

# **HOLOGRAPHIC RELIEF MAP PRODUCTION BY USING TOPOGRAPHIC LINE MAPS (DIGITAL CARTO-HOLOGRAMS)**

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Most of the inventions in the history discovered by accidentally or inspire of irrelevant association between things. In most cases, somewhere in time, someone else has already imagined it before, but has not been materialized yet. It is so hard to match the idea and the final product in reality, and therefore many of people throws their ideas to the mind trash. But addiction to the idea prepares all the circumstances and brings every possible opportunity to make it real.

The thought of a Digital Carto-Holograms (DCH) or Holographic Relief Map (HRM) came into mind such a way a few years ago. It was so popular on those days to have 3D Hologram Eye on the cell-phone's screen among teens. This idea was a perfect practical marketing strategy for a production company. On the other hand it was an innovative object to a person who manufactures Plastic Relief Maps (PRM). Main problems with the PRM were inflexibility, lack of depicting objects without their heights and aligning features on the plastic sheet with the relief itself. It could be possible to eliminate these disadvantages of PRM with DCH.

After preparing theoretical background for over 5 years, it was possible to create the frontier of DCH by using sample vector map data within six months. The Digital Elevation Model (DEM) of the terrain was used to create the perspective, Topographic Line Map (TLM) data, such as line, point and area features were converted to 3D objects, in place of imaginary 2D map symbols, and the aerial photograph to give more realistic view. Exaggeration was implemented on the 3D models to prevent from vanishing on the terrain. After finishing this 3D TLM, it was possible to edit the model by using Autodesk's 3D Studio Max software. The model then posed on a suitable film to produce the Computer Generated Hologram (CGH).

In this paper you'll find the story of this product, benefits of holographic techniques for relief maps, development phases, suggested procedures to follow, main problems for such a production line and the product itself. Although it is a demonstration product, there are too many issues have to be solved in the near future to create 3D TLM for producing thousands of map sheets. This innovation of the very first and primitive Holographic Relief Map (HRM) gives us hope to solve some disadvantages of Classical Plastic Relief Maps.

**Keywords:** Holography, Digital Holographic Cartography, Holomap, Topographic Holomap, Holographic Line Map, Computer Generated Holography, Plastic Relief Map, Hologram, Holographic Relief Map

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## **Introduction: What is Holography and Hologram?**

Holography is one of the most significant discoveries humankind has ever made. Its discovery has had such a profound effect on our lives, that the person who discovered the process in 1947, Dr. Dennis Gabor, Hungarian physicist, received the Nobel Prize in Physics in 1972. (1)

His theory was originally intended to increase the resolving power of electron microscopes. Gabor proved his theory not with an electron beam, but with a light beam. The result was the first hologram ever made. The early holograms were legible, but plagued with many imperfections because Gabor did not have the correct light source to make crisp, clear holograms as we can today nor did he use the off axis reference beam. What was the light source he needed? The LASER, which was first made to operate in 1960. LASER stands for light amplification by stimulated emission of radiation. Without the laser, the unique three dimensional imaging characteristics and light phase recreation properties of holography would not exist as we know them today. Two years after the advent of the continuous wave laser, c.1959-1969, Leht & Upatnieks (at the University of Michigan) reproduced Gabor's 1947 experiments with the laser, and launched modern holography. (2)

Laser light differs drastically from all other light sources, man-made or natural, in one basic way which leads to several startling characteristics. Laser light can be coherent light. Ideally, this means that the light being emitted by the laser is of the same wavelength, and is in phase. (2)

Wavelength, usually symbolized by the Greek letter  $\lambda$  for lambda, and frequency, symbolized by the Greek letter  $\nu$  pronounced nu, have a reciprocal relationship  $\nu \lambda = C$ . The amplitude is the height or intensity of the wave. For example, a laser rated at 5mW (milliwatts, or thousandth of a watt) would give off light at the same frequency and wavelength as another laser of the same type rated at 1 mW. But the wave heights of the 5 mW laser light would be five times higher than that of the 1 mW laser. The wavelength is the distance from one crest to the next; this is also one cycle. It seems logical that we would need some constant measure of time in order to count the cycles. This constant unit of time is usually one second. Thus the term cycles per second, or cps, which is often referred to as Hertz or Hz (in honor of the German Physicist Heinrich Rudolph Hertz, who discovered radio waves). Wavelengths of visible light are between 400 and 700 nanometers or billionths of a meter in length. (2)

In holography, an object is illuminated with a beam of light and the light scattered from this object reaches a recording medium. A reference beam also illuminates the recording medium. Therefore, it is the interference between the object beam and the reference beam that is recorded on the beam, the light diffracted by the reference is identical to the light field which was scattered by the original object. (3)

