3D TERRESTRIAL LASER SCANNER USED TO REPLICATE A REAL MILITARY VEHICLE SUITABLE TO CONDUCT STATIC AND DYNAMIC TESTS IN A VIRTUAL SCENARIO

Marco Giorgi[a], Francesco Longo[b], Pier Carmine Bosco [c], Letizia Nicoletti[d]

[a)(c)]NATO Modelling & Simulation Centre of Excellence
[b]DIMEG, University of Calabria
[d]CAL-TEK Srl

[a]mscoe.sp02@smd.difesa.it, [b]f.longo@unical.it, [c]mscoe.ds04@smd.difesa.it, [d]l.nicoletti@cal-tek.eu

ABSTRACT
The aim of this paper is to provide the reader with an accurate description of all the steps and procedures needed to use a Laser Scanner as suitable tool for creating 3D models from real objects/environments. By following the steps and procedures described in the paper it is possible to carry out a physical survey of the object being modeled, create a mapping assessment in term of object measurement, execute in a simple and quick way the scanning activity (also in a limited time), use the 3D model for Virtual and Constructive simulations.

Keywords: 3D Models, Laser Scanner, Virtual Simulation, Military applications.

1. INTRODUCTION
With the more and more technology available in the field of Modeling & Simulation, a Laser Scanner enables users to recreate (with high accuracy) 3D models of real objects and/or environments. Such a result allows using 3D models in Virtual and Constructive simulation with the aim of carrying out what-if analysis as well as supporting simulation based design and systems acquisition.

Objects are replicated with very high accuracy (i.e. less than 1 mm error rate from 120 m detection point) and then they can be placed into simulated scenarios. Nowadays Laser Scanner is versatile and user friendly tool which aim at reaching a good trade-off between the accuracy of the 3D models and their appearance as part of the simulated scenarios. This is got through pictures taken by the camera working with the Laser Scanner. As explained throughout the paper the procedure to get the final result is simple and fast with the engagement of very few operators. The application example presented in this paper is related to the creation of military armored vehicle called "Freccia" from the Italian Army conducted through a 3D Terrestrial Laser, property of NATO Modelling & Simulation Centre of Excellence in Rome. The overall dimensions of the vehicle are 8,6 m in length, 2,9 m in width and 3 m in height.

As any military vehicle, the Freccia vehicle is quite complex and includes a number of relevant structures and components that need to be perfectly replicated in order to provide the user with the sensation (during the virtual simulation) to deal with a real military vehicle. The scanning activity has been conducted in two phases:
- 1st phase: on the field to scan the real vehicle using also a mobile pad to bounce off any surface of the vehicle. It lasted three hours with two operators;
- 2nd phase: data processing conducted at home. It lasted six hours with two operators.

By following this approach it is also possible to create libraries of 3D models to be used in different simulation models (the 3D models can be then easily exported in different file formats and therefore imported by many 3D CAD tools).

2. RELATED WORKS
A brief survey of the current state of the art, clearly reveals that the 3D Terrestrial Laser Scanner has been used for different purposes and applications. As follows a review of some references is reported to provide evidence on the relevance of the proposed approach.

Indeed the 3D Terrestrial Laser Scanner is not only used in the Military Sector but also in other relevant sectors including Archaeology, Environment, Geology, Industry and Defense.

3D laser scanning has been applied in cultural heritage conservation and civil engineering applications succesfully (Abmayr et al. 2005) Moreover in the field of cultural heritage, terrestrial laser scanning has been integrated with photogrammetry and thermal imagery in order to record accurate and exhaustive information about World Heritage Monument (Rönnholm et al. 2007). Nguyen et al. (2012) use the 3D laser scanner to create 3D models of real monuments, historical buildings, churches; the results of the paper clearly show how the method proposed by authors can effectively and quickly used to reconstruct 3D object geometry with many details (for cultural/archaeological heritage purposes).

In a modeling and Simulation oriented perspective 3D laser scanning has proved to be a valuable support for generating geometrically correct and complete 3D models of objects and environments (El-Hakim, 2000).

To this end Sequeira et al. (1999) propose an integrated approach aimed at developing textured 3D scene of building interiors from laser range data and visual images. As a result this approach leads to reality models that could be applied in a wide range of virtual reality driven tools.

