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ROS-based architecture for autonomous vehicles

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Introduction

This paper presents the advances of the autonomous vehicle iCab (Intelligent Campus Automobile), which is the research platform of the University Carlos III of Madrid to foster intelligent and autonomous transportation systems in urban environments. The aim of the paper is to describe the initial steps to achieve a functional Robot Operating System (ROS) architecture, that is, the ROS-based architecture achieves the fusion of multiple sensors and provides a time-stamp of overall sensors. The architecture manages huge data from the surrounding environment provided by the computer vision and laser scanner systems. In present state, the architecture, cope with the autonomous navigation requirements and real-time data processing, outperforming former works in autonomous vehicles and fostering the urban mobility.

Autonomous vehicles is an important topic in intelligent transportation systems, where a recent work shows that driver-less vehicles could become widely available in the next 5 to 10 years [1]. These improvements of autonomous vehicles have been outperformed mainly by environment perception through computer vision and laser scanner. They overcome the most significant technical limitations, such as robustness to face the changes in the environmental conditions due to illumination variation, such as shadows, low lighting conditions, night vision among others. Accordingly, perception applications ensure the suitable robustness and safety in case of large variety of lighting conditions and complex perception tasks [2]. Additionally, the use of computer vision is well-established in recent researches about autonomous vehicles; for example the route from Mannheim to Pforzheim by Mercedes Benz S-Class car. The car navigated 103 km on the route autonomously, it was equipped with computer vision systems and radar sensors along with digital maps [3].

The initial improvements reached by ROS-based architectures was the possibility to generate the mapping and localization for the autonomous navigation, where the results outperformed other algorithms [4, 5]. ROS-based systems provide an operating system-like services to operate robots with the fusion of multiple sensors data and time stamp of different devices [6].

This paper presents the first steps in the implementation of a ROS-based architecture to foster an autonomous vehicle in urban environments, to accomplish autonomous navigation and path planning approaches, based on image processing and laser scanner data interpretation. This architecture achieves the data handling of the on-board sensors and synchronizing low-level data. So, the presented ROS-based architecture allows the coordination of the drivers and middleware, simplifying the complex tasks of global data acquisition and sensor synchronization.

Hence, the iCab architecture fosters the sensor fusion processes, where the proposed architecture communicates the processes with each other in order to refine information and knowledge. The decision-making processes have been also enhanced, such as, the decision to avoid safely the collision with an obstacle or pedestrian in autonomous navigation. Then, this proposed architecture enables the inter process communication in an independent and modular way, enabling the on-board computer to run multiple and parallel algorithms in order to achieve both low-level objectives, such as sensor data acquisition and data preprocessing, and high-level objectives, such as pedestrian detection, obstacle avoidance, autonomous path planning and navigation.

Materials and methods

The research platforms are two electric vehicles, E-Z-GO model (Figure 1), which has been modified to fulfil the autonomous navigation, path planning and cooperation objectives.

Fig. 1: Research platforms: iCab 1 and iCab2

The first environment perception system that is integrated in both electric vehicles is a laser rangefinder (SICK LMS 291). This device has over 180 degrees scanning range with 0.25 degrees angular resolution [7], and it is mounted on the front vehicle bumper at 30cm height above the ground. The second perception system that is also in both iCabs is a stereo vision binocular camera (Bumblebee 2). The camera has a maximum of 1032x776 pixels resolution at 20 frames per seconds [8]. This perception device is mounted on the front windshield of the vehicle at 160 cm height above the ground and orientation of -45 degrees. The stereo camera processing has three purposes: (i) to build a free road map in order to navigate in the environment, (ii) to obtain real-time visual odometry, and finally, (iii) to detect and avoid pedestrians or obstacles.
These devices are connected to an on-board embedded computer, where each iCab has a Intel Core i7 processor that is working under Ubuntu operating system. The display unit is a TFT LCD touchscreen, which is installed on the vehicle front dashboard of each vehicle in order to view the system's interface software, and display the current and desired locations in the map. Figure 2, displays the on-board human-machine interface to communicate with the iCab passenger along the autonomous navigation service.

