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ATLASCAR – Technologies for a Computer Assisted Driving System on board a Common Automobile

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Abstract—The future of intelligent vehicles will rely on robust information to allow the proper feedback to the vehicle itself, to issue several kinds of active safety, but before all, to generate information for the driver by calling his or her attention to potential instantaneous or mid-term risks associated with the driving. Before true vehicle autonomy, safety and driver assistance are a priority. Sophisticated sensorial and perceptive mechanisms must be made available for, in a first instance, assisting the driver and, on a latter phase, participate in better autonomy. These mechanisms rely on sensors and algorithms that are mostly available nowadays, but many of them are still unsuited for critical situations. This paper presents a project where engineering and scientific solutions have been devised to settle a full featured real scale platform for the next generation of ITS vehicles that are concerned with the immediate issues of navigation and challenges on the road. The car is now ready and running, and the data gathering has just begun.

I. INTRODUCTION

WHEN people think about cars of the future, the first sight is a driverless vehicle moving at high speeds in crowded traffic clusters, as popularized by science fiction. This image may indeed contain some of the future trends in intelligent transportation, but it hinders a vast set of concerns in the fields of perception, security and behavioral based motion that has been attracting the attention of researchers and engineers in the recent decades.

Although fully autonomous cars are the apparent long term goal, this is not the unique pathway to pursuit, since many drivers will remain attached to the will, and pleasure, of deciding most of the vehicle maneuvers and behaviors on the road. On the other hand, what all drivers will not dismiss is the need for security and assistance in more demanding traffic conditions, and even preventive automatic actions will be tolerated in case of accident imminence due either to external agents on the road, or driver failure due to distraction, fatigue or misinterpretation of perception.

Bearing all these concerns in mind, the group for Robotics

and Automation from the Department of Mechanical Engineering at the University of Aveiro, Portugal, has setup and adapted a common commercial automobile to provide a versatile framework to develop studies and research on Advanced Drivers Assistance Systems (ADAS), and ultimately allow for autonomous decisions, envisaging at the long term the very autonomy itself. This activity is inserted in the ATLAS Project which originated some time ago on the robotics competition framework [1], and from the early small scale (1:5) cars that outperformed their competitors several years in a row since 2006, the project now grew in scale and the full size ATLASCAR has been developed [2].

The general philosophy has been to enrich the car with different kinds of sensors, to account for different types of perception and cover for redundancy, and thus allow different types of research in data fusion and interpretation for the future developments in this project.

The challenge in developing this system comprises many scientific issues in data acquisition, processing, fusion and interpretation, as well as efficient storage and dataflow, but also many other engineering concerns have risen such as adequate architecture for computational process inter-communication.

The purpose of the vehicle transcends the mere massive collection of data, which it can do very well, but also use that data to create models for enhanced perception and data fusion. The main points driving this project are:

1) Sensorial redundancy using different physical principles.
2) Capability for massive data logging, including multiple sensor time and spatial registration.
3) Scalability of hardware and software solutions.
4) Power autonomy and safety both by surging mechanical power from the car engine and proper interface for using wall socket power when parked.
5) Maintain the car's legal conformity and compatible with human driving.

II. MECHANICAL/ELECTRICAL INTERVENTIONS

The chosen platform was a standard gasoline-powered, manual gear, Ford Escort Wagon (Fig. 1).

The intervention had two main concerns: installing sensors, computers and cablings, but also set up and install a system for power generation and distribution for sensors and computers.

