Chapter 4
Unmanned Ground Vehicle *Otonobil*: Design, Perception, and Decision Algorithms

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Abstract Unmanned ground vehicles (UGV) have been the subject of research in recent years due to their future prospective of solving the traffic congestion and improving the safety on roads while having a more energy-efficient profile. In this chapter, the first UGV of Turkey, *Otonobil*, will be introduced detailing especially on its hardware and software design architecture, the perception capabilities and decision algorithms used in obstacle avoidance, and autonomous goal-oriented docking. UGV *Otonobil* features a novel heuristic algorithm to avoid dynamic obstacles, and the vehicle is an open test-rig for studying several intelligent-vehicle technologies such as steer-by-wire, intelligent traction control, and further artificial intelligence algorithms for acting in real-traffic conditions.

Keywords Autonomous car • Dynamic obstacle avoidance • Sensor fusion • Unmanned ground vehicle

4.1 Introduction

The unmanned ground vehicle (UGV) *Otonobil*[1] (Fig. 4.1) is essentially an urban concept small electric vehicle (EV) which is mechanically converted to modify the driver–vehicle interfaces for autonomous operation. Hardware conversion process

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[1] *Otonobil* is one of the major projects at Mechatronics Research and Education Centre of Istanbul Technical University supported by Turkish Ministry of Development since 2008.

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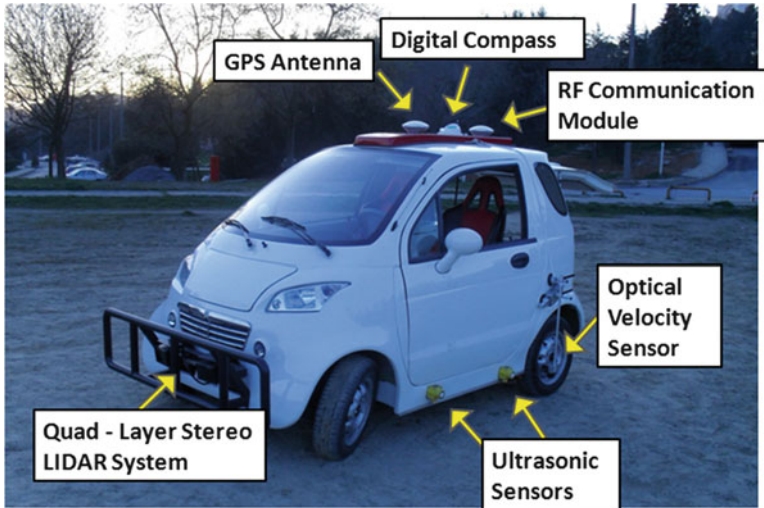e-mail: gulay.oke@itu.edu.tr

Fig. 4.1 Unmanned ground vehicle *Otonobil* at Istanbul Technical University, TR [1]
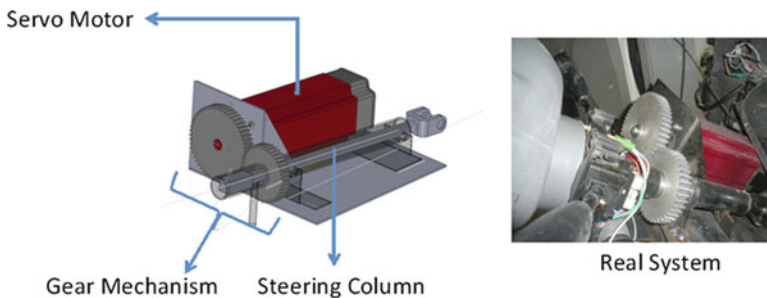

Fig. 4.2 Automatic steering system for *Otonobil* [2]

is divided into two main parts as mechanical and electrical modifications. Interface circuit, interface software, additional power system, selection of the sensors, and computer hardware are given in electrical modifications part. The multisensory perception capabilities of the UGV are given in Sect. 4.2, and the decision algorithms representing the artificial intelligence of the car is mentioned in Sect. 4.3.

The mechanical modifications on the vehicle are mainly performed on the brake and steering wheel for autonomous operation. Two separate external servo motors with a gear box are used to activate the steering wheel column and brake pedal, each according to the commands sent by the main computer onboard. The modified steering system can be seen in Fig. 4.2.

Additional mechanical modifications are in the form of extra components such as the top unit for carrying the GPS, IMU, and RF unit and the cage design in front of the car for supporting the LIDAR units.

