cycles of 40 ms up to five objects could be tracked with one MPC. Object detection in ODT was achieved in 26 vertical search windows covering about one third of the image with gradient masks of size 5 by 3 pixels. Up to 180 edges may have resulted which were grouped into up to twenty contours; from these, up to five objects were extracted, each characterized by 18 attributes. At 25 Hz evaluation rate this results in 1800 Bytes/second (B/s) data rate per object, i.e. a maximum of 9 KB/s output data rate per '4-D Object

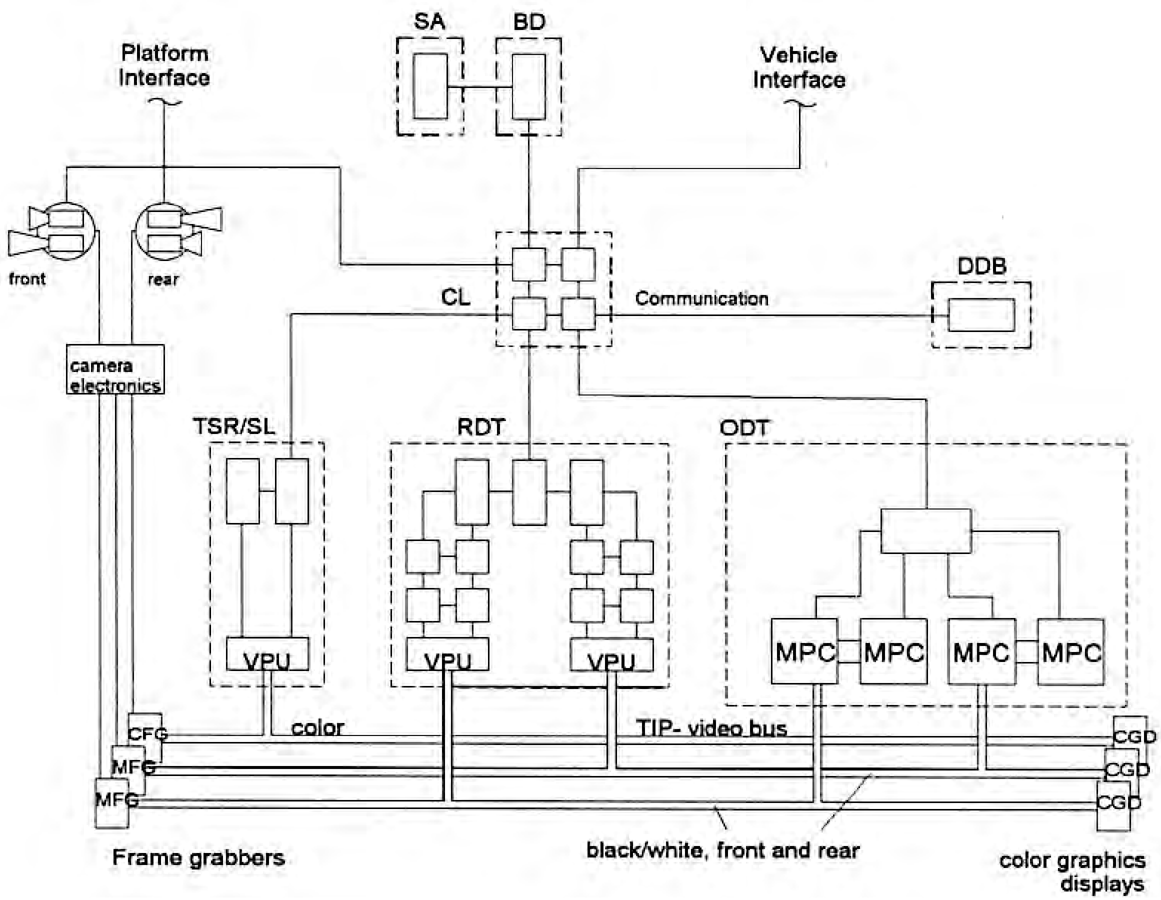

Figure II.7: Transputer / MPC system architecture for visual perception and control; intermediate system during the transition to more powerful microprocessors in 1995.

Processor' (OP) as compared to the image input data rate of 2.048 MB/s per image; this corresponds to a data rate reduction of 228, hopefully with little loss of information with respect to objects in the scene depicted. More details may be found in [Thomanek et al. 1994; Thomanek and Dickmanns 1995; Thomanek 1996]. All data transfers from the sensors to the processors and from there to the control devices distributed over the vehicles continued to be handled by specific transputer subsystems (not detailed in Fig. II.7; see part III).

