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Research and development of an integral system for monitoring, diagnosis and prediction of road state using the digital twin model

#ICA4point0

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The road infrastructure is one of the most important and valuable assets of any country, not being Spain an exception, since the equity value of road infrastructure rounds 185,000 million euros, of which 70,000 million euros belong to the Network of State Highways (NSH), while 115,000 million euros correspond to the regional and provincial network according to data from the Spanish Road Association. Although an annual investment of around 2% of its equity value is recommended for its correct maintenance, the negative effect of the economic crisis suffered by the country produced a decrease in the resources allocated to maintenance of up to 30% since the year 2009. The Spanish Highway Association (AEC) is already warning of investment needs in this sector that can be multiplied if the maintenance strategy does not change and the problem is not addressed on time. In fact, at present, a total of 6,574 million euros are needed to replace and reinforce all the Spanish roads. These figures reflect that 72% of the network has cracks, while 38% show cracks, disintegrations, deformations and potholes, being these defects the main risks of traffic accidents. If these interventions are not carried out, it is estimated that a large part of the network will need to be rebuilt.

Predictive maintenance of roads can currently be carried out using multifunction vehicles with a multitude of high-tech equipment (laser systems for the detection of deterioration, profilometers or georadar) capable of detecting deteriorations of the pavement, as well as the geometry of the road and its comfort parameters. However, due to the cost of the devices used and the need to travel through each of the lanes of the highway platform (the same itinerary must be replicated as many times as lanes are), the cost of the service maintenance is high. That is why the most inspections are carried out manually through the analysis of video images, with the high cost of time and money it entails.

In response to the current situation, BECSA, in collaboration with the UPV's Multidisciplinary Mathematics University Institute (MMUI), has developed a comprehensive system that allows monitoring, diagnosis and prediction of the condition of roads in real time based on the generation of the Twin Model of the road that allows a predictive maintenance strategy focused on acting on certain elements at the right time, thus preventing them from reaching advanced stages of deterioration.

1. INTRODUCTION

At present, there are different methodologies to carry out the auscultation of the pathway, being the LCMS laser system the most used among the existing solutions. However, this system allows detecting cracks and defects in the pavement just on the lane you are driving on, in addition to being made up of expensive equipment. There are also some developments in carrying out inventories of road elements, but without actually offering their status.

After analysing the current situation, the need to have a high-precision measurement system that reduces the cost of the maintenance service and allows the diagnosis and prediction of the state of conservation of roads from the generation of the Twin Model is detected. This system is a virtual replica of the real environment of the highway (geometry and elements of the road, as well as its state of conservation, and other relevant information) using a twin model fed, in real time, by data from the auscultation carried out in order to develop maintenance plans in real time. In addition, the twin model allows having predictions about the behaviour of what was previously detected to optimize maintenance plans.

Twin Road is proposed as a comprehensive and multifunctional system that aims to considerably improve current monitoring systems that do not allow diagnosing the road infrastructure network efficiently and at low cost due to their inability to monitor from a single lane, in addition to the cost of the equipment used.

2. DEVELOPMENT OF THE SYSTEM FOR AUSCULTATION, DIAGNOSIS AND PREDICTION OF THE STATE OF THE ROAD

2.1 Design and development of the Hardware subsystem

The hardware subsystem is responsible for acquiring the necessary data to carry out the detection and classification of the deterioration of the pavement of the road, making an inventory of the existing elements in the road infrastructure, as well as their state of conservation and generating a Twin Model of the road to evaluate the state of the road and its elements and make predictions about the behaviour of the road.

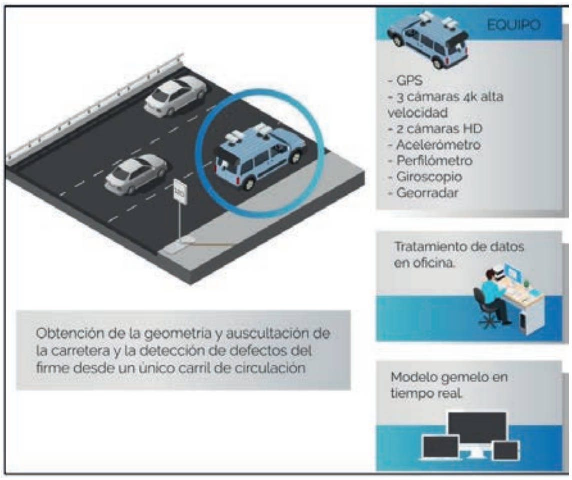


Figure 1 Diagram of the system

2.1.1 System components

2.1.1.1 3D model

A multi-camera system has been selected to reconstruct a 3D model, that consists of using different high-speed cameras (120 fps with 4k resolution) positioned so that there are different angles and overlap between the images that are captured.