4.2 Multisensor Data Acquisition, Processing, and Sensor Fusion

In this section, the multisensor platform in the UGV is examined together with data processing and sensor fusion strategies and algorithms. The system architecture is especially an important design consideration since the real-time performance of the applications depends heavily on the communication and general architecture such as distributed versus central structure and the communication protocols used. Another aspect of multisensor platform on the vehicle is that the platform can be used in both data acquisition/logging mode and real-time processing mode.

4.2.1 System Architecture

The sensors used in *Otonobil* are mainly for localization and state estimation purposes. The list of the sensors is given in Table 4.1.

The full system with their connection schematics and communication paths is given in Fig. 4.3. The computational components are mainly NI-PXI box used for localization, mapping, and path planning; DSpace MicroAutoBox used for local trajectory planning and tracking including low-level control of steering, braking, and wireless communication; and IBEO ECU used for object and raw data of the obstacles in front of the car. The related processing hardware and software structure is given in Fig. 4.4. Using this structure, several software pieces work in their own cycle time and the computation results are sent finally to local controller for the operation of the vehicle. These pieces are mainly image processing, LIDAR processing, vehicle state estimation, local mapping, motion planner, local trajectory planner, trajectory tracking, and wireless communication.

For digital signal processing applications used in UGV *Otonobil*, it is essential to have accurate, synchronized, and real-time logged dataset. This dataset can give the opportunity to perform the implemented algorithms in simulations to observe the performance and errors in the algorithm. First, we need the dataset in order to be able to simulate the motion. Without obtaining the data first, it would not be

Table 4.1 Sensor list of *Otonobil* for state estimation and mapping

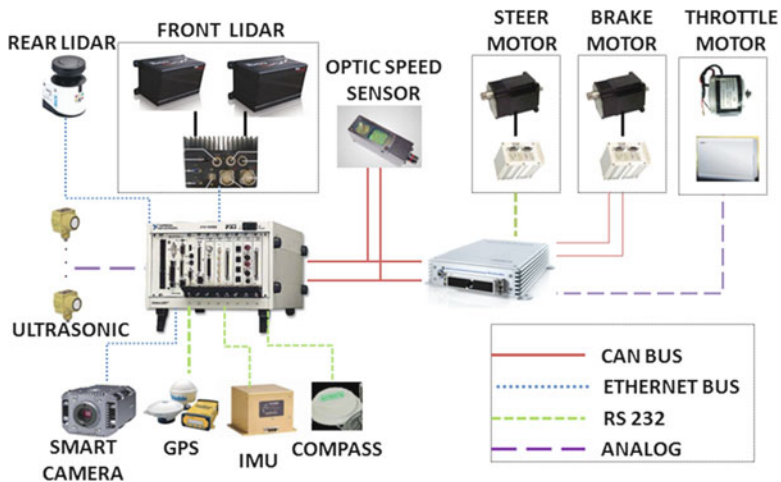|	Sensor type	Quantity	Brand/model
Mapping sensors	Laser scanner	2	IBEO-LUX
	Laser scanner	1	SICK LMS 151
	Camera	1	SONY-XCI-SXI100
	Ultrasonic sensor	6	Banner-QT50ULB
State estimation sensors	Differential GPS	1	Trimble SPS851 & SPS551H
	Digital compass	1	KVH Azimuth 1000
	IMU	1	Crossbow VG700AB-201
	Optic speed sensor	1	Corrsys–Datron LF IIP

