Project Acronym:	**RECOVER**
Project Type:	***Co-operative Research***
Project Title:	**Photorealistic 3D Reconstruction of Perspective Paintings and Pictures**
Contract Number:	**COOP-CT-2005-017405**
Starting Date:	**01-10-2005** *Ending Date*: **30-09-2007**

Deliverable Number: 15 (D7.3)
Title of the Deliverable: Publishable Final Activity Report
Period covered: from 01/10/2005 ***to*** 30/09/2007
Task/WP related to the Deliverable: T7.1/WP7
Type (PU, PP, RE, CO): PP
Nature (Prototype, Report, Specification, Tool, Other): Report
Version: draft
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Contractual Date of Delivery to the EC:	***30/09/2007***
Actual Date of Delivery to the EC:	***14/11/2007***

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Executive Summary

The RECOVER project (full title *Photorealistic 3D Reconstruction of Perspective Paintings and Pictures*) aims at the development of a system for the semi-automatic extraction of three-dimensional (3D) models of scenes depicted in perspective paintings. 3D models of paintings constitute a new and exciting way for the general public to experience and appreciate fine art. The viewer can experience a feeling of immersion; paintings are no longer perceived as static artefacts from a long-gone past but as living, vibrant entities. With the aid of appropriate software, the viewer can literally dive into the painting, interacting with it and observing it from various viewpoints in impressive walk-throughs and inspiring fly-bys. This enables non-specialists to step into history and experience the scene in the space and time frame perceived by the artist. Ultimately, the viewing of paintings becomes a more appealing, exploratory endeavour, arousing the public's interest in fine art and cultural heritage in general. In addition to them being used in interactive multimedia applications, textured 3D models reconstructed with the RECOVER system can be employed in applications such as virtual reality, video games, 3D photography, digital visualization, visual metrology, art history study, etc.

1. Introduction and Background

The following subsections provide an overview of the task of extracting 3D models from images along with some relevant background. More specifically, this background information consists of the motivation for pursuing this project, a brief account of the use of perspective in painting and an introduction to linear perspective.

1.1. 3D Models from Images

Widespread deployment of information and telecommunications technologies has triggered an ever increasing demand for digital content to support a variety of applications. In particular, advances in three-dimensional (3D) model rendering and visualization have emphasized the need for 3D digital content to be employed in computer graphics, mixed reality and communication. This in turn, has created a tremendous potential for techniques capable of producing digital 3D models corresponding to scenes and objects, transforming the relevant research into a hot topic for several years. Equally important to the production of digital content is the capture of the content's semantics with appropriate metadata, aiming to improve content reuse, personalization, searchability, interchange and management.

Being non-intrusive and cheap in terms of the required equipment, approaches that are based on the processing of images provide a particularly attractive paradigm for achieving 3D reconstruction and at the same time adding geometric semantics to images. *RECOVER* (full title "Photorealistic 3D Reconstruction of Perspective Paintings and Pictures") is an EU-funded FP6 co-operative research project that focuses on the development of a system for the semi-automatic extraction of 3D graphical models corresponding to scenes depicted primarily in Renaissance perspective paintings but also in sketches, gravures, postcards and photographs.

To infer the 3D scene structure, Single-View Reconstruction (SVR) computer vision techniques are employed, aiming to "invert" the process of perspective image formation that lays down the geometric rules followed by artists when drawing. SVR is approached in an uncalibrated framework, in which there is no need for the camera pose or internal parameters to be known beforehand. To disambiguate among the infinitely many 3D reconstructions that are compatible with a given 2D image, simple geometric knowledge about the imaged scene should be available. This knowledge is supplied by a user based on his/her interpretation of the scene and concerns constraints such as coplanarity, parallelism, perpendicularity, etc. For this reason, single view reconstruction necessitates some manual intervention and concerns paintings rich in geometric regularity. The resulting 3D information is refined and enhanced with the aid of interactive editing tools, yielding a photorealistic 3D model of the depicted scene.

1.2. Motivation

According to the current state-of-practice, fully manual reconstruction techniques based on the use of CAD and 3D modeling tools for reconstructing paintings are quite tedious and labor-intensive, therefore time-consuming and costly. Laser scanning techniques cannot be applied due to the fact that the canvas used for painting is 2D. Conventional photogrammetric approaches and multi-view geometry vision techniques are also inapplicable due to their need for several images acquired from different viewpoints. RECOVER's approach, on the other hand, capitalizes on recent research results in order to bridge the gap between the research state-of-the-art and the state-of-practice in the construction of 3D models from 2D paintings.

Textured 3D models constitute a new and exciting way for perceiving and appreciating paintings. Their viewer can experience a feeling of immersion; paintings are no longer perceived as static artifacts from a long-gone past but as living, vibrant entities. With the aid of appropriate software, the viewer can literally dive into the painting, interacting with it and observing it from various viewpoints in impressive walk-throughs and inspiring fly-bys. This enables non-specialists to step into history and experience the scene in the space and time frame perceived by the artist. Ultimately, the viewing of paintings becomes a more appealing, exploratory endeavor, arousing the public's interest in fine art and cultural heritage in general. Multimedia content such as images is often annotated with some form of metadata that describe it. Annotation of images typically refers to the task of describing their semantic content with a set of keywords or a caption. Annotations of this sort are primarily used for image retrieval in large databases through keyword-based search. A 3D model reconstructed from an image can be considered as an alternative means of annotating the latter. Such an enriched image, accompanied by metadata in the form of a 3D model reconstructed from it and possibly additional graphical elements can support several visualization types for the imaged scene. Furthermore, the 3D model can be reused in a wide spectrum of applications such as virtual reality, video games, 3D photography, visual metrology, etc.