Holography is the only visual recording and playback process that can record our three dimensional world on a two dimensional recording medium and playback this world as a true three dimensional image to our naked eyes. The image displays complete parallax and depth-of-field (parallax is the ability to look around an object to see objects behind it and depth-of-field is the ability to focus through a scene from near to far). The image can be made to float in space either behind, in front of, or straddling the recording medium. (1)

The hologram, that is, the medium which contains all the information, is nothing more than a high contrast, very fine grain, black and white photographic film. There are other photosensitive materials such as photo-chromic thermoplastics and ferro-electric crystals. The film designed especially for holography is capable of very high resolution which is defined as LPI-Lines Per Inch. One way of judging resolution of film or lenses is to see how many distinguishable lines can be resolved within a certain width, in this case it's a millimeter. Relatively slow film such as Kodak Pan X can resolve 90 lines per millimeter (depending on processing), while a good film designed for holography, such as AGFA Gaevert 8E75 is able to resolve up to 3000 lines/mm. Holographic film is also especially prepared to be sensitive to a certain wave length of light and each type of film is given a code number - AGFA 8E75 is sensitive in the red region and thus is used with ruby

or HeNe lasers; Kodak 649F is also, however, about 10 times slower. Kodak 120 plate or SO173 film is very similar to AGFA 8E75 but not quite as sensitive. (2)

It'll be very useful to understand the hologram by comparing with the photograph. A **photograph** is basically the recording of the differing intensities of the light reflected by the object and imaged by a lens. The light is incoherent, therefore, there are many different wavelengths of light reflecting from the object and even the light of the same wavelength is out of phase. The emulsion of film will react to the light image focused by the lens and the chemical change of the silver halide molecules will result from the photon bombardment. There is a point to point correspondence between the object and the emulsion. On the other hand, a hologram is not a recording of a focused image as in photography, but the recording of the interference of laser light waves that are bouncing off the object with another coherent laser beam, i.e., a reference beam which will be described below. (2)

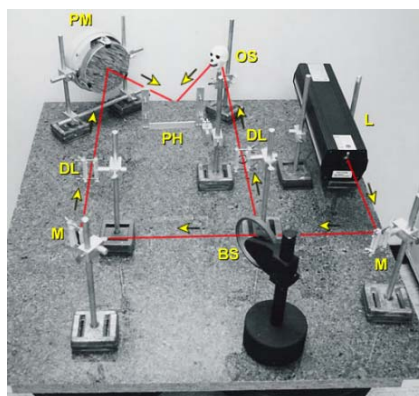


Figure-1: A basic holography system. (1)

This particular system has five basic optical components. They are the laser (L), beam splitter (BS), directional mirrors (M), diverging lenses (DL), and the parabolic mirror (PM). In addition to the optical components, there is the object or scene (OS), the photographic plate holder (PH), the table mounts, the optical holders, and the optical table. (1)

Using the diagram in Figure-1, here's what happens during the recording process. The laser beam from the laser (L) travels to the first directional mirror (M) and is reflected to the beam splitter (BS). At the beam splitter, the beam is split into 2 beams. These 2 beams are given names. One is the reference beam (R) and the other is the object beam (O). The reference beam (R) travels through the beam splitter to a second directional mirror (M) and continues through a diverging lens (DL) to a parabolic mirror (PM) that reflects and spreads the beam to the recording plate (PH). At the same time, the object beam (O) travels through a diverging lens (DL) that illuminates the three dimensional object scenes (OS) which then reflects the laser beam to the recording plate (PH). The interference of the light from the reference beam and the object's reflected light at the recording plate creates a hologram within the hologram plate at the microscopic level. After the plate is processed, it is placed back in the plate holder. The object is removed and the reference beam is allowed to illuminate the plate. Looking through the plate from the opposite side that the reference beam is illuminating the plate, you can see the original object suspended in space, as if the original object were still there. (1)

There are two main types of holograms;

- **Transmission Hologram:** This hologram is viewed by placing a light source behind the hologram and looking through it (like a window). The hologram is recorded in a two-dimensional format on the film plate.(4) Reconstruction of the hologram and readouts are shown on Figure-2.

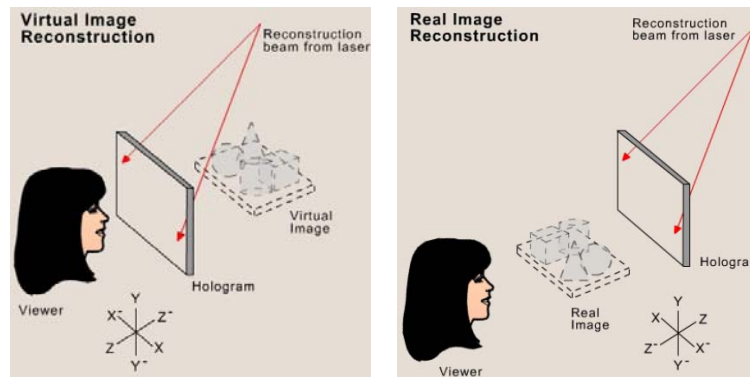


Figure-2

• **Reflection Hologram:** holographic fringes being recorded in three-dimensions. This hologram is viewed by looking at the reflection of a light source in the hologram (like a mirror). This type of hologram depends on the (Bragg reflection) on the film plate.(4) Reconstruction of the hologram and readouts are shown on Figure-3.

