Hologram: The Future of the Cartographic Publishing

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Abstract. Dr. Denis Gabor most probably could not think of every usage of the hologram when he invented it, but he might had a strong feeling that he opened a new window for human being. History has shown that it was not only a scientific discovery, but it also led to a new philosophical explanation of the universe. Although it has not been a century, the technology of the holography already passed the horizon of his vision. Countless inventions and applications on holography have had remarkable influence on our daily lives. We have been using holograms in many places such as security, entertainment, measurement, training and so on. Why wouldn't we use it for our most essential need which was map? As cartographers we have been discussing this question for more than ten years. Finally, we could achieve to find a new way of presentation of cartographic productions. The restrictions of the conventional medium, the paper, have not obstructed the cartographers to manufacture more visual contents and cognitive products, by using the power of the computers which is unquestionable. The rise of Paper-Era is reaching the saturation point and has been limiting the artists, publishers and cartographers. In this article, we will discuss the usage of holography in a cartographic perspective; interrogate the advantages and disadvantages of the hologram as a hard copy medium, evaluate a prototype of holographic map which is produced by General Command of Mapping, Turkey and exposed by Hangyo International Corp., Korea Republic. Finally what we suggest the future of cartographic publishing.

Keywords: 3D map publishing, carto-holograms, hologram map, holographic cartography, holographic map, topographic hologram map, holographic relief map,

1. The Evolution of Publishing Media

"**The medium is the message**" is a phrase coined by Marshall McLuhan meaning that the form of a medium embeds itself in the message, creating a symbiotic relationship by which the medium influences how the message is perceived. The expression was introduced in his book, "*Understanding Media: The Extensions of Man*", published in 1964. The author suggests that a **medium** itself, not the content it carries, should be the focus of study. He said that a medium affects the society in which it plays a role not only by the content delivered over the medium, but also by the characteristics of the medium itself (Wikipedia). Since the invention of the writing, mankind has been transferring messages by using the medium which is available within that time period. Although the message was similar, the medium changed and every change of the medium human being evolved.

The earliest known maps are of the heavens, not the earth. This prehistoric map of the night sky dating to 16,500 BCE found on the ***walls*** of the Lascaux caves, including the three bright stars Vega, Deneb, and Altair. Together, these stars are popularly known as the Summer Triangle (the Summer Triangle asterism) (Wikipedia). The ***wall*** itself is the first medium which helps to our ancestors to transfer the ***message*** beyond time to us. A fascinating and ancient ***clay*** map in Old Babylonian, found in Niru, Babylonia, 1684-1647 BC (Mitchel A & Schoyen collection). It is a clay tablet, 9,5×12,0×2,8 cm, 22 lines and captions in cuneiform script. It can be said that the ***clay*** was the second type of the ***message*** carrier and humankind evolved again. The next medium was the ***papyrus*** which was first manufactured in Egypt as far back as the third millennium BC (Bell & Skeat 1935). An ancient Egyptian map drawn on a scroll of ***papyrus*** was discovered between 1814 and 1821 by agents of Bernardino Drovetti, the French Consul General in Egypt (Harrell & Brown 1992). It was drawn about 1150 BC by the well-known 'Scribe of the Tomb' Amennakhte, son of Ipuy. The invention of the ***papyrus*** was another jump for mankind and human evolved again. The message carrier became more common and the information could reach to far distances. The earliest piece of ***paper*** found, at Fangmatan in Gansu province inscribed with a map, dates from 179-41 BC (Encyclopædia Britannica). During the Shang (1600–1050 BC) and Zhou (1050 BC – 256 AD) dynasties of ancient China, documents were ordinarily written on ***bone*** or ***bamboo*** (on tablets or on bamboo strips sewn and rolled together into scrolls), making them very heavy and awkward and hard to transport. The light material of ***silk*** was sometimes used, but was normally too expensive to consider. The most precious silk artifacts was found at ancient tomb known as the No.3 Han Tomb at Mawangdui, Changsha, Hunan Province, China (Buck 1975). There were three maps drawn on ***silk*** which depicts a topographic map, a military map and a prefecture map.

