Intelligent system for driver assistance in overtaking manoeuvres using multiple Camera and Radar Sensors - part 1

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Abstract. This paper describes a method and an associate device to analysis overtaking or lane changing manoeuvres to be performed or those in which the vehicle is already engaged. The device assists the driver in the overtaking manoeuvres by automatic analysis of distances, speeds and accelerations of the overtaken and the incoming vehicle from the opposite sense, having the possibility of optical and acoustic warning in the event of a prohibited, dangerous or risky overtaking, or validating a safe manoeuvre that can be performed risk-free. The studied sensors are FMCW radar and video cameras cooperating in a “sensor-fusion” concept. The paper describes a series of experimental tests designed to establish the necessary parameters that the respective sensors must meet to ensure the effective monitoring of an overtaking maneuver. The main parameters theoretically designed and experimentally measured are perception distance to the objects of interest (small, medium, large cars, motorcycles, bicycles, pedestrians, etc.), the maximum relative speed that can be noticed, the minimal angular resolution for correct perception of two nearby vehicles.

1. Introduction

The unprecedented increase in the number of vehicles traveling on a road network that cannot be developed at the same rate and magnitude, neither spatially nor temporally leads to an unwanted increase in the number of accidents. Modern safety systems designed to assist the driver in handling and car driving (ADAS) have one of the fastest development rates, becoming an integral part of research in the field of automatic vehicles and autonomous driving. The most common assist driver warning in unauthorized or risky lane keeping, maintaining a safe and constant distance to front vehicle (ACC), parking the car, pre-sensing about various possible obstacles, collisions or traffic hazards and finally allowing automatic communicate with other vehicles or traffic stations like V2V or V2X systems. The most sophisticated systems make a step ahead with automate recognition of pedestrians, traffic signs or participants, ensuring automating braking in critical and emergency situations (AEB), or even an autonomous emergency steering feedback to avoid possible collisions (AES). Most of these systems use short, medium, or long-range radars to detects this potentially dangerous traffic situations or unsafe driver conditions.

Unfortunately, in the case of overtaking these systems, excepting for V2V are not useful, and must be automatically deactivated when the driver initiates such a manoeuvre. Obviously, the ACC system for tracking the vehicle in front is incompatible with the overtaking, although it includes several useful components in monitoring the space around the vehicle that initiates overtaking, in this case a radar.
The concept of the ACC system is opposite to overtaking, but it should not be ignored because many of its components can be very useful in assisting, and even automating the full overtaking manoeuvre taking into account the capabilities offered by the radar sensor in measuring speeds and distances of the overtaken vehicle, or of those traveling into other lanes (in same or opposite direction), as well as the possibilities of an automatic acceleration or braking required to maintain a constant distance. Although radars are currently used in ADAS applications such as ACC, parking, lane change or blind spot monitoring, in the near future this device will play an active role in controlling vehicles especially those with autonomous driving, in an effective accidents prevention system, or for traffic control especially in crowded intersections.

Integration of all the functions of a radar transceiver into a single integrated circuit, the unprecedented reduction of the size of a complete radar device (to half that of a credit card) and especially the possibility of a single chip to control up to 16 antennas (four transmission and four reception) in a MIMO type structure have made the price of these devices drop a lot thus becoming extremely attractive for new designs and technologies.

2. Device architecture

From the perspective of overtaking manoeuvre, the Overtaking Manoeuvre Monitoring System (OMMS) device was designed to ensure an automatic monitoring of the vehicle environment both through radar and video camera sensors. In addition to front traffic surveillance, rear monitoring is absolutely necessary as it can detect a possible overtaking manoeuvre in progress performed by the rear vehicle, while a side view allows the assessment of the safety lane in which the overtaking vehicle carry-out. Thanks to this facility, the device can aid the driver during the entire overtaking manoeuvre starting from the moment it is initiated and continuously reacting during its execution, depending on the different situations that occur in traffic. The operation of the device is independently from the presence or absence of the aforementioned ADAS devices and, in addition to recording data and dynamic parameters from the vehicle in traffic allows also to memorize all of information related to an overtaking in progress or in the intended stage (started and immediately cancelled). Based on these data, the device can also create a useful driver profile for car insurers, police or employers working in people and goods transportation companies.