The set of sensors is currently limited by the availability in the research team lab, but accounts already for the following: cameras for wide angle and foveated vision

mounted upon a pan-and-tilt unit for active perception purposes, a custom 3D laser, a stereo camera with a dual base line for enhanced 3D perception, a thermal camera, a 2D laser, a GPS receiver, and an Inertial Measurement Unit (IMU). Other sensors are on developing phases or planned, namely to monitor the driver actions (inertial and contact units for pedals, gear and wheel drive) and cameras to monitor driver gaze and level of awareness.
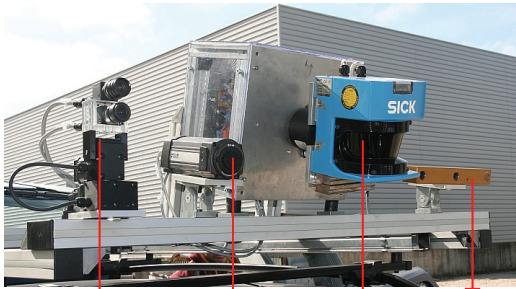

Fig. 1 – The car with external sensors shown.

| Foveatead and active vision unit | Thermal | 3D laser | Stereo camera |

To ensure power supply under most circumstances, a versatile solution was implemented using an auxiliary generator driven by the vehicle propulsion engine, and also keeps the car power circuits independent from the newly installed unit, in a similar way as performed in the Stanley and Highlander vehicles in the DARPA Grand Challenge [30][31]. This was achieved by redesigning the electro-mechanical power generation inside the engine compartment (Fig. 2, top). This redesign consisted of relocating the original alternator to a higher position (Fig. 2, bottom) in order to get room for the new generator, which supplies 1.2 to 2.5 kW (depending on engine rpm's), the DC output of which is then converted, through an inverter, to a higher-voltage line (220V, AC).

The power chain ends at an Uninterruptible Power Supply (UPS) to ensure proper power stabilization for all sensors and computers. Fig. 3 shows a diagram of the power distribution and switching onboard the vehicle, along with the main component connections.
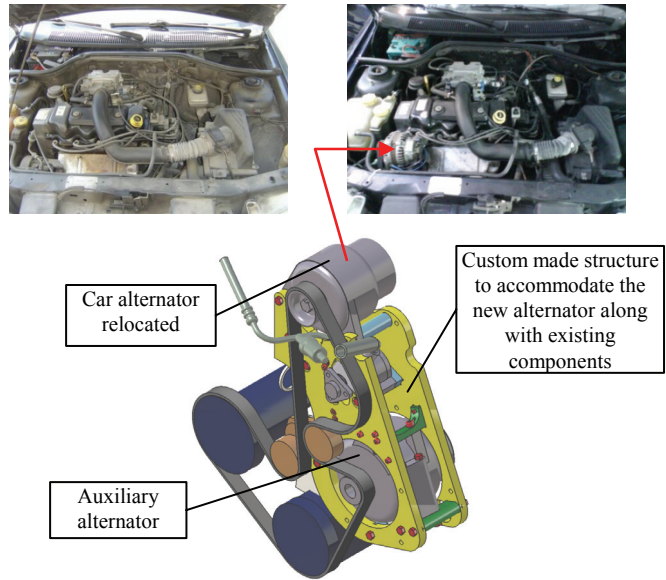

Fig. 2 – The engine compartment before and after the power alternator modification (top), and a schematic illustrating the alternator relocation and the extra generator (bottom). The auxiliary generator is not visible.

The UPS is the interface from which stems the power distribution to all devices added to the car. The electric panel is composed of three modules, where a Mitsubishi FX2M PLC is included to provide the interface to two power regulators at 12VDC and 24VDC which feed different types of devices and sensors. Currently, the task of the PLC is mainly to allow a software-based reset and power switching capabilities of sensors and other hardware (Fig. 3). Computers and screens are supplied directly from the UPS. Fig. 4 shows the components as installed in the car.
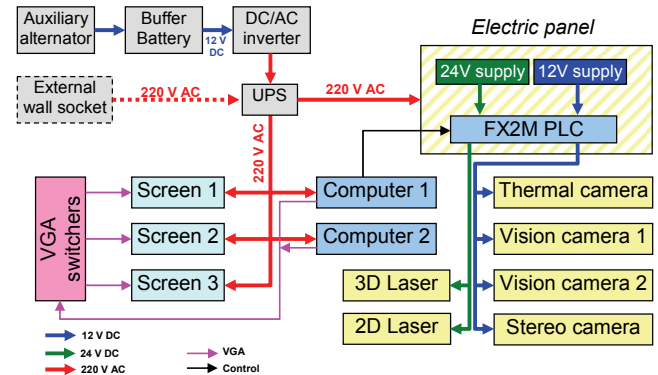