1.3. Perspective in painting

Until the beginning of the 15th century, artists lacked the knowledge of creating an illusion of the third dimension in their works, which essentially look "flat" and fail to represent volume. Objects and characters were typically drawn depending on their importance rather than their distance from the observer. Such drawing practices were abolished during the Renaissance. The Italian painters of the time were the first to be interested in naturalism and studied the geometry of image formation in order to rationalize the representation of space by reproducing the perspective effects in the images of the world that they were creating. Giotto di Bondone was the first painter to treat a painting as a window into space, being concerned with the third dimension, the proportions and the natural appearance of surfaces. However, it was not until the writings of Florentine architects Filippo Brunelleschi and Leon Battista Alberti that linear perspective was formalized as an artistic technique aimed at creating a systematic illusion of space behind the canvas. The comprehension of the relations of perspective to perceptual aspects of depth and space, allowed painters to take advantage of the impressive ability of the human visual system to infer 3D properties of shape from a single 2D image. Hence, the use of perspective revolutionized the art of painting and raised it to a prestigious level among the fine arts. Renaissance masters such as Masaccio, Piero della Francesca, Leonardo da Vinci and Albrecht Dürer pushed theory to a considerably sophisticated stage, paving the way for its complete mathematical formulation. This mathematical system that allows the creation of the illusion of depth and volume on a flat surface has become to be known as *linear perspectiv*e and is briefly presented next.

1.4. Elements of linear perspective

Intuitively, the basis of perspective image formation involves rays of light that travel from scene objects and through the imaging plane to a viewer's eye or a camera. A perspective image corresponds to the intersections of the light rays with the image plane and is formed by a pinhole camera, a device that performs central projection of points in space onto a plane.

One of the more striking features of perspective projection is that the images of infinite objects can have finite extends. For instance, an infinitely long scene line projects to an image line that terminates in a finite point. This point is known as the *vanishing point* and depends only on the 3D line's direction and not on its position. Thus, parallel 3D lines share the same vanishing points. In a similar manner, the vanishing points of sets of non-parallel, coplanar 3D lines lie on the same image line, which is known as the *vanishing line* of the underlying plane. The vanishing line of a ground plane is often referred to as the *horizon*. Parallel planes share the same vanishing line. After identifying the image projections of at least two parallel 3D lines, their corresponding vanishing point can be detected as their point of intersection. Knowledge of a length ratio defined by three collinear points forms the basis for an alternative scheme for vanishing point detection. The vanishing line of a plane can be detected from at least two vanishing points corresponding to different directions that are parallel to the plane in question. Alternatively, a vanishing line can be directly determined from the images of three parallel 3D lines with known ratios of distances among them.

A 3D plane that is viewed on a planar image under perspective projection induces a general plane-to-plane projective transformation that is known as a *homography*. Homographies also encode the transformation between different images of the same 3D plane. A particularly useful kind of planar homography is that referred to as a metric rectification homography. Such a homography maps the image of a plane to another one so that it removes the effects of projective distortion (i.e., spatial foreshortening). A metric rectification homography allows metric properties of the imaged plane, such as angles, length and area ratios, to be directly measured from its perspective image. Furthermore, a metric rectification homography is of utmost importance in texture mapping, since it allows the synthesis of a distortion-free texture map for a non-frontoparallel (i.e. slanted) plane. The most straightforward way to estimate a metric rectification homography is through identifying a scene rectangle (e.g. a window frame, a group of floor tiles, etc) with known aspect ratio (i.e. height over width ratio) and associating its four corners with those of the quadrangle corresponding to its image projection. Alternatively, a metric rectification homography can be estimated from the vanishing line of its underlying plane along with at least two constraints arising from combinations of line segments with known angles or length ratios.

2. Project execution

The second part of this document provides an overview of the project's activities and results. More specifically, it includes a summary description of the project objectives, the contractors involved, the methodologies and approaches employed, the work performed and end results. The project's achievements are also related to the state of the art, explaining their impact on the project's industry sector. Sample 3D models reconstructed with the developed system illustrate the results of the project.

2.1. Strategic Objectives

RECOVER addresses the strategic objectives outlined next:

- To enable SMEs that are active in the cultural sector to gain access to innovative technologies. More specifically, the goal is to bridge the gap between the state-of-the-art and the state-of-practice in the construction of 3D models from perspective 2D paintings, drawings, postcards and single photographs.
- To empower SMEs to improve their competitiveness by capitalizing upon innovation.
- To facilitate the international cooperation among participating SMEs and RTD performers, which will create opportunities for all involved parties.
- To promote the formation of a “virtual heritage”, thus improving access to Europe's cultural resources.
- To contribute to Community policy and societal objectives.

2.2. Scientific and Technical Objectives

The scientific and technical objectives of RECOVER have been the following:

- To develop informative and easy to use interactive single view reconstruction (SVR) techniques. These techniques will assist users to extract 3D information from paintings, avoiding the laborious and time-consuming process of obtaining such information manually.
- To develop flexible image-based editing and manipulation tools for refining the imperfections of the 3D structure provided by SVR and providing the missing information due to self-occlusions.
- To implement a semi-automatic software system that will integrate the SVR and model editing techniques, thus facilitating the photorealistic 3D reconstruction of selected perspective paintings and pictures.
- To create sample photorealistic 3D models extracted from paintings, gravures and lithographs.