The equipment used is based on a black-box system developed by the authors in a previous grant contract described in [1] and [2] which is also the subject of two patents. The basic system was equipped with video recording functions from four video cameras, also with a 10 Hz refreshing rate GPS monitoring system and a 9 DOF inertial IMU and was subsequently modified to allow communication with radar devices via Ethernet LAN. Due to the increased computing power needs, especially those related to spectral, FFT and other DSP functions, graphics acceleration, image processing and others, it was necessary to redesign the existing control unit module on the old black-box device. It is important to note that in this design phase the device was provided only with monitoring functions, without interacting with the vehicle's propulsion system to control dynamically the overtaking manoeuvre. CAN communication parameters like Suspect Parameter Number (SPNs), message’s Parameter Group Number (PGNs) with the other ECUs in the power chain, access to internal proprietary software and control algorithms are strictly secret data and far too complex to be approached from the outside. However, the possibility of a future extension in this respect should not be neglected, and the ways to achieve it should be considered from the design phase and in this respect, device was provided with two high speed CAN-FD interfaces.

In our tests, the device has operates independently, not connected to the internal network of the vehicle, requiring from the beginning to be provided with a series of sensors and its own communication network, although in other circumstances a lot of necessary data could be taken from other on bord electronic control units ECU via CAN or OBD communication. For example, most of the dynamic vehicle parameters required for overtaking manoeuvre analysis can be taken directly from the Electronic Stability Program (ESP) system via the propulsion-associated CAN network (CAN C). From the point of view of vehicle automatic and independently handling, electrically operated systems
such as electronic throttle, electric power steering, automatic transmission and electronic brake modulation (ESP) present on all modern vehicles can ensure and sustain the execution of an overtaking manoeuvre by controlling speed and acceleration, assisting steering and maintaining determined spaces and distances considered safe and optimal for this handling. This interference with partial and temporary takeover control from the driver is already functional in the ESP systems, disabling braking from the driver as a result of vehicle entering a state of instability such as skidding, over or understeering.

As can be shown in figure 1 device 4 designed as overtaking manoeuvre monitoring system embeds three electronic modules 1, 2 and 3, which operate in parallel running distinct algorithms with module 1 supervising module 2 from which it takes data using a LAN communication, via an ethernet switch 6, and module 3 with which it communicates through a CAN FD connection, 5b.

![Figure 1 System architecture of the overtaking manoeuvre monitoring system](image)

1. Master Module; 2. Radar control module; 3. Video, GPS and IMU control Module; 4. Overtaking Manoeuvre Monitoring System (OMMS); 5. CAN Network; 5a Vehicle Internal CAN; 5b- ODAS CAN-FD Network; 6, 7. Ethernet switches; 8. EPS (Electric Power Steering)-ECU; 9. ESP-ECU; 10,11,12,13 FMCW Radar Sensors placed in front, side and rear locations of the vehicle; 14, 15, 16, 17 high resolution video cameras placed in front, sides and rear locations on the vehicle; 18. GPS-antenna; 19. Inertial Measuring Unit (IMU) 9 DOF

2.1. Description of OMMS Modules

Module 2 receives information from the four radar sensors simultaneously via an Ethernet switch 7 to provide a transfer band required for a real-time monitoring at 360 degrees surrounding area. A car traveling as for example at a speed of 140 km/h covers every 10 ms a length equal to its own, therefore the latency of the detection process (from the sensor to the actuator) is of the milliseconds order. Of primary importance is the monitoring of the front and rear areas of the vehicle both for the radar and video cameras. When the driver operates the turn-on light signalling lever, OMMS analyses first if another car is in adjacent band in the area next to or behind VI. The overtaking manoeuvre is decisively influenced by the vehicles in front, and the front radar will must have a maximum detection range of over 300 m as it results from our experiments. For the rear sensor, a maximum detection range between 100-150 m is sufficient to detect vehicles already overtaking on the other lane at a maximum distance from which engaging in a VI overtaking is risky or prohibited. As for the side radars, their role is to ensure a safe distance between the two vehicles when the VI passes parallel to the overtaken vehicle, or when returning to the original lane and are less important in overtaking. For
this reason, the two side radars are of short-medium radius with the detection range between 25-60 m. All these fields are shown graphically in figure 2.

The radar sensor measures the distance, speed and angular orientation of any object that reflects to the receiver some of the energy transmitted by the transceiver, enough to be received and processed. Obviously, the reflected waves depend primarily on the transmission power, the distance between the radar and the target as well as the reflective cross section (RCS Radar Cross Section) of the target.