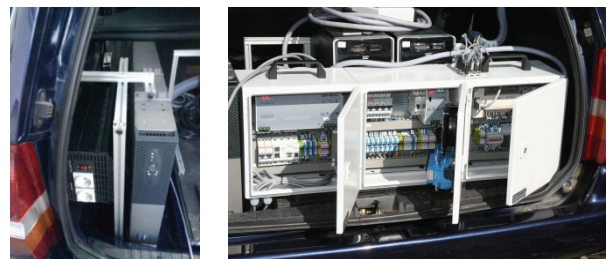Fig. 3 - Diagram of the electric power supply system onboard the vehicle.

Fig. 4 - (Left) a power inverter plus an UPS (220 AC) and, (right) the general electric panel, including PLC and 12 & 24V DC power supplies.

III. Vision Sensors and Perception

Onboard perception will rely on multiple sensors to allow redundancy and advanced studies in sensor interpretation and fusion. One of the most relevant types of perception used is vision, due to its passive nature. Advanced vision based algorithms are currently being developed.

A. Inverse Perspective Mapping

Over the last years, many researchers have employed the Inverse Perspective Mapping (IPM) technique in order to ease the road recognition process. Pomerleau's RALPH defined a trapezoid in the input image. This trapezoid is then transformed into a low resolution birdview of the road by a "simple geometric transformation (…)" that "(…) requires no explicit feature detection" [3]. It is also said that "the parallelization of road features (…) is crucial for the second step of RALPH processing, curvature determination" [3].

Bertozzi and Broggi also advocate the advantages of perspective effect removal "The perspective effect associates different meanings to different image pixels, depending on their position in the image. Conversely, after the removal of the perspective effect, each pixel represents the same portion of the road, allowing a homogeneous distribution of the information among all image pixels." [4]. More recently, Mcall and Trivedi have employed steerable filters for lane markings detection and argue that "Filtering on the inverse perspective warped image allows a single kernel size to be used over the entire area of interest." [5].

The technique consists of transforming the images into a reference frame where the perspective effect is corrected, usually defined based on the road plane and so that the resulting images become a top view of the road. One of the advantages is that the subsequent perception algorithms can be computed in 2D, which significantly eases tuning the size of convolution filters [5], the stability of neural network's inputs [3], or the detection of features of interest [4].
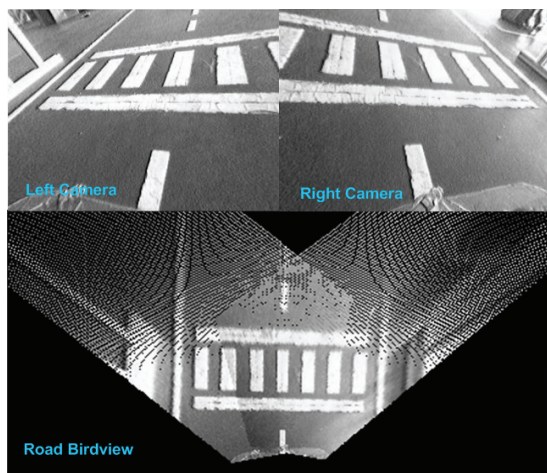

Fig. 5 - Example of IPM resultant image (bottom) obtained after applying the operation to two cameras (top).

The authors' research group has developed a highly flexible kinematics/optical model for the calculation of IPM, including the real time fusion of multiple camera images.