Indeed, creating 3D models of real world scenarios is an important research topic and may have applications in many others areas such as Industry and Defense. The main challenges in this research field include the acquisition of large-scale data, the complexity of the scenarios under investigation and eventually the difficulties to cope with variations in the scenes resolution in order to reduce the computational workload (Matos et al. 2004). To this end, even if advanced commercial solutions are available, their prices are not affordable therefore researchers have often proposed alternative techniques (i.e. Dias et al., 2004 propose a 3D reconstruction technique for real world environments based on a traditional 2D laser range finder modified to implement a 3D laser scanner). Moreover Bornaz et al. (2002) propose a fully automatic software that makes use of laser scanner data for engineering and environmental applications. In this area Bellian et al. (2005) explain the work-flow to use the 3D laser scanner for geology purposes and discuss the construction of rock-based 3D Digital Outcrop Models. In addition Lkeuchi (2001) introduces the modeling-from-reality (MFR) project whose goal was to develop techniques for modeling real objects and/or environments into geometric and photometric models through computer vision techniques. In general, this brief state of the art overview reveals that 3D laser scanning applications can drastically shorten the developing time of virtual scenarios usually time-consuming and undertaken by Human programmers thus a greater level of automation allows reducing developing costs.

At NATO MSCOE there are some ongoing researches that see the use of the laser scanner for creating 3D models to be integrated within Hybrid Worlds for Multi Robot Cooperation (the first presentation of the above mentioned activities was made at ITEC 2013, in Rome). In addition other NATO research centers (i.e. the NATO Centre for Maritime Research & Experimentation) are using the Laser Scanners for tests related to the control awareness of threats coming from the sea, for simulation based acquisition prototype systems (to avoid not appropriate investments or commitments with industries), for civil protection purposes to monitor landslides.

As clearly explained in Bruzzone and Longo (2010), and Bruzzone et al. (2011) one of the major issues in creating 3D models for Virtual Simulation is the trade-off between the appearance of the 3D model within the Virtual Environment and the workload of the computer graphic card. A real object such as a military vehicle contains thousands of faces (modeled as triangles); faces are then mapped with textures in order to have a realistic representation. Consequently, the computational effort could easily exceed the graphics card capabilities of a low-cost hardware platform. To avoid computational overload, high-resolution and low-resolution graphic detail levels must be implemented. The levels are activated (activating one excludes the other) according to whether the observer is close to or far from the object being observed. Bounding boxes define the portions of space – within which the vehicle of interest is located – whose confines, if crossed by the observer from inside to outside, lead to a switch from one high-resolution texture to one low-resolution texture.

3. ABOUT 3D LASER SCANNER

The 3D Laser Scanner bounces its laser rays off the surfaces of the objects to be scanned. The return of the rays provides the position of the point captured. The main part of a Laser Scanner consists of a main body connected with a special mirror able to provide millions of measurements in few seconds (according to the model of the Scanner, the desired definition and quality). The output is a Points Cloud into a coordinate system SOCS (Scanner's Own Coordinate System) related to the instrument and survey station (initially spherical polar coordinates which are then translated into Cartesian coordinates). To each of these points it is also associated the intensity factor (phase variation or Laser Scanner color).

Figure 1 shows the 3D Laser Scanner owned by NATO M&S COE. There are two different typologies of Laser Scanner:

- Time of Flight Laser Scanner: this specific Scanner sends out a laser impulse which is bounced back from the object. A sensor measures the time taken to receive back such impulse. Since the speed of Laser ray is known (Speed of Light in air) the distance is then easily calculated.

Figure 1: 3D Terrestrial laser scanner at NATO M&S COE

- Phase Shift Laser Scanner: in this case, when calculating the distance, the "Time of Flight" also takes into consideration the shift of phase between the ray sent out and the one received back. This kind of measurement is more accurately executed if compared to the one given by time of flight Scanner, but the radius of action of the tool is reduced significantly.