![Figure 2: Useful Radar sensor ranges for overtaking monitoring](image)

Radar sensor must accomplish certain parameters manifested under specific conditions to be successfully used in monitoring overtaking manoeuvres. All these situations are presented graphically in figure 3. Regarding the determination of the distance between radar and a vehicle, in addition to the maximum detectable range \((a-b)\) it is also important to determine how radar measures distances under the conditions of the simultaneous presence of several vehicles, or how close can be two vehicles so that they can be perceived distinctly \((c\)-radar range resolution\).

![Figure 3: Measuring distance, relative velocity, and azimuth angular resolution with FMCW MIMO radar](image)
Regarding the determination of vehicle speeds, we are interested in the radar sensor capability to distinguish between two or more close vehicles, located at the same distance from the radar but moving with different velocities, that is velocity resolution ($d$). In this case multiple chirp waves must be transmitted to the target. How does the radar perceive two vehicles at the same distance but placed symmetrically on the median axis of the primary transmitted beam (angular resolution - $e$)? For angular measurement one transmitting and one receiving antenna are not enough. MIMO radar (Multiple Input -transmitting antennas -- Multiple Output -receiving antennas) must be used in this case. It is extremely important that all these parameters be correctly estimated related to overtaking manoeuvre by a judicious choice of the type of radar sensor used and by a correct programming, the latter operation being complex and difficult because it involves a deep knowledge of how to operation and the physical-mathematical principles that control FMCW MIMO radar.

**Module 3** performs recognition functions of those objects identified in parallel by radar sensors controlled by previous module 2. It is built around a central controller with extended image processing capabilities, a hardware-type graphics accelerator with an extended computing capacity oriented in deep learning neural networks, TensorFlow, CNN (Convolutional Neural Network), OpenCV, as well as a high-speed memory with large capacity. A NVIDIA Xavier SOM (System On Module) has been selected for this purpose. After processing the images from the video cameras, graphic information regarding the recognized vehicles found in the surrounding area of VI and, if is possible also numbers of their license plates are selectively passed to the Module 1. Once the overtaking manoeuvre is initiated, Module 1 sends a command to Module 2 which will strictly store the images of the vehicles directly participating in the overtaking manoeuvre, i.e. the front and rear, respectively the first object recognized as the vehicle appearing on the opposite front lane. In addition, processing the images from the front camera allows Module 2 to detect possible traffic lanes markings to determine the type of current road (road type, lane number). An extensive mathematical model and simulation example for lane detection are found in [6] [8] and adopted in ours project. This information could also be validated processing data received from Module 1 (GPS coordinates) and positioning VI on an electronic map in case of the existence of this option.

For a more judicious usage of the storage space, it can be chosen that the storage of the previously referred images be activated only if the driver ignored the warnings of the device while engaging in overtaking, or performed the manoeuvre on road sections, where it is forbidden. Given the graphics processing capabilities of Module 3, an additional traffic sign recognition function is also possible.

The most important function of Module 3 consists in image acquisition from the four video cameras allowing in a first phase overtake monitoring throughout its progress, and later through a graphical images post-processing the classification, detection and recognition for a limited category of objects as for example car, truck, buses, respectively differentiating between different traffic participants (pedestrians, cyclists, motorcyclists). These image processing are based on the theory of neural networks thus defined and deep learning (trained) to recognize the classes of objects mentioned above. In particular, the learning process requires a high computational power given the real-time search in an extremely large database, impossible to store on a car computer. Each new image taken from a camera is analysed by Module 3 and compared with hundreds of thousands of other images judging on whether it recognizes anything within them. Approaching for a vision processing application, acquiring using different video formats, convert raw data from video cameras, training a data set of images, and implementing the resultant inference algorithms in an efficient way are very complex and difficult tasks, especially for those persons not involved in that field.

Thus, the use of existing programs and libraries that automates the process of acquiring images, deep learning process or training different model based on the user data, and which include different algorithms for numerical computation, image recognition is recommended and welcome. Especially Caffe and TensorFlow API packages ensures very fast processing speed and a low percentage of error in recognizing an object (algorithm ResNet [11] showed an error rate of just 3.6% and provide performances better than humans). In this context we decided to choose a Nvidia Jetson SoM (System on Module) board [10] as a base for Module 3. Many of the graphical image processing and shape
recognition examples found in Nvidia Multimedia API Samples Applications were adopted and run per se on Module 3.