Bone, wood and ***bamboo*** tablets, ***silk***, ***leather***, ***paper, and so on*** have been used by the people (cartographers, historians, authors, clerks etc.) to transmit the most important messages about their time through the ages. Every evolution of the medium can be said a breakpoint on the history of mankind.

Twentieth century was the raise of the nations. Information technology (especially computers, paperback books, public education, and the Internet), telecommunications, and mass media made the world's knowledge more widely available. New mediums were on the stage. The flood of information at dizzying speed forced everyone to be aware of their environments.

2. Background

Until the discovery of the stereoscopy mankind had been limited to 2D presentation of the real world. By the absence of 3th dimension, the human brain has been evolved to process and project the information from 2D into 3D. The next stage was the invention of holography by the Hungarian-British physicist Denis Gabor in 1947, while developing a high resolution electron microscope. The humankind had a new perspective and this experience was very natural. Since the invention of the stereoscopy and holography, human brain has been evolving to process the next dimension. There is no more need to project the information into 3D. The reality is obvious and there are more rooms for other mental processes. In addition to the digital media, this state-of-art medium has been used in many areas of science and products.

To understand the process of the 3D information, it is essential to touch on the human visual system which relies on large number of cues for estimating distance, depth, and shape of any objects located in the three-dimensional space of the environment (Reichelt et al. 2010). Humans use oculomotor cues such as accommodation, myosis and convergence and visual cues such as binocular stereopsis, relative size, occlusion, texture gradient (Bruce et al. 2003) and retinal blur to perceive depth in a 3D scene. Retinal blur (Figure 1) is a visual cue that enables depth perception even with a single eye (Pentland 1987). Visual depth cues can be classified into monocular and binocular cues. Kinetic depth effect, motion parallax, dynamic occlusion, linear perspective, heights in picture plane, interposition, texture gradient, relative and known size, light and shadow distribution, and aerial perspective are the monocular cues of visual depth perception. Binocular stereopsis (Figure 1) is the sensation by which the brain interprets depth information, by making use of the two different perspectives seen by two eyes (De Silva et al. 2011). Accommodation, convergence, and pupillary constriction, so-called ocular near triad, are evoked when eye fixes on near distance targets. Accommodation is the mechanism by which the human eye alters its optical power to hold objects at different distances into sharp focus on the retina. Convergence is the simultaneous inward movement of both eyes toward each other, usually in an effort to maintain single binocular vision when viewing an object. Since the human eyes are horizontally separated, each eye sees a slightly different perspective of a natural scene. The retinal images are thus slightly different with so-called crossed or uncrossed disparity for objects in front of behind the fixation point, respectively. Stereopsis is based on the different perspective of the two retinal images, which provides a major cue for relative depth perception (Reichelt et al. 2010).