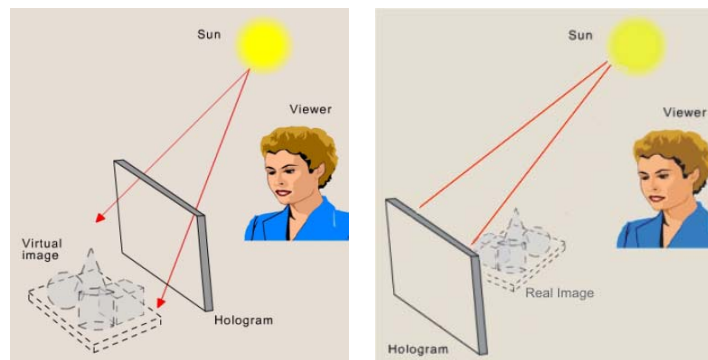


Figure-3

### What Is Plastic Relief Map (PRM)?

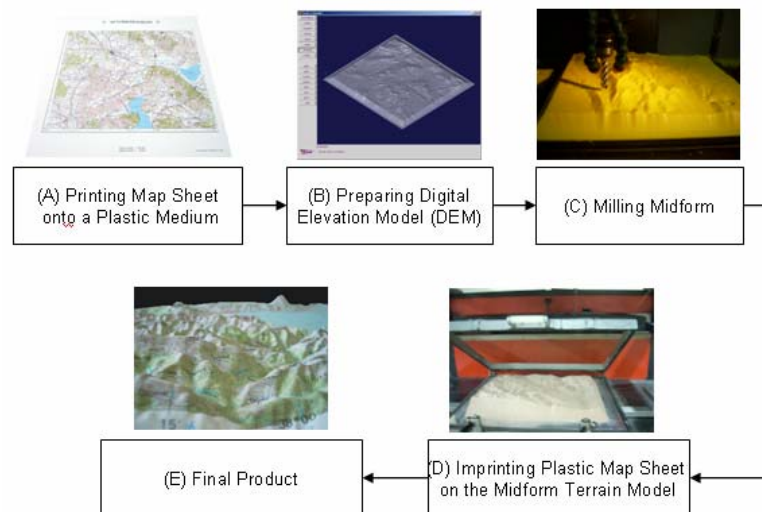


Figure-4: General Workflow of a PRM

A PRM is a kind of hard-copy map which has the ability to depict the real 3D terrain model of a relevant map extent. It's commonly so hard for a human to recognize and visualize the elevation model of a terrain from a printed Topographic Line Map, unless one is not an expert. Without an accurate recognition of 3D information, map users could make wrong decisions and it could cause unpredictable failures of projects and works. It is one of the main objectives for the cartographers to transfer most realistic information about land/earth data. Thus, the most common way to do it, imprinting 2D maps on a PRM plates.

This simple demonstration of the PRM production system has five steps (Figure-4). Cartographic Vector Data are prepared by using Karto25 (TLM Production System) which is based on ESRI's ArcInfo Workstation and developed by General Command of Mapping, Turkiye. (A) Once the postscript of the map sheet is ready, color separation is done by Kodak - Quantum II 800 CPT and plastic plates are printed by Heidelberg Trendsetter CD 102. (B) Digital Elevation Model (DEM) is prepared by using ArcInfo Grid module and converted to Grid ASCII format. WORKNC software is used for converting the ASCII file to the WNC format. (C) After preparation of the DEM data for CNC Machine, TNC software is used for sending data to milling head. The CNC machine carves the Midform block, a special soft and durable material in the industry more than still, by using 3D coordinates received from the computer. (D) The preparation of 3D Midform block, a special machine is used for molding the Plastic Map Sheet. (E) The final PRM product of the topographic map.

### Computer Generated Holography (CGH)

Basically the CGH can be defined as the process of synthetically producing fringe patterns from digital data by using computational methods. A holographic image can be generated e.g. by digitally computing a holographic interference pattern and printing it onto a mask or film for subsequent illumination by suitable coherent light source.(5) Holographic image can be reconstructed by a holographic 3D display. In recent times the term "Computer Generated Holography" is increasingly being used to denote the whole process chain of synthetically preparing holographic light wavefronts suitable for observation.(6)

Optical holograms need a real object for recording, contrary, CGH does not require a real object, has unlimited capacity of creating 3D holograms and can be reconstructed with many different medium or devices. Besides the advantages of CGH, there are obvious lower and upper bounds in terms of computational speed, image quality, resolution and adherence to the real object. Wavefront calculations are computationally very intensive; even with modern mathematical techniques and high-end computing equipment, real-time computation is tricky. There have been many different methods for CGHs proposed for calculating holographic interference patterns. (7,8,9,10,11) Basically the computational algorithms can be grouped in two main concepts in holography.