This capability permits the implementation of visual multi-tasking, i.e., cameras may be employed for other different tasks (for example using the pan and tilt unit to perform visual tracking), while the system is able to continue to compute the IPM regardless of the cameras pose [6], as shown in Fig. 5.

B. Visual Search and Attention Mechanisms

Visual search is a mechanism that occurs during the pre-attentive stage of a vision system and is responsible for the selection of particular features for posterior in depth processing. Studies suggest that only a small set of basic features like color, size, motion, and orientation are used in a visual search, which, as stated in [7], results in reaction times that are somewhat independent of the amount of objects in display. This weak or inexistent correlation between the amount of features and reaction times seems to imply that they "… only use information about the categorical status of items. In orientation, that means that it is only easy to find a target if it is uniquely steep, shallow, tilted left or right" [7].

Simple color recognition may work as a good attention mechanism. Ude et al. [8] use it as sign detectors that deploy attention on a particular image blob. The object to be followed can be physically tagged with color markers and these will capture the system's attention. Alternatively, the object's dominant color can be set as one worthy of attention. Color recognition is performed in the HSV color space.

Another possible attention capturing property is based on movement detection. Optical flow techniques try to find corresponding pixels (or features, for that matter) in two sequential frames. Using this correspondence, a vector for the movement of each tracked pixel/feature can be obtained [9]. Currently, the authors have implemented color and motion detection techniques as attention capturing mechanisms. For color, HSV color space fixed thresholds are used and motion is detected using a sparse set of features and the Lucas-Kanade optical flow technique. These techniques are capable of significantly reducing the initial search space of possible objects of interest for an ADAS system.

C. Peripheral/Foveated perception

Object recognition using computer vision is a complex problem. View-based strategies are receiving an increasing attention because it has been recognized that 3D reconstruction is difficult in practice and also because of some psychophysical evidence for such strategies [8]. To have a detector that can recognize an object and track it from every possible view is still a very demanding challenge. Furthermore, the dimension of a database to contain all of the object's important points of view should be immense, unleashing problems concerned with real time processing.

Our group proposes an alternative method [10] for tracking rigidly rotating objects based on Haar features

[11][12] that are used as a single view identifier and complemented by template matching to track a previously classified object. Templates are self-updated when Haar features fail and redefined when they succeed, allowing the object to freely move and rotate, and overcoming temporary failures of the identification module.

One of the setups onboard the ATLASCAR consists of a dual camera system mounted on a Pan and Tilt Unit which provides active perception capabilities. When a particular object raises attention in the peripheral view, wide lens camera, the system moves the cameras so that the object is positioned at the center of the second camera, with a narrow lens, allowing an in depth analysis of the object characteristics.

D. Thermal imaging

In general from dusk to dawn, in tunnels and other artificially lighted public places, drivers are normally requested by law to turn on the automobile's artificial lighting. During that period, the pupil is highly dilated and the eye becomes very sensitive to changes in lighting, which occur for instance when crossing with another car. At the same time, there is a greater lag in perception; guidance of the car may require constant head motion and faster reaction requiring higher levels of awareness and making cerebral stress and tiredness easily incipient. In order to assist the driver in these conditions, it is important to enable an artificial vision capable of perception in these low lighting conditions. Conventional vision systems normally lack the sensitivity, or more importantly the adaptive capability in variable lighting, that enables safe detection of pedestrians and their pets, for example. There is no global solution to this problem and that is why infrared imaging is a very promising technique to detect thermal signatures of interest.

A FLIR 320 infrared camera has been added to the sensor set installed onboard the platform. This camera is interfaced via Ethernet and data is transferred via the Real Time Streaming Protocol over TCP/IP connection. Data transfer between modules is that implemented in IPC [13][14][15], so Gstreamer [16] plug-in communicates with the camera and publishes the message. Fig. 6 shows a typical image retrieved during the night.

Fig. 6 - Raw infrared image taken at night.