The 3D Terrestrial laser scanner type LIDAR (Ligth Detection and Ranging) used for the application example proposed in this paper is a 3D Terrestrial Phase Shift Laser Scanner security class 1. Figure 2 depicts a schematic representation that shows how the 3D Laser scanner works.
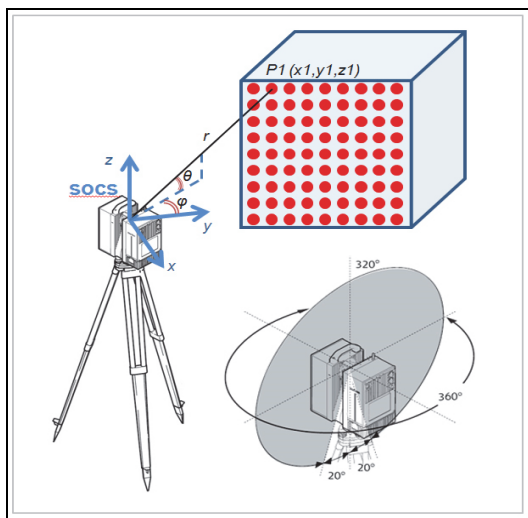

Figure 2: Schematic Representation of the idea behind the 3D Laser Scanner way of working

The result of the laser scan activity is the object replicated through millions of points each of those processed by the 3D Terrestrial laser scanner with space references (x,y,z) and intensity factor (I). All data is stored inside the machine and the output is represented as a points cloud.
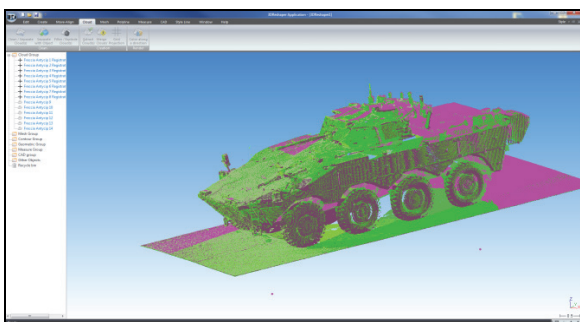

Figure 3: The points Cloud of the Freccia Vehicle

The fully loaded weight of the Laser Scanner is only of 12 Kg and it is easily transportable; its setup is also simple to execute. It is placed on a tripod in parallel with the floor. A bubble level helps to do this manually for the roughly phase. The final phase is executed automatically which is a due operation before starting with the activity. The scannering of the object is also completely automatic and it can be carried out in the night as well or with scarce luminosity. In addition, it is possible to give geo references to the cloud of points detected by the Global Navigation Satellite System (GNSS). What is very important to take into account is:

- The Laser Scanner detects data only from the surfaces in its sight (320° V, 360° H, like cone field of view). For this reason the scannering implies more than one point where we detect from, taking into account the shape of the object itself and making available superimposing of pictures. This is needed in the post-processing phase for linking all clouds without any gaps in images.
- It is needed to operate inside the radius of action of the machine according to the model we are working with (the one used for the specific activity has 180 range). The more you walk further from the object the less accuracy you get;
- Different surfaces have different reflections. Some of them can even absorb the ray or send it back distorted (glasses, water surface, mirror). This is way it is required to assess the best position where to detect from. The last factor to take into account is also the angle of incidence for the object detected.

4. THE "FRECCIA" FIGHTING VEHICLE 3D MODEL

The real word object that we take into consideration in this case study is the "Veicolo Blindato Medio Freccia" 8×8 infantry fighting vehicle (IFV).

This is a medium armoured vehicle developed by the consortium Iveco-Oto Melara. It is the first digitized vehicle to enter into service with the Italian Army. The IFV overall dimensions are the following: length: 8.6 m, width 2.9 m, height 3 m, weight 26 tons. The IFV hull and turret are aluminum with a layer of ballistic steel fitted to provide higher protection. The armored personal carrier can carry a crew from three to eight soldiers. It is fitted with a Hitfist Plus turret with an Oerlikon KBA 25mm automatic cannon(in prototype model) a pointing laser device and a thermal night camera.

Figure 4: The 8×8 infantry fighting vehicle (IFV)

The decision to carry out the activity on the military vehicle has been made for the following peculiarities:

- complex shape of the vehicle;
- short time available since the object has a real operational role in the Unit for training purposes;
- all real details are available on a real object rather than on a scale drawing. If a drawing had been used a longer time would have been necessary.

In the post-processing phase the Modelling of a 3D object by a 3D Laser Scanner can be integrated by an hand-made work on specific piece of surface, especially if we deal with simple geometrical shapes as parallelepiped for a building or a cylinder to replicate circle shapes. The aim of this activity had to meet two requirements:

- to get a very detailed object in order to give to operators of the vehicle in training phase the opportunity to survey the object which had the highest level of fidelity;
- to add the object into virtual or constructive simulated scenario easy to interact with.