**Module 1** is responsible to detect the road configuration as well as to recognize the overtaking manoeuvre initiated by the driver. The main parameters monitored are the steering wheel angle, car's turn signal lever switch, the acceleration and brake pedal angles, the longitudinal and lateral acceleration, the angular speeds and roll-over angle, the tilt angle on the two axles to estimate road slope and optional transmission shift gear. An important part of the above-mentioned parameters can be taken from the ESP (9) (Electronic Stability Program) system through the CAN 5b network. In independent operating mode the same parameters (except the steering wheel angle) can be measured or estimated by combining IMU + GPS. To determine the steering wheel angle, that information can be retrieved via a common OBD ELM327 Bluetooth interface. This method is explained in more detail in [3].

GPS precise position monitoring (18) and anticipated knowledge of the road configuration are mandatory and very useful because crossing into adjacent lane on a 2-lane road may definitely designate an overtake, but in a multi-lane configuration it may be an overtaking or a simply a lane changing. In this sense, the inclusion in digital maps such as Google Maps of information like the lanes number, road category, radius of curvature or the road slope would be of real utility in automating driving and increasing traffic safety. For testing purpose, a button on the steering column has also been provided to inform directly OMMS about the intention to initiate an overtaking and to request the automatic verification of the possibility of engaging in a safe manoeuvre.

Starting from the values of steering angle, lateral and longitudinal speed and acceleration and angular speed, module 3 determines the radius of the curve, more precisely the curve of the trajectory followed by the vehicle (see [3]). To determine the trajectory in a curve, the simplest method is to use the so-called corrected angular offset speed, taken from the ESP system via CAN or OBD networks. Instead, this parameter can be measured with a MEMS gyro or IMU precision device (19) included in Module 3.

Denoting yaw angle and yaw ratio with $\psi$, respectively $\dot{\psi}$ and the longitudinal speed with $v_x$, the curvature of the path travelled by the vehicle and denoted by $\kappa_v$ (inverse of the curve radius R) can be calculated according to the relation (1):

$$\kappa_v = \frac{d\psi}{dt}/v_x$$  \hspace{1cm} (1)

Instantaneous values are passed through a low-pass filter to obtain an average value.

A second method of determining the curvature $\kappa_y$ of the road results from the well-known relationship between the velocity, centripetal acceleration (lateral acceleration $a_y$ measured by IMU) and the radius R according to relation (2):

$$\kappa_y = a_y/v_x^2$$  \hspace{1cm} (2)

Compared to $\kappa_v$, the determination of the curvature $\kappa_y$ from the lateral acceleration is less accurate, especially in the case of lower travel speeds, or in the case where the curve section is in slope or ramp.

Less precise values of the trajectory curve can also be determined from the Ackermann geometry starting from the front wheels steer angles relative to the wheelbase, assuming that the continuous variation of the steering ratio is well known. This variation is more difficult to be determined or to be acquired in the case of electric power steering systems or active steering systems.

All the methods listed above show deviations from the actual curvature of the road, especially when the curve stretches over long road sections and involves sudden variations in radius and direction. Under these circumstances, to increase the accuracy of the curvature estimation, additional information coming from the navigation system or acquired from video cameras, or even continuous distance monitoring from front vehicle using radar or lidar sensors can be particularly useful. In particular, the recognition and determination of curvature using video systems and image processing can bring a considerable increase in accuracy, but also in the price of the system. There are already
driver assistance systems, many as options, that to warn of irregular or accidental change of lane and other which recognizing traffic signs that can be used successfully for overtaking assistance.

Based on the values of steering wheel angle, car speed and steering gear lever status, Module 1 automatically determines if the driver is initiating an overtaking manoeuvre. The difference between overtaking and turning left is usually clarified depending on car speed because turning left is done at low speed and deceleration, while for overtaking manoeuvre speed must be higher (in principle over 60 km/h) and acceleration positive. An electronic map that allows the anticipation of a few hundred meters of the presence of an intersection, fork or branch of the road would be of real use, especially for the detection of areas where overtaking is prohibited. Also, automatic detection of traffic signs prohibiting the respective manoeuvre is necessary.

3. OMMS operating algorithms

Throughout this paper, the references to distances, speeds, accelerations, and vehicles engaged in the overtaking manoeuvre are those expressed graphically in figure 4.

The vehicle that initiates overtaking manoeuvre was marked with VI and is equipped with the OMMS device that allows the measurement of the distance and speed of all vehicles detected in the surrounding area. At time zero these are:

- the first vehicle in front of VI that will be overtaken is marked with VD1 and is located at a distance $l_{d1}$ from VI;
- the second vehicle VD2 moving before VD1 exceeded at a distance $l_{d2}$ from the originating vehicle VI and which may be or may not be detected by VI radar;
- the vehicle behind VI, on the same lane marked VS at distance $l_s$ from the initiator vehicle VI, which may also be engaged in an overtaking manoeuvre;
- the VO vehicle traveling in the opposite direction on the lane adjacent to the distance $l_{omax}$ from the initiator vehicle VI and which may be detected from a certain maximum distance $R_{max}$ representing maximum radar detection range.