A long-distance test drive by VaMP

After Carnegie Mellon University (CMU) in the USA had shown in 1995 their capability of driving "Hands-off " all across America from the East- to the West Coast with their **partially autonomous vehicle 'NavLab 5'**, UniBwM decided to demonstrate the capabilities of **VaMP by driving fully autonomous** to a project meeting from Munich to Odense (Denmark, near Kopenhagen). The goal was to collect statistical data on the performance capabilities of the new system in long-distance travel on the Autobahn, still confined to black-and-white images and edge feature extraction with adjacent average gray values as the only image data used for perception of the environment. On this basis the next development steps were to be considered for the third-generation vision system intended to start after 1996. A condensed summary of the results is given in Fig. II.8. Only the front hemisphere has been observed and analyzed with the new vision system during this mission; lane

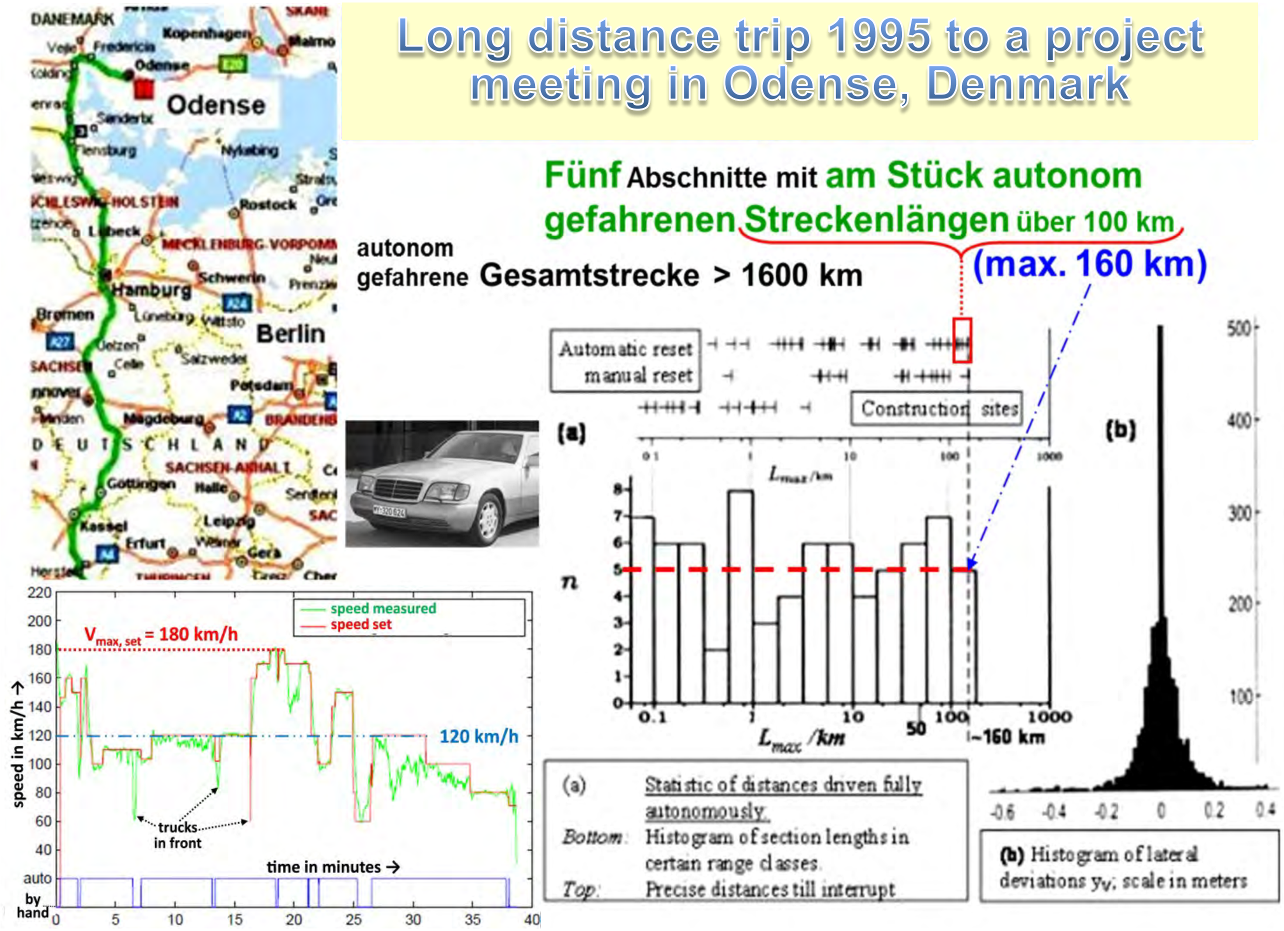

Figure II.8: Some results of the fully autonomous (lateral and longitudinal) long distance test drive of VaMP in 1995 from Munich to Odense (Denmark): (upper left) map of northern part of route driven; (lower left) speed profile (km/h over minutes) in the northern plane with maximum close to 180; (right) histogram of lateral deviations: number of events stored over maximum offset in meters; (center (a)) statistic of distances in km driven fully autonomously: number of cruise phases in distance classes (rectangles). The longest of five autonomous drive phases of more than 100 km was close to 160 km (upper right, red rectangle).

changes have been performed autonomously after the safety driver asked for one by setting the blinking lights.

The many short driving phases with frequent interruptions and resets (center (a), top left) are due to construction sites where in Germany yellow lane markings overrule the remaining standard white ones; in b/w-images they look the same, so that the system is confused and quits. It will fail again when an automatic reset is done; so on construction sites the human driver had to take over until it was finished. In standard road sections the automatic reset capability often helped regaining the autonomous driving status (top line in center a). One case may be seen around minute 17 in the lower left sub-figure, where the 'auto'-line at the bottom continues steadily even though the automatic braking behind a truck in front from 120 to 60 km/h was answered by the safety driver by setting the desired speed up to 160 km/h. After achieving this speed, the desired speed was increased twice to 170 and 180 km/h; in this phase at around minute 18 a manual interrupt occurs (see abscissa). This may be due to the missing range capability of the vision system mistrusted by the safety driver. The desired speed was taken back to 170 and then to the standard 120 and even to 100 km/h before raising it back to 150 until another slow vehicle was met at around minute 25.

