IDT3D: Identification and Tracking in Controlled Environments Using a 3D Unified User Interface

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ABSTRACT

Identification and tracking of objects in specific environments such as harbors or security areas is a matter of great importance nowadays. With this purpose, numerous systems based on different technologies have been developed, resulting in a great amount of gathered data displayed through a variety of interfaces. Such amount of information has to be evaluated by human operators in order to take the correct decisions, sometimes under highly critical situations demanding both speed and accuracy. In order to face this problem we describe IDT-3D, a platform for identification and tracking of vessels in a harbour environment able to represent fused information in real time using a Virtual Reality application. The effectiveness of using IDT-3D as an integrated surveillance system is currently under evaluation. Preliminary results point to a significant decrease in the times of reaction and decision making of operators facing up a critical situation. Although the current application focus of IDT-3D is quite specific, the results of this research could be extended to the identification and tracking of targets in other controlled environments of interest as coastlines, borders or even urban areas.

1.0 INTRODUCTION

The growing terrorist threat, illicit use of infrastructures, cargos theft under low surveillance conditions or the uncontrolled entries and departures of ships along coastlines are some examples of critical events requiring a continuous monitoring and identification of targets. In particular, research actions regarding this last issue have been classified as a priority by the European Programme for Surveillance of Borders, Coastlines and Harbours (SOBCAH [1]).

This is also the case of leisure, commercial and especially, military ports where precise information about specific events is required to support decisions and define responsibilities. Currently, anomalous behaviours in this kind of environments have to be detected and evaluated by operators using a large number of systems, such as video-cameras, radars and AIS track data. Research activities and system developments intended to improve the management and control of ships traffic and moorings are, therefore, extremely valuable.

Previous approaches to this problem aiming to provide a unified representation of critical events (e.g. in a coastline environment [2]), can be found in literature. A common weakness, however, still remaining in available solutions is the lack of an intuitive 3D user interface (the most advanced of them are based on quite limited 2D GUIs).

The feasibility of applying advanced 3D user interfaces in order to manage and efficiently visualise real-time events and environments has been previously studied by the authors in [3]. Through the research described in this paper, the authors aim to continue reinforcing the assumption that real-time visualization of fused data over intuitive and user-friendly 3D interfaces enables an increased situation awareness over critical events involving a great amount of variables and reduces the related times of reaction and decision making.

We therefore purpose IDT-3D, an integrated platform aimed to automatically identify and track a set of events and targets of interest that take place or move within a controlled environment. For the visualization of these events, a unified 3D user interface has been implemented based on the virtual representation of the environment. The dynamic virtual scene is built (and continuously updated) over fused data collected from two major sources: the Automatic Identification System (AIS [4]) and the video surveillance system, which comprises a set of cameras deployed across the monitored area.

In order to provide a comprehensive description of IDT-3D functionalities and components, we have structured this paper as follows: Section 2 presents the initial requirements considered to accomplish the design and development of IDT-3D. Section 3 introduces the platform architecture. Sections 4 to 6 describe in detail the three major components of IDT-3D: the monitoring, information management and 3D visualization modules, respectively. Finally, some conclusions and future challenges are discussed in Section 7 and Acknowledgments and References are presented in Sections 8 and 9, respectively.

2.0 INITIAL REQUIREMENTS

The objective of the research project supporting the development of IDT-3D was to provide a unified, intuitive and realistic real-time representation of targets and events moving/taking place within a controlled environment (i.e. infrastructures, refineries, seaports, security perimeters...), in order to increase the situational awareness of security operators over the monitored area. In consequence, the platform was aimed to:

- gather and process a wide variety of distributed multi-sensor data;
- coherently correlate and fusion the multimodal data received;
- identify and classify targets, detect critical events from the analysis of fused information and generate the corresponding warnings and alarms; and,
- provide an enhanced real-time 3D visualization of the monitored scene through a Virtual Reality user interface accessible from any point of the network.

In the project, a demonstrator based on a shore scenario that accurately represents the harbor of Cartagena (Spain) and its surrounding relief was implemented for validation purposes (see Figure 1).

Figure 1: Harbor of Cartagena: (a) Aerial view, (b) 3D model.

The following set of initial conditions was defined:

- *Track data sources:* Two data sources have been considered: (1) The *AIS system* (Automatic Identification System), that allows ship vessels to communicate their position and other specific data in real time; and, (2) A *video surveillance system* made up of a set of long range high resolution fixed cameras distributed along the coast (strategically situated to maximize coverage over the area of interest).

The first source is intended to be used to obtain specific data of the targets (e.g. size, speed bearing, etc.) and the second one, to provide the video stream image that will be further processed and analysed for detection/identification of critical threats (e.g. unidentified targets, risk of collisions,...), incoherencies, etc.

- *Ship classification:* a general catalogue of ship vessels categories based on international European standards was adopted for classification (see Table 1). Two sequential levels are available: the first one allows a gross classification considering the general purpose of the vessel while the second one provides more detailed information about its type, shape and specific activity.