![Figure 4. Graphical description of the initial condition, immediately before the vehicle VI initiate the overtaking manoeuvre on a two-lane road](image)

Module 1, which analyses the data taken from Module 2 and Module 3 takes the decisions to validate overtaking, but also signalling the situations in which manoeuvre is not possible to be performed, or its execution involves risks and should be avoided. The signals corresponding to each situation are optical, acoustic, and in the future can be considered haptic reactions (like trembles of the accelerator pedal and a harder pressure on pedal pressing, or small vibrations or oscillations sensed on the steering wheel, etc.).

In the first step, Module 1 cooperates with Module 3 to determine the location and type of road on which VI is moving, by analysing information coming from the GPS block (18) in cooperation with video cameras information received from Module 3. It is very important to determine whether the manoeuvre is made on a two-way road with a single lane in each direction, or it is a multi-lane road, in this case positioning of the vehicle on a certain lane being mandatory. Related information are
obtained through a fusion of video, GPS coordinates and digital map data (Google Maps, Microsoft Bing Maps, MapQuest, Garmin or TomTom). Processing graphical images from video cameras allows detection of the white marking line separating two lanes, also to know the direction in which vehicles travel on adjacent lanes or possible overtaking restrictions, dangerous curves, etc. by automatic traffic sign detection and recognition. All these types of digital analysis and processing are currently used in modern driver assistance systems (ACC, Lane Change Assistance, Traffic Sign Detection and Recognition System).

In this context, the detection of curves is particularly important for the OMMS system to differentiate if the sudden change in steering wheel angle is due to approaching a curve or entering an overtaking manoeuvre.

In step two, based on the speed and acceleration of VI and on the fusion data from Module 2 (distances, relative speeds and accelerations to other vehicles from surrounding area) Module 1 checks whether the space between VI and VD1 fits into the safety threshold and the affirmative case, the distance required for a safe overtaking is determined. The determination of the safety distance between two vehicles, in our case VI and VD1 is extensively dealt in relation to ACC system, the calculation algorithm being treated in [4], [5] and adopted in our project with minor modifications. As a rule of thumb, a safety distance in meters is half the value of speedometer current velocity in km/h (based on a reaction time less than 1.8 sec). If this minimum safety distance is not met, or the speed of vehicle VD1 exceeds a certain predetermined value depending on VI powertrain and dynamic capabilities, or the maximum speed allowed on that road, a red light LED pass into a blinking mode warning driver about the danger of engaging in such a manoeuvre. At a higher level of development, using the capabilities of processing image algorithms to detect and recognize traffic signs allows the device to warn that overtaking is prohibited.

Main programme will continuously pass through these two steps in a loop until the initiation of the overtaking manoeuvre is detected, either automatically by module 1 or expressly requested by the driver by pressing the button.

A schematic diagram of the vehicles and distances involved in a two-lane road overtaking manoeuvre which are used in algorithm calculus are depicted in figure 5. Two types of overtaken manoeuvres can be recognized in car handling practice. The most dangerous involves cut-in from one lane in the adjacent lane with inverted traffic sense, a situation most often encountered on two-lane roads (one per sense). Most accident studies have established a reduction in the number of overtaking, including those that are risky or hazardous, as the number of lanes increases, with most accidents occurring due to inattention and not a wrong approach of overtaking. The second overtaking manoeuvre involves four-lanes road or multi-lane one-way roads, most of them not allowing entry in the opposite direction of traffic without the initiating vehicle passing in the opposite direction of travel and is practically identified with the lane change.

Figure 5. Overtaking manoeuvre phases for a two-lane road with the and highlighting of the associated spaces and times, respectively of the involved vehicles

Main programme exposed as an flowchart can be show in figure 6. Once detected the initiation of an overrun manoeuvre Module 1 will decide which of the two branches of the program will be given
control, each one being processed by different algorithms. In case of first type of road detection, Module 1 starts the execution of Algorithm 1.