The requirements below have been met, in particular:

- the high resolution of the detection and the very low rate of error (< 1 mm.) has been a outstanding achievement (static survey);
- the chance to import the object in a dynamic scenario by a software called "Scenario Generator Animator", is given by excluding unnecessary details of the vehicle to make it light to play it dynamically.
- The same data after the detection activity has been elaborated to get two 3D models of the same object:, one for static use and one for dynamic use. The step to move from the first one (more detailed) to the other, has been possible by software tools available at the NATO M&S COE Center.

5. 3D MODEL PROCESS RECONSTRUCTION

The following part of the paper describes the procedure and steps followed to create the 3D model of the IFV; in particular there are four main steps:

- Data Acquisition
- Noise Reduction and cloud cleaning
- Registration Process
- Texturing operations

5.1. Data acquisition

In order to create to acquire the data to create the 3D Model of the IFV, the Laser Scanner has been used with the Leica Geosystem HD-S /7000 by operating 9 scanning through the object from different positions with "High Density" resolution (with a point spacing at 10 m of 6.3 mm) and " High Quality" as setup of the Laser. This activities has taken us 3 hours and has involved 2 operators.

Figure 5 – A view of the IFV during scanning operations

Figure 6 – An operator working on the laser scanner during the acquisition process

Pictures have been taken simultaneously by a Camera NIKON, reflex mod. D 7000 equiped with a view finder Nikon fisheye 10.5 mm. Pictures will be used as textures linked to the cloud of points to obtain a realistic representation of the IFV. Other pictures have also been taken by the same camera, but with a view finder 50 mm. All data of 9 scans with pictures has been transferred to a workstation to proceed with data elaboration by using the Cyclone version 8.0 software.

5.2. Noise Reduction and cloud cleaning

Before using data the "cleaning of the noise is required. To this end we remove manually what is not necessary from the cloud. We take into consideration that everything which is in the FOV (field of view) during our scanning is captured by the laser scanner. Thus what is not part of the object must be deleted. The following step was to filter automatically all data by SW Cyclone which operates also on those points due to the multipath reflection.

5.3. Registration Process

The registration process operation has the purpose to bring back to a single reference system all the points clouds of the (single) respective scans. Transformation between different coordinate systems, once defined the coordinate system of a station S1 as the reference of the project turns out to be a rigid transformation including rotation and translation in space for all the K stations carried during scan activity.

This process transfers all cycles of scanning to the same coordinate systems with the aim of linking the several clouds all together. Note that some "targets" are needed during the scanning activity; these targets are some recognized points in the environment where the object is placed. It is important to have at least three common targets for each contiguous scanning to make sure to have the exact coordinates to be registered in the main system.

The registration phase has been operated by using the software Cyclone. Having significant number of contiguous scanning (in our case 9 scannings) and using the "targets", we were able to link the different points clouds through a multi station adjustment (MSA) function (in order to minimize the error of alignment).
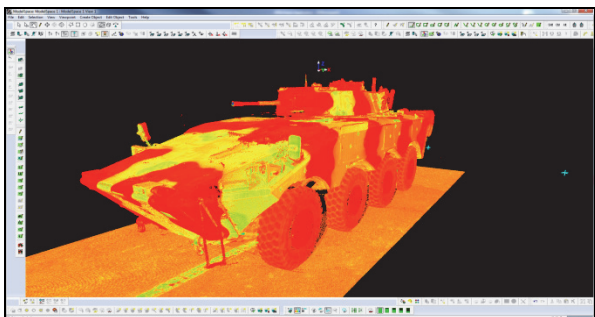

Figure 7 – the 3D Model of the IFV resulting from linking the 9 points clouds

The result of the linking of all "clouds" is the Vehicle Freccia represented in its real dimensions (error rate < 1 mm.), at the appropriate resolution for a 3D static model.
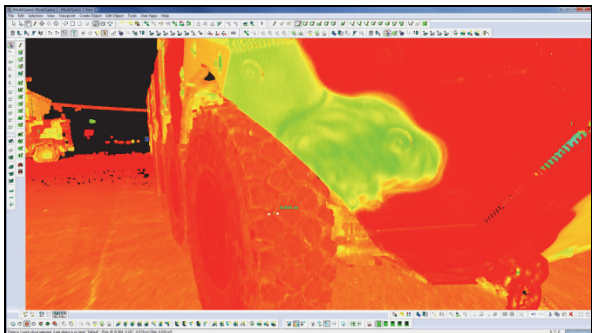

Figure 7 – A view of the IFV wheel

While the registration process allows recreating the 3D Model of the IFV, the model still miss a realistic representation that can be obtained by carrying out the texturing operations as described in the next section.