IV. LASER SENSORS

A. Planar laser and obstacle tracking

To allow a fast and accurate perception of the imminent vicinities of the car, a Hokuyo UTM-30LX, 30 meters range, planar laser was installed. With this, navigation through nearby obstacles whilst avoiding collisions is a much easier task.

In order to estimate time to collision with obstacles and to allow for a dynamic path planning, knowledge of the dynamic behavior of other obstacles is required (moving cars, pedestrians, posts, etc.). The tracking algorithm starts off by clustering the laser data based on the spatial depth and angular disparity of consecutive measurements, allowing for segmentation of non colliding obstacles; then a specific data reduction algorithm [17] is applied to allow a faster and easier processing of data. Tracking is achieved by Kalman filtering applied to a constant velocity kinematics model with white noise errors, the white noise is intended to account for the highly time varying acceleration [18].

A search area for the most probable location of each object has been defined with the shape of an ellipse whose depends on the object size, velocity and occlusion time, centered at the estimated position. When an object first appears, meaning there's no match within the currently tracked objects, its search area is very large to allow tracking of objects that appear on the scene with initial velocity. The algorithm is able to track obstacles successfully even when occlusion occurs, as long as the occluded object's motion remains under modeled parameters. If this happens, the object is successfully identified once the occlusion condition ceases. If an obstacle remains occluded more than a predefined time, it is set as lost and removed from tracking.

B. Custom 3D laser

Most of the sensors installed onboard are passive, and ideally that is how it should be to guarantee trouble-free sensor coexistence. However, there are several limitations which can only be overcome by using active sensors, e.g. with a single time of flight laser rangefinder distances under most lighting conditions and to most materials can be obtained, there being presently no conventional passive counterpart.

Perception of the 3D environment facilitates navigation including obstacle avoidance and even environment modelling. With additional processing it is also possible to segment and identify in order to improve decision making. Technically, to date, the most viable solution to generate 3D data for driver assistance and automated driving is to use 3D laser range finders.

Though Velodyne now produces the HDL-64, which is a robust and eye safe 3D laser, it is expensive (around €60k) and has 26.8° vertical field of view, which is relatively small for having simultaneous short and medium range perception needed in urban environments. Because a solution considered ideal to most researchers is still lacking, several

research teams have proposed that a 2D range-finder may be converted at low cost into 3D with wide field of view [19][20][21][22][23][24].
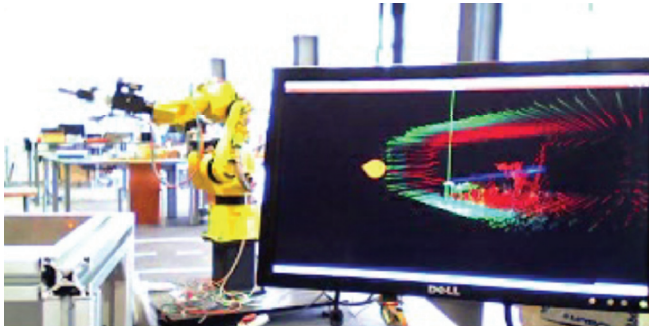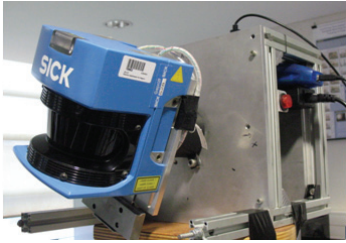

Fig. 7 - Custom developed 3D range-finder (top). Sample scan of a lab environment showing the real world and a 3D model on a computer screen.

The Laboratory for Automation and Robotics at the University of Aveiro has developed its own prototype solution for 3D range finding [21][25], in the form of a spinning forward looking 2D SICK as seen in Fig. 7. The scanner is rotated continuously by an additional controlled external shaft; a typical 3D scan is shown in Fig. 7. Both data acquisition and control of the external shaft are performed by a single module which interfaces with the IPC environment (section VII.A). Real-time analysis of 3D laser range data is presently a very important research topic [26].

