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. Therefore, 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, and certainly a long way is still ahead in sensor integration for highly reliable passive and active safety devices. In this line, 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 vehicle 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 on the 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 project (ATLAS) 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.

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 or more mundane problems such as power autonomy or the crude mechanical fixation of LCD displays for the researchers to monitor of the system performance.

The purpose of such an equipped 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 of 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.

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II. MECHANICAL/ELECTRICAL INTERVENTIONS

The chosen platform was a standard gasoline-powered Ford Escort Wagon (Fig. 1) with 75 HP and a 460 L trunk. This vehicle has manual gear and autonomy for more than 500 km.

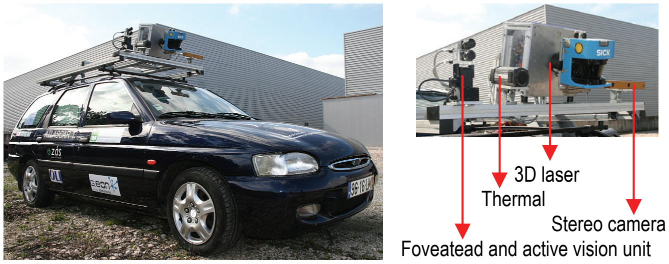

Fig. 1 – The car with external sensors shown.

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 3D laser, custom-developed by the team; a stereo camera with a dual base line for enhanced 3D perception, a thermal camera, a 2D laser; a GPS receiver; and a Inertial Measurement Unit (IMU) for system proprioception. Other sensors are planned, namely to monitor the driver actions (inertial and contact units for pedals, gear and wheel drive) and cameras looking inward to monitor driver gaze and level of awareness.

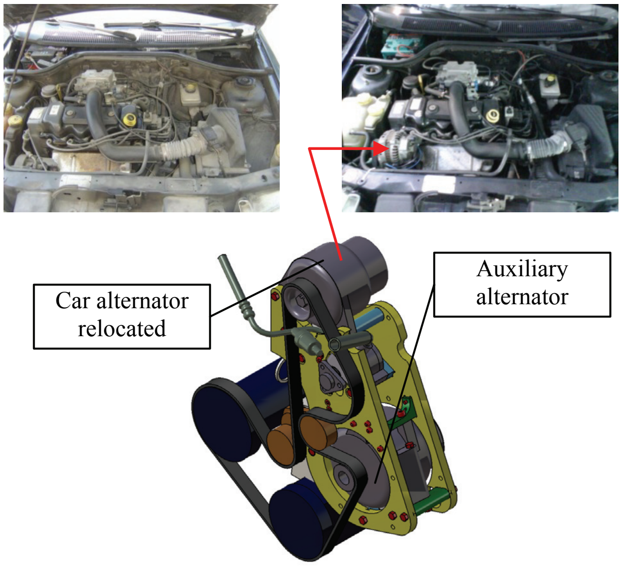

Fig. 2 – The engine compartment before and after the power alternator modification (top), and a schematic illustrating the alternator relocation and the extra generator (bottom). The auxiliary generator is not visible.

To ensure power supply on most circumstances, a versatile solution was implemented using an auxiliary generator driven by the vehicle propulsion engine, and also keep the car power circuits independent from the new installed unit, in a similar way as performed in the Stanley and Highlander vehicles in the DARPA Grand Challenge [29][30]. This was achieved by redesigning the mechanical electric 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). Its DC output is then converted to a higher-voltage line (220V, AC) through an inverter.

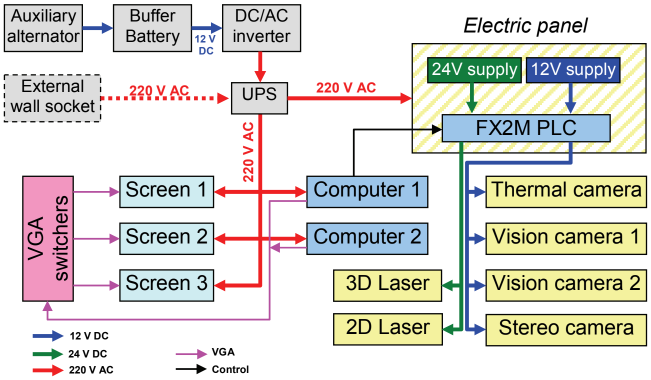

Fig. 3 - Diagram of the electric power supply system onboard the vehicle.

The power chain ends at an EATON 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. To allow versatility, the system is also prepared to operate directly from a regular wall power socket for in-house developments.