5.4. Texturing operations

To complete the work, we carry out some texturing operations on the clouds. The pictures taken during the acquisition phase, have been processed by the software tool PTGUI vers. 9.1.3 which transforms them into cubic equirectangular, suitable format to be textured onto the clouds. Only at this step we can have the IFV vehicle available for static survey (see figure 8).
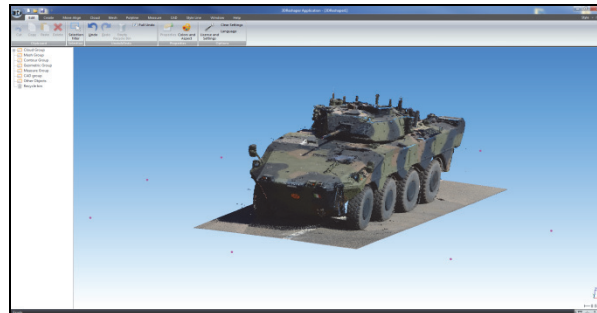

Figure 8 – The IFV 3D Model after Texturing operations

You can make such a model available (on line or intranet/internet) by the software Cyclone browsing on Internet Explorer or use the free plug-in TrueView that allow you surfacing the object as well as perform measurements (see fig. 9).

6. 3D MODEL REPLICA OF VEHICLE FRECCIA FOR VIRTUAL/CONSTRUCTIVE SCENARIO

The goal of this paragraph is to outline the process to replicate the same Vehicle also for dynamic use given the cloud from the 3 D Laser Scanner. The authors have a remarkable experience in developing Virtual and Constructive simulation models in different areas, including Defense (Bruzzone et al., 2011; Longo 2012); Tremori et al., 2009), Industry (Longo et al. 2012) and Logistics (Bruzzone and Longo, 2013).
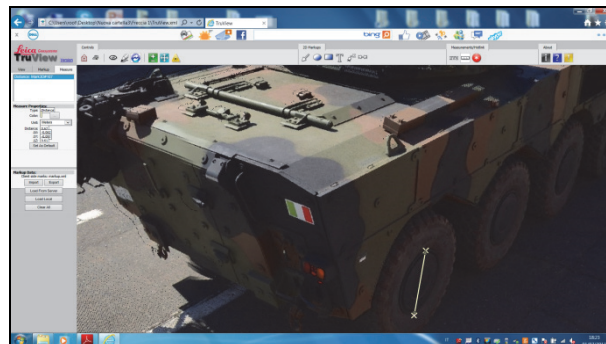

Fig 9 IFV 3D Model used for static survey

6.1. 3D DATA MODELLING

The process of Data Modeling is the step required to replicate a 3D Model (in this case the IFV) for dynamic use in simulated scenarios. To make the IFV 3D model available for use in virtual/constructive simulated scenario, it is necessary to build the model as made by continuous surfaces. The cloud data has to be converted into a polygonal surface through a triangulation called Mesh representing the discrete surface of the scanned surface.

To do this the software tool 3D Reshaper ver. 7.1.2. has been used. Through appropriate algorithms (reconstruction algorithms), the cloud has being transformed combining the closest points and calculates some new ones, making up surfaces interconnected each

other. The process provides a 3D model of the object consisting of a triangles linked each other (see figure10). In this phase additional activities to finish off the work might be necessary if we have some defects due to the reconstruction algorithms mentioned above. These activities are manually executed and include:

- Spikes removal (triangles generated by meshing algorithms concerning points which actually are not connected each other);
- edges correction;
- correction of the normal orientation needed to orient consistently surfaces;
- triangles insertion to full gaps of the mesh due to a possible lack of data for that specific area of the object;
- polygons editing to reduce as much as possible the number of polygons to make the object lighter (optimization, filtering and decimation)