V. VEHICLE PROPRIOCEPTION

A. Monitor driver actions

To monitor the driver's actions, but keeping the system easy to install without changing the vehicle structure, the current approach focused on the use of inertial sensors, as they need to be fixed only to the interest object, contrary to absolute displacement sensors such as potentiometers or LVDTs which need to be fixed both at interest object and at the vehicle structure. Modern inertial sensors are also more affordable than a combined system using displacement and force sensors.

Since high precision inertial modules have prohibitive costs, and because there is a lack of free space inside the vehicle, the team turned the attention to Micro Electro Mechanical Systems (MEMS), which are housed in very small packages and have a very attractive cost [27].

As there were no inertial modules small enough in the market, the team decided to develop custom five-axis inertial modules, based on one three-axis accelerometer and a two-axis gyroscope from ST Microelectronics. The result

is a $12 \times 21.2 \times 5.5$ mm^3 module that can be discretely attached to any moving parts controlled by the driver (pedals, steering wheel, hand brake and gear lever).
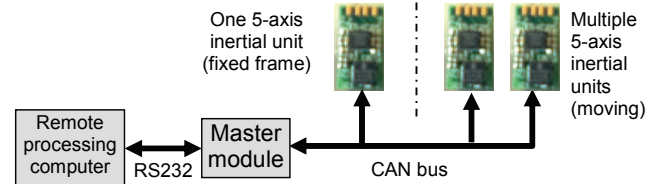

Fig. 8 Dual inertial systems to decouple individual part motion with vehicle global dynamics. Applied on levers and actuators moved by the driver.

To compensate for the module's lack of resolution (when compared to high precision inertial modules), but also to decouple global inertial perturbations, a redundant system was implemented where there is one, or possibly more, modules fixed to the vehicle frame, and one module attached to each moving part (Fig. 8). By using differential inertial techniques among the fixed modules and each of the moving units, decoupling individual motion from the global system dynamics is possible.

B. Attitude and localization measurement

The attitude of the vehicle is measured using a fixed Xsens IMU, composed by 3-axis gyroscopes, accelerometers and magnetometers together with a GPS receiver. It is important to notice that there is not the intention to implement a dead-reckoning system in this project to precisely locate the platform globally. Instead of that, the satellite navigation will only provide a rough estimation of the absolute position of the vehicle, together with an estimation of its speed and heading. The most important information that is required for the other sensors are the roll and pitch of the vehicle, as they directly affect the Inverse Perspective Mapping of the acquired image and, therefore, a high precision sensor was desired.

VI. SYNERGISTIC SENSOR INTEGRATION

Most state-of-the-art autonomous vehicles merge sensorial information from multiple sensors of similar nature; for example, several range sensors may all contribute to build and update an occupation grid based representation of the environment around the robot. Thrun *et al.*, [28], use three distinct maps for vision, laser and radar sensors and perform a separate analysis of the onboard sensor array based on the nature of the data collected by each sensor.

In the trend of some leading research, in the ATLASCAR project, the fusion of the information streaming from the sensors, regardless of the nature of the data, is now taking the first solid steps. This will lead to a multi dimensional description of the environment around the vehicle. Despite the expected difficulties involved in analyzing multidimensional data, the authors are convinced that there is an advantage in looking at the information holistically. This will be hardly achieved for all the possible objects on the scene and incites the use of attention mechanisms to

effectively select the objects of interest within the complete scene. By giving attention on few, yet promising, regions of the scene, one may then make use of the computational resources to perform in depth multi-sensorial analysis.

Up to now, the team has developed algorithms that are capable of extracting the RGB colored 3D profile of a given object. In the future, there is the intention to further extend this holistic internal representation to several other sensors. The authors believe that only in possession of the integrated information will it be possible to develop ways of synergistically combining the intrinsic value of each sensor.