Table 1: Ship classification levels.

Classification Level 1		**Level 2**
Type 1	Merchant	Cargo ship
		Tanker
		Tanker (Dangerous cargo)
Type 2	Passengers	Passengers
		Passengers – high speed
		Leisure
Type 3	Fishing	-
Type 4	Services (including port services)	Tug boat
		Port Services
		Save&Rescue
		Offshore
		Special-purpose
Type 5	Gobern / Academy	Militar - Navy
		Militar - Submarine
		Coastguard
		NOAA
		Research (hydrographic, ocean, etc.)
		Nonprofit (Hospital entertainment, activist)
Type 6	Unknown	-

- *Critical features:* a set of ship features of interest for identification and security purposes were defined to be enhanced through the 3D user interface. These features are considered to provide relevant information about vessels in terms of security and, in consequence, must be evaluated with precision and in a short time interval by the human operator (see section 5). These critical features include ship position, bearing, speed, color, dimensions and nationality.

- *Other features of interest:* detailed information provided by the AIS system is also displayed by request (as required by the operator) using a contextual menu.

3.0 SYSTEM ARCHITECTURE

IDT-3D architecture comprises three main elements (see Figure 2): the Monitoring Module, the Information Management Module and the 3D Visualization Module. The communication among system modules has been implemented following the publishing&subscribe model oriented to application services. In particular, the framework used has been the Windows Communication Foundation (WCF [5]) that enables secure transactions between the different components [6]. This scheme makes possible to easily expand the platform in the future to include other type of scenarios and functionalities.

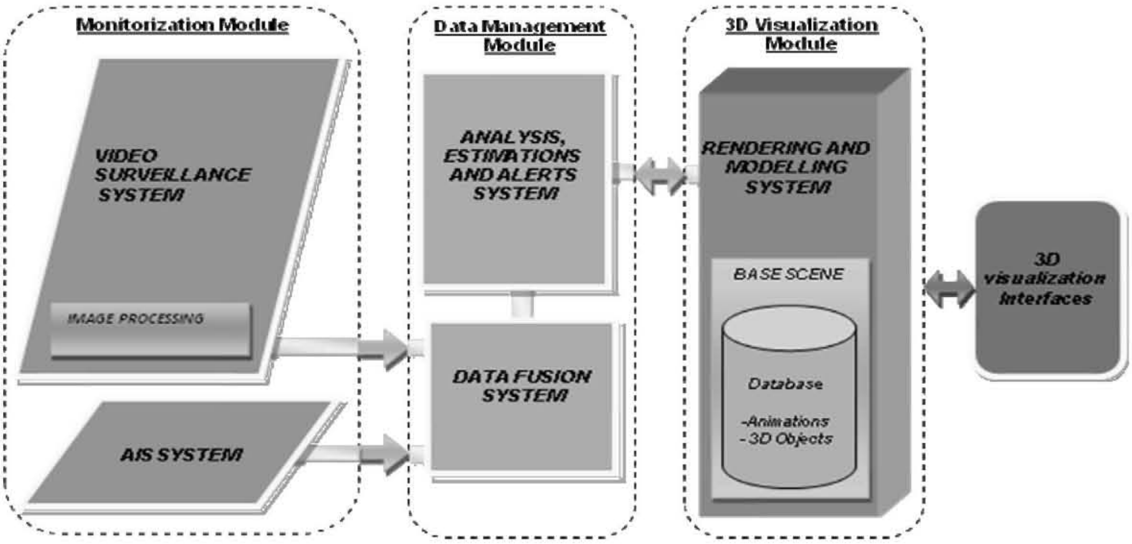

Figure 2: IDT-3D architecture.

The most relevant functionalities and components of IDT-3D modules are described as follows:

- *Monitoring Module*: This module is responsible for collecting and preprocessing the data coming from each source in the real scenario. As it has been previously stated, AIS and video surveillance systems are currently used in the platform for track data acquisition.

- *Information Management Module:* This module processes and fusions the information data coming from the different elements of the Monitoring Module. Grid computing techniques have also been applied to improve user comprehension of valuable information concerning the controlled environment (a previous work successfully applying this technology to vessels monitoring is described in [7]).

This module is comprised of two major components:

- The analysis, estimation and alerts system aimed to detect critical events; and,
- The data fusion system oriented to integrate information data associated to each target being monitored through different sources. Afterwards, this fused piece of information can be visualised in a unified way with independence of its original source.

Data tracks coming from the AIS and video surveillance systems can reach the information management module at random intervals. In contrast, the information management module has been designed to provide fused update messages containing all the available information related to ship features and alerts at regular intervals.

- *3D visualization Module:* This module generates the 3D model aimed to represent the real environment providing the baseline scenario for the unified visualization of monitored targets and events. The visualization is intended to be dynamic, both in real time or using stored data for retransmissions and to provide additional valuable information and critical data concerning those targets and events in an intuitive and graphical way. The main components integrating the 3D Visualization Module are:

- *Base scene*, comprising the 3D representation of the maritime environment, the earth infrastructures and the surrounding relief of the harbour of Cartagena (Spain).
- *Dynamic object-relational database*, containing 3D objects and scripts associated to each type of monitored target and critical event, plus generic objects/animations used to represent targets unidentified or pending of characterization.