2.3. Contractors List

Participants to the RECOVER consortium as well as their short names and logos are listed in the following table:

Participant name	Country	Logo
Foundation for Research and Technology - Hellas (FORTH) *(Coordinator)* *http://www.forth.gr*	*GREECE*	
Space S.p.A. (SPACE) *http://www.spacespa.it/*	*ITALY*	
Cultural Heritage On-Line (CHOL) *http://www.museum-images.com/*	*FRANCE*	
Unicity SpA (UNICITY) *http://www.unicityonline.it/*	*ITALY*	
RIGEL Engineering s.r.l. (RIGEL) *http://www.rigel.li.it/*	*ITALY*	

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2.5. Methodologies and Approaches

In the context of RECOVER, objects are modeled using surface rather than volume representations. Thus, planar faces are reconstructed as opposed to polyhedral primitive solids such as prisms, parallelepipeds and pyramids. This is because solid primitives are often not fully visible in a single image due to factors such as occlusions and field of view limitations, therefore their reconstruction is not possible without considerable, arbitrary generalization. Reconstructed points are represented by their Euclidean coordinates while planes are represented using the Hessian normal form, i.e. with their normal vectors and distances from the origin. Blender[1], the open-source 3D graphics platform has been selected as the development platform for the RECOVER prototype system. In this manner, all the advanced features present in Blender become readily available for use by the prototype.

Roughly speaking, the workflow for obtaining a reconstruction from an image involves three steps. First, the image has to be calibrated in order to determine the optical properties of the device that acquired it, be it a camera or a painter's eye. Then, a preliminary reconstruction of a set of planes and associated points is recovered. Finally, this reconstruction is refined in order to adhere to user-supplied geometric constraints. Whenever possible, more than one techniques for achieving the same result have been implemented, allowing the end-user to choose the one that seems the most natural for a particular image. More technical details concerning the reconstruction workflow can be found in the EVA 2007 paper describing RECOVER[2] and references therein.

To increase the realism of a reconstructed 3D model, textures automatically extracted from the corresponding image are mapped on the model's surface. These textures are thus photorealistic and are saved in standard image formats (JPEG & PNG) after being compensated for perspective distortion effects using their corresponding rectification homographies. On the one hand, this last choice

[1] See http://www.blender.org.
[2] M. Lourakis, P. Alongi, D. Delouis, F. Lippi and F. Spadoni, "*RECOVER: Photorealistic 3D Reconstruction of Perspective Paintings and Pictures*", Proceedings of EVA London 2007, London, UK, 2007.

renders easier the editing of extracted textures using ordinary image editing software and on the other hand, facilitates the generation of extended textures with the aid of texture synthesis or texture transfer algorithms: One of the main shortcomings of SVR is its inherent inability to cope with occlusions that result in "holes" in the reconstruction. To fill in the missing information, occlusion filling techniques can be employed. More specifically, non-parametric texture inpainting and synthesis algorithms are incorporated, which are capable of masking out certain image regions that correspond to unwanted objects or enlarging small patches by synthesizing stochastic textures based on their structural content.

Recovered reconstructions are saved in the VRML (Virtual Reality Modeling Language) text-based scene description language, which is an open, ubiquitous standard for 3D graphics on the Web. For the purposes of RECOVER, VRML/X3D is very convenient for visualizing the reconstructed 3D models and importing them to a wide variety of 3D graphics software for further use. Another useful feature offered by VRML is the support for various sensors that monitor a viewer's actions and can trigger events. Such events can be used for loading web pages, displaying billboards and triggering animations which combined with the reconstructed virtual world, considerably augment a viewer's interaction with an image.

During the development of RECOVER, the Unified Process (UP) approach for software testing has been adopted. According to the UP approach, the verification and validation activities are done in the construction and transition phase, and are targeted to verifying that the software is coherent with the software specifications and use cases defined in the early design phases.

2.6. Work Performed and End Results

The development of a software system for semi-automatic single view reconstruction has been divided into five technical workpackages, namely requirements (WP2), 3D reconstruction (WP3), 3D model manipulation (WP4), integration (WP5) and testing and validation (WP6). The following paragraphs summarize the work performed for each workpackage. A collection of 3D models reconstructed with the aid of the developed software system can be found online at http://www.ics.forth.gr/recover/results.php.

The requirements workpackage involved the formal specification of (a) the user requirements, (b) the desired functionality of the RECOVER system, (c) the software and hardware platforms to be employed by the system (d) the interfaces between different components and integration planning (e) the definition of the validation trials and (f) the selection and acquisition of proper data to be used as test inputs by developers during the development phase.

Within the framework of the 3D reconstruction workpackage, several computational vision techniques, which are essential prerequisites to SVR, have been developed. These techniques include the extraction of straight-line segments (i.e. line detection), the determination of lines from sets of points (i.e. line fitting), the determination of vanishing points and lines, the estimation of plane projective transformations (i.e. homographies and homologies), the fitting of conics to sets of image points, the metric rectification of planes, etc. Several techniques for single view camera intrinsic calibration based on (possibly combined) cues such as mutually orthogonal vanishing points, vanishing lines and their orthogonal vanishing points, metric homographies, imaged circular points and a priori known scene metric properties, have also been developed. Furthermore, techniques for obtaining 3D measurements directly from images (e.g. computation of the camera viewpoint's position and orientation, computation of segment angles and length ratios, measurement of heights, etc.) have been implemented.