• **Fourier Transform (FT) Method:** Fourier Transformation is used to simulate the propagation of each plane of depth of the object to the hologram plane. The FT concept was first introduced by Brown and Lohmann (12). Calculation of the light propagation from 3D objects is performed according to the usual parabolic approximation to the Fresnel-Kirchhoff diffraction integral. The wavefront to be reconstructed by the hologram is, therefore, the superposition of the Fourier transforms of each object plane in depth, modified by a quadric phase factor. The vast majority of hologram computation methods employed so far have been predicated on the understanding that the field distribution seen by the viewer will be very close to the two-dimensional Fourier Transform of amplitude arrangement in plane of the hologram. (13)That is,

$$o(\mu, \nu) = \iint h(x, y) e^{j2\pi(x\mu + y\nu)} dx dy$$

Where the coordinates  $(\mu, \nu)$  in the output plane are simply the hologram-plane coordinates  $(x, y)$  scaled by a constant factor determined by specific reconstruction geometry chosen. That a simple

encoding of the hologram could proceed directly from an inverse Fourier description of the output amplitudes is quite ingenious, and the pioneers of the methods by which was accomplished must be commended. (14)

- **Point Source Holograms:** The second computational strategy is based on the source concept, where the object is broken down in self-luminous points. An elementary hologram is calculated for every point source and the final hologram is synthesized by superimposing all the elementary holograms. This concept has been first reported by Waters (15) whose major assumption originated with Rogers (16) who recognized that a Fresnel zone plate could be considered a special case of the hologram proposed by Gabor. But, as far as most of the object points were non-zero the computational complexity of the point-source concept was much higher than in the Fourier transformation concept.

Another concept which leads to Point-Source CGHs is the Ray tracing method. Ray tracing is perhaps the simplest method of computer generated holography to visualize. Essentially, the path length difference between the distance a virtual “reference beam” and a virtual “object beam” have to travel is calculated; this will give the relative phase of the scattered object beam. (5)

### **What is a Digital Carto-Hologram(DCH) or Digital Holographic Relief Map (D-HRM):**

It is said that printed media will be used more over 20 years from now on. So the need for PRM will gain more importance for the map users. Besides the advantages of the PRM, there are also some very important disadvantages such as inflexibility of the medium and being not suitable for carrying which restrict the usability of the PRM on the field.

The idea behind DCH is to merge the capabilities of PRMs and Holography and append more abilities on it. An DCH is more than a 3D reconstruction of a Topographic Line Map on a 2D flat medium. There can be found numerous usages for the DCH which will supersede Paper Maps (PM) and PRMs. Table-1 lists some of the advantages and disadvantages of DCH, PRM and PM.

<b>Feature</b>	<b>DCH</b>	<b>PRM</b>	<b>PM</b>
Perception of 3D topography of the terrain	Full	Full	Pseudo
Perception of 3D view of the geographic features	Yes	No	No
Automated production direct from TLM data	Needs Improvement	Yes	Yes
Cost for the same size	\$200-\$2000 per sheet	\$30-\$50 per sheet	\$1-\$5 per sheet
Ability for tiling of large areas	Yes	Yes	Yes
Flexibility of the medium	Yes	No	Yes
Ability to show animated information	Yes	No	No
Printing quality	High	Acceptable	High
Deformation of printed data on the medium	Low	High	Low
Ability to store layered information	Yes	No	No
Resolution of the medium	<8000 line per mm	<1200 dpi	<1200 dpi
Computational time for preparation of the master digital data	High	Low	Low
Level of suitability for mass production	Low	Medium	High

Table-1: Comparison of DCH, PRM and PM

Although it is not cost effective for now, in the near future there will be acceptable prices for the expensive high technology materials and holoprinters. Today most of the holograms are exposed on photosensitive materials such as Silver-Halide and Photopolymers. Also holographic instruments such as holoprinters, computers, lasers etc. are commercially expensive and not

suitable for mass production. Another concern is very high computational time to produce the master digital data and exposure time for the master plate.

Besides disadvantages, DCH has so many benefits for the cartographic production. Mass production of topographic maps will be possible with the development of new algorithms and techniques for Computer Generated Holography.

There are some commercial companies which lead the holography world, already developed big sizes of holograms up to ~1x2 meters square and new algorithms to compute holographic images. Zebra Imaging™ (17) is one of these companies, leads the holography world with their innovative approach for the holography and the inventor of photopolymer material. Geola (18) is another leading company and is a supplier of holographic materials.