- *Rendering and modeling system,* whose functions are: to receive and process output data from the fusion and analysis, estimation and alerts system; to guarantee the coherence and synchronization between real targets, events and critical characteristics and their corresponding representation in the 3D model; and, to support on-demand visualization of off-line sequences, contextual information, alerts and alarms.

The following sections provide a detailed description of each IDT-3D module and their most relevant components.

4.0 MONITORING MODULE

As mentioned before, two monitoring frameworks are responsible for collecting track data in IDT-3D: the AIS communication system and the video surveillance system. Both of them work in an independent way to capture and provide relevant features concerning the monitored targets. In this section, a brief description of the monitoring technologies involved is provided. Some considerations regarding the final implementation and integration with the complete platform are also discussed.

4.1 AIS Communication System

AIS devices are on board broadcasting systems that allow ships to communicate their position, among other relevant data, in real time. They act in a similar way to a transponder, transmitting the information in the maritime VHF band with a capacity of over 4500 reports per minute and updates every two seconds.

One of the main features of AIS technology is the message delivery protocol. This system sends different type of messages depending on the data to be updated, increasing the difficulty of the fusion module to count on a queue of historic messages during the operation process. In order to guarantee the scalability of the platform in terms of the integration of new types of information sources, in IDT-3D the functionalities of the AIS system have been encapsulated into a control driver providing a unified data model. This solution also allows working with more than one AIS system simultaneously, as it is shown in the next diagram (see Figure 3).

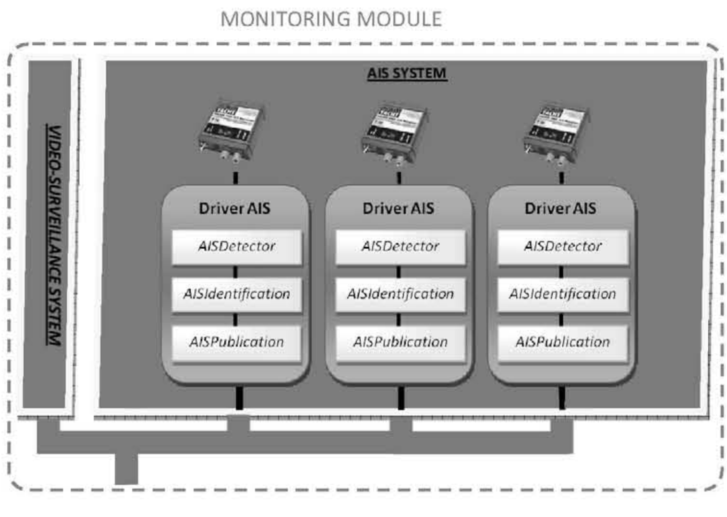

Figure 3: AIS system integration in IDT-3D platform.

The information gathered from the AIS system is transmitted to the information management module using the publication&subscribe model. From this data, some of the most important fields are the MMSI

(Maritime Mobile Service Identity), the ship type code and several course-related parameters to be updated in real time in the virtual scene (e.g. latitude, longitude, speed, course, etc.).

4.2 Video Surveillance System

The video surveillance system comprises a set of cameras strategically deployed to cover the controlled environment. The gathered video signals carry a great amount of information that can be extracted using a variety of image processing techniques. The majority of these existing techniques are aimed to detect movement and presence, not taking advantage on the rest of features available in the image.

A major challenge in IDT-3D has been to provide a platform able to work efficiently under heavy load conditions. In order to overcome the limitations imposed in this sense by the resource and time intensive video signal processing required for features extraction, we have divided the work load into separated processes called graphs, which are executed in different computers (see Figure 4).

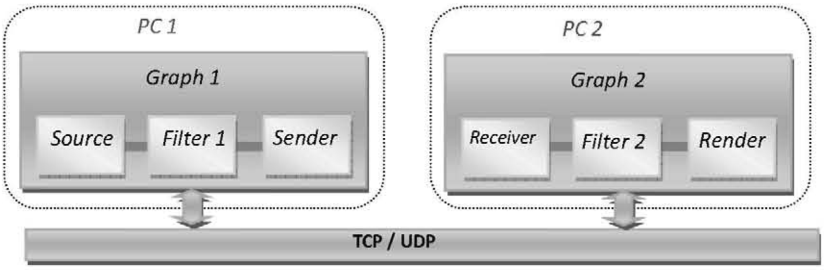

Figure 4: Graphs communication diagram.

We have also implemented a 'sender' and a 'receiver' filter over a DCOM (Distributed Component Object Model) in order to support data communications among graphs. The first one allows graph 1 to transmit the video stream to the network while the second one is responsible for receiving the signal in graph 2 to continue the video process.