Concerning 3D reconstruction per se, a scheme for obtaining a preliminary reconstruction of points and planes has been developed. This scheme alternates between reconstructing points and planes and allows the reconstruction of points and planes that are sufficiently "linked" together by means of shared, common points; in certain cases it is capable of dealing with planes with unknown vanishing lines. Due to various errors, such preliminary reconstructions have often the drawback that planes that are parallel or perpendicular in a scene (in general having known dihedral angles), do not end up being reconstructed as such. Depending on the image, this contingency might not be acceptable since it hampers a viewer's correct geometric perception of the scene. Therefore, a technique has been devised that permits an preliminary reconstruction to be refined in order to satisfy a set of geometric constraints corresponding to a priori scene knowledge that are supplied by the user. Treating the preliminary reconstruction as a starting point, this technique attempts to jointly refine the set of initial point and plane parameter estimates for finding the set of parameters that most accurately predict the locations of the observed points on the image and, at the same time, satisfy the supplied geometric constraints. Suitable such constraints concern orthogonality and parallelism of planes and coplanarity of points. Apart from the 3D geometry, the reconstruction permits the estimation of the viewpoint of the employed camera. In the case of a painting, this is equivalent to its *vantage* point, i.e. the location from which the observer experiences the liveliest three-dimensional illusion regarding the painted scene. The set of all implemented techniques related to reconstruction were packaged into a reconstruction engine consisting of a software library and associated API.

The work carried out regarding the 3D model manipulation workpackage, has focused on means for enhancing a reconstruction that has been obtained via semi-automatic computer vision techniques. In particular, the issues examined concerned the editing of 3D geometry, the extraction of textures originating from non-frontoparallel scene planes, the filling of holes and the removal of unwanted objects by means of on non-parametric texture inpainting and synthesis algorithms that synthesize stochastic textures based on their structural content, the segmentation of arbitrarily-shaped image regions (i.e. human figures) by interactive tracing of their silhouettes and the canceling of lighting effects. Combined with the work carried out in the reconstruction workpackage, this workpackage permits the recovery of textured 3D models that pertain to perspective images and are encoded in VRML.

Both camera calibration and 3D reconstruction techniques require certain interactive user input for defining the calibration constraints and the spatial extend of scene planes along with geometric relationships, respectively. Hence, the integration workpackage has been related to developing an appropriate interaction model and graphical user interface for the reconstruction engine developed during the execution of WP3. This interface took the form of a plug-in for Blender. In addition to the development of the user interface, several verification tests were conducted to ensure the correctness, accuracy, efficiency and reliability of the integrated system and accordingly permit its fine-tuning.

Finally, during the testing and validation phase, the integrated system has been validated through validation trials defined during the requirements analysis phase. Validation investigated the compliance of the software to requirements and use scenarios defined at an early design stage. Furthermore, validation concerned the evaluation of the degree to which the whole system meets quality criteria such as usability, efficiency and interoperability.

2.7. Project Achievements, State of the Art and Intentions for Use

RECOVER has successfully investigated the topic of semi-automatic single view reconstruction from one perspective image. With the combined efforts of all partners, a prototype system capable of interactively extracting textured VRML 3D models from images has been developed. To the best of our knowledge, this system possesses a set of characteristics that render it unique among the set of existing commercial software products that assist the recovery of 3D models/measurements from images. For instance, most of the existing such products (e.g. Eos PhotoModeler, Realviz ImageModeler, Vexcel FotoG) require multiple images of the same scene, whereas a single image suffices for RECOVER. Other such products primarily focus on aiding the user perform measurements directly on images (e.g. iPhotoMEASURE) rather than producing 3D models. The class of software products that focus on strictly one image is quite limited and consists of products that are currently either discontinued (e.g. Metacreations Canoma, GeoTango SilverEye) or not yet fully available (e.g. Freewebs Fotowoosh). The RECOVER system also strives to be flexible, offering several different means of achieving the same result and avoiding making assumptions that restrict it to a particular class of images (e.g. aerial/satellite images such as those targeted by SilverEye). Another advantage offered by RECOVER is that it lets the user get involved in the reconstruction process, thus exploiting the remarkable capability of the human brain to interpret 3D structure from a single image. More details regarding products competing with RECOVER can be found in RECOVER's "Final Plan for Using and Disseminating Knowledge".

The primary envisaged use of the RECOVER system is to employ it for creating 3D models that will serve as digital content for developing interactive multimedia applications related to cultural heritage. Evidently, such usage has the potential for important societal implications related to improved accessibility and visibility of European cultural resources. Furthermore, RECOVER technology can have a broad spectrum of possible practical applications ranging from the study of art history and assistive technologies for people with special needs to video games, 3D photography, visual metrology, digital visualization, architectural photogrammetry, urban visualization and planning, forensics, guidance and e-learning. From a more abstract perspective, a 3D model reconstructed from digital content in the form of an image, can be thought of as a means of annotating the latter with metadata. Such metadata can improve content reuse, personalization, searchability, interchange and management.

The SME partners of RECOVER are interested in exploiting the project's results along the following main axes:

- Direct sales of SVR products and services,
- Commercial and distribution agreements with application re-distributors, system integrators, and consultants willing to exploit the functionality of the SVR products,
- Consultancy contracts for providing software development and business technological advice on multimedia content management, processing, distribution and on-line delivery as well as implementation, customization, configuration and maintenance for the related systems.

2.8. Sample Results

This section provides images of sample results from the RECOVER prototype. Most of these results can be also found online at http://www.ics.forth.gr/recover/results.php. The first result concerns the 15th century painting titled “La Città Ideale” shown in Figure 1 and illustrating a typical example of Renaissance architecture and urban planning. The painting was executed using one point perspective, under which the sides of buildings recede towards the vanishing point, while all vertical and horizontal lines are drawn face on. Camera calibration was based on the homography of a three by two rectangle formed by floor tiles. The sole finite vanishing point was estimated from the intersection of inwards oriented parallel lines provided by the user and, since the horizon is horizontal, sufficed to estimate the latter. The outlines of planes to be reconstructed were then interactively marked on the painting and plane parallelism & perpendicularity relationships were specified by the user. Following this, the reconstruction was carried out automatically, producing a textured VRML model three views of which are illustrated in Figure 2.