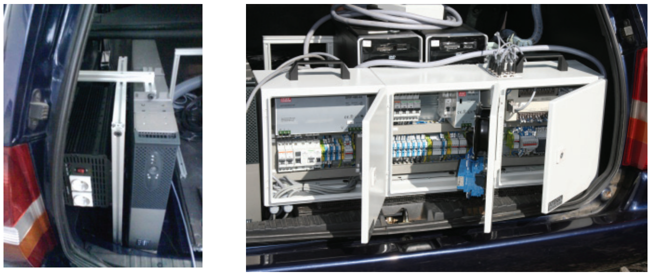

Fig. 4 - (Left) a power inverter plus an UPS (220 AC) and, (right) the general electric panel, including PLC and 12 & 24V DC power supplies.

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 actual components installed on the car.

III. VISION SENSORS AND PERCEPTION

Onboard perception will rely on multiple sensors to allow redundancy and advanced studies in sensors interpretations and fusion. One of the most relevant types of perception used is vision, due to its passive nature. Therefore, advanced vision based algorithms are 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" [2]. It is also said that "the parallelization of road features (…) is crucial for the second step of RALPH processing, curvature determination" [2].

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." [3]. More recently, Mcall and Trivedi have employed steerable filters for lane markings detection. They sustain that "Filtering on the inverse perspective warped image allows a single kernel size to be used over the entire area of interest." [4].

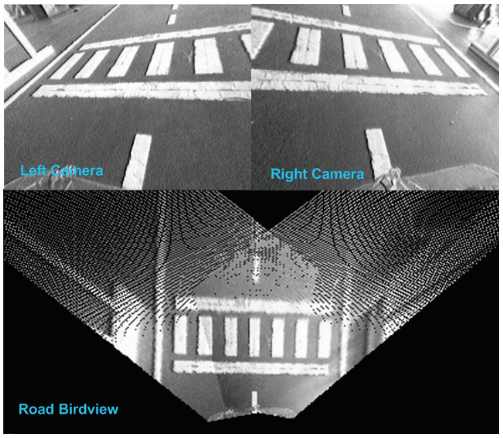

Fig. 5 - Example of IPM resultant image (bottom) obtained after applying the operation to two cameras (top).

IPM is a technique that removes perspective effects from an input image. Considering onboard road detection setups, cameras are usually mounted somewhere close to the rear view mirror of the vehicle, facing the road in front of it. The camera's position and orientation induces perspective associated effects to the captured images.

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

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 [5], 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 of biological vision systems suggest that only a small set of basic features like color, size, motion, and orientation are used in a visual search. Also, pre-attentive processing (where attention plays its role) produces reaction times that are somewhat independent of the amount of objects in display, as stated in [6]. This weak or inexistent correlation between the amount of features and the reaction times in pre-attentive processing 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" [6].

Simple color recognition may work as a good attention mechanism. Ude et al. [7] use it as signal 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. Given these clues of the attention mechanisms involved in biological vision systems, it makes sense to attempt one or several simple implementations of attention capturing mechanisms.

Color recognition is performed in the HSV color space which suits perfectly for color recognition since, unlike RGB, it separates color from light intensity and saturation. Another possible attention capturing property is based on movement detection. Motion detection techniques are now quite standard. Some of them have been implemented. 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 [8]. 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. Though quite standard nowadays, these techniques are nonetheless capable of reducing significantly 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 [9]. Therefore, 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 objects possible points of view should be immense just for each single object, unleashing some other problems concerned with real time processing. Our group proposes an alternative method [10] for tracking fully 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 overcoming temporary failures of the identification module.

Fig. 6 - Sscene viewed both by the peripheral (left) and foveal (right) camera.

One of the setups mounted onboard the ATLASCAR is made up of a dual camera system mounted on top of a Pan and Tilt Unit which provides active perception capabilities. As stated, the attention capturing mechanisms are responsible for deploying the system's attention to a particular object of interest. Attention is generally triggered by the peripheral camera, which has a wide view angle (Fig. 6). When a particular object raises attention, the system moves the cameras so that the object first viewed in the peripheral camera is positioned on the center of the second camera, a narrow lens camera. This camera, called the foveal camera, captures high resolution video stream of the object, allowing a much more in depth analysis of the objects characteristics.

D. Thermal imaging

In outdoor environments, in general from dusk to dawn, and in particular 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, because the pupil is highly dilated and the eye becomes very sensitive to changes in lighting, which occur for instance when crossing with another car, the driver's eye stress limits are largely above those of daytime. At the same time, because there is a greater lag in perception, guidance of the car may require constant head motion and faster re-action requiring higher levels of awareness. Thus, cerebral stress and tiredness is 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 presently no global solution to this problem and that is why thermal imaging is a very promising technique to catch human and other systems with thermal signatures. Besides persons, those includes as spots of artificial lighting, the pavement at dawn when heated by the sun or the exhaust pipes of fuel burning automobiles.