Fig. 4.3 Sensor connection and communication schematic view

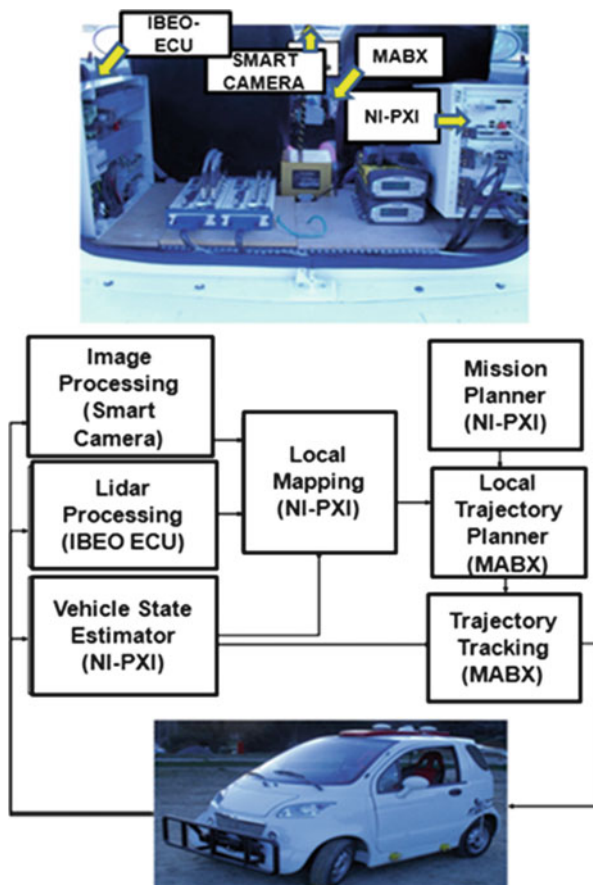**Fig. 4.4** Processing hardware and software structure of *Otonobil* [2]
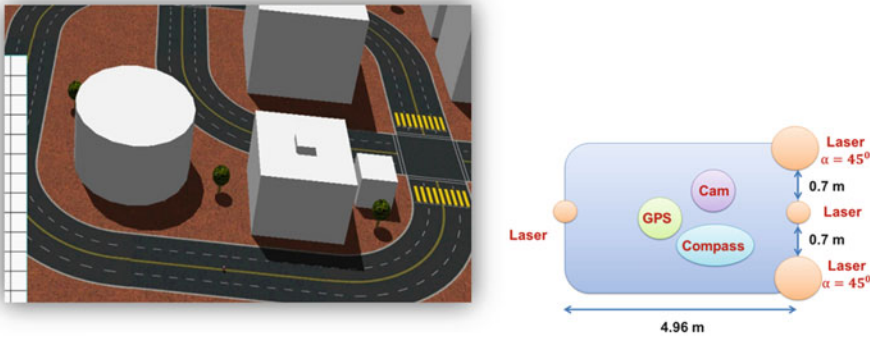
Fig. 4.5 The simulation environment in *Webots* and UGV with virtual sensors

possible to simulate the vehicle dynamics and kinematics with precision. The acquisition, processing, and logging of the sensors are performed in real-time module of *LabVIEW* since these applications require deterministic real-time performance that general purpose operating systems cannot guarantee. After acquisition and processing are performed, the data should be transferred via global variables since the data logging and the data acquisition processes are performed in different loops so that data wiring is impossible. However, this may cause race conditions because global variables could violate the strict data flow structure of *LabVIEW*. To overcome such a condition like this, functional global variable (FGV) or semaphores could be used. After the data is acquired and processed, it is transferred via an FGV to the data-logging loop which runs parallel to the acquisition and processing loop [3].

4.2.2   Sensor Fusion and Mapping

The sensor fusion and mapping algorithms are crucial in designing of a UGV because all the perception and decision making depends on the results from such calculations. For example, for path planning, an obvious map must be constructed. In context of intelligent vehicles, on board obstacle detection is an essential part. Obstacles must be detected in a correct and fast manner because the obstacles might be dynamic quickly changing their location and velocities with respect to UGV. Here, a sample algorithm for obstacle detection using laser scanner, camera, GPS, gyro, and compass is detailed. First, the vehicle is modeled as a platform with multiple sensors, and it is embedded in a simulation program (*Webots*) for simulating real driving scenarios as seen in Fig. 4.5.

Since the UGV has multiple sensors and none of these sensors are adequate for a precise measurement of the obstacle locations, a Bayesian inference method is used for detecting and tracking the obstacles. Some simulation results are given in Fig. 4.6 showing the obstacle map learning using different number of sensors.
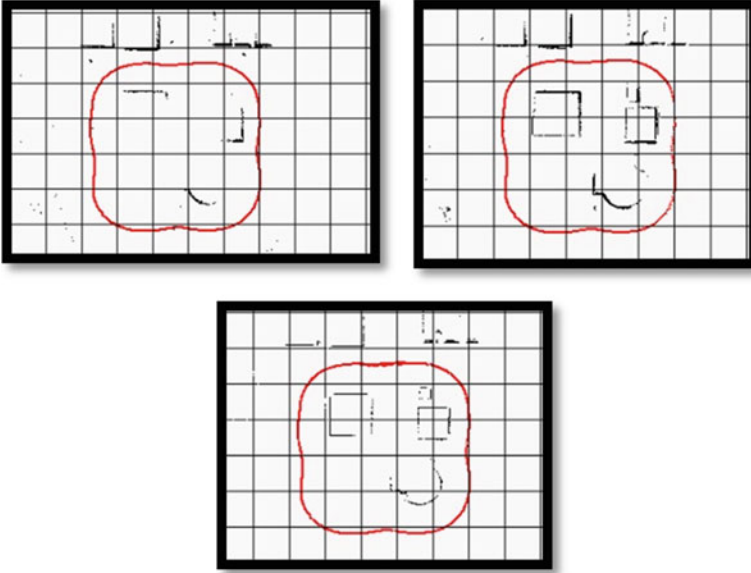
Fig. 4.6 Bayesian learning results using one, three, and four laser sensors

