Automatically adjustable rear mirror based on computer vision

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Abstract

A well-researched topic dealing with the automotive market concerns the development of innovative devices to improve security and comfort. Along these lines, this paper proposes a fully automatic system based on computer vision that can orient the interior rear view mirror of a car so as to seamlessly provide the driver with a correct rear view.

A cheap 2D camera is mounted over a motorized rear view mirror and used to scan the interior car space in order to identify the driver's face and eyes. Detection does occur effectively regardless of the number and position of car occupants and allows the system to compute the correct orientation and adjusts the mirror accordingly.

1. Introduction

In a car, or a vehicle in general, the driver's gaze must be directed out of the windshield glass, ahead, towards the way, most of the time. This position is the best for passengers' safety because it enables the driver to perceive danger and react in a short time. Sometimes it is also necessary to look backward, to the rear of the car, e.g. to safely change lane or park. This problem was already known about a century ago, when people began using cars. Patent [1] deals with the invention of the rear mirror, which allows the driver to see the rear of the car by moving only the head while keeping the hands on the steering wheel. The head movement is indeed quite small (sometimes an eyes movement is enough), which implies that the time needed to come back to the best safety position is very short.

Though the rear view mirror is a great invention that increases car safety notably, it needs to be accurately oriented to enable the driver to see the rear of the car through it. The optimal position is different from one driver to another, depending on height and posture. Hence, if a car is shared between people, like in a family or a car-sharing service, a company car, a taxi or bus, the rear mirror orientation would likely require adjustment every new time a driver starts using the car. Thus, users of shared cars may possibly appreciate a rear mirror capable to automatically adjust its orientation in order to adapt it to the person that is going to drive.

The work described in this paper concerns an automatic system based on computer vision that correctly orients the interior rear view mirror of a car to provide the driver with a correct rear view. Fig. 1 depicts a block diagram of the system: a camera captures a picture that is used by suitable computer vision algorithms implemented in software to identify the driver's face and measure its position in space. Subsequently, the optimal orientation of rear mirror is calculated and the mirror accordingly moved by means of servo-motors.

There are many problems that must be solved to actually realize such system: detecting the driver's face in the camera picture, also in presence of multiple passengers, estimating the face 3D position, calculating the optimal orientation of the mirror, ...

Moreover, one major goal concerning the overall design has been to keep the system as simple as possible. In particular,

- Simple to make: the system uses a simple and cheap 2D camera, like a webcam;
- Simple in software: reusing libraries and frameworks already available;
- Simple to use: to adjust the mirror, the driver needs only to push a button and look at the mirror.

The system consists of three main parts:

- a 2D grayscale camera or a webcam; in the current prototype we use a CMOS camera with ad analogue PAL Composite output;
- a PC as processing unit, but the software may be implemented on a embedded system like the Raspberry;
- an electric motorized rear view mirror.

As for the last part, so far we have built a prototype version (see fig. 2) that has enabled to study and characterize the mechanics of an electric mirror.

This paper is organized as follows. Section 2 presents previous works, while Section 3 and subsections present our work: the detection of driver's face, how computing right mirror angle even without have the correct driver's distance, how the system can compensate low ambient light and other. Section 4 discuss experimental tests made and Section 5 argues for future optimization and applications of the system.