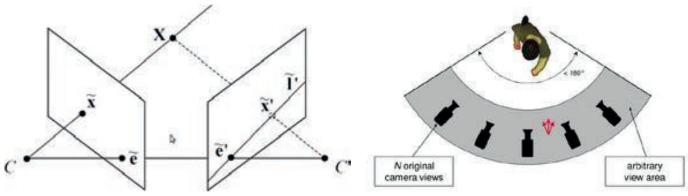


Figure 1. Point triangulation and multi-camera positioning for 3D reconstruction1

To capture the environment it is necessary to use a camera located on the front of the vehicle with a resolution of 1280x720 and 284 fps.

2.1.1.2 Road defect detection

The detection of defects in the road is carried out from the images captured by high- speed cameras, which makes it technically feasible to develop defect detection algorithms based on the images obtained.

2.1.1.3 Detection of horizontal and vertical signage

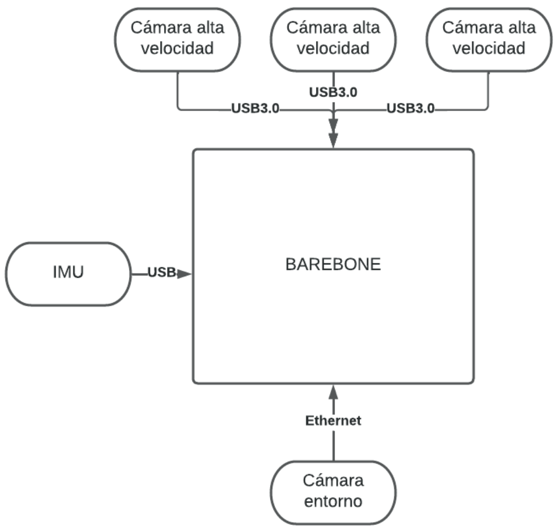
To carry out the detection of vertical and horizontal signalling, complex algorithms have been used what, with the help of a camera system and software for image processing, it is possible to inventory and classify the defects present on the road.

2.1.1.4 GPS positioning of the detections made

One of the most important elements of the auscultation system is the GPS, which provides geolocated data so that the images or videos are georeferenced, in order to be able to locate all the elements or defects detected.

2.1.2 Integration of system components

The integration of the components consists of connecting the high-speed cameras via USB3.0 to a computer so that they are initialized simultaneously and synchronized. As for the environment camera, it is connected via Ethernet, and the Inertial Measurement Unit (IMU) has a board that allows it to be connected directly to the computer.



2.2 Design and development of the Software subsystem

The software subsystem presents the necessary algorithm for the detection and classification of the damage present in the pavement, using the images captured by the high-speed cameras. To carry out this process, the defects that are going to be detected and the implementation of a neural network that allows the recognition of these defects in images, have previously been specified and defined.

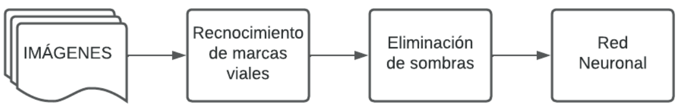


Figure 3. Overall scheme

2.2.1 Detection of road markings

Through the images captured by the cameras, the different road markings and the lanes of the road are identified. This is done to optimize the damage detection process, since a region of interest is established in which the defects will be searched and not the entire image, which improves processing and computation time.