The different filters taking part in the video signal processing have been implemented using *Microsoft DirectShow* multimedia framework. This technology is built upon the mentioned DCOM model and is directly supported by both the operating system and hardware manufacturers through their API interfaces. This issue is very important to guarantee scalability and maintenance in the future and has shown to behave efficiently during the different tests performed within the project.

4.2.1 Video Signal Processing

The video captured by the surveillance cameras has to be treated conveniently so relevant data and features can be extracted from it. In this phase, one of the most important challenges faced during the project was the insufficient quality of the image resulting from the important degradation effects introduced by adverse atmospheric conditions restraining visibility in the monitored area.

In IDT-3D we implemented the following filters in DirectShow framework in order to improve image quality:

- Genetic algorithms: from the multiple techniques and filters developed during the last decades to improve image quality, it was necessary to find the most suitable configuration providing the best results at every moment for the specific conditions of our application. After a comprehensive evaluation, we have selected a genetic algorithm to achieve this goal. During the process, the image is classified using a quality function and the best configuration of filters (genetic operators) is chosen depending on the final score (see Figure 5).

- Vibration stabilizer (Deshaker): cameras are forced to work under difficult conditions that produce vibration in the captured image, mainly because of wind presence. To solve this problem, a filter aimed to stabilize possible vibrations has also been implemented. The filter compares consecutive video frames to automatically detect the amount of vibration produced and generate a panoramic image of the scene surrounding the objects. Extracting features from a video stream pre-processed with deshaker has resulted much easier and given more accurate results than without the filter.

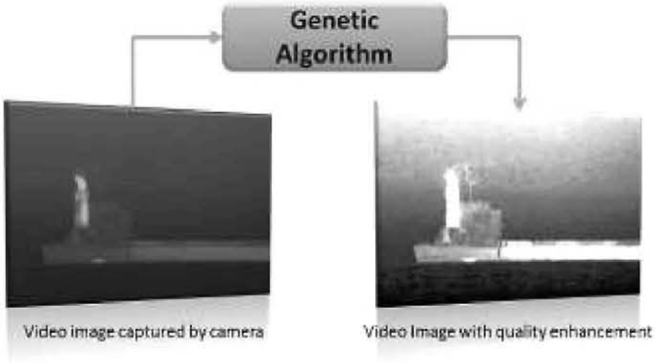

Figure 5: Image enhancement with genetic algorithm.

4.2.2 Univocal Detection

Once the image has been processed using the previous filters, every frame is analysed in order to detect and classify each vessel. As a result, a set of *objectives* are identified within the field of view of each camera, bearing in mind that one objective can be seen by multiple cameras at the same time. The collected data corresponding to each of these objectives is stored in objects called *tracks*.

The detection is accomplished by a DirectShow filter called Track Generator following the workflow shown in Figure 6. The video image coming from the camera is filtered (ItemsDetector) to separate a set of characteristic points (foreground) from the rest of the scene (background). To solve the problem related to the different image sizes for each camera involved, the stored position in 2D coordinates is then converted to relative percentages of the image by the TrackCreator block.

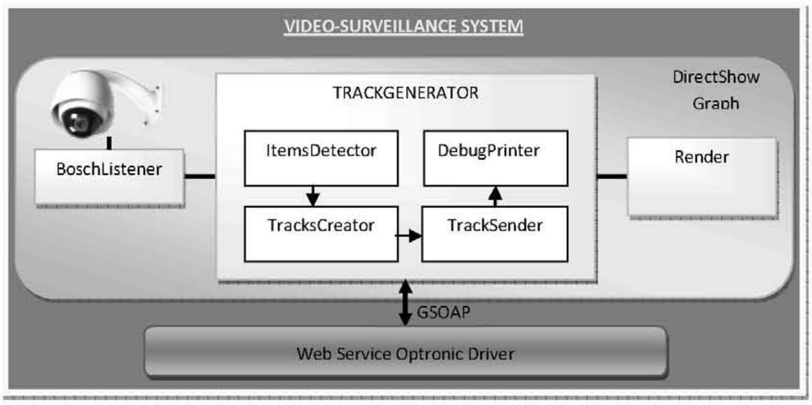

Figure 6: Block diagram of the *TrackGenerator* Filter.

As soon as all the objectives and associated tracks have been identified, they are sent by the TrackSender block to the multi-camera tracking module to calculate the spatial coordinates. Optionally, they can be highlighted and visualised directly in the video image as seen in Figure 7.

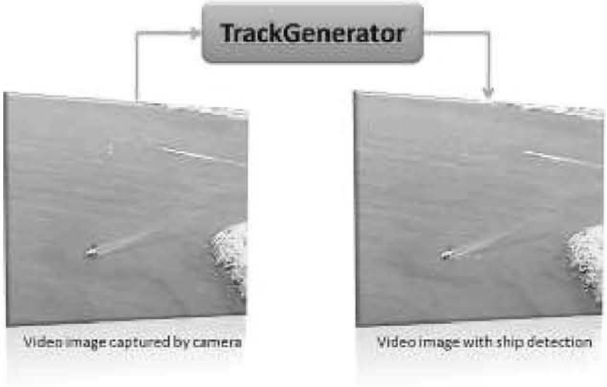

Figure 7: AIS system integration in IDT-3D platform.