Figure 1: “La Città Ideale”, Galleria Nazionale delle Marche, Palazzo Ducale di Urbino. Painter unknown; attributed to Luciano Laurana, Piero della Francesca and Leon Battista Alberti, c. 1470.

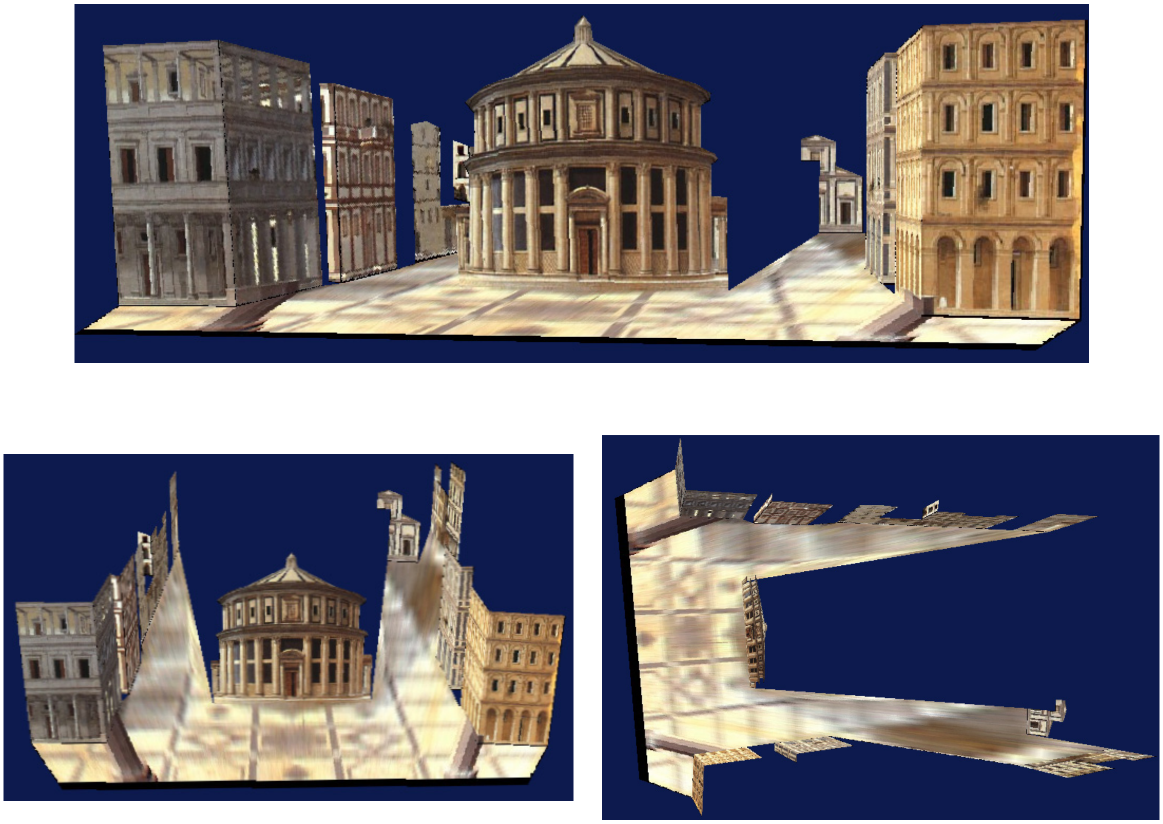
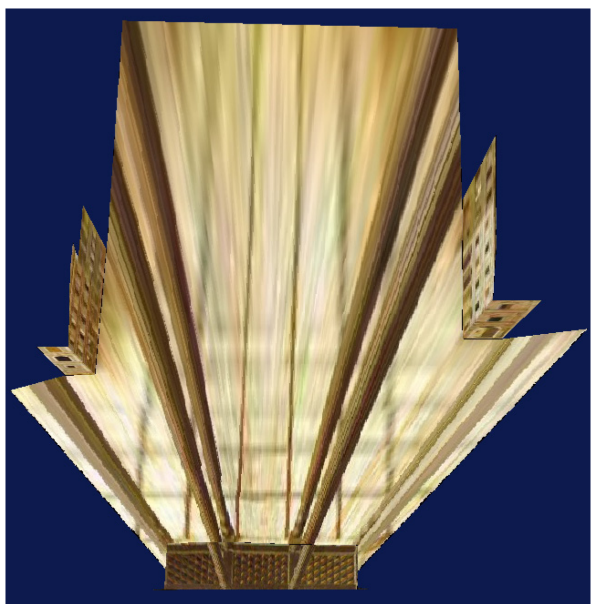


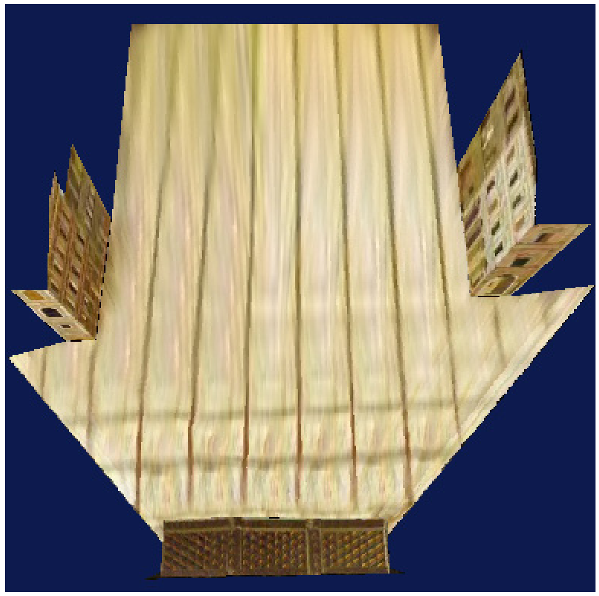
Figure 2: Different views of the 3D model reconstructed from Figure 1. Notice the ground plane pattern that is exposed in them while not being clearly visible in the painting itself.