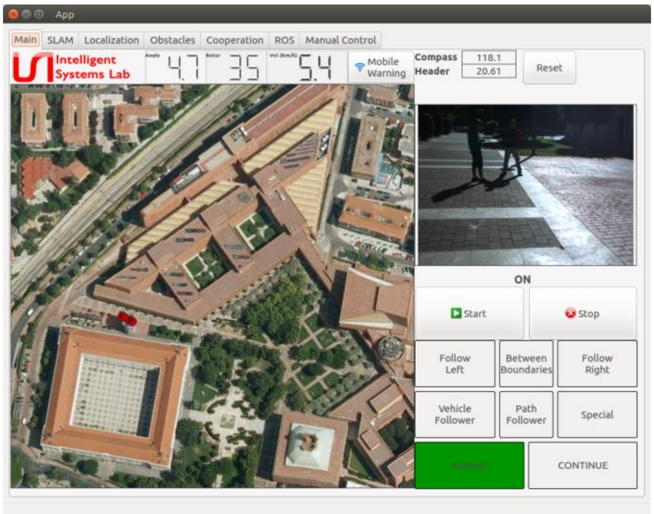

Fig. 2: Human-machine interface in iCab 1 and iCab2

In this work, the main objective is to implement a complete ROS-based architecture with various levels of complexity categorized in three layers; deliberative, sequencing and reactive skills [9]. The advantages of this type of architecture are the ability to add more skills and modify the algorithms to obtain more efficient results during the development stage. For the architecture layers, the low-level has the simple reaction skills in the reactive layer, which controls the actuators and read the sensors data from the environment. It is followed by the sequencer in the hybrid layer, which incorporates a high level behaviour through logic sequence to the low-level layer to achieve the required behaviour. The highest level consists of the path planner in the deliberative layer, which generates the commands for the iCab to follow.
The reactive skills of the architecture have been completely developed, where the low-level control structure of the autonomous vehicle is implemented in this layer. So, the basic commands, such as “Move Forward”, “Move Backward”, “Turn Left”, “Turn Right” or “Stop”, have been tested thoroughly, and the results have consolidated a high-performance in the low level control.

Figure 3 shows the recent advances in the development of the ROS-based architecture, where sequencing and deliberative tasks are accomplish in detail for iCab1 and iCab2. In the deliberative layer, each input is considered as a specific task, where the complexity of this layer resides in the accuracy of generating simple skills like “follow_left”, “follow_right”, “between boundaries” or “path_follower”. The behaviour of the iCabs is managed by the sequence of these simple tasks where a more complex task can be accomplish easily. That is, a complex task provided by the deliberative layer, such as “local path_planning” or “global path_planning”. These high-level tasks manage the desired actions from an iCab-user towards the autonomous vehicle to achieve efficiently the localization, the path planning, the navigation and the mapping.