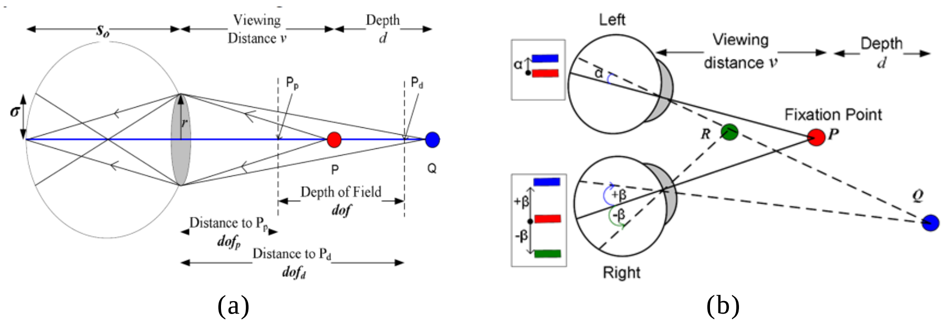
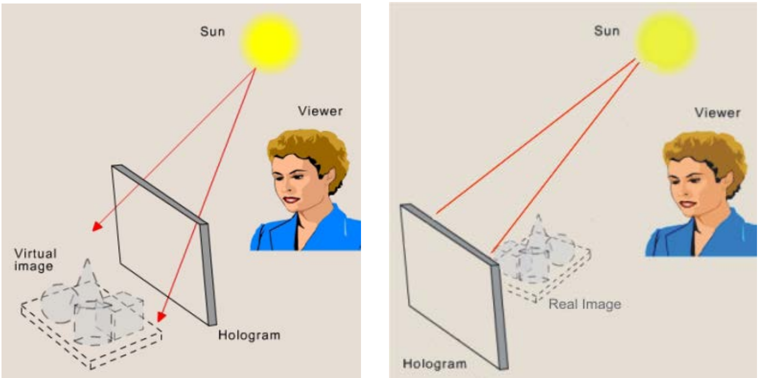


Figure 1. (a) Geometry of retinal blur, (b) Geometry of binocular stereopsis

Charles Wheatstone, F.R.S. (1802-1875), published his discovery of stereograms in a remarkable paper to the Royal Society in 1838. Various technologies for visualizing 3D scenes have been developed after this extraordinary invention. Among them are the well-known stereoscopic Wheatstone's stereoscope, Brewster's stereoscope, Wilhelm Rollmann's anaglyph technique, parallax barrier, lenticular foils, multi-view and volumetric displays. Another revolutionary technology is *Integral Imaging* which provides stereo parallax, full motion parallax and allows multiple viewing angles is becoming more popular today. Finally, holographic displays, capable of reproducing a scene in a most natural way, are the next generation of 3D visualization.

Holography (Figure 2) 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 (Dalkiran 2009). The natural visual process works with the reception of light waves. Because of the physical properties of the retina the process of representation of a three-dimensional object leads to a loss of the spatial information in the wave field. This loss, again, leads to a reduced, two-dimensional display on the retina, which is only built up to a spatial 3D model by the physiological processes (Ostrowski 1988). Holography is known for its excellent properties of depiction. During the generation of a picture object the complete, incidental light on the hologram surface is used. Due to this characteristic feature the hologram is able to transfer the spreading of light intensity of the object which should be depicted without any significant distortion (Buchroithner & Kirschenbauer 1999).



(a) (b)

Figure 2. Reconstruction of the hologram (a) and readouts (b)

3. Hologram: State-Of-The-Art Publishing Medium

Holography is the only known-technique for 3D reconstruction of the real world objects, which provides all of the required physiological characteristics of human vision system. Unlike other techniques, such as lenticular flat-panel displays, auto-stereoscopy, and volumetric systems holography is very natural for human brain while processing 3D information. Although holography provides natural 3D imaging, it is difficult to display images dynamically because the information content is potentially enormous (Takahashi 2007). In 1989, Benton and colleagues at the Spatial Imaging Group at the MIT Media Laboratory succeeded in producing a working prototype holographic video system by reducing the amount of information and rapidly generating computer generated holograms (CGHs) with a supercomputer. However, holographic fringe patterns could not be calculated in real-time even though today's fastest computers and would not seem to be possible in the near future.

The rapid expansion of the digital and online media has brought about a significant change in the core business model of the publishing industry. In an industry that has been driven by the print medium, publishers have to find new innovative ways to deliver contents to their consumers. It's emphasized in the book of "The Future of EBooks" all experts agree that digital and printed media will co-exist. The market researches show that within next decade, printed books will still account for the majority of sales (PwC LLP). Technology may change rapidly, but people's habits do not. People still want to have tangible medium, instead of having a device needs to be recharged periodically. Another big concern is the copyright protection of the product and intellectual properties.

The situation is almost