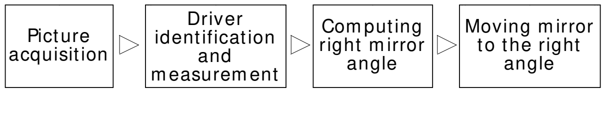

Fig. 1 - Block diagram of the system

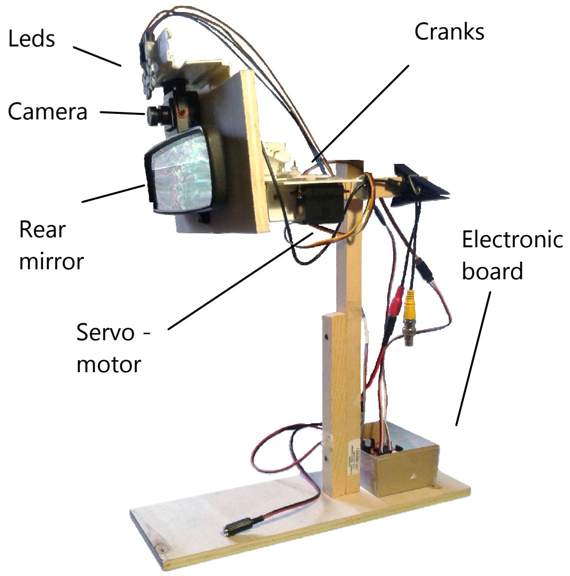

Fig. 2 - The prototype made

2. Previous work

Throughout the years, many studies have investigated on how to improve the safety and comfort of a car driver. Statistical studies ([2]) show that many car accidents are caused by driver's distraction, tiredness or falling asleep. As pointed out in [3], several surveys demonstrate that the probability to make an accident would fall down if someone into the car alerted the driver upon an incoming hazard. And that is true even when the danger is driver's own distraction. Motivated by these well-known studies, in the last years significant research efforts have devoted toward deploying computer vision for automatic detection of driver gaze and fatigue. All these vision-based systems tackle the key problem, also relevant to our work, of detecting the driver's face and eyes from images taken by an in-vehicle camera. Nanda and Fujimura [4] use a depth sensor connected to the camera to detect the head position. Then through a classifier (PCA or neural network), they obtain a coarse estimation of driver's gaze. Many papers (such as [5][6][7]), and commercial systems alike (e.g. [8][9]), rely on a stereo camera to capture head photos already in a three-dimensional space, though this approach may increase system complexity and cost significantly.

Conversely, many other works use only a 2D camera. For example, [10] relies on a single camera located in the dashboard. Color predicates (histogram-like structures used for color identification) are deployed to detect the driver's face, lips and, subsequently, the eyes. Measuring relative distances between these points and the border of the frame of the camera, enables to detect head movements and rotations. [11] is another work that places the camera on the dashboard. They use the Parametrized Appareance Model (PAM) with the Supervised Descent Method (SDM) for describing and retrieving the face in the picture captured from camera. This system collects some features described by SIFT from the face in order to estimate the head orientation: a 3D face model is constructed and modified until the difference between its projection and the SIFT feature vector is minimum. The work of Murphy-Chutorian and Trivedi ([12]) is somehow similar, as they also use the difference between a projected 3D model and the captured picture. However, they use Adaboost for face detection and coarse estimation of head pose, which is then refined by LGO (Localized Gradient Orientation) and Support Vector Regression. Other works use Adaboost for face detection and, sometimes, coarse head orientation estimation. For example, [13] and [14] retrieve the face into the picture using Adaboost, then collect features in different ways. [15], instead, deploys Adaboost also to attain coarse head orientation and detect eye and mouth positions. This work is also peculiar in leveraging on the use of a smartphone rather than presenting a system conceived for tight integration into the car.

Similarly to our work, Rho et al. in [16] propose a vision-based system for automatic adjustment of car mirrors. They use a stereo camera and first search for the driver's nostrils, then, in a second step, for the eyes. This approach relies on the assumption that, though the nostrils are always visible, the eyes can be hidden by sunglasses. In this latter case, they use a face model to predict the eyes positions based on the calculated nostrils positions. Then, the author detects the 3D position of the eyes using the depth information associated with the stereo image pair and computes the orientation of car mirrors accordingly. There exist also some patents inherent to an automatic mirror adjustment system. [17] proposes a system based on a stereo camera positioned into the internal rear view mirror. However the patent does not describe how to detect the face. Others patents provide more general system concepts, without actually specifying relevant technical details concerning for example, the detection of the driver's face ([18]).

Eventually, other patents describe systems that memorize the mirror orientations for some drivers, so to allow mirrors to be automatically adjusted upon identification of the driver ([19]).

The system described in this paper tackles some problems similar to those addressed in other papers.