In the absence of other possibilities, vehicle VI will estimate the travelling sense on the adjacent lane at the moment of cutting into this lane, depending on the distance relative to the first vehicle VO that is detected as traveling in front of it. In case the distance between vehicle VI and VO is reduced and relative speed will be higher compared to each one the adjacent lane will have an opposite sense and Module 1 enter in Algorithm 1. Otherwise it will run Algorithm 2 not treated in this paper.

**Figure 6. Main programme algorithm flowchart**

Step one of algorithm 1 is activated at the start of the overtaking manoeuvre as results from the Main program organigramme. Program determines the required time for initiating vehicle VI to overtake the first vehicle VD1 in front of it. At the entrance on the overtaking lane Module 2 will determine the distance \( l_2 \), between the vehicle VI and the first vehicle VO encountered on the overtaking lane, as well as its speed \( v_o \) and acceleration \( a_o \). In this phase is possible that Module 2 detect the presence of another vehicle VD2 preceding vehicle VD1 and to determine the relative distance and speed between VD1 and VD2 also transmitting this information to Module 1. To allow a more accurate calculation of the distance that VI have to travelled in overtake, Module 1 can estimate from Module 3 information...
concerning VD1 category (car, truck, bus, motorcycle, bicycle, tow truck, etc.), thus associating an estimated length $L_{VD1}$ with it.

In the next step, algorithm 1 determines passing times from current to adjacent lane $t_{12}$ and vice versa $t_{21}$. These values depend on the VI’s speed $v_i$, and acceleration $a_i$, being determined experimentally and saved in a 3-D lookup table (cartogram) located in the non-volatile memory. The total time of overtake manoeuvre is calculated in Step 3 by summing the durations of the three component phases: cutting into adjacent line - $t_{12}$, parallel travel $t_2$ and returning to the current lane - $t_{21}$, possibly between the first overtaken vehicle VD1 and the second vehicle VD2.

$$t_d = t_{12} + t_2 + t_{21}$$

having a minimum value for $t_2 = t_{2min}$.

All these operations are made when Module 1 detects the debut of an overtaking by VI cutting into the overtaking lane, or by the driver pressing the overtaking button to monitor the conditions for a possible overtaking manoeuvre. Starting from a minimum speed value $v_i^*$ that the vehicle VI has at the initial moment to perform a safety overtaking manoeuvre and which can be considered approximately equal to that of front vehicle VD1 we can compute a minimum value for the overtaking time using the relation (4):

$$t_{2min} = \frac{l_{1d} + L_{VD1}}{v_i^*}$$

On the next step algorithm 1 estimates the returning space that VI dispose to re-enter in the current lane according to relationship (5), all the distances involved being graphical described in figure 4 and figure (5)

$$\Delta l = l_{d1} + l_0 + L_{VD1} - l_{vd} - l_{vo}$$

where $l_{d1}$ is the initial distance between VI and VD1, $l_0$ denotes the variable space from VI to VO measured on the adjacent lane during overtaking, $L_{VD1}$ represents an estimate of vehicle VD1 length made by Module 3.

$l_{vd}$ and $l_{vo}$ represent the continuously variable distance travelled by VD1, respectively VO which can be calculated by Module 1 on the basis of the data transmitted by Module 2 (according to the relations (6) and (7)):

$$l_{vd} = v_d t_d + \frac{1}{2} a_d t_d^2$$

$$l_{vo} = v_o t_d + \frac{1}{2} a_o t_d^2$$

In step 5 Module 3 compares the calculated value of the return space $\Delta l$ with a predetermined safety value in relation to the vehicle type VI, VD1, VO and possibly VD2 and, if this is not satisfied the whole calculation is repeated into a loop starting with a new value of the required overtaking speed resulting from the initial speed $v_i^*$ to which is added a certain predetermined quantum $\Delta v_i$ according to the dynamic possibilities of the overtaking vehicle VI (power, maximum speed, acceleration time, vehicle category, etc.). The program continues to run in a loop until a maximum threshold value $v_{i_{max}}$ is determined, depending on several parameters among which: road category, maximum speed allowed on the route or any speed restrictions identified by the video cameras. If the safe returning
space $\Delta l$ cannot be determined, the overtaking manoeuvre will not be allowed, and the driver will be warned optically and acoustic. If, however, the overtaking continues, Module 3 will receive the command to permanently store (in a special area of non-volatile working memory) the video sequences from the cameras recorded throughout the manoeuvre. Deactivation of this mode, implicitly of the optically and acoustic signalling will be possible only by reducing the speed below a certain threshold, or by stopping the engine. On the contrary, if this safety returning space is obtained, the associated speed will be displayed on board as the minimum speed required to perform overtaking.