The procedure used in the TrackGenerator filter for classification and detection has been implemented in three separate phases:

- Highlighting: image noise and redundancy is reduced using highlighting techniques. The applied techniques are decided using genetic algorithms that can vary from contrast stretching, equalization and filtering, shadow correction and noise reduction.
- Feature Detection: the image is analysed to find relevant patterns that help to determine regions of interest (ROI). This way the available information to optimize the classification process is reduced. For this task, the SURF (Speeded Up Robust Features) algorithm has stood out to be the most appropriate in terms of speed and efficiency.
- Pattern classification: the detected objet is compared with a database of previously identified ships. When a match is found, the detected object is grouped in a ship category accordingly. The classification method is based on using random trees optimized with boosting techniques that assign a probability value to each possible candidate.

4.2.3 Multicamera Tracking

This task is focused on tracking the ships that have been detected in the video signal coming from one or more cameras of the surveillance system. Within the general architecture, it has been implemented inside the Optronic Driver (see Figure 8). The most important functionalities of this driver are:

- Communicate with each camera to receive the tracks associated to the detected objectives.
- 2D track data coming from the univocal filter attached to the cameras are converted using triangulation techniques to 3D world coordinates of latitude, longitude and altitude for every objective detected.
- Organize and store tracks. At this point, several camera tracks can be related to the same objective, so this filter has to verify and arrange the detected objectives for each camera track.
- Send the resulting tracks so the new information can be considered by the rest of the modules of the architecture.

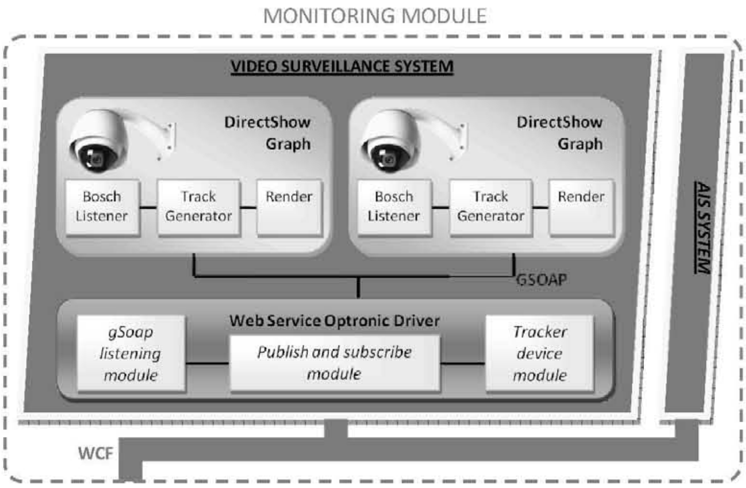

Figure 8: Video surveillance system integration in IDT-3D platform.

5.0 INFORMATION MANAGEMENT AND DATA CORRELATION

The architecture of IDT-3D is based on the "net centric" concept, where data can be physically located at any point of the network at a given time. The basic element of this architecture is the concept of *driver*, which is responsible to obtain the data from the sensors and to distribute it in a unified format among the nodes of the system.

The fusion driver is responsible for receiving the data from the different information sources and for merging that information so that it can be published to be used and visualised by the rest of the platform components. A great effort in this project has been made to support the integration with new sensor providers, so for the task of fusing the physically distributed data, a regular algorithm based on Euclidian distance has been used. The following diagram shows the communication established between sensors and the fusion driver in IDT-3D platform.

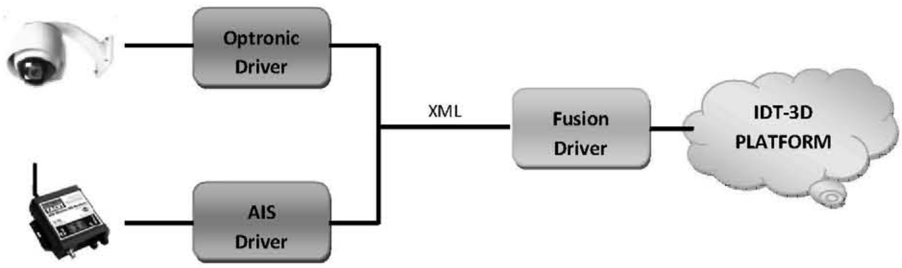

Figure 9: Video surveillance system integration in IDT-3D platform.

The other major functionality of the information management module is to analyze the consistency of the data received by the driver and generate alerts in case a critical event is detected. For this purpose, a list of sensible events to be identified by the platform has been implemented in IDT-3D:

- Collisions: given the current state and course of two identified vessels.
- Tracking failures: caused by losses of coverage of an objective from a sensor (sensor failure or out of range) and its automatic recovery.