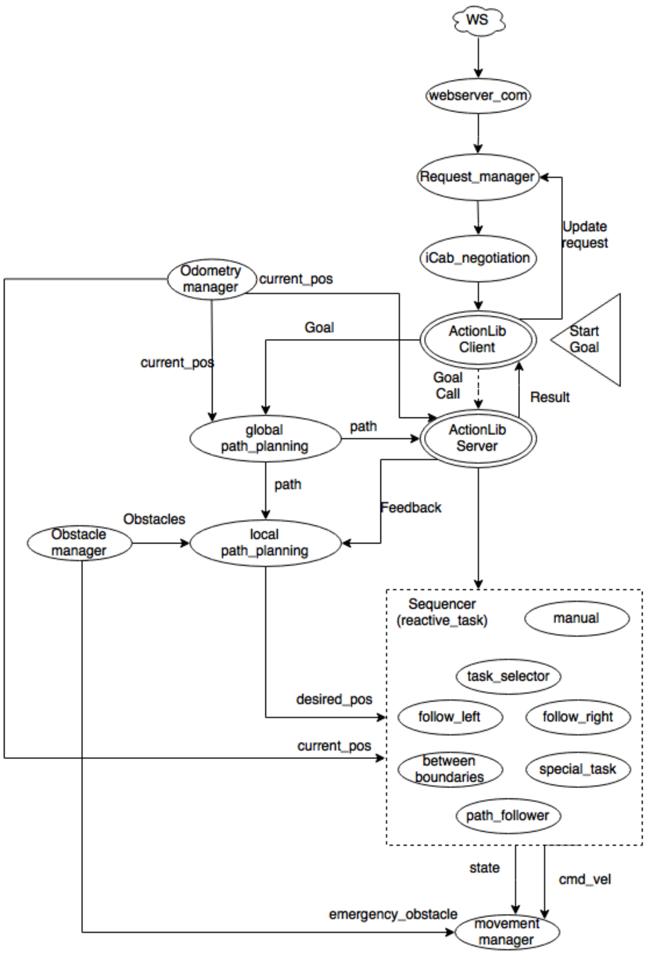

Fig. 3: ROS-based architecture diagram

The proposed architecture is implemented in ROS-based system, where the packages involved are described following. The low-level layer is developed in C++ in a ROS package called “movement_manager”, see Figure 3.

This node receives the iCab status every 20ms (50Hz); in terms of encoders reading, battery voltage, heartbeat, PID configuration elements and state errors. These readings are published by “/movement_manager/status_info” topic. It contains a custom message, which enables other nodes to subscribe to it and operate with the information. The simple reactive skills layer contains the information to activate the actuators in moving forward, moving backward, turning left, turning right and stopping the vehicle.

The “Odometry manager” and the “Obstacle manager” tasks are implemented in the architecture and are explained in the results section in detail. Both tasks, receives interpolated data from both cameras (left and right: “stereo_camera/right” and “stereo_camera/left”) and laser rangefinder perception (the “sicktoolbox_wapper” package). Moreover, the “disparity” package, which has the rectified images as inputs, generates the disparity map for the next tasks, where the free space of the environment uses an algorithm implemented by Musleh et al. in [10]. Finally, the node “free_map” receives the disparity map as an input, then it publishes the name-space known as road profile by “free_road” topic. This road profile is the result of the analysis of the u-v disparity for the environment and it split the image into free spaces and obstacles.

Results and discussion

The section presents the initial results of the proposed architecture, where the data management of the perception devices of the iCab platform are evaluated based on manoeuvres in urban environments. The urban scenarios have been evaluated in several experiments, however this section summarizes one representative scenario of overall set of experiments.

The results have been obtained using the iCab platform where ROS-based architecture has been implemented in the on-board embedded computer. Figure 4 displays the representative outdoor scenario in order to show the performance of the architecture managing the iCab safe movement, where obstacles appear in front of the vehicle and the perception skills are managed robustly by the iCab ROS-based architecture.

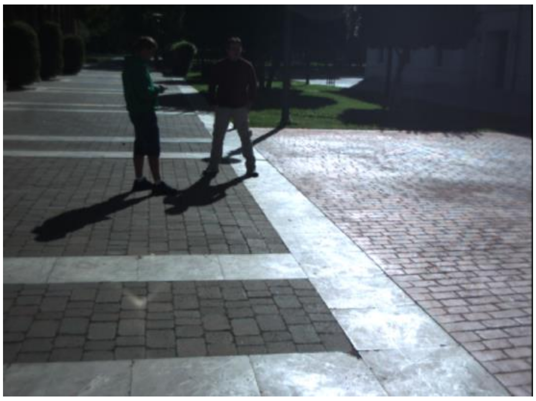

Fig. 4: Outdoor scenario with obstacles

The following Figure 5, displays the result obtained by the disparity map package, where the iCab ROS-based architecture uses the laser rangefinder and the stereo camera in order to fuse data and enhance the perception of the autonomous vehicle. Both perception devices publishing and processing data in real-time and this fusion result is shows in Figure 6 through ROS-based architecture.

Fig. 5: Disparity map of the scene in front of the iCab

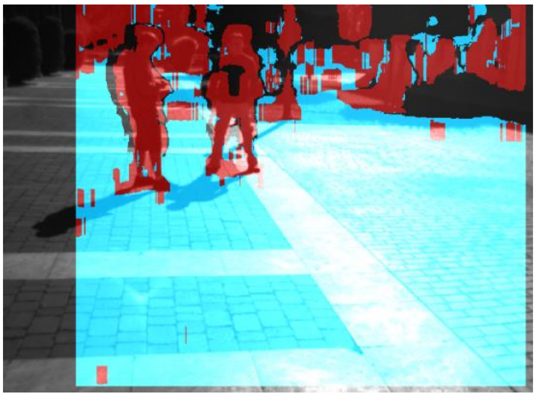

Fig. 6: Disparity map of the scene with classification: blue is the free space to navigate and red are the obstacles to avoid

Finally, the overall results are provided in Figures 7 and 8, where the exemplification of the architecture accomplish a sensor fusion task for safe obstacle detection and an autonomous navigation task, while the iCab performs a manoeuvre to move in an urban environment with two pedestrians in front of the iCab. This high-level behaviour by ROS-based architecture has been achieved successfully and demonstrate the perception-action loop in real-time of the iCab vehicle.