One key problem is about finding the driver's face. While a number of previous works, such as e.g. [5][6][7], rely on a stereo camera or other types of depth sensors (e.g. [4]), our system deploys just a simple 2D camera, such as a webcam, the only requirement concerning the field of view, which must be large enough to see the entire driver's face. Then, the finding the face within the 2D picture alongside with knowledge of the camera position and intrinsic parameters enable us to localize the face in 3D. This approach cannot be found in any other paper. The second problem deals with computing the mirror orientation, which is addressed by just a few works (e.g. [16]). Similarly to previous work, we develop a suitable mathematical approach, i.e. derive equations that describe the system and can be solved to compute the mirror orientation. However, while previous work relies on algebraic methods, we develop a numerical algorithm, that can find a solution with an error lower than a given threshold.

Finally, as this work concerns a rear mirror that can adjust itself, the mirror must be equipped with motors. Purposely, some related works take advantage of pre-built automotive systems, like [16] that leverages on the electric mirrors of a Hyunday Equus. We instead built our own prototype using a mechanical structure with a real rear mirror pivoted on it, two servo motors and some cranks to provide the movement.

3. Overall system

The prototype built in this work is depicted in fig. 2. It consists of a handmade wood structure that sustains a real rear view mirror. Over the latter is installed the camera and some white led that the system uses to light up the driver's face in case the environment is too dark. Following the "keep it simple" principle, the camera is a standard, low-cost CMOS analogue camera with PAL Composite output and about 50° FOV. Given the average distance between driver and rear mirror, the chosen FOV enables viewing the whole driver's face in a single frame. Though not shown in fig. 2, an analog frame-grabber is used to connect the camera to the PC.

The mirror is mounted on a wood plate pivoted to the structure, so it can rotate according to pitch and yaw angles. To allow movements, the structure is connected to two analogue servo-motors by two cranks. The whole mechanic of prototype has been modeled and implemented into software, so that the system can always know how the parts are positioned and oriented, particularly the mirror and the camera.

All the hardware devices (servos and leds) are driven by an Arduino board ([20]). A support board (visible in fig. 2) was made because the Arduino board driving capability is too low to power all the devices. Moreover this board implements a hardware dimmer that can turn on leds according to different light intensities. A PC running the software is connected to the camera and Arduino board.

3.1. Finding the driver's face

Our system uses the OpenCV implementation of the well-known Boosted Cascade Classifier based on Haar Features by Viola and Jones ([21]) to find faces in camera pictures. In particular, we apply the algorithm twice: first, to detect the driver's face, then to retrieve the eyes within the face area, as realization of our system mandates knowing where the driver's gaze is pointing at. To detect both faces and eyes, some pre-trained classifiers were tested in several challenging conditions, such as e.g. very low ambient light, to select the best configuration in terms of detection ability as well as execution time.

Unlike other proposals, in our system the camera can rotate as it is mounted over the mirror. Also, the system is designed to still allow the driver to manually adjust the mirror if she/he so wishes. Thus, as the camera is not always focused on the driver's face, the system must be able to actively search for it.

To achieve this goal, when the driver push the button and the system starts operating, the camera is rotated and the software starts taking photos: thereby, the system scans the workspace to look for the driver's face. An exemplar result is shown in fig. 3a, where the images captured during the scan have been approximately aligned. In each of them, thus, the system tries to find faces using the previously mentioned classifier. As the intrinsic camera parameters are known by a standard calibration, upon detection of a face the system can determine the parametric line that links the camera to the face. Subsequently, using the mechanical model to detect the camera 3D orientation from the mirror pivot point that is used as reference, the system calculates a 3D vector from this reference point to the face (more explanations can be found in Subsection 3.3).

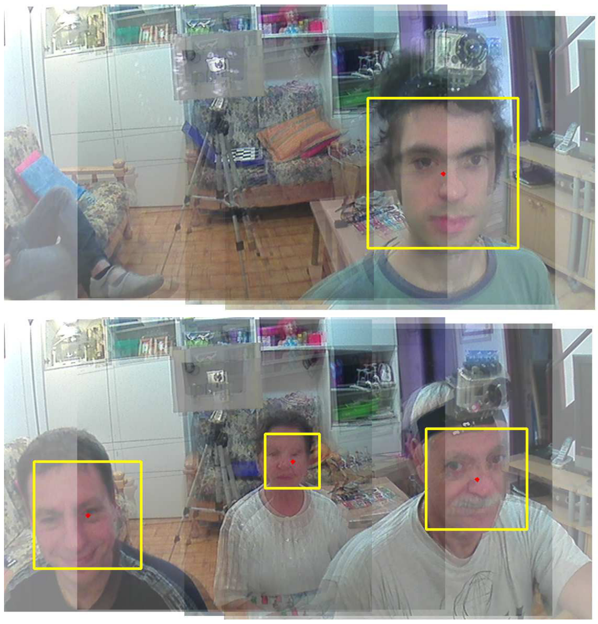

Fig. 3 - Images obtained after scanning to seek driver's face. Here the faces have been already detected.