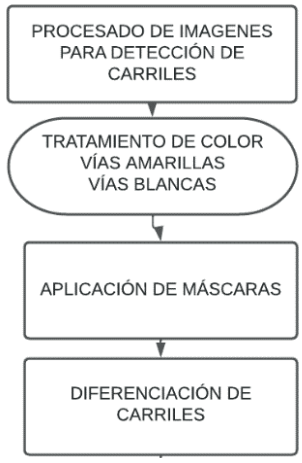


Figure 4. Road marking detection scheme

To carry out the detection of road markings, an image treatment is carried out based on the different colours and continuities of these.

Figure 5. Original image example[2]

The captured image is converted to the HSL colour scale.

*The HSL scale is a model of colour in terms of its constituent components. The HSL model is graphically represented as a double cone or a double hexagon. The two vertices in the HSL model correspond to black and white; the angle corresponds to hue, the offset to saturation, and the black-white offset to luminance.

Figure 6. HSL colour scale[3]

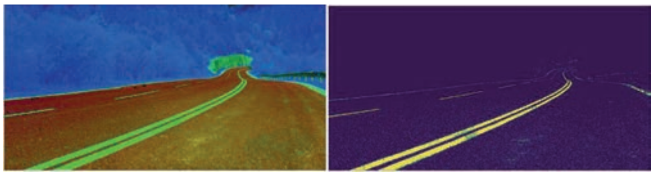


Figure 7. Image after treatment and transformation to HSL (left) and image after application of HSL mask (right)

Once the image shown on Figure 6 (left) has been obtained, a mask is created in RGB and HSL colour scales, in order to create a more robust image treatment that avoids data loss.

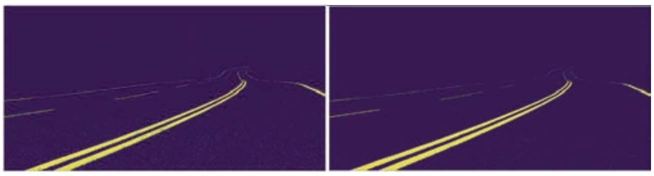


Figure 8. Image after mask application (left) and filtering and cleaning after erosions (right)

To finish the treatment of the images, a cleaning of distorting elements is carried out. With this image, the lanes can be differentiated by their location in the image, assigning colors to the lines in order to differentiate the direction of the vehicle in red on the right side, and the opposite direction in blue on the left side.

Figure 9. Lane marking

2.2.2 Shadow removal

An algorithm capable of detecting the areas in which there are shadows to subsequently eliminate them and prevent them from causing erroneous results in subsequent algorithms or in detections using neural networks has been developed.

*YCbCr is a family of colour spaces used as a part of the colour image pipeline in video and digital photography systems. Y′ is the luma component and C_B and C_R are the blue-difference and red-difference chroma components.

Figure 10. Original image (left) and YCbCr image (right)

From this image in YCbCr color space, a classification of the pixels that are shadows and those that are not is carried out to later be binarized and thus obtain white areas where there is a potential shadow, and black areas where there are no shadows.

Figure 11. Binarization (left) and region of interest and removal of regions of non-interest (right).

With this area detected, the original image is modified, clarifying the shadow areas that, despite being visible, will be functional so that the shadows in later phases are not detected as defects or deterioration of the pavement.

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Figure 12. Modified ROI image.

2.2.3 Defect detection using a convolutional network (YOLO)

A pre-trained network known as "You Only Look Once" is used to detect defects in real time. This algorithm makes use of a single convolutional neural network to detect objects in images. For its operation, the neural network divides the image into regions, predicting identification frames and probabilities for each region. The algorithm learns generalizable representations of the objects, allowing a low detection error for new inputs, different from the training data set.

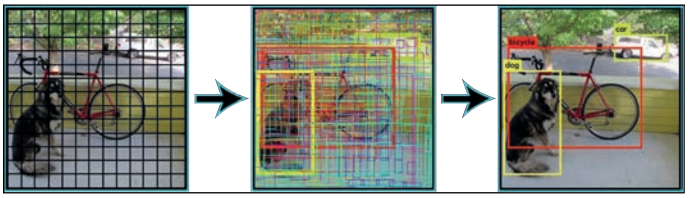

Figure 13. YOLO grid generation[4]

2.2.4 Database, network pre-training and validation

A large number of images is needed to pre-train the algorithm, in order to increase the probability of detecting and recognizing objects. In addition, it is not only necessary to obtain the images, but also to frame where the deterioration is in the image. To carry out this task, external software called Labeling is used, which allows images to be cropped and labelled according to the desired categories or labels (in our case, defects).