The flowchart of the algorithm 1 is depicted in figure 7.

![Flowchart](image_url)

**Figure 7. Algorithm 1 Flowchart**

In case of the existence of another VD2 vehicle, further on the normal lane in front of VD1, it is possible that immediately after overtaking VD1 and after measuring the distances and relative speeds to VD2, VO and VD1 for the algorithm to decide and inform the driver regarding the possibility of continuing safely to continue overtaking of the vehicle VD2 or it is mandatory to return on its own...
lane between VD2 and VD1. If the driver decides to return on current lane without intending to continue to overtake VD2, the algorithm is reset by returning to the initial starting point.

4. Tests description
The main purpose of the experiments carried out in this first phase of the project is to establish the safety distances between the vehicles involved in a simple overtaking (only two vehicles VI and VD1), to determine the passing times from one lane to another at various speeds and to determine the time required for the parallel travel phase in the event that the overtaken vehicle respects or does not comply with the obligation not to accelerate. In the next phase, the same tests will be performed under the conditions of the participation of three vehicles (VI, VD1 and VO).

For tests purpose, Module 1 was implemented with a mini PC Asus UN65U and partially taking over the functions of Module 2, as for Module 3 it was chosen a Racelogic VBoxPro video logger with 4 Sony video cameras. Each camera has a resolution of 752x582, enough to provide quality images and continuous streaming of data with memory on a memory card, and/or a continuous streaming of video through a CAN interface. A Racelogic VBOX 3i logger with an IMU device was used as the IMA and GPS device due to the acquisition speed of 100 Hz compared to 10 Hz in the case of Video Box Pro. Two long-range sensors AWR1243 from Texas Instruments with a maximum distance up to 150 m were used as radar devices in front and rear of the VI vehicle, and for the sides two AWR1843 for medium range. Images with this equipment mounted on the VI vehicle are shown in figure 8.

The biggest challenge was the synchronization of data and information from the front radar, with images taken by front, rear and side cameras, also with GPS and IMU coordinates respectively vehicle dynamic parameters and all these with data from the second vehicle VD1. As can be seen from figure 9 the second vehicle was provided with a VBox Mini GPS&Inertial unit measuring data at a rate of 10 Hz. Perfect synchronization of this data was achieved using a unique time base provided by GPS equipment and Racelogic VBOX Test Suite as a processing software program.

In this phase all data from radars and video camera has been processed off-line. In case of radar, raw data captured by radar transceiver are sent via LAN connection to central processing station (Module 1, or Mini PC) for post-processing for creating range-Doppler response. Post-processing includes 1D, 2D, 3D Doppler -FFT [7], creating Range-Doppler Map (speed-range), Range-Doppler
Response Map (Doppler Frequency-Range) are achieved using Matlab scripts from Phased Array System Toolbox™ and Communications Toolbox.

![Figure 9. VboxMini GPS &Inertial unit monitoring VD1 dynamics; video images taken from video cameras and side radar mounted on VI car](image)

Figure 10 presents a sensor-fusion post-processing and synchronized data from front radar and video cameras captured in one of the tests performed.

![Figure 10. Processed data from radar and video cameras](image)

To make accurate time estimates of each overtaking phases (cutting-into the adjacent lane, moving parallel and returning to the own lane) images taken from the front video camera was analysed, frame by frame, reporting the deviation of the right front end of the car relative to the centre line of the road chosen as a reference and associating each frame with the quantum time provided by the GPS equipment. The manoeuvre of crossing into the opposite lane presented in Figure 11 as a sequence of four frames (due to the paper space restriction) is processed to display the evolution in time of the speed, longitudinal acceleration and distance travelled by the vehicle VI.

Each image from the front, rear and side of the car has a time stamp a which allows their synchronization with certain values of speed, lateral acceleration and travelled space as can be seen on the graphics in figure 12. In this way, the time intervals corresponding to the three phases of the overtaking manoeuvre can be isolated on the respective graphs. Simultaneously, using timing synchronization the dynamic parameters of the overtaken vehicle VD1 can also be presented on the same graphic.

With the objective of determining the times in the three phases of the overtaking manoeuvre, respectively of the distances covered by the two vehicles, approx. 50 overtaking tests with the two vehicles running at different speeds were performed. We have analysed both the situation in which the VD1 vehicle regularly approached the manoeuvre keeping constant speed throughout the overtaking,
and the situation, not infrequently in traffic in which the overtaken vehicle accelerates in turn based on the impossibility to accurately identify its associated dynamics.