Having the above reasoning in mind, 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 is multicast. Because presently the data transfer framework between modules is that implemented in IPC [13][14][15], a Gstreamer [16] plugin has been developed to communicate with the camera and publish the message through IPC. Fig. 7 shows a typical image retrieved inside the lab, during the day, from the camera server in MP4 compressed video format. People are easily spotted in the figure, as are the window locations.

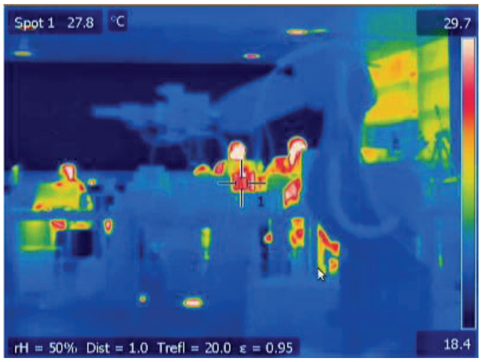

Fig. 7 - Infrared image of an indoors scene where people pop out easily.

IV. LASER SENSORS

A. Planar laser and obstacle tracking

To allow a fast and accurate perception of the eminent vicinities of the car, a planar laser was installed. This laser is a Hokuyo UTM-30LX which has a range of 30 meters. With this system, the navigation thru 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.). In order to obtain this information, obstacles are tracked over time using planar laser data. 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. The performed tracking is based on motion models for the objects and a Kalman filter. All objects are modeled has having a basic behavior of constant velocity with a superposition of white noise, the white noise is intended to illustrate the highly time varying acceleration [18]. The Kalman filter is used to estimate the motion of the objects thru the various iterations.

Using the estimated motion a search area on the most probable location of each object can be defined. In this work, the search area was defined with the shape of an ellipse; the size of the ellipse axes depends on the object size, velocity and occlusion time; all these factors increase the ellipse axes and each object ellipse is centered at the object predicted position. When an object first appears, meaning that none of the current tracked objects match the new object, its search area, ellipse, is very large, since this object is new the Kalman motion estimation is incorrect and thus the large search area allows for the 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 stays under modeled parameters (linear motion with constant velocity). If this happens, the object is successfully identified once the occlusion condition terminates. If an obstacle remains occluded more than a predefined time, it is considered 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. There are commercially available 3D systems, most of which are not meant for use in populated outdoor environments also because they are not eye safe.

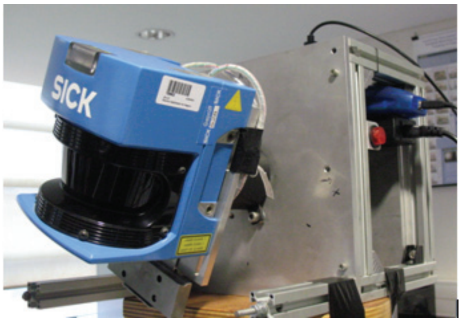

Fig. 8 - Custom developed 3D range-finder.

Though Velodyne now produces the HDL-64, which is a robust and eye safe 3D laser, it is expensive (around €60k) and has 26.8º vertical field of view, which is relatively small for having simultaneous short and medium range perception needed in urban environments. It is not adequate, for instance, to simultaneously detect the pavement or pedestrian at close proximity and a tunnel's height at medium range. 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].

The Laboratory for Automation and Robotics at the University of Aveiro has developed its own prototype solution for 3D range finding [24], in the form of a spinning forward looking 2D SICK as seen in Fig. 8. The scanner is rotated continuously by an additional controlled external shaft and a typical scan is shown in Fig. 9. Both data acquisition and control of the external shaft are performed by a single module which interfaces with the IPC environment (section VII.A). The module sends angular velocity requests via USB to an MCU which interfaces with a stepper motor power unit. Preliminary results are very good, especially in static motion; when adding ego-motion to the sensor data interpretation becomes much more challenging. Real-time analysis of 3D laser range data is presently a very important research topic [25].