Fig. 3 highlights that pictures are partially overlapped, to avoid missing any space region during the scanning sequence. In this manner, however, the same face can be detected in multiple pictures, and if there are passengers into the car, different faces can show up in the pictures. How can the system tell part the faces belonging to the people in the car, both the driver as well as the passengers? As previously discussed, for every detected face the system is able to compute the 3D vector linking it to the reference point. Thus, the same face would yield the same vector when seen multiple times, unless the person moves significantly during the scan. Accordingly, the system can cluster together the detected faces belonging to each car occupant based on the similarity of the measured 3D vectors.

Eventually, if more than a single face is found by the scan, which one is the driver? As shown also in fig. 3b, the driver's face has got two main simple features: it appears larger than those of passengers sitting behind and it is positioned more rightward than the face of the passenger in the front sit (that is true in a right-hand traffic country like Italy, while in the left-hand case it is the opposite). Therefore, the system assigns a score to every detected face based on both its image size and

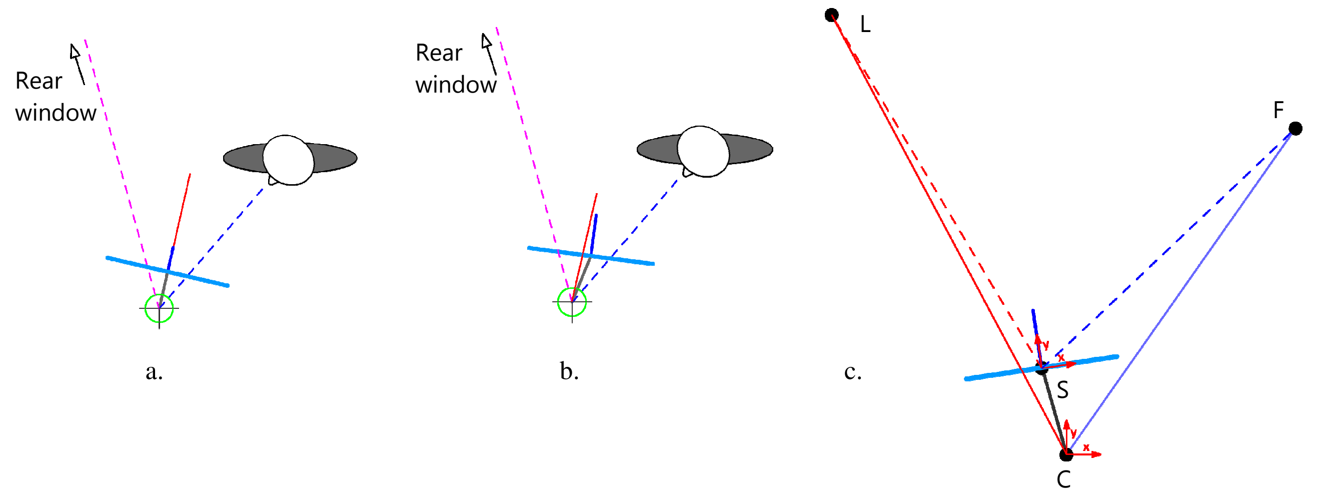

Fig. 4 - The problem of computing the correct mirror orientation.

position (both normalized). Then, the detected face yielding the highest score is selected as the driver's face.

3.2. Computing the correct mirror orientation

The key issue is now how to determine the correct mirror orientation given the driver's face. As described in the previous paragraph, if the system knows which face is the driver's, it also knows a 3D vector between that face and the reference point. Further, we assume as known the 3D vector from the reference point to the car rear window.

The problem is depicted in fig. 4.