- Course estimation: for any objective the future course it would take based on the current speed and bearing (example, detect the disembark area).
- Access to restricted areas: in case a ship is found to enter or exit a special region previously classified with restriction access.
- Inappropriate speed: or velocity to be found out of range.

As not every stated event has the same need of situational awareness, depending on the generated alarm the functionality was finally decided to be implemented whithin the information management module or the motoring module. For instance, collisions detection, access to restricted areas or inappropriate speed need to operate with all the information available from sensors, so it is reasonable to implement these functions at the fusion driver. On the other hand, tracking failures has been developed within the monitoring module in order to provide the necessary intelligence for avoiding duplicating objects that could have temporally disappeared from the system database for any reason.

6.0 3D VISUALIZATION MODULE

The 3D visualization module comprises the following elements: the *base scene* made up of the virtual 3D model of Cartagena seaport, its surrounding relief and the water plane; the *dynamic object-relational database* containing a variety of 3D objects and scripts representing each type of vessel and its associated features; and, the *rendering and modelling system,* aimed to represent the monitored targets and events in real time through the 3D visualization interface. The following sub-sections describe the implementation details and functionalities of these three elements supporting the 3D unified real-time visualization of the monitored targets and events.

6.1 Base Scene

The 3D model representing the real environment of the harbour of Cartagena was created using 3DStudio Max 9 (Autodesk), an advanced design tool supporting the creation of 3D contents. The modelled objects can be exported using a plugin provided by 3DStudio, in a compatible file format suitable to be imported from Virtools, a powerful 3D visualization and development tool.

The scene consists of three main elements: the water plane, the harbour infrastructures and the surrounding relief and shore. The first element has been developed using a 2D plane and applying to its material a set of textures and a shader. Using this technique, a very realistic result is obtained with a low computational cost (see Figure 10).

Figure 10: Water plane.

The other two elements of the scene have been built using cartographic maps and satellite images. The coexistence within the seaport of military and civil facilities conditioned the availability of high resolution orthoimages. Finally, lower resolution images had to be used for the military section of the harbour.

The original maps corresponded to a square area including the sea; therefore the next step was to remove the mesh of information with no interest. High quality textures were applied afterwards to the resulting mesh to generate a realistic composition, as shown in Figure 11.

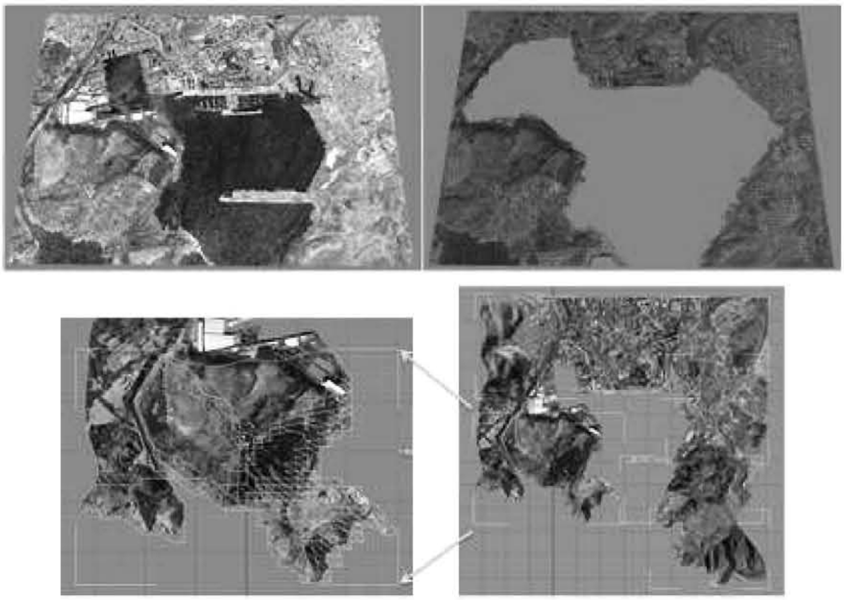

Figure 11: Mesh simplification and texture details.

The same process was applied to the harbour. It was divided in sections to facilitate the adjustment of the high resolution textures, using UVW coordinate maps. The process is depicted in the next sequence of figures.

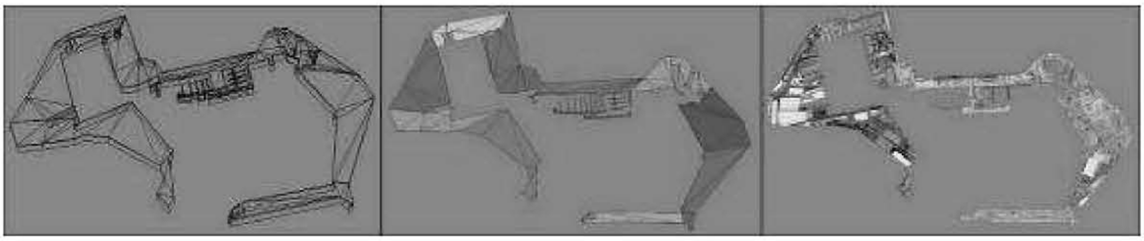

Figure 12: Harbour of Cartagena: (a) Mesh, (b) Sections, (c) Textures.