The mesh operation can be integrated also manually (by 3using 3D modeling software tool such as Presagis Creator) using the same cloud as reference.
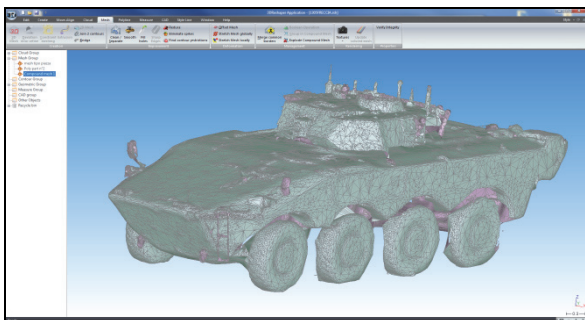

Figure 10: IFV 3D Model after the meshing operation executed on the points cloud

6.2. TEXTURING THE 3D DYNAMIC MODEL

For a realistic visualization of the model we move to map the 3D model by using the pictures taken by the SLR (single lens reflex), camera. Images are mapped on the surface already elaborated (mesh): the color of each pixel of the surface will be modified according the derived color from the texture (color mapping). Fotos are taken by view finder fish-eye and view finder with focus 50mm.

7. 3D DYNAMIC MODEL 3D MODEL ANIMATION

The IFV 3D model at this stage is done and well defined statically, visible by using both 3D CAD tools and graphic engines. In order to use the model for dynamic purposes in a simulated scenario it must be equipped by movement ability to make it realistic. To do this the tool Creator is used to split the model in several parts and assign to each of them a related degrees of freedom and constraints.
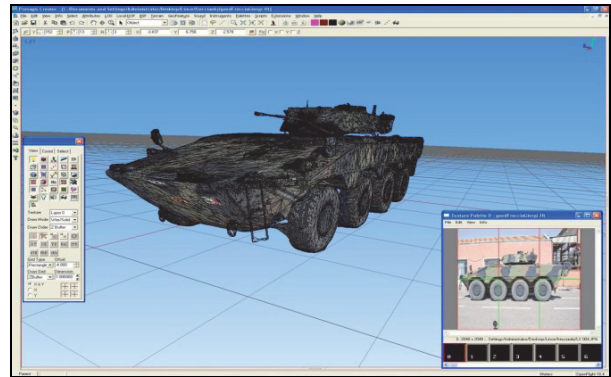

Figure 11 IFV 3D model after texturing operations executed in Presagis Creator Software

These are preliminary actions to get the model ready to implement (by writing programming code) the physics of the vehicle (i.e. engines, steering, shock absorbers, weapon systems, etc.).

The IFV 3D model has been divided into the following components:

- Outer hull: static part able to move in translation parallel to the terrain;
- wheels: rotating parts in a clockwise direction on a surface orthogonal to the terrain;
- tower: rotating part in inverse clockwise direction at round angle parallel to the terrain.
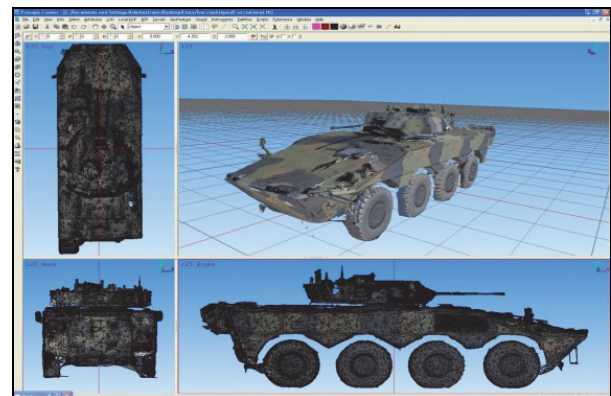

Figure 12: preliminary operations for getting the IFV 3D model ready for physics implementation

The process to replicate the IFV 3D model is complete. It is capable to interact with the simulated scenario. Using the tool Scenario Generator Animator (SGA) available at the NATO M&S COE, the Model is now associable with an entity in simulated scenarios. Its kinematic behavior is linked to the above entity and its related parameters (i.e. position, angle, position of the tower, speed and direction of movement, etc). In addition to the kinematic behavior we are able to associate radio sensors behavior, optical sensor behavior, fire capability.
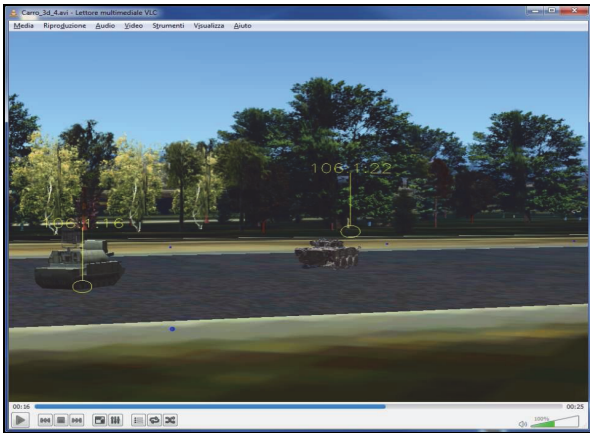
Figure 13: IFV 3D model in a virtual simulation