The fig. 4a shows the simplest case of a mirror pivoted in its centre. Here, the correct mirror orientation is easily found as the angle bisector line (red in fig. 4a). Unfortunately, the real problem is more complicated, as illustrated in fig. 4b: the mirror is roto-translated with respect to its pivot point. Thus, the solution is nontrivial and involves solving some equations.

$$SL = \begin{bmatrix} a \\ b \end{bmatrix} \qquad SF = \begin{bmatrix} p \\ q \end{bmatrix} \tag{1}$$

$$L\hat{S}Y = \text{atan}\begin{pmatrix} a \\ b \end{pmatrix} = \text{atan}\begin{pmatrix} p \\ q \end{pmatrix} = F\hat{S}Y \tag{2}$$

$$SL = M_\theta \cdot CL \tag{3}$$

$$SF = M_\theta \cdot CF \tag{4}$$

The above equations refer to fig. 4c, where L represents the rear window, F the driver's face, S is the mirror and C is the mirror pivot point. C is the origin of the reference system at the pivot point, while another reference system has its origin at S. Vector CL joins the pivot reference point and the rear window, while CF is the 3D vector between the face and the reference point.

In this situation, the mirror is roto-traslated, i.e. between the two reference systems there exists a roto-translation described by matrix M_θ , the translation component given by SC and the rotation angle denoted as θ. The problem can thus be cast as finding the angle θ that renders the mirror correctly oriented. To allow the driver to see the rear space through the mirror (i.e. F sees L through S), the angle LSF must be bisected by mirror normal Y. In other words, the angles LSY and FSY must be equal. Thus, the problem boils down to finding θ such that

$$\text{LSY} = \text{FSY}. \tag{5}$$

Let us define vectors SL and SF through their components (1), relatively to reference system on S. The two angles LSY and FSY are the arctangents of SL and SF, as shown in (2). However, the system does not know SL and SF, but, rather, CL and CF. Through the roto-translation matrix M_θ, though, it is possible to get vector SL from vector CL, and SF from CF alike (3)(4).

As the analytical solution of these equations is hard to find, we realized a numerical algorithm that can find a solution with an error lower than a specified threshold. If the mirror is correctly oriented, the angle LSF is exactly bisected by Y axe of the mirror reference system. The angle between the bisector and the axe is zero. The system knows CF and CL and the current 3D orientation of the mirror respect the reference system C, in other words it knows a roto-translation matrix M between S and C.

Initially, the algorithm obtains SF and SL from CF and CL using matrix M like in (3) and (4). Then computes the difference between the LSF bisector and Y axe and uses this as an estimation of θ. Now start an iterative cycle to lower the error of the estimation:

- using the mechanical model implemented into software, the algorithm simulates a mirror movement of angle θ;
- re-computes new roto-traslation matrix M and new SL and SF;

- finds the LSF bisector and the angle between it and Y axe, this is the current position error
- if the error is lower than a specified threshold returns the current θ angle, else computes a new θ varying it by half of the error and starts again.

3.3. Driver's distance

As previously mentioned, the intrinsic camera parameters allow for determining the line between the camera and the driver's face. Then, using the mechanical model, the 3D vector between the mirror pivot point (used as reference point) and the face can be calculated. However, that is possible only if the distance between the camera and the face is known, which, indeed, is not the case in our settings. To measure such a distance one may think of deploying an additional sensor, such as a depth sensor or a stereo-camera. As already highlighted, we aimed at maximizing simplicity, though. Thus, we investigated on the error in which the system would have incurred had we taken the simplest possible approach, namely just using a fixed and approximately pre-determined distance. More precisely, the idea is to use the numerical approximation algorithm discussed in the previous paragraph to estimate the error by a simulation. Fig. 5 shows the simulation model: the mirror is placed 2 m apart from the rear window, like in a normal car, the driver's seat is located on the blue dashed line because it can be moved back and forth. The "fixed distance" is depicted by the purple circle, centered at the mirror, of radius 55 cm, that is an average of measures taken in some cars. As the figure highlights, the seat line intersect the mirror circle at point A: in this position the error is zero. When the driver is located at point B or C, the system would wrongly place her/him at points B' and C' respectively, thereby either underestimating or overestimating the distance . Points B and C are placed at a distance of 20 cm from A, so the maximum movement the seat can undergo is 40 cm, higher than average movement in a car that is about 20-30 cm. Using the numerical algorithm were computed the mirror orientations for points B' and C', and, using the model, for B and C. The angular errors of mirror positions are 0.5° for B-B' and 1° for C-C', and therefore can be considered extremely small and, in essence, neglectable as far proper functioning of our system is concerned. Moreover the driver moves while driving, which renders the above error level even more reasonable. A test was made with a seat movement of 60 cm (see Section 4) also provided satisfactory results.