Finally, the three components of the base scene were integrated obtaining a realistic representation of the real environment, as shown in Figure 13.

Figure 13: Integrated 3D model of the base scene.

6.2 Dynamic Object-Relational Database

IDT-3D database is filled dynamically with the targets detected in the scene. Each row contains the following data: type of vessel, track ID, position, speed, course, name, dimensions, color, nationality and functional scripts associated to the type of vessel (see Table 1).

Initially, the system has a table containing a list of ship categories and their associated features. This generic data will be replicated in the target database and updated every time a new element is detected in the scene.

As a great number of targets can be present in the scene simultaneously, the 3D models representing them were developed as simple as possible in order to minimize the computational cost and to keep a good frame rate during execution. One specific 3D object representing each vessel category was modelled, plus a set of generic objects representing unidentified targets. To discriminate among vessels of the same category and represent a variety of visual features, the following graphic elements were implemented:

- *Speed:* a vessel speed relative to the fluid in which it travels is measured in knots, varying from 0 to 102 knots. In IDT-3D, a particles system effect is used to simulate the wake of the ship, increasing or decreasing its length and intensity according to the vessel speed (Figure 14).

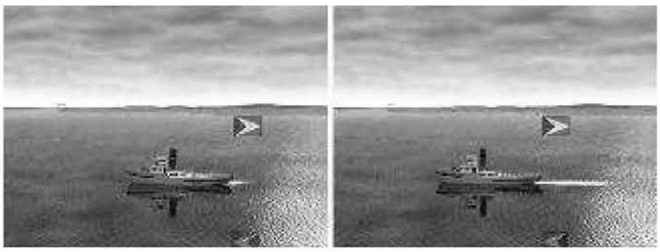

Figure 14: Speed representation.

- *Color:* although every 3D element has more than one color, when the platform detects one predominant color the target database is updated and the texture applied to the model changes dynamically. A sequence of textures for each vessel type has been built (see Figure 15(a)).
- *Nationality:* another relevant parameter is the vessel nationality, identified within the platform with a flag number that is used to calculate the coordinates of the graphic representation inside a flag database.
- *Dimensions:* once known, the size of a vessel is invariant and its representation in the 3D model will be scaled according to the observer point of view. However, the size of the flag attached to

the vessel has associated a zoom effect, in order to allow the identification of nationalities of all the ships present at the scene from a panoramic view.

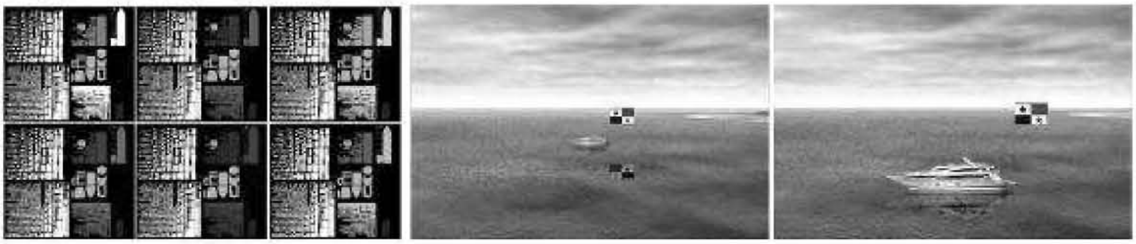

Figure 15: (a) Sequence of textures, (b) Nationality, (c) Flag resize.

Finally, as shown in Figure 16, is possible to select every 3D object in the scene in order to visualize in detail the associated relevant information stored in the target database. When the user points to a given element, a green mask is automatically applied indicating that the object can be selected. Likewise, a selected element is highlighted in red. The interface displays the contextual information using a pop-up window.

Figure 16: Vessel selection.

6.3 Rendering and Modelling System

The rendering and modelling system guarantees the correct real-time execution of the virtual scene implementing a set of algorithms that support the following functionalities: receive notification messages about new elements or features detected and parameters updates; update the database and the virtual scene according to the actual state of the composition; and, provide the required tools to support the navigation through the virtual scene.

As can be seen in Figure 17, the system receives periodical tracks data and parses the information to be stored and visualised. If the elements belong to the target database then the system updates the information, otherwise a new element is created from the generic database and stored in the target database. Finally, the updated scene is displayed.