Especially Zebra Imaging™ has an innovative approach about using holograms such as representing architectural designs and geospatial data (Figure-5). Geospatial holograms used in commercial and government applications typically enhance conventional 2D maps, aerial photos, and 3D physical scale models. Complex environments can be well understood using geospatial holograms much faster than with conventional 2D media. General commercial and governmental uses include the following; (17)

- Spatial Planning
- Project Planning
- Land and Real Estate Development
- Industrial Process Planning
- Event Logistics (e.g. determining a secure route for VIPs)
- Before- and After-action Briefing and Debriefing
- Emergency Management
- Undersea and extra-terrestrial planetary visualization
- Mapping the “common operating picture”
- Battle-space visualization
- Mission/rescue/evasion/logistics planning
- Intelligence and reconnaissance
- Force protection planning
- Anti-urban terrorism prevention planning
- Simulation of terrorist activity
- Line-of-site analysis for sniper activity
- Evacuation and recovery planning
- Damage assessment and damage estimation
- Human Intelligence (HUMINT)



Figure-5: Presentation of Geospatial Data and Architectural Designs (17)

### **Principles of Digital Holographic Cartography (DHC) (Suggested)**

When anyone googles on the internet, could easily find the term “Holographic Cartography”, would possibly is not relevant the usage of it in this article. Although it’s not a new idea to print the aerial photograph as a hologram over DEM data, what we invest here is to bring up the



application of cartographic rules to produce Digital Carto-Holograms which are topographic maps portrayed by holographic means, usually for military use (21). Also we recommend a methodology how to make more realistic Digital Carto-Holograms by using existing GIS vector data and suggest the fundamentals for this new branch of cartography.

In the “*Elements of Cartography*” book, the authors describe the *Cartography* and the *Map* as “...when we communicate with someone by describing a spatial relationship, we want our description to evoke a similar image in that person’s mind. The best way to be sure that will happen is to provide a visual representation of the geographical setting is what we call a map. Cartography is the making and study of maps in all their aspects... Cartography is concerned with reducing the spatial characteristics of a large area – a portion or all of the earth, or another celestial body – and putting it in map form to make it observable... it’s most fundamental function is to bring things into view... All maps are concerned with two elements of reality: locations and attributes... All geographical maps are reductions. Thus, the map is smaller than the region it portrays... All maps involve geometrical transformations... All maps are abstractions of reality... All maps use signs to stand for elements of reality... All map symbols used to portray data consist of various kinds of marks, such as lines, dots, color, tones, patterns, and so on.” (19)

It’s well known that human perception is more triggered by visual stimuli. We approach the world with information acquired through models of reality in the form of maps. Maps on papers could only depict a static and unchanging world and the mental representations that we derived from them limited our interactions with reality. Worst of all, these models could not be used, or used effectively, by most people – leaving a large segment of the population essentially illiterate. Cartographers have a moral obligation to effectively communicate spatial information to as large an audience as possible. One of the major problems associated with maps is that of map use. It has been estimated that well over half of the population do not have a basic competency with maps. (20)

The main purpose of the cartography is to transfer all necessary information from earth to the reader’s mind by using any medium or device as real and recognizable as possible. The process of transmission of geographic information is named as *Cartographic Communication*. Maps establish this communication by using map symbols as words or sentences. Symbols are graphical representations of real objects and vary according to culture, location, time, subject etc. Unlimited number of symbols or graphics can be used on maps. These are mostly 2D illustrations, images or 2.5D illustrations of the geographical objects.

On the other hand holography has more opportunities than a classical paper map. It gives a real 3D perception of the reality and symbols can be both 2D and 3D. Even though, a holographic map (Holomap) can include many layers which can be viewed by using different light sources. Many other types of products can be introduced once Digital Holographic Cartography (DHC) becomes a new branch in the near future.

Although this is a very short article to cover all aspects of the suggested DHC, we must consider only the main themes. The principles suggested here is the adaptation of some of the cartographic expression and design rules. Robinson, A.H. offers “For cartographers, the most important principles are legibility, visual contrast, figure-ground and hierarchical structure” for 2D cartography. (19) On the other hand 3D Cartography needs more preferences to depict the real world. With the development of 3D GIS, some of the classical cartographic rules would be changed by new rules and principles. Some of the suggested principles and features for HC are given below.

- 3D Hierarchical Exaggeration
- 3D Visual Contrast
- Visibility
- Lighting
- 3D Symbology

- Level of Detail
- Resolution of Perception
- 3D Generalization
- Labeling in 3D
- 3D Thematic Expression
- Representation of Textual Information
- Layering
- Coloring etc.

Some of the suggested components for holomaps can be listed as below.

- 3D Terrain Model
- Converted 3D Models of 2D Geographical Features
- 3D Textual Information of Relevant Features
- 3D Charts or Graphics for Thematic Expression
- Aerial Photographs
- Spatial Information Such as Grid lines and Coordinate Labels
- 3D Labels
- 2.5D Illustrations of 2D Features
- Representation of Other Cartographic Elements...