The accuracy of lane following is shown in the right sub-figure: With most values stored below 0.2 m this is equivalent to or even better than the usual human driver will perform in general. In total, more than 1600 km have been driven autonomously during this test mission. About 95 % of the distance tried could be handled by the system without human support. The essential points derived for improving performance of the next-generation system with computing power increased again, were the following:

- Add color processing capability for at least one of the cameras of the multi-focal system.
- Install error detection capabilities on all levels from feature detection over object tracking to situation asessment; improve automatic reset capabilities by increased exchange of information between the levels.
- Increase viewing range L_5 to 250 to 300 m (one pixel corresponds to 5 cm orthogonal to the viewing direction, ~ 0.2 mrad / pixel); this entails the need of inertial stabilization at least for the tele camera. A large simultaneous field of view is needed in parallel.
- Once fast active gaze control is available, it should be used also for gaze fixation on feature sets of special interest and for saccadic shifts of attention.

These requirements led to the concept of "**E**xpectation-based, **M**ulti-focal, **S**accadic" (EMS-) vision and to a bifurcation in the development of vision systems for guidance of ground vehicles in Germany.

II.5 Bifurcation in the development of vision systems

Because of the high initial costs of dynamic vision systems with higher performance levels, the group of UniBwM preferred to develop a system that was capable of handling a variety of tasks and that could adapt to different task environments and situations. Like a human driver, the system should be capable of driving on different types of roads with and without lane markings and with different surfaces (sealed with concrete, bitumen, or cobble stones, and unsealed with gravel or partially covered by grass). Beside road running also detection and recognition of cross roads with the parameters of the intersection (angle and road width) should be possible. First steps in these directions have been achieved by VaMoRs in parallel activities in the defence realm [Mysliwetz 1990; Behringer et al. 1992; Hock 1993, Mueller 1992; 1996].

Our industrial partner DBAG intended to continue developing simple systems for driver assistence with cameras mounted directly onto the vehicle body (lower part of Fig. II.9); for the reasons given in the upper part of the figure, UniBwM decided to follow the path nature had taken millions of years ago by