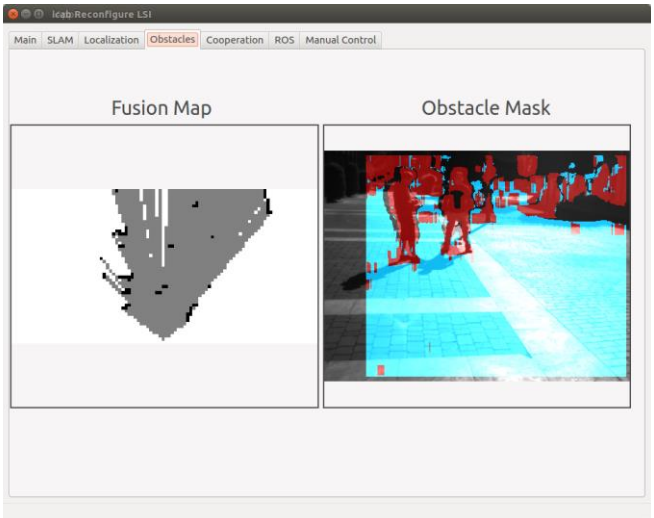

Fig. 7: Sensor Fusion result through ROS-based architecture

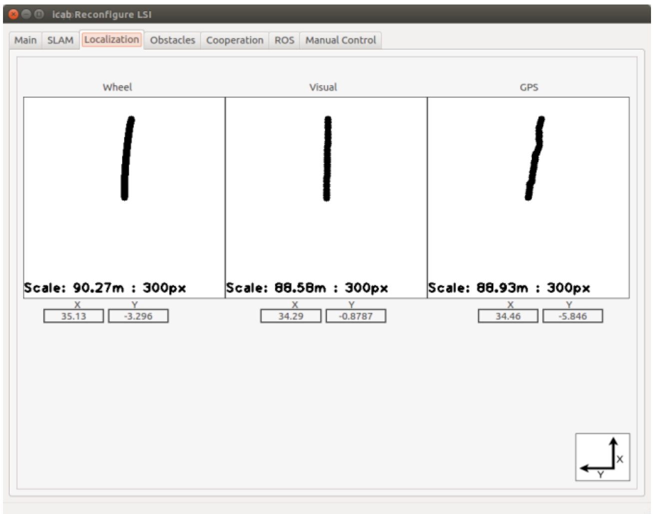

Fig. 8: Autonomous navigation based on three methods

Then, the ROS-based high-level processes in real-time with obstacles in front of the vehicle is shown to perform an accurate manoeuvre for avoiding a collision. The performance of the proposed architecture in the high-level perception loop obtains the sensor fusion and autonomous navigation in real-time.

Conclusion

This paper presents the first high-level results of a ROS-based architecture for the iCab autonomous vehicles of the Carlos III University of Madrid in urban environments. The aim of the architecture is to provide to both iCab platform the capabilities to be used as a functional intelligent transportation vehicle. The perception-action processes are accomplished by proposed architecture using the laser rangefinder, the stereo camera and motor commands, where the exemplification of the ROS-based architecture by real-time data acquisition, time stamp and perception processing has been demonstrated.

The future aspects of research include the full integration of ROS-based high-level reasoning to accomplish path-planning, navigation and trajectory planning tasks for autonomous movement. At which, the vehicle navigates in a given environment avoiding static obstacles and manoeuvring dynamic ones. Moreover, the iCab platform can be extended to deal with more than one vehicle and create Multiple Vehicle Communication System (MVCS), at which the coordination and cooperation between the vehicles is necessary to achieve a network of autonomous transportation systems in urban environments.

Acknowledgements

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