8. CONCLUSIONS

This article describes the main steps to be taken to recreate a 3D model of a real object by using the 3D Terrestrial Laser Scanner, a camera reflex with regular view finder, fish eye and appropriate software. The choice of the IFV is because this vehicle has been selected by the Italian Army as part of a project to integrate all Command & Control Systems. Making available a 3D model has been useful to import it in:

- electromagnetic environment simulator which takes in account the specific devises installed on board (radios, transmitting systems, jammer etc), frequencies uses, etc;
- Immersive 3D environments used for serious games and Virtual Simulations

Further researches are still on-going recreating other 3D objects with the aims of build a library of 3D object models that can be used at NATO M&S COE; additionally other research efforts are now devoted to define in details the physics of the IFV (this is useful not only for providing the IFV with a realistic behavior but also for developing a model that can be successively used for training purposes)

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AUTHORS BIOGRAPHY

Marco Giorgi joined the Italian Army in 1993 as a Signal Corp Officer. As a Lieutenant he was a peloton Commander at the 44th Signal Regiment in Rome, where he had responsibility for all the broadcast communication for the Centre of Italy. As a Captain he was assigned as Company Commander of the Signal Logistic Regiment in Rome and was responsible for the maintenance and supply of the signal equipment owned by the Brigades and Regiments located in the South of Italy. He was deployed in Bosnia in 2001, in Iraq in 2007, and in Lebanon in 2009. Since September 2010 he has served at the NATO Modelling & Simulation Centre of Excellence based in Rome, as a Communications Information System Section Chief, and he is involved in 3D laser scanner activities carried out by the Centre of Excellence. Major Giorgi has a degree in electronics and a bachelor's degree in management and organizational sciences.

Francesco Longo obtained his degree in Mechanical Engineering, *summa cum laude*, in 2002 and his Ph.D. in Mechanical Engineering in 2005 from the University of Calabria, Italy. He is currently an Assistant Professor in the Department of Mechanical, Energy, and Management Engineering at the University of Calabria, where he also serves as Director of the Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES). He is an Associate Editor of *Simulation: Transactions of the Society for Modeling and Simulation International*. He has also been Guest Editor of two issues of *International Journal of Simulation and Process Modelling*. He has been active in the organization and management of a number of international conferences in modeling and simulation, serving as General Chair, Program Chair, Track Chair, and/or member of the International Program Committee. He has published in *International Journal of Production Economics*, *Computers & Industrial Engineering*, *International Journal of Production Research*, *International Journal of Computer Science Issues*, *Simulation*, *Journal of Simulation*, *International Journal of Simulation and Process Modeling*, and other publications.

Maj. Pier Carmine Bosco joined the Air Force Academy in Pozzuoli in 1995. As a Liutenant he was assigned to the G.E.A. maintenance group, 41st Wing, at Sigonella, Italy, with the role of Aircraft Flightline Maintenance Section Chief. There he was responsible for aircraft maintenance and he was qualified as "Breguet Br.1150 Atlantic maintenance Supervisor". He was deployed in Afghanistan in 2007 as Air Operation Support Unit Deputy. Since September 2010 he has served at the NATO Modelling & Simulation Centre of Excellence based in Rome, as "3D Visualization Officer" of the Distributed Simulation Branch, and he is involved in 3D laser scanner activities carried out by the Centre of Excellence.

Letizia Nicoletti is currently completing is PhD at University of Calabria working at MSC-LES lab. Her research interests including distributed and interoperable simulation with specific applications related to training in marine ports and decision making involving human modeling aspects. She is also serving as CEO of CAL-TEK Srl a start-up company working in the M&S area following different research projects in the Logistics and Defense area.