These are only suggested features, principles or components for HC which could be a new branch for Cartography in the near future. Cartographers may extend this state-of-the-art branch, once it comes to the arena of the Science of Cartography.

### **Case Study: Production of a Digital Carto-Hologram (a D-HRM) from Topographic Line Map**

GCM (General Command of Mapping) has been producing digital Topographic Line Maps (TLM) for more over 10 years by using a custom Map Production System (MPS) which is called Karto25. It is specially designed and developed over the ESRI's ArcInfo Workstation Technology. The data structure of Karto25 is well defined by extending DIGEST's Feature Attribute Coding Catalog (FACC) and is composed by point, line or polygon covers which are categorized by their abstract class such as hydrology, transportation, population etc. These vector maps have been used for both GIS applications and printed productions such as paper maps or PRMs. These products have been widely used and proven its power of usage in the field.

The idea of the holomap, almost a decade before, came from a small hologram on a cell phone display, used for protective-cover. After searching on the internet we found that the term *holomap* was first used by the [CIS](#) to analyze the [Battle of Geonosis](#) in Star Wars, the movie by George Lucas. It was a 3D display table which shows starships in the battlefield space. We were impressed with this idea and started to focus on holography and its applications. We started investigating the visual effect of the hologram by producing an analog hologram. This was a ~15x20 cm wooden block of the relief of a mountainous area. The visual perception was very impressive. Color and vertical parallax were not sufficient, but it gave us a vision to improve our investment. We did an intensive search over all literature to find how to produce holomap from vector based topographic map data. There were no articles or written documents. Thus we decided to find a way. After working over 6 months we were able to create a hologram from TLM data by using CGH techniques. Below you can find the pathway of this basic work which we are still working to improve.

a. Deciding Area of Interest (AOI): It's essential for one who is producing a special map, to start with minimal in order to restraint unpredictable events, than progress step by step. So we accept this approach as a leading viewpoint. First we restrict the data model for only simple geographic features such as roads, railways, simple buildings, border lines, marker points, bridges,

simple texts, streams. While selecting these features we focused on the minimum required geographic objects to compose a simple map. We chose a terrain for a better True-3D perception of topography. We picked out geographical elements that are suitable for conversion to quite uncomplicated 3D GIS objects such as cubes, spheres, cones, pipes and cylinders. Also we were compelled to limit the borders of the terrain and number of the features in order to prevent from long computing time.

b. Selecting 3D GIS Primitives: As an initial classification, object representations may be described as surface-based and volume-based (Li, 1994) (22). Li called an object a surface-based representation if the object was represented by surface primitives. It is volume-based if an object's interior is described by solid information. Table-2 shows subtypes of these categories.









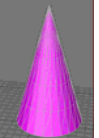
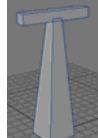


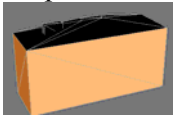
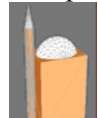


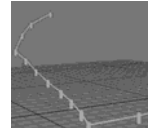
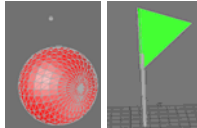
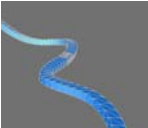
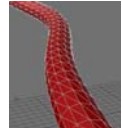
Surface-Based		Volume-Based	
Grid		3D Array	
Shape		Octree	
Facet		Constructive Solid Geometry (CSG)	
B-rep		3D Tin	

Table-2 : Subtypes of 3D GIS Object Representations.

We used a hybrid approach to select the object representations. While some of the elements are CSGs, some others B-reps, Facets and so on.

c. Creating 3D Symbol Library: We used Newtek's Lightwave Software to create required 3D symbols for modeling and coloring. Table-3 depicts these models which are very simple for rendering purposes. After preparation 3D models started to convert each selected features from TLM data layer by layer (Table-4). Point features are the more suitable besides line features. Although it is possible to do it automatically, we converted line features by manual editing to 3D model and textured with color patterns for a better perception. This conversion requires more sophisticated algorithms and software to be developed which is not available for now in the market.

GSM Tower 	Electricity Pole 	House 	Water Tower 
Apartment 	Mosque 	Single Tree 	Simple Text 
Power Line 	Land Marks 	Stream 	Road 

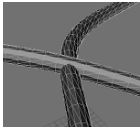
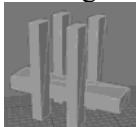


Railroad 	Bridge 	Petroleum Pipe Line 	Country Border 
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Table-3: 3D Symbol Library for Holomap