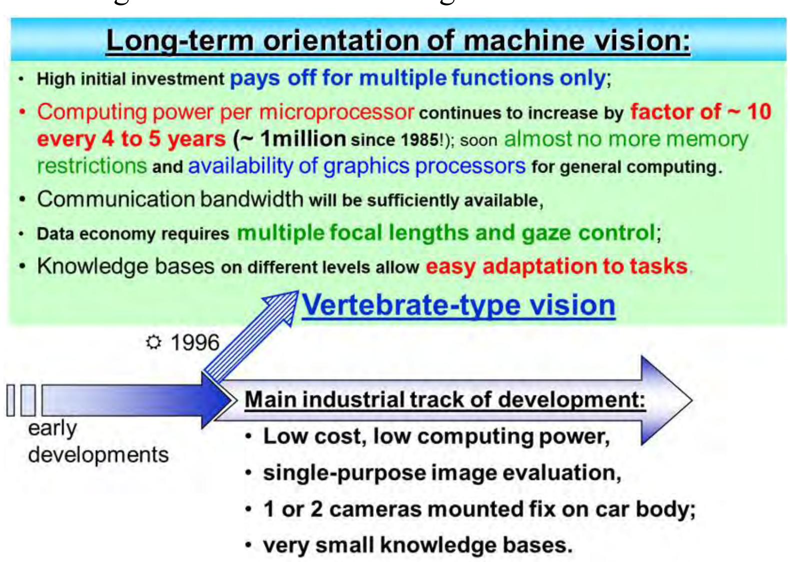

Figure II.9: Bifurcation in the development of vision systems for road vehicle guidance.

vertebrate-type vision that has been so successful. However, this is to be understood merely with respect to functions realized; of course, structure and hardware realizations in silicon had to be different from those in carbon that nature had available as building blocks only.

Since an intimate exchange with US-American researchers had developed in the field of real-time machine vision for ground vehicles over the last years, the ministries of defense in the framework of an existing Memorandum of Understanding (MoU) formulated a joint project dubbed "AutoNav" in which the best components of each side should be merged. The goal was to develop a "scout-type" vision system capable of guiding vehicles (with wheels or tracks) through networks of minor roads including off-road passages and the necessary transitions. Beside obstacles above the driving plane (dubbed 'positive') also 'negative' obstacles (like ditches or large holes) should be detected, tracked and avoided using stereo vision.

Therefore, the cooperation with Daimler was finished in 1996 in order to concentrate on the third-generation dynamic vision system in cooperation with US-American partners. On both sides of the Atlantic ocean also industrial companies have been involved; on the German side this continued to be Dornier GmbH (and follow-on), with whom a cooperation in the defense area has been successful over more than a decade. These developments will be discussed in Part III of this survey.

II.6 Conclusions

The broad support by the EUREKA-project PROMETHEUS and the intimate exchanges between European automotive industry and university groups working in the field of computer vision applied to guidance of road vehicles has resulted in fast progress towards practically useful machine vision systems based on Commercial-Off-The-Shelf (COTS) digital microprocessors. The increase in computing performance by at least two orders of magnitude with reduced constraints in geometrical size and electrical power needed has allowed final demonstrations of fully autonomous driving in standard public traffic on three-lane highways with guests on board. The full speed range allowed on French Autoroutes up to 130 km/h could be handled including free-lane running, convoy driving, and lane changes.

As basic structural elements in the 4-D approach to machine vision for the guidance of road vehicles, three levels have emerged: **1.** The (image) **feature level** including all original measurement data and their grouping from different types of sensors (including video images, inertial as well as odometric measurement data, and states of subsystems for measurements and control application. **2.** The **object / subject level** for describing real-world objects in 3-D space and time. **Subjects** have been defined as objects with specific capabilities of measuring properties of the environment and of other objects / subjects, of combining these data with stored data from previous experiences, and of deriving proper control actuation in temporal loops. Goals and quality levels for actions performed are the basic elements for deriving decisions on which control to apply. **3.** The **situation level** taking all aspects of environmental and situational conditions into account for favorable control actuation over time (maneuver elements and maneuvers, transitions between mission elements etc.).

The long-range trip to Odense has been used to derive the most essential steps for the third-generation dynamic vision system based on COTS-components. Expectation-based, Multi-focal, Saccadic (EMS-) vision with growth potential close to the level of human vision systems has been defined as next goal. Since German automotive industry went in a different direction, cooperation with US-American partners in the framework of a Memorandum of Understanding in the defense realm has been chosen. Development steps and results are discussed in Part III of this survey.

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www.dyna-vision.de : Website with many details about the development of real-time machine vision systems at UniBw Munich, including dozens of video-clips in a variety of applications.