3.4. Automatic rear window setup

As discussed, we suppose that the system knows vector CL, or, in other words, the relative position between car rear window and the mirror pivot point. That is true in a car because the two parts are fixed, positioned and assembled in the car manufacturing process. Thus, the system may straightforwardly be programmed with a static information concerning the CL vector.

Conversely, in our Lab-made prototype, the rear window is simulated by a simple paper screen, so the CL vector is not at all fixed and known but, rather, must be estimated before running each new experiment. To simplify this process, we devised the following procedure. During the initial setup of the mirror, a planar chessboard pattern is placed over the simulated rear window. The system acquires an image of the pattern through the camera placed on the mirror and computes a 3D line between the reference point and the chessboard pattern as described in Subsection 3.1. Then, by standard functions of the OpenCV library, the system can estimate the extrinsic parameters matrix that describe the relative position and orientation between camera and chessboard pattern. Thereby, the system obtains a distance measure and uses it to create a 3D vector. An average across several estimates is taken as the CL vector.

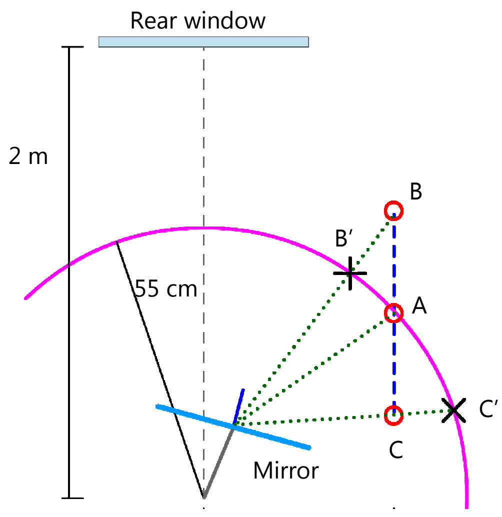

Fig. 5 - Simulation model to study driver's distance estimation error.

3.5. Light compensation

The prototype is equipped with white leds that can be driven by the Arduino board. The system continuously examines the gray-levels histogram of the camera picture to estimate the degree of darkness of the ambient light. This is accomplished by a very simple method: the histogram bins are divided into three regions, such as "dark", "mid-tone" and "bright". Then the percentage of dark pixels is calculated and used as an estimate of the darkness of the ambient. Then, a simple algorithm that smooths measurements over time and filters out spikes allows for determining how many led must be turned on through the dimmer to ensure that the images taken by the camera turn out bright enough.

3.6. Arduino

In our prototype, the Arduino board is used as a sort of interface between software and hardware, as it allows the PC to drive the motors and leds.

The prototype mounts analog servos. These motors are already equipped with a automatic control that makes them controlled in position, which is quite suitable to this project. However they do not provide a feedback and move very fast, with sudden accelerations that may damage or break some mechanic parts. Therefore, we also implemented an automatic control that smooths servo accelerations on the Arduino board. To accomplish this without any feedback from motors,

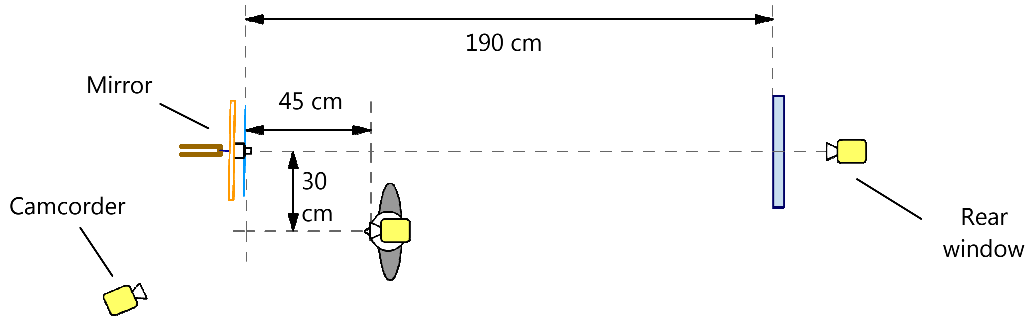

Fig. 6 - The test environment.