The second result concerns another painting also known as “La Città Ideale”, depicting a city square through a colonnade. The reconstruction process has been quite similar to that detailed for the painting of Figure 1 above, with the main difference being that in this case, occlusion filling techniques have been employed for the floor’s texture: By exploiting regularity, it has been possible to synthesize the texture of floor areas that have been occluded by the pillars in the original painting. The floor’s texture before and after occlusion filling is shown in Figure 4(a) and (b), whereas Figure 4(c) illustrates a novel view of the final 3D model.

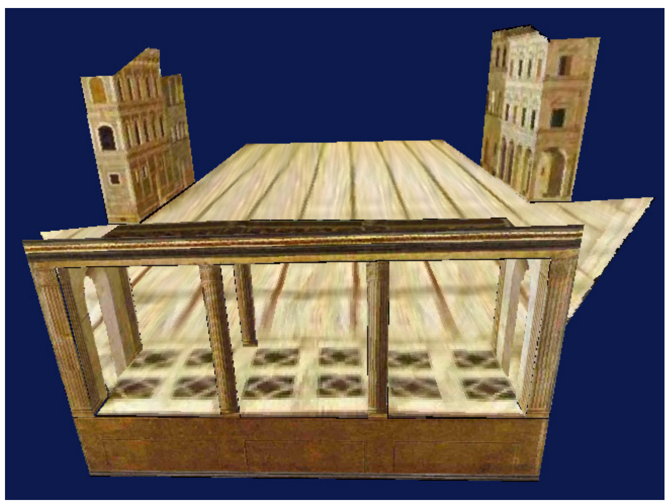
Figure 3: Yet another version of an ideal city, attributed to Francesco di Giorgio Martini, 1470s.



(a)



(b)



(c)

Figure 4: (a) Top view of the 3D model reconstructed from Figure 3. Notice the erroneous texture of floor areas that are occluded by the pillars in the original painting. (b) Top view of the reconstructed model after editing the floor texture. (c) Side view of the final model.

The third result was obtained with the aid of the painting by Piero della Francesca shown in Figure 5 and entitled “Flagellazione di Cristo”. Views of the 3D model reconstructed from it can be found in Figure 6. This result illustrates the use of the image segmentation facility to delineate the complex silhouettes of the several human figures present in the scene. Note also that the texture of the floor has been extended to account for occlusions due to the standing humans.