4.2.3 Localization and Navigation

A fundamental capability of a UGV is navigation. Using the information from various sensors, a UGV should be capable of determining vehicle's kinematic states, path planning, and calculating the necessary maneuvers to move between desired locations. To reach this objective with desired reliability, multisensor data fusion of various sensors is essential. For this objective, *Otonobil* is equipped with sensors like IMU, GPS, motor encoder, digital compass, and optic speed sensor. All the information from these sensors is fused using EKF algorithm given in Fig. 4.7. Also a stand-alone orientation estimation algorithm is proposed in order to have an accurate transformation of the information measured in vehicle's body frame into navigation frame. Full details of the work can be referred to for further information [4].

4.3 Dynamic Obstacle Avoidance

In UGV Otonobil project, a novel obstacle avoidance method called "follow the gap" is designed and it has been tested in the real scenarios. The method is easy to tune and considers the practical constraints in real vehicle such as limited field of
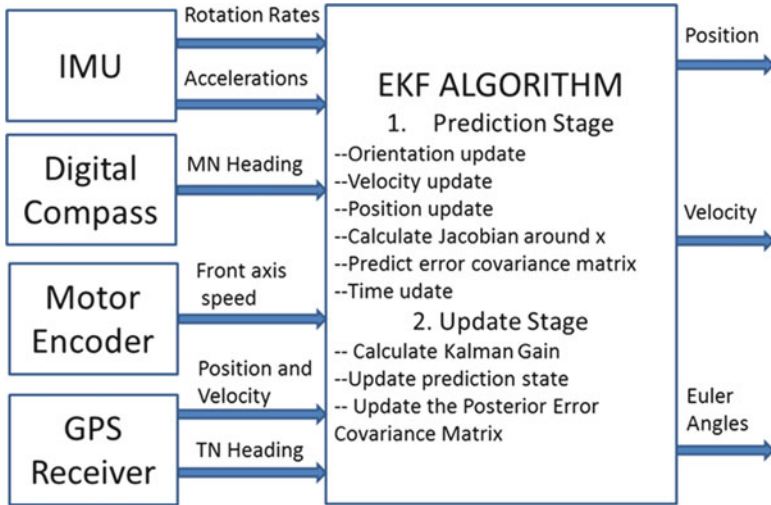
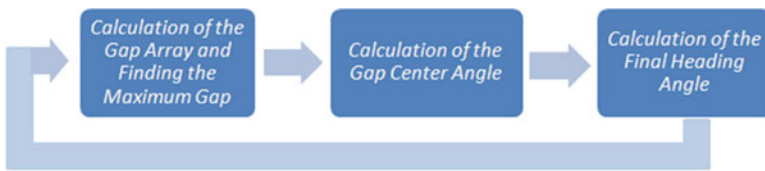**Fig. 4.7** Multisensor data fusion algorithm used in *Otonobil*

Fig. 4.8 Steps of the "follow the gap" method

view for sensors and nonholonomic motion constraints. A brief explanation and experimental results of the developed method is detailed here; however, the full details of the work can be referred to for further information [5].

4.3.1 "Follow the Gap" Method

The method assumes that both the UGV and the obstacles are circular objects with minimum diameter covering all the physical extensions of the real objects. "Follow the gap" method depends on the construction of a gap array around the vehicle and calculation of the best heading angle for heading the robot into the center of the maximum gap around, while at the same time considering the goal point. The algorithm can be divided into three main parts as illustrated in Fig. 4.8.

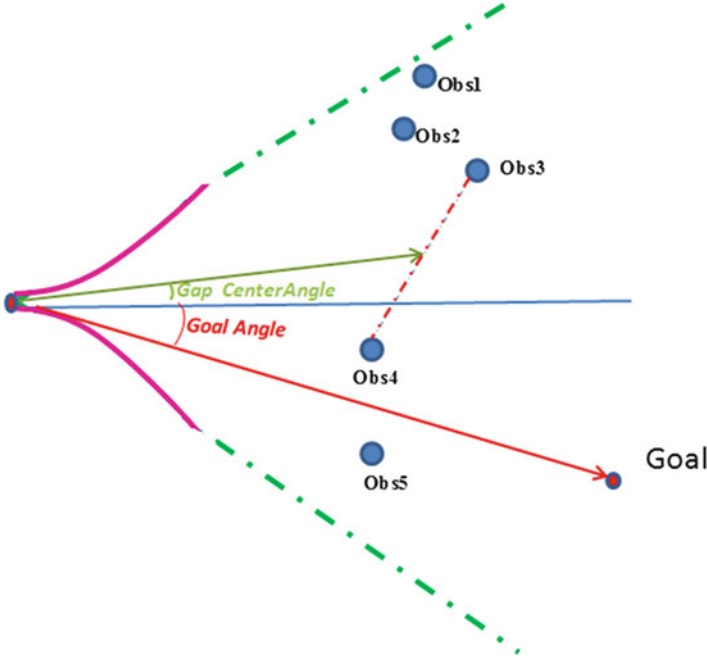Maximum gap, the gap center angle, and the goal angle can be understood in Fig. 4.9.