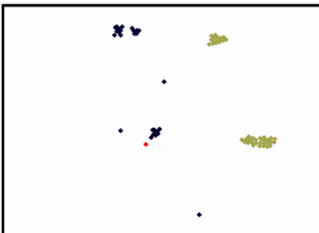
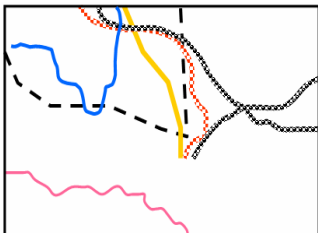
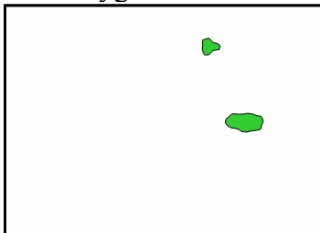
Point Features 	Line Features 	Polygon Features 
---	--	---

Table-4: Layered TLM Data

d. Preparing Terrain Model: It's essential that preparing a feasible terrain model for sufficient detail and computing time. We'd tried several resolutions for the TIN model and decided 100x100m mesh is suitable. An Arc Macro Language (AML) procedure was written to convert elevation coverage to TIN model. Then this model is converted to Autocad's DXF format. This mesh file has more then 50000 facets.

e. Setting Up Scene And Camera: All 3D GIS objects were gathered in a workspace and loaded to 3DS Max and grouped by their abstract classes. 3D terrain model imported and was textured by the geo-referenced aerial photograph of the field. To represent the holographic plate we put a non-renderable plane in front of the 3D map scene (Figure-7). Then we setup a virtual camera which would move from left to right in front of the scene. This horizontally aligned camera's Field of View (FOV) is set to about 82 degree. The total frames of the camera movement from left to right were 640 frames. Figure-8 exhibits some viewpoints of the final scene.

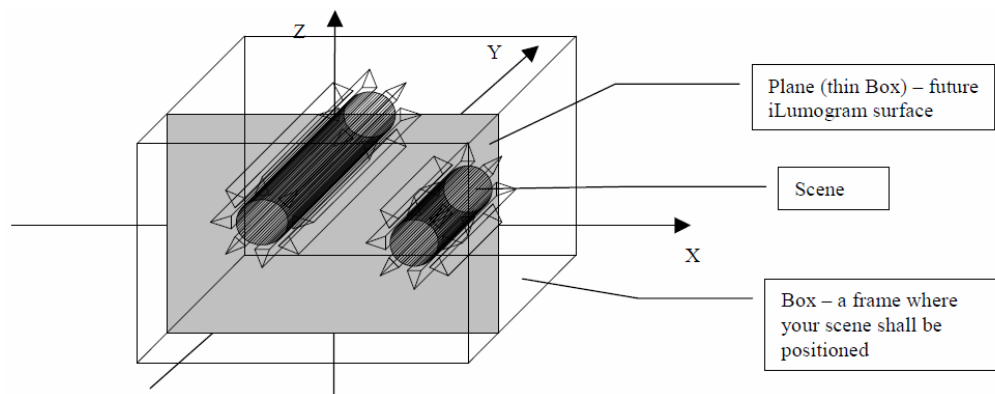
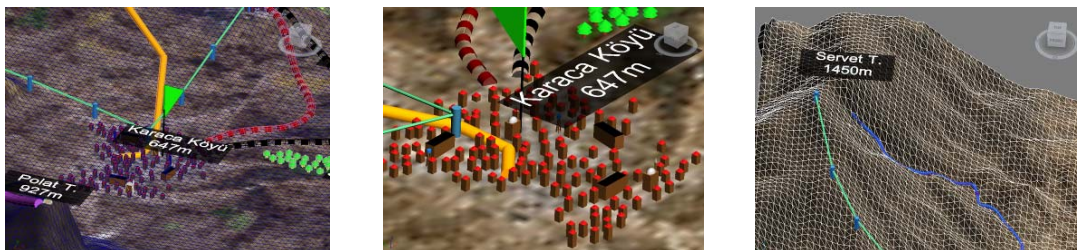


Figure-7: Position of the non-renderable plane. (24)



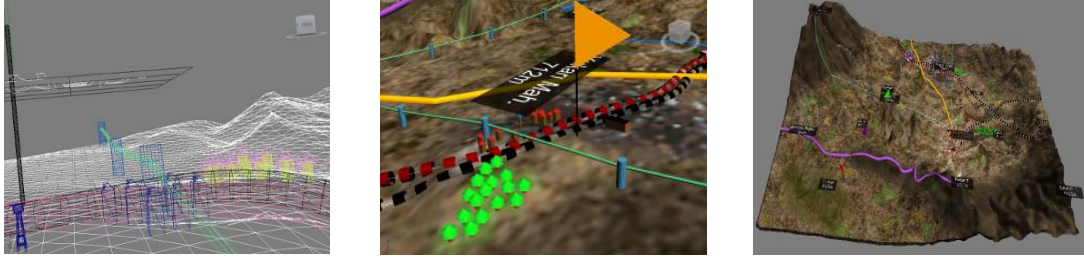


Figure-8: Viewpoints of Final Map

f. Rendering: After preparation of the scene and camera, we set up the rendering engine parameters. Unlike normal rendering to a single movie file like AVI or MOV, a high quality image sequence is required for the CGH. Thus we allocated a workspace on the hard disk which is more than 10GBs. We also selected the highest quality of the rendered image to preserve more quality. After starting the rendering process, the last frame was rendered after almost a day later. Figure-9 portrays the rendered holomap from several view points.