**Figure 11. Image analysis to calculate time of cutting into the adjacent lane**

First of all, we were interested in changing the overtaking times and spaces in both situations to draw conclusions about the necessary parameters (maximum detection range and maximum speed) that the radar sensor must cover to successfully respond to the proposed project objectives.

**Figure 13** depicts one of the correct done manoeuvres with overtaken vehicle VD1 keeping a constant speed of 87 km/h and vehicle VI finishing manoeuvre in 7 sec. It can be clearly seen that during the overtaking manoeuvre the acceleration of the vehicle VD1 is zero.

**Figure 12. Determination of the timing interval for each phase of an overtaking manoeuvre using optically identification as presented on figure 11**
On a contrary, in figure 14 the vehicle VD1 accelerates when VI engages in overtaking observing the increase in travel speed compared to the previous situation. In this situation, the parallel travel phase lasts a significantly longer time, and the vehicle VI is forced to travel at a speed of approx. 20 km / h higher. It is particularly important that Module 1 determines with the help of the radar sensor this acceleration (practically increasing the speed) and depending on the power reserve of VI to decide if the manoeuvre can be continued.

Figure 13. Speed, longitudinal acceleration, and distance travelled for both VI and VD1 in a correct overtaking maneuverer

Figure 14. Speed, longitudinal acceleration, and distance travelled for both VI and VD1 in an incorrect overtaking maneuverer approached by VD1

In these situations the greatest danger comes from a vehicle moving in the opposite direction (VO), on the overtaking lane because in this additional 5 sec that VI is forced to travel vehicle VO will move
at a speed of 90 km/h withs 125 m, reducing the safe returning distance for VI. Obviously, a radar with a maximum range of 150m is not useful in such situations.

In the graph in figure 15 were grouped the variations of the velocities and longitudinal accelerations measured for the vehicle VI both in situations of correct overtaking and in abnormal situations.

![Figure 15. Speed and longitudinal acceleration in seven overtaking manoeuvres tests with overtaking times $t_d$ between 6 to 16 sec](image)

Radar azimuth angular resolution is also important to establish the lane on which a vehicle is placed at a certain distance from the VI. The angular resolution depends on the number of receiving antennas. A SIMO system (1 transmitting antenna and 4 receiving antennas) ensures an angular resolution of 30°. By increasing the number of receiving antennas to 8, the resolution decreases to 15°. Adding multiple transmitter antennas (MIMO) improves the angle resolution even more. A sensor of the type used in the tests has an angular resolution of approx. 5° (3 Tx antenna and 4 Rx antenna) which ensures a minimum distinguishing distance of 8 m between two objects.

As can be seen from figure 16 a conventional radar sensor (image a) will perceive the two vehicles at a distance of 45 m on separate lanes as a single object while a system based on 4 sensors cascaded (image b ) with 12 transmitter and 16 receiver antennas can correctly detect the two machines. At 350m away, the same angular resolution of 5° increases the separation distance to 30 m making it impossible to distinguish between vehicles on different lanes. In all this context, the possible sources of noise were not considered. To ensure correct perception in the two adjacent bands, the radar should provide angular resolutions of 1.4°.

A relatively recent technique allows cascading of several transmitters and receivers, each with its own processing chain (LNA, Mixer, filter, analogue/digital converter ADC) that allow coverage angles of 60 ° and maximum detection distances of approx. 350 m.
Figure 16. Azimuth angle resolution for a conventional radar (5°) -a and a cascaded (1.4°)-b

5. Conclusions
In this paper was presented a complex equipment designed to assist the driver in overtaking which monitor, warn, and inform about manoeuvre conditions, evolution and parameters and consequently making it safer.

A modular device was proposed, with various functions regarding radar signals processing, graphical images acquisition from video cameras attached to the vehicle and all this data fusing with GPS information and dynamic parameters taken from an IMU system.

The designed video system allows a detailed monitoring of the overtaking maneuverer phases and will be upgraded without major modifications to perform functions of recognition of certain categories of vehicles in traffic, including pedestrians.

Tests performed allowed the establishment of reference values regarding the estimated times associated with the overtaking phases, respectively some parameters associated with the radar sensors necessary for a correct detection and monitoring of all involved vehicles.

Experiments demonstrate that in the event of a violation of the rules on maintaining a constant speed or even reducing it by the overtaking vehicle, the frontal radar sector must ensure a field of perception of at least 350-400m and an angular resolution of 1.4° are mandatory.

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