Fig. 4.9 Maximum gap, gap center angle, and goal angle together with obstacles

Gap center angle is calculated in terms of the measurable parameters using the trigonometric relations as illustrated in (4.1)

$$\phi_{gap\_c} = \arccos\left(\frac{d_1 + d_2 \cos(\phi_1 + \phi_2)}{\sqrt{d_1^2 + d_2^2 + 2d_1 d_2 \cos(\phi_1 + \phi_2)}}\right) - \phi_1 \qquad (4.1)$$

In this function, the variables are defined as follows: ϕ_{gap_c} is the gap center angle, and d_1, d_2 are the distances to obstacles of maximum gap. ϕ_1, ϕ_2 are the angles of obstacles of the maximum gap.

The final heading angle of the vehicle is computed using both center angle and goal angle. A fusion function for the final angle calculation is given in (4.2):

$$\phi_{final} = \frac{\frac{\alpha}{d_{\min}}\phi_{gap\_c} + \beta\phi_{goal}}{\frac{\alpha}{d_{\min}} + \beta} \qquad where \quad d_{\min} = \min_{i=1:n}(d_n) \qquad (4.2)$$

In this function, the variables are defined as follows: ϕ_{goal}, goal angle; α, weight coefficient for gap; β, weight coefficient for goal; n, number of obstacles; d_n, distance to n-th obstacle; and $d_{\min}$, minimum of d_n distance values.

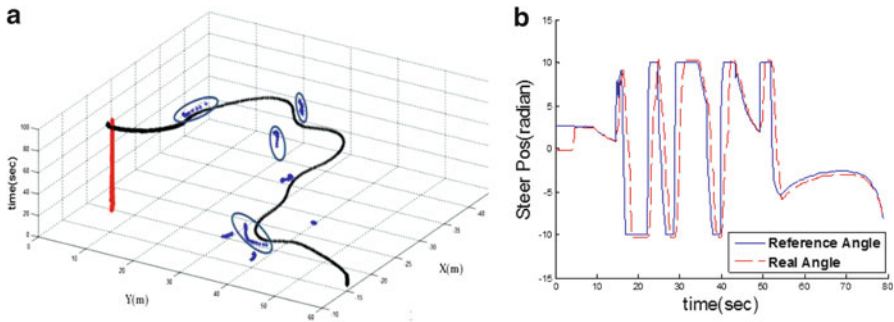The α value defines how much the vehicle is goal oriented or gap oriented.

Fig. 4.10 Results of dynamic obstacle avoidance experiment. (**a**) Vehicle trajectory with obstacle measurement. (**b**) Steering wheel reference and real angle

4.3.2 Experimental Results

Obstacle avoidance algorithm based on "follow the gap method" is coded using C programming language. The real-time code runs in MicroAutoBox hardware. The only tuning parameter, alpha, is selected as 20 in experimental tests as in the simulations. The field of view of the LIDAR is 150° and its measurement range is restricted with 10 m. The first test configuration is composed of seven static obstacles with a goal point. In the second test scenario, "follow the gap" method is tested using dynamic obstacles. The results of the dynamic obstacle tests are given in Fig. 4.10 with a 3D graph showing the time-dependent locations of the obstacles and their perceived trajectories by the vehicle.

4.4 Conclusions

An *UGV* named Otonobil is introduced in this chapter detailing on its mechatronics design, perception, and decision algorithms. First the modifications on an urban EV are mentioned briefly to convert the vehicle for autonomous operation. Then the multisensory structure with several processing units is given to emphasize the importance of data acquisition and real-time processing needs of such applications. Finally a novel dynamic obstacle avoidance algorithm developed for Otonobil is explained briefly. The vehicle will be used in similar research projects in the field of active vehicle safety and intelligent vehicles in future work.

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