Annex 1: Time and milestone plan of UniBwM for the first years of Pro-Art

Zeit- und Meilensteinplan

Methode, Aufgabengebiet — Bearbeitungszeitraum	88	89	90	91	92	93	94	
1. Integrierter Ansatz für die Merkmalextraktion in Echtzeit			∇1		∇2		3∇	M
1.1 Weiterentwicklung des Ansatzes zur gesteuerten Korrelation								
1.2 Auflösungspyramiden zur Verbesserung der Merkmalextraktion								
1.3 Untersuchung von Textur und Farbe zur Verbesserung der Merkmalextraktion								
1.4 Erarbeitung angepaßter Hardwarestrukturen								
1.5 Weiterentwicklung aufgabenspezifischer Programmgeneratoren								
2. Systemuntersuchungen zu Kamerakonfigurationen und -steuerungen			∇1		∇2			K
2.1 Flüssigkristallblende								
2.2 Kamerakonfigurationen und Blickrichtungssteuerung								
3. Modellbanken				∇1				B
3.1 2D- und 3D-Formen								
3.2 dynamische Modelle								
3.3 Umweltschemata								
4. Situationserkennung: Hypothesenbildung, Parameteranpassung, Modellauswahl								S
4.1 Fahrbahn und Umgebung			∇1					
4.2 Einzelobjekte					∇2			
4.3 Gesamtsituation						∇3		
5. Verhaltensrepertoire								V
5.1 Spurfahren		∇1						
5.2 Reaktion auf Hindernis in der Spur				∇3				
5.3 Spurwechsel (Ein-, Ausfahrt, Überholen)			∇2		∇4			
5.4 Kollisionsvermeidung								
5.5 Monitor- und Warnfunktionen			∇5		∇6			
6. Weiterentwicklung des integrierten Ansatzes								I
7. Einheitliche Soft- und Hardwarekonzepte zur Wissensverarbeitung								E
7.1 Parallelisierbarkeit			∇1					
7.2 Eignung von Programmiersprachen				∇2				
7.3 Eignung von Mehrprozessorsystemen								
7.4 Realisierung und Erprobung eines Konzeptes								
8. Schaffung und Weiterentwicklung von Experimentierhilfen								H
8.1 Ausbau des Simulationskreises und des Experimentierfahrzeugs (VaMoRs)								
8.2 Geräte, Programme und Simulationsmittel für die Bildverarbeitung								

Annex 2

The first three visually guided vehicles of Daimler-Benz AG (DBAG) with vision systems from UniBw Munich

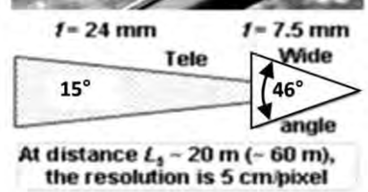
1. **BMFT**-Project ‚**Autonom Mobile Systeme‘** (AMS), 1986 – 88: Equip a ‚Spurbus‘ of DBAG with the image sequence processing system ‚**BVV2‘** of UniBw Munich, existing in **VaMoRs**. Demonstrate **autonomous visual guidance** and **stopping in front of an obstacle** from speed driven of 40 km/h in 1988 on test track Daimler-Rastatt**.**
Video 07 **VaMoRs Stat.Obstacle Rastatt 1988** in www).

2. EUREKA-Project ‚**Prometheus‘** (PRO-ART), 1987 – 94:

2.1 Equip a 7-t van ‚**VITA**‘ of DBAG with an advanced industrial copy of the image sequence processing system ‚**BVV2‘.** Demonstrate **autonomous visual guidance** and convoy driving behind another vehicle at speeds up to 60 km/h in 1991 on the FIAT- test track near Torino.
Video 09: **VisionBasedStopBehindCar Torino 1991** .

2.2 Equip the ‚**C**ommon **E**uropean **D**emonstrators‘ (CED‘s) of DBAG, one each ‚Mercedes SEL-500‘ of DBAG and of UniBwM, with the newly developed ‚Transputer-Systems‘ with up to 60 parallel processors. The basic software for communication and image sequence processing has been generated by UniBwM. Both vehicles were equipped with two bifocal ‚VehicleEyes‘ (see fig. bottom right), one each looking to the front and to the rear. This allowed detecting and tracking of two vehicles in both the own and the immediately neighboring lanes to the left and right; the relative state to all of these vehicles has been estimated recursively by vision only (up to 12 vehicles in total).

Twin vehicles VITA2 and VaMP **(1994)**



video 19 **Ground vehicles learn to see 1986-95**).

In October 1994 the CED‘s demonstrated as the only vehicles of the project autonomous driving in standard 3-lane traffic on Autoroute-1 near the airport Charles-de-Gaulle of Paris at speeds up to 130 km/h and with guests on bord. Both free-lane and convoy-driving as well as autonomous lane changes have been demonstrated.

Video 18 **TwofoldAutonLaneChangeParis 1994** .

for details see
www.dyna-vision.de