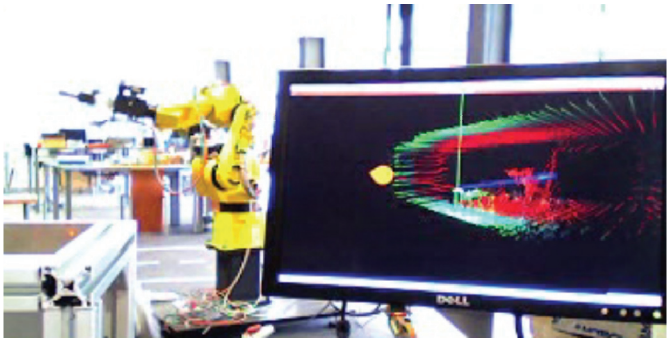

Fig. 9 Sample scan of a lab environment showing the real world and a 3D model on a computer screen.

V. VEHICLE PROPRIOCEPTION

A. *Monitor driver actions*

To monitor driver's actions, but keep the system easy to install without changing the vehicle structure, the current approach focused in 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 [26].

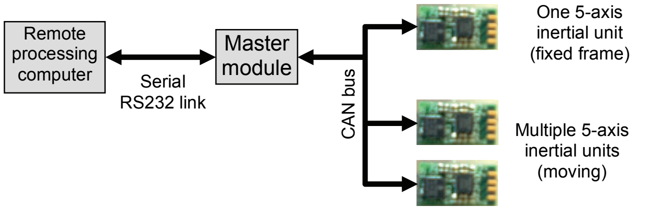

Fig. 10 Dual inertial systems to decouple individual part motion with vehicle global dynamics. This is to be applied at the moving levers and actuators driven by the car driver.

As there were no small enough inertial modules 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 12×21.2×5.5 mm module that can be discretely attached to any of the driver's controlled moving parts (pedals, steering wheel, hand brake and gear lever).

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 module fixed to the vehicle frame, and one module attached to each moving part (Fig. 10). Measured data is then the result of the difference between the fixed module and each of the moving units. This decouples individual motion from the global system dynamics.

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 simple handheld GPS receiver. It is important to notice that there is no desire to implement a dead-reckoning system in this project, neither 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

The large number of sensors onboard the ATLASCAR, as well as their completely diverse natures, may be considered a cumbersome problem to handle. Most state-of-the-art autonomous vehicles merge sensorial information from multiple sensors but usually 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.*, [27], 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, for the ATLASCAR the fuse all 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 vast amounts multidimensional data, the authors are convinced that there is an advantage in looking at the information holistically.

Since this will be hardly achieved for all of the possible objects on the scene, there is the intention to use several 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. For example, if an object in front of the vehicle is selected as interesting for analysis, a 3D representation of the object is stored. Then the object is tracked and attention is triggered. Several processes will then come into play, for example foveating the object and obtaining a high resolution image, calculating the temperature using the infrared camera or other relevant caracteristics may be extracted.

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 [28][29][30][31][32], a scalable architecture brings several benefits. The main concept behind a scalable system is its modularity. Instead of a single and massive 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 and is more comprehensive for new developers. The programmers do not need to understand all the robot's aspects but only a small part of the whole. There is also an increase in the robustness, as it is possible to have redundant modules, responsible for the same task, and providing the same information.

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.

In this architecture, the information flows encapsulated in messages. Each message is defined with a name and a structure with known fields and data types. In this way, whenever a message is sent from one module to another, the IPC deals with all the aspects of decomposing the structured message into a data stream, the transmission of the stream, and composing the stream back into a message structure, at the destination modules.

IPC provides two forms of message transmission, the publish-subscribe and the client-server methods, to which was added a modified method, developed at our Lab, using shared-memory capability to improve speed for large data sets, 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 type. The advantage of this method is that a subscriber module will receive a message whenever it is published, and does not need to explicitly ask for it. This is particularly important with messages that have a higher priority than others as all modules that subscribed to it will be informed of a publication 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. Although this approach increases messages exchange, required to negotiate a message transmission, no message will be transmitted if no module requested it. This saves precious bandwidth and processor time.

To overcome the limitations of large messages transmission over TCP/IP connections, a client-server paradigm was modified to be able to use shared memory [13]. The shared memory is a form of distributing information between programs with the allocation of a Random Access Memory (RAM) area that can be accessed (shared) by distinct processes.

The main difference from the previous methodology is that instead of the server transmitting the data message through a socket, it 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 was develop. 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 serves as a header file (*log_header*) containing only witch messages were logged and their timestamps, the second file contains the contents of the messages (*log_data*).

Messages are first marshaled into to a byte array and then saved on the data file, the position in the file were the byte arrays starts is also saved in the log header file. 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 “know” that they are using logged data and not real time data, and thus allows for simulation with 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, the exteroception, and also the vehicle own status, the proprioception. Besides these sources of data, 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. 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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