we simulate in software a dynamic system, with feedback and controller, and use it to calculate the PWM control signals to the servos.
As already mentioned, the Arduino board generates also a PWM signal to drive the hardware led dimmer, based on the darkness parameter estimated by the PC software.

4. Experimental results

Due to the prototype size, it was not possible to carry out tests in a real car. Hence, we created a test environment having dimensions compliant to an average car (fig. 6). All tests have been documented with camcorders from some view angles: for example in fig. 3 it is visible a camera placed over driver's head to capture approximately his point of view.

As the goal of this project is to allow the drive to see the rear window into the mirror, a test is considered passed if:

- the driver's head camera sees the lower side of rear window into mirror (not the whole window because the camera is placed over driver's eyes);
- the driver's eyes are visible through the mirror from a camera placed behind rear window.

With such tests we would check two aspects of this project:

- the ability to find the driver's face, even in low light or in the dark, or when more people are present into car;
- the ability to both compute the right mirror position as well as to move it correctly.

For the first point some tests are made in different light condition like light from ahead, behind or completely dark. In this latter case, the face is illuminated only by mirror leds. The system fails only when the light was placed behind the driver. However this are limits of the face detection algorithm used, and found also in other works. Moreover, in a real car the lighting conditions might be even more challenging, for example the face turning out partially lit. All these problems can be solved with a IR illuminator, and/or with a better adaboost classifier training.
In all tests dealing with multiple people seen by the camera the system was able to find correctly the driver's face. Fig. 3b provides an exemplar result concerning these tests.
As regards the second aspect, we carried out numerous experiments, with people of different heights and placed in diverse seat positions, so to address also the "fixed distance" issue (see Subsection 3.3). In all the considered settings, the system passed the test. As a final experiment, the seat was moved extremely back and then ahead, with a total variation of 60 cm. In those extreme cases, the driver still can see the rear window but not entirely and he needs to move himself a bit.
All tests were timed: the current prototype takes about 20 seconds since the driver push the start button to the mirror stops moving at the right position. This time is mainly due to the motor movements and secondarily to the software. Optimizations are certainly possible, but they were not between the objectives of this work.

5. Conclusion

We have conceived, designed, implemented and tested a fully automatic system based on computer vision to orient correctly the interior rear view mirror of a car.
The developed prototype uses only a simple and cheap 2D camera, which, differently from previous works, is directly mounted on the rear mirror. This latter is motorized, so the system can move it to the right orientation. An Arduino, with another electronic support board developed within this project, provides the interface between hardware devices such as motors and the software running on a PC. The system deploys the OpenCV library for basic image processing operations as well as for the Adaboost Cascade Classifiers used to detect faces and, within her/his face, the driver's eyes. As soon as switched on, the system scans the environment by moving the mirror-mounted camera to seek the driver's face, correctly identifying it even in presence of multiple car occupants. Upon finding the driver's face, the system computes the correct mirror orientation and adjust it accordingly. The system has been tested with people different in sex, age and height; in diverse light conditions and changing the position of driver's seat. The only problem was a failure of the face detection step in some lighting conditions (when the light is placed behind the person). The face detection module of our system may certainly be improved, so to possibly minimize the potential failure cases. Nonetheless, the system can easily be endowed with a simple and reliable auto-diagnosis features so that, upon detection of

a failure, it would ask the user to either try again or adjust the mirror manually.

We foresee main future improvements dealing with optimizing and porting the software on an embedded platform, like Raspberry, and the re-design of the mechanics, so as to render it as small as to occupy the little space between the rear mirror and the windshield glass. This may permit to develop a fully standalone device that the owner would buy and have easily installed into the car. Moreover, our system may be deployed together with other systems, such as [22], that can adjust the side mirrors based on the orientation of the rear mirror.

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