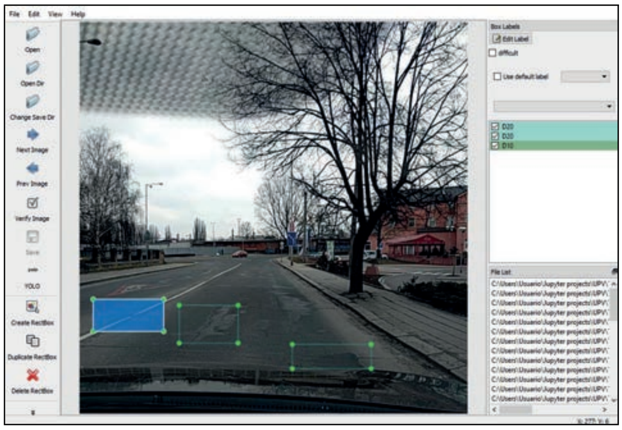

Figure 14. Labelling

Each defect is assigned a defect identifier:

ID	Description
D00	Fissures and cracks (longitudinal), ruts
D01	Longitudinal linear joint
D10	Fissures and cracks on the side of the road.
D11	Side linear joint
D20	Crack (crocodile type)
D40	Potholes, Rutting, Brazier, Ripples, Peeling, Fleshing
D43	Pedestrian crossing with defects
D44	White line with defects
D50	Elements (sewers, etc.)

Table 1. Defect identifiers

Using an existing database of images and defects, there are, in general, more than 4000 images of each one of the defects.

After a pre-training process, real images are taken with the cameras equipped in the vehicle, and images are acquired that are later analysed by the existing neural network, detecting existing defects on the road.

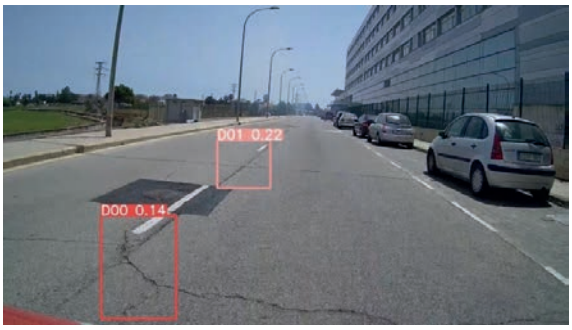

Figure 15. Detection of defects in real images

2.3 Integration of the Twin Model on the road

Once the algorithm and neural networks necessary for the detection of pavement defects and their identification have been developed, it is necessary to integrate all this into a digital model that allows the user to view and record all those detections that have been made.

The twin model is defined as the replica of the real environment of the road (geometry and elements of the road, as well as its state of conservation, and other relevant information) using a twin model fed by data from the auscultation carried out, which allow it to be constantly adjusted and calibrated. The Twin Model of the road will be generated from the survey carried out by means of the hardware and software subsystem; and will allow the inclusion of monitored input variables.

Using visual odometry and SLAM (Simultaneous Localization And Mapping) as a foundation, the methodology that allows us to obtain our 3D model using the images acquired by the cameras is developed. To do this, the following steps will be followed:

1) Getting matches between images.

2) Extraction of camera positions.

3) Generation of the point cloud

2.3.1 Matching matches

With the sequential relationship of the images, and the images themselves, matches are established between them, in order to obtain the camera positioning relationship to generate the reconstruction. Representative points are searched for in each of the images to assign them to the next image.

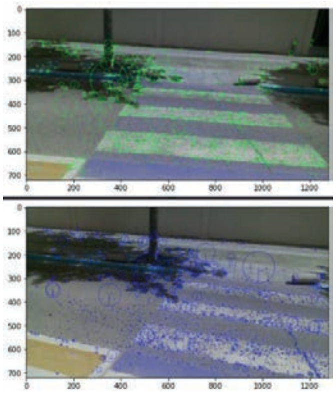

Figure 16. Representative points of the images.

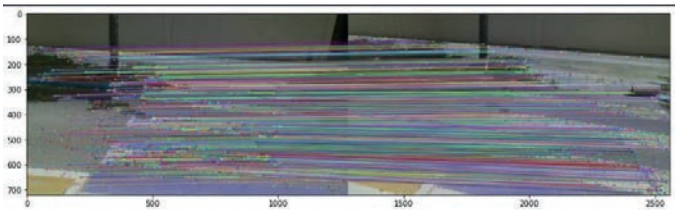

Figure 17. Match points between two different images.

With this information, the relational map between images is generated.

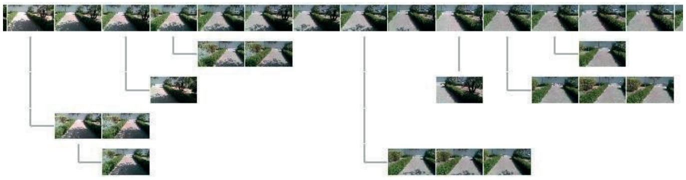

Figure 18. Relational map of images.

2.3.2 Camera positioning

With the information available so far, it is possible to make a first approximation to the 3D reconstruction, based on the relational map and the matches found between the different images. All this information will be used to position each of the cameras, in this case a total of 185 cameras have been calculated, that is, 185 different camera positions that allow the reconstruction to be carried out.

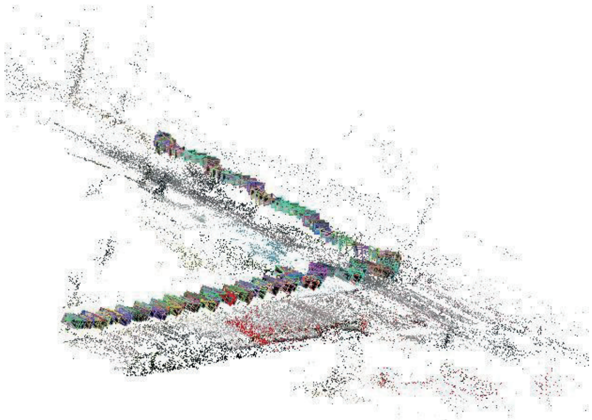

Figure 19. Location of the cameras and representative points.

2.3.3 3D reconstruction

3D reconstruction is a process by which it is possible to reconstruct three-dimensional objects from non-three-dimensional information. For the 3D reconstruction, the passive dense method of points has been used, which consists of reconstructing the object from acquired images in such a way that the cloud of points is densified, generating an environment more similar to reality.

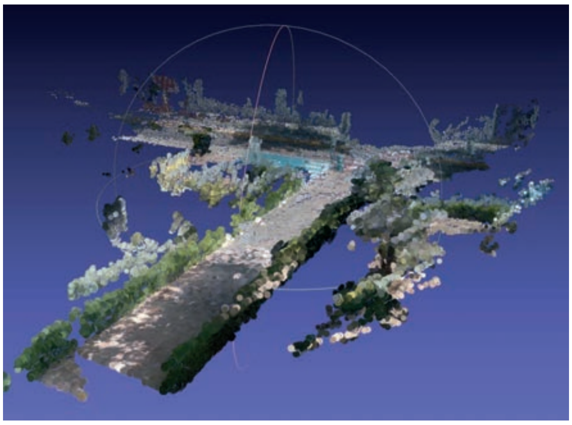

Figure 20. 3D reconstruction

3. CONCLUSIONS

A multifunctional system has been developed that improves the existing auscultation systems since it allows the high cost of the service to be reduced, while maintaining a high measurement precision.

The Twin Model is a complete road maintenance management tool whose objective is to optimize the economic resources available for the maintenance of road infrastructure. The digital model makes it possible to review the history of the state of conservation of the road, so that its state can be evaluated over time and verify the effectiveness of the preventive measures applied.

The solution that has been developed for monitoring and diagnosing the condition of roads from a single traffic lane (right) makes it possible to reduce service execution times and improve their flexibility.

At the end of writing this communication, the web platform is being developed that will allow access to updated information simultaneously, improving transparency with the public administrations responsible for the maintenance of road infrastructures.

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