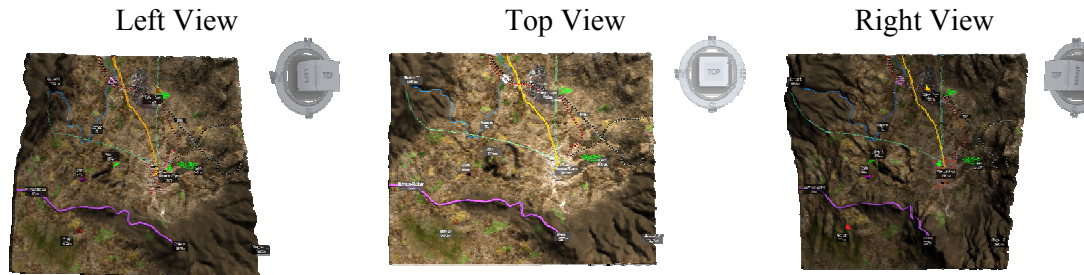


Figure-9: Viewpoints of Holomap

g. Printing Process: All of these images afterwards printed on a Silver-Halide plate by a Holoprinter. It took 6 hours to finish the job. During manufacturing of each digital hologram image special photographic material are exposed pixel by pixel forming images in all three (RGB) colors by laser radiation under certain algorithm. This plate was referred as a master, and used for manufacturing multiple copies. Figure-10 shows final product from the top view.



Figure-10: Picture of the Final Product - Topographic Holomap or Digital Carto-Hologram(DCH)  
Some of the properties of this product are given below (Table-5).



Medium Type	Silver-Halide
Resolution of the medium	5000 lpm (lines per mm)
Dimensions of the plate	50x41 cm
Horizontal Viewing Angle	75°
Vertical Viewing Angle	25°
Number of Vertices in 3D Model	55664
Number of Facets	111324
Space used for sequential images	~5 GB
Time required for rendering	~24 hours
Time required to exposure	~6 hours
Number of selected geographical point features	96
Number of selected geographical line features	8
Optical Resolution of the hologram	0.8 mm/pixel
Number of selected geographical polygon features	2
Resolution of the aerial photograph	150 dpi

Table-5: Some of the Properties of Final Product

### Conclusion and Future Works

The point of this project was to examine the feasibility of producing D-HRM by using standard Topographic Line Map data. There were neither a previous work documented nor principles of holography in cartography suggested – at least we can reach. Being unfamiliar to holography made all things difficult for us to solve the problems. There were some specifications for 3D GIS applications that could guide us to convert 2D vector data to 3D GIS data. But no special software has been developed suitable for our purpose. We had to do it manually by available tools and software, discover a workflow and define initial principles and rules for Digital Holographic Cartography. Here are some of the results for our case study.

1. The optical resolution is sufficient to meet user requirements but the pixel size needs improvement for better understanding and higher information throughput. So, it needs improvement at least down to 0.2mm/pixel.
2. 3D perception level is adequate for now. In this work, the real image is below the surface. More realistic reconstruction can be achieved by setting the real image above the surface. There is a limit for coming up from the film surface. For a 40cm by 50cm holomap the coming up limit is around 10-12cm's. This is enough for vertical exaggeration.
3. Computer process time is very important for such a work. Decision of adding more 3D geospatial objects in to the DCH could possibly cause more computing time for rendering still images.
4. Applying cartographic rules to the DCH was not so easy for us. We have had foregoing discussions about implementation of principles and rules of cartography.
5. Viewing angles of DCH can't compete with the PRM. Although technology allows up to ~120 degree in horizontal and ~40 degree in vertical, it requires more improvement on vertical reconstruction.
6. When we look at the color space, we must consider only RGB colors instead of CMYK. On the other hand vivid colors can be still generated.
7. The source of light for reconstruction can be sun light, ~50W halogen bulb or ~8000 candela Led bulbs. The plate has to be illuminated by certain angle (~45 degree) for the best result.

This study has opened our vision to a new area of the cartography which is first suggested in this article. More sophisticated scientific works should be done once it's accepted by the cartography

experts and community. In this conference, we suggest Digital Holographic Cartography as a new branch and a working group could be established for further discussions.

Our future works involve developing principles of Digital Holographic Cartography, improving the DCH production, building a new DCH Production System for mass manufacturing. We will also try to start a new project to develop software which creates DCH by using TLM data.

## ACKNOWLEDGEMENT

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