Figure 5: “Flagellazione di Cristo”, Piero della Francesca, c. 1470

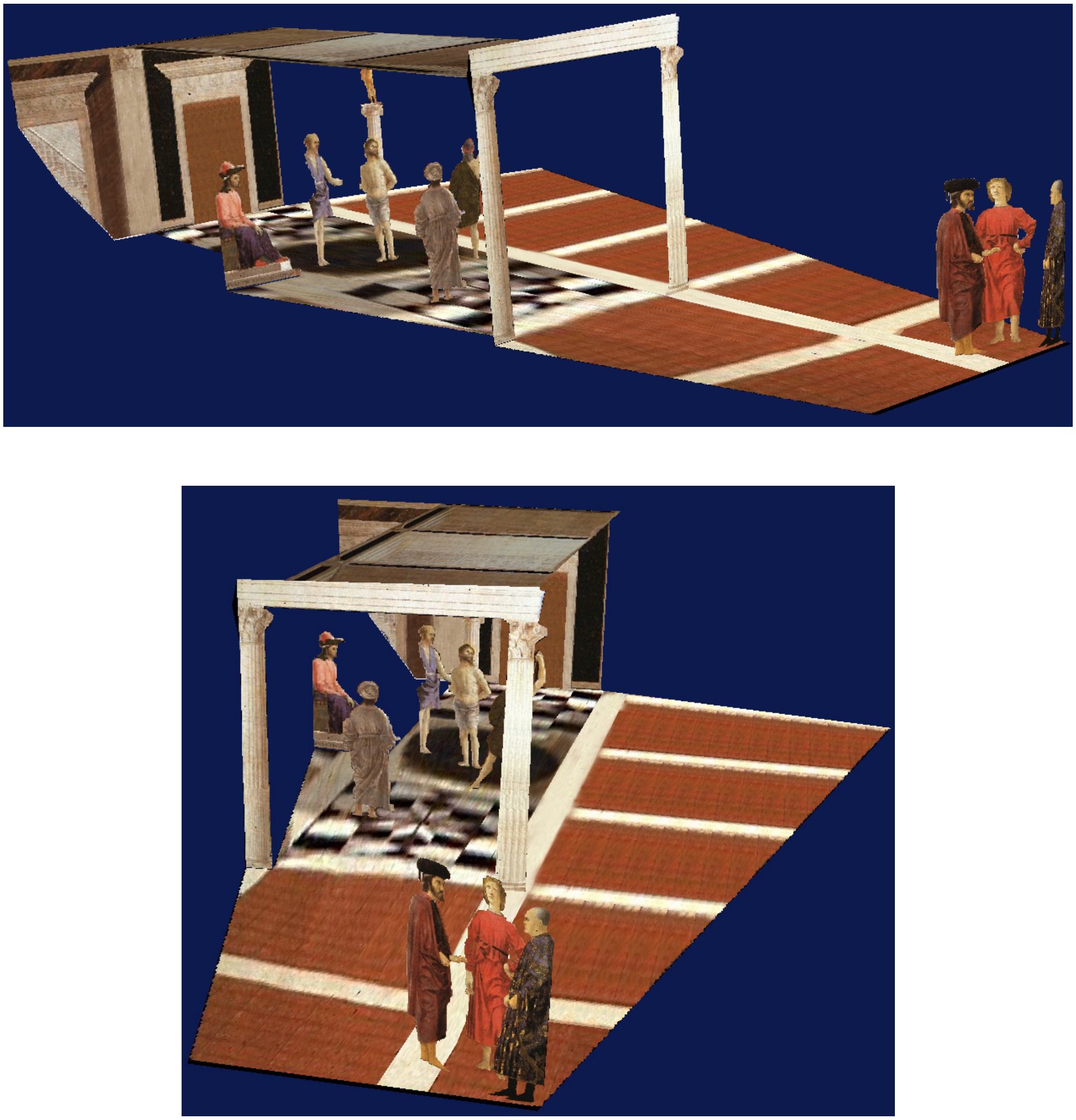


Figure 6: Different views (after texture editing) of the 3D model reconstructed from Figure 5. Notice the star-shaped floor patterns reconstructed on the left.

The next result concerns the painting shown in Figure 7, titled “The Old Town Hall of Amsterdam” and painted by Pieter Saenredam. This painting has certain geometric inaccuracies with respect to the capture of perspective, nevertheless the construction of a convincing 3D model from it has been possible as shown in Figure 8.

Figure 7: “The Old Town Hall of Amsterdam”, Pieter Jansz. Saenredam, 1657.

Figure 8: View of the 3D model reconstructed from Figure 7.

Yet another painting to be reconstructed is shown in Figure 9. It is entitled “The Arsenal: the Water Entrance” and was painted by the Venetian artist Giovanni Antonio Canal, better known as Canaletto. The painting depicts a rather complicated scene and requires extensive texture editing to cope with occlusions and shadows. Figure 10 illustrates a top view of the reconstructed 3D model.

Figure 9: “The Arsenal: the Water Entrance”, Canaletto, c. 1732.

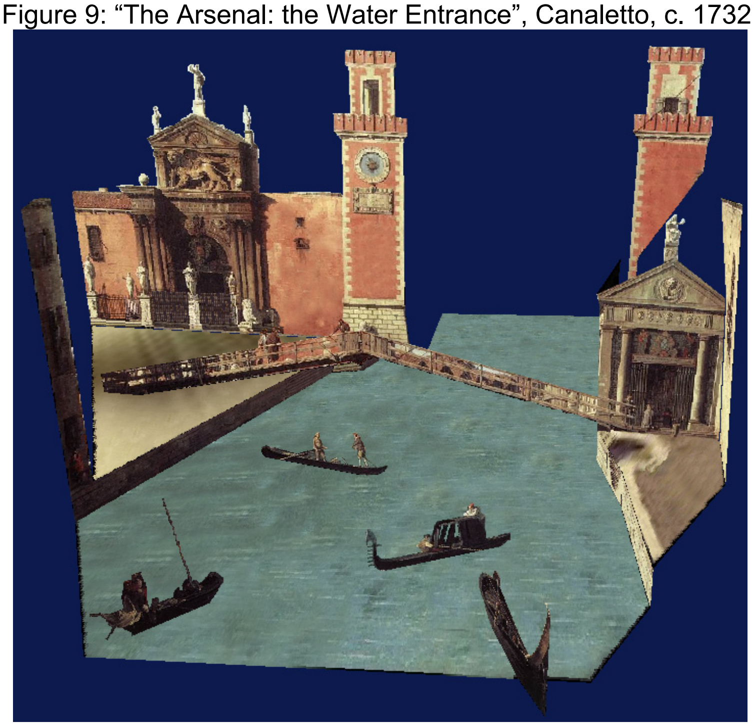


Figure 10: Novel view of the 3D model reconstructed from Figure 9.

A result obtained using an ordinary digital photograph is presented next. This result aims to illustrate that the developed SVR techniques are also applicable to conventional imagery and not just paintings. Towards this end, the photograph shown as Figure 11 was employed. This photograph was found on the Web and depicts a real object, namely a bell tower at the Haghpat monastery in Armenia, a religious complex founded in the 10^{th} century and included in the UNESCO World Heritage List. Figure 12 shows a new view of the 3D model reconstructed via the SVR techniques developed in RECOVER.