VII. SCALABLE COMPUTATIONAL ARCHITECTURE

As indicated in related works [29][30][31][32][33], a scalable architecture brings several benefits. The main concept behind a scalable system is its modularity. Instead of a single and monolithic program, several modular programs work together and intercommunicate to achieve better performance. This is especially true in modern computers with two or more processing cores and in computer clusters, as it is implemented in this framework. In the current implementation, two computers with 4 cores each are responsible for data acquisition, logging, preprocessing and also some more complex algorithms that have been developed.

The implemented architecture is based on CARMEN [14], a collection of open source modules for mobile robots that provides useful tools for new modules development and for information exchange between modules.

The modular architecture also decomposes the complexity of an extensive code, as each module has a simple group of tasks, it is more comprehensive for new developers and there is an increase in the robustness because it is possible to have redundant modules.

A. IPC messaging

The information exchange in the modular framework plays a central role in the implemented architecture. This is accomplished using IPC [15]. It is a software package that provides several high level tools for data exchange using TCP/IP sockets, so information can be exchanged between distinct computers and different operating systems.

IPC provides two forms of message transmission, the publish-subscribe and the client-server methods, to which shared-memory capability was added at our Lab to improve speed for large data sets, such as image acquisition. In all used methods, a central module handles the TCP/IP connections for the transmitted messages.

In the publish-subscribe method, a message is broadcasted to all modules that subscribed to a certain message. The advantage of this method is that a subscriber module will receive a message whenever it is published, not needing to explicitly request. This is particularly important with high priority messages, as all modules that subscribed to it will be informed and may change their behavior based on that.

The client-server method implements a different paradigm. In this case the clients have to actively request messages to a certain server. This approach increases negotiation time but no message will be transmitted if no module requested it. This saves precious bandwidth and processor time.

To overcome the speed limitations of transmitting large messages over TCP/IP connections, a client-server paradigm was modified to use shared memory [13]. Instead of transmitting the data message through a socket, the server only informs the client that new information is available at a shared memory address. Although this method lacks the capability of working over a distributed network, it is the fastest method of all, making it well suited for large amounts of information exchange, as real time video or 3D laser ranging.

B. Data and process logging

In order to allow simulation with real data, a logger/playback software has been developed. The software logs IPC messages that are transmitted by the sensor modules into data files; the software was inspired in the CARMEN logger module [14] but uses a different data storage method. Each log consists of two files; the first is a header file in XML format, describing which messages were logged along with their timestamps and other session related data, and the second file holds the actual messages' data.

The logger is able to log simple publish-subscribe messages and also more complicated query-server messages such as the ones exchanged through a shared memory (when efficiency is required). The playback module starts off by indexing all messages in the log header file and once playback starts it reads the necessary message data, converts it back from byte array to message format, and publishes it. Using this method, modules that subscribe the logged messages do not distinguish the source of data: it may come from this logged data or data generated in real time; this process allows the simulation using real data.

VIII. CONCLUSION AND FUTURE WORK

Before reaching real world autonomous driving, intelligent vehicles must first have robust perception capabilities. This accounts both for information from the external environment and agents, and also the vehicle's own status. Intelligent vehicles will also monitor the driver actions and, to the extent possible, his state of awareness. All this concurs to create unprecedented safety and assistance during road driving, be it highway or urban like. Due to the complexity of stimuli and the dynamics of the environment, sensorial redundancy must be used for the aforementioned robust safety. The first step is then to set up such a car, and expose it to real world conditions and study the real data and develop algorithms and perception skills to enable its safety and assistance roles. This has now been done by the authors; a sensor-rich car is now running on the

streets and roads, driven by a human, and gathering massive amounts of multisensory data that will later be processed and shared. This will open many fronts of research in data interpretation, fusion and integration. When the necessary abilities are developed, providing passive security, the future widens broadly to other developments, including active security, and ultimately moving towards autonomous driving.

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