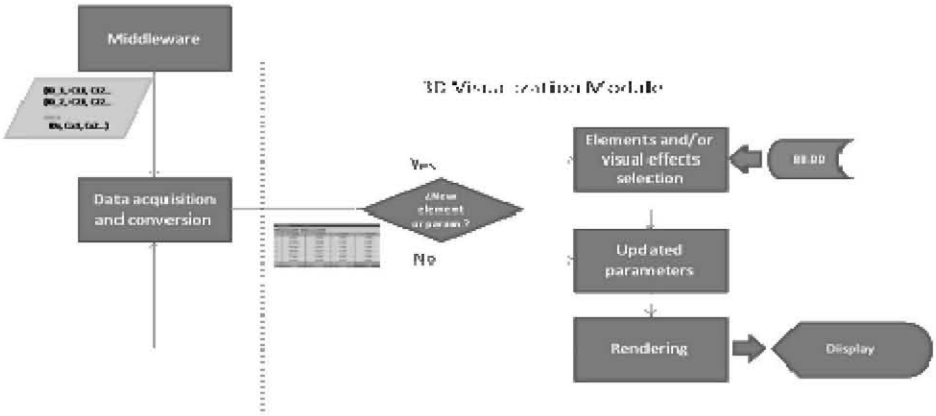

Figure 17: Diagram of elements representation and update.

On the other hand, the navigation through the 3D scene allows total interaction with the virtual model using different hardware inputs. According to the preferences of the user, the navigation can be accomplished through a mouse and keyboard, a joystick/PAD or any other control device available.

6.4 The integrated 3D visualization module

The most relevant functionalities supported by the integrated 3D visualization module can be summarized as follows:

- *Free spatio-temporal navigation and viewpoints:* The user is able to navigate through the 3D scene as in a videogame; this allows visualising a target or event from any perspective, avoiding the "blind angles" of the video surveillance system. Additionally, the interface supports the definition of fixed viewpoints and the automatic selection of one of them in order to easily move from one sight to another.
- *Embedded video:* The video cameras deployed across the monitored area have also been represented into the 3D model and the corresponding video signal can be visualised as desired, both in streaming or from a recorded sequence (see Figure 18).
- *Detailed data visualization:* A contextual menu providing a list of values and features associated to a selected target can be deployed at any time by the user (see Figure 16).
- *Warnings and alarms:* The system is also able to generate warnings and alarm messages and to visualise them through the interface using graphical effects.

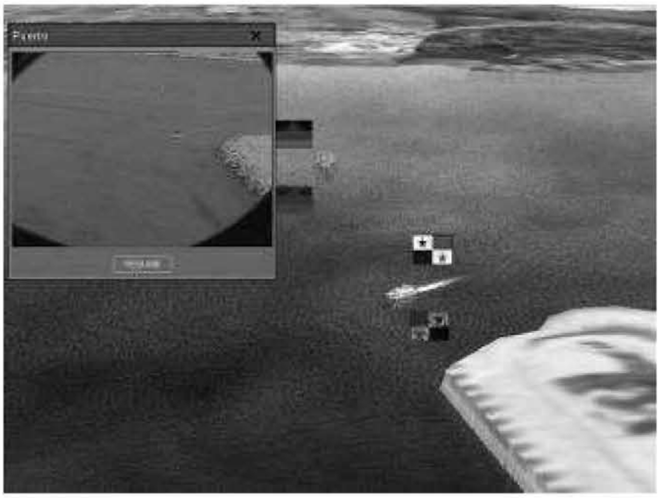

Figure 18: Video signal embedded into IDT-3D interface.

Figure 19 shows several perspectives of a 3D scene representing a hypothetic situation simulated during the in-lab validation of the 3D visualization module. Once accomplished the integration of the platform, current efforts are focused on its validation with final users.

Figure 19: Perspectives of a 3D scene representing a simulated situation.

7.0 CONCLUSIONS

This document has described the implemented functionalities and general architecture of IDT-3D, a platform focused on the identification and tracking of ship vessels in controlled environments. The emphasis is on the novel and advanced but also highly intuitive 3D user interface, aimed to represent the real environment and to visualize in a unified way fused information concerning a set of monitored targets and events.

The main goal of the project has been to study the major challenges and technical feasibility of this new approach for monitoring issues. In consequence, once completed the development and integration phases, current efforts are focused on the validation of the demonstrator with real users. Some preliminary results from this phase point to a simplification of procedures and a decrease in the number of steps to be executed by an operator in order to identify a given event requiring his attention. Likewise, this also suggests an impact in the times of reaction and decision making.

IDT-3D functions are supported by an open and scalable architecture in which the AIS and video surveillance systems have been proved to work properly using WCF technology to communicate the different modules. This modular architecture can therefore be easily scaled up in order to integrate other sources of information such as traffic radars, sonar equipment or other control systems like GMDSS or Lloyd's and to support almost any other kind of monitoring technology in the future.

Likewise, the application of IDT-3D as a unified tool for identification and tracking of specific targets can be of interest to other controlled environments as refineries, frontiers, airports and sensitive infrastructures in general, as well as to secure military installations, controlled perimeters and in general, any surveillance application in which situational awareness and times of reaction and decision making be critical.

8.0 ACKNOWLEDGMENTS

The IDT-3D platform is the result of a project developed in collaboration with Amper Sistemas , S.A and Novagenia Information Technologies, S.L. Authors would like to thank all the participants involved (in particular Jose Ignacio García, Manuel Díaz and Eduardo Mayor), as well as the Spanish Ministry of Industry Tourism and Commerce for the support provided through the funded project TSI-020100-2009-67.

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