Figure 11: Haghpat monastery bell tower

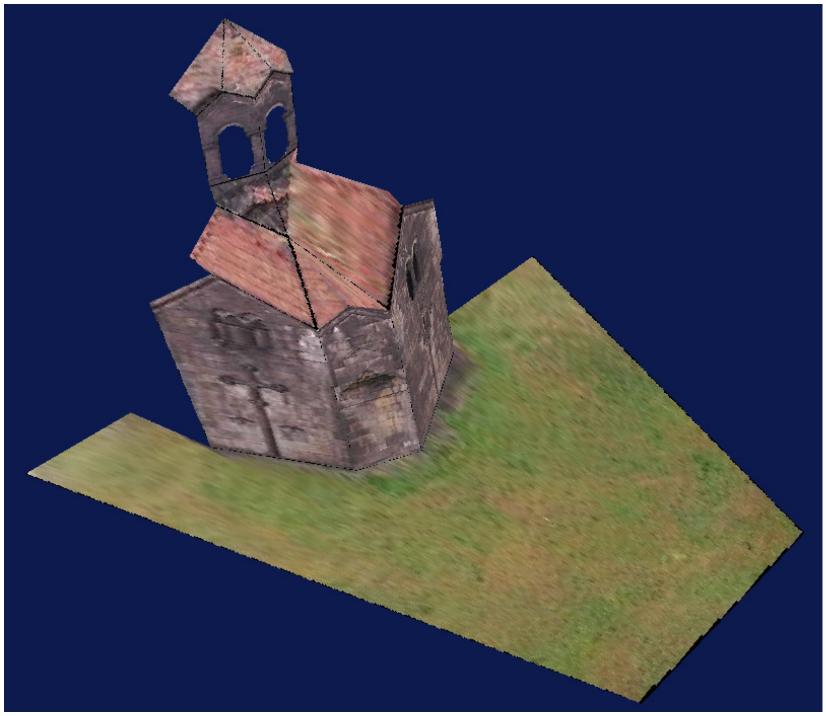
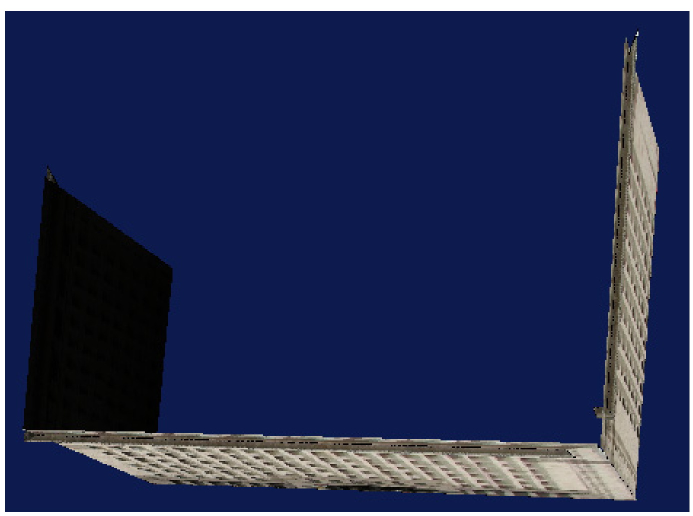


Figure 12: Novel top view of the 3D model reconstructed from Figure 11.

The last result included here concerns two real images taken with a digital camera and is intended to provide evidence for a somewhat different use of the RECOVER system. More specifically, the two images of a building shown in Figure 13 were acquired. Clearly, due to self-occlusions, capturing the complete geometry of the building with a single image is impossible. Therefore, a detailed 3D model cannot be reconstructed from a single image alone. However, partial 3D models reconstructed form different single images can be combined together, producing a more complete representation. This is illustrated in Figure 14(a) and (b), where the two models obtained from the images of Figure 13 have been merged. The red pyramids in Figure 14(a) correspond to the camera viewpoints from which the two images have been acquired. As it can be seen from Figure 14(b), the two side walls of the reconstructed building are not of equal length. This is indeed correct, as can be verified from the Google Earth top-down view of the actual building shown in Figure 14(c).


Figure 13: Two views of the Adelaide House, London Bridge, London EC4R 9HN, England.

(a)



(b)

(c)

Figure 14: (a), (b) side and top views of the 3D model reconstructed by stitching together the two partial models reconstructed from the images in Figure 13. Notice that the wall on the right is wider compared to the one of the left. (c) Top view of the building from Google Earth from which it is clear that the two side walls are not of equal size.

2.9. Project Logo

2.10. Project Website

http://www.ics.forth.gr/recover/

3. Dissemination and use

RECOVER encompasses a versatile set of techniques for achieving single view reconstruction from a single image. These techniques support a set of functionalities that place RECOVER at a unique position among similar systems. More specifically, RECOVER offers techniques for single view intrinsic camera calibration from a variety of cues, geometrically constrained 3D reconstruction with minimal user interaction, texture mapping as well as manipulation and 3D model completion and editing. The developed techniques are coupled with an interaction model targeted to single view reconstruction, which describes the effects of user actions to the system model and vice versa. The core reconstruction techniques have been implemented in ANSI C and have been packaged into a MS Windows DLL accessible through an API. The user interface has been developed as a plug-in for the Blender open-source 3D modeller, using Python scripting. More technical details about RECOVER can be found in the following overview papers and in their cited references:

- M. Lourakis et al, "*RECOVER: Photorealistic 3D Reconstruction of Perspective Paintings and Pictures*", proceedings of the 2007 Electronic Visualization and the Arts London Conference (EVA London 2007).

- M. Lourakis et al, "*Enriching Pictorial Cultural Content with 3D Models*", to appear in the Variazioni Electronic Magazine as part of the "Technologies for Content Enrichment in the Web2.0 Era" workshop that is to be held in conjunction with the 2007 International Conference on Automated Production of Cross Media Content for Multi-Channel Distribution (AXMEDIS 2007).

The primary envisaged use of the RECOVER system is to employ it for creating textured 3D models from perspective paintings. Such models will serve as the digital content for developing interactive multimedia applications that will improve the accessibility and visibility of cultural resources. Furthermore, a 3D model reconstructed from an image can be considered as an alternative means of annotating the latter. Such an enriched image, accompanied by metadata in the form of a 3D model reconstructed from it and possibly additional graphical elements can support several visualization types for the imaged scene. Thus, apart from the sector of cultural informatics, RECOVER models can be reused in applications such as virtual reality, video games, 3D photography, digital visualization, visual metrology, art history study, etc.

The RECOVER system has been developed as a demonstration prototype. While core functionalities have been carefully developed and have proven the feasibility of the approach, it is estimated that in order to reach industrial maturity, a few more months of further development, mainly focusing on the user interface, will be necessary.

The SME partners of RECOVER are interested in exploiting the project's results along the following main axes:

- Direct sales of SVR products and services,
- Commercial and distribution agreements with application re-distributors, system integrators, and consultants willing to exploit the functionality of the SVR products,
- Consultancy contracts for providing software development and business technological advice on multimedia content management, processing, distribution and on-line delivery as well as implementation, customization, configuration and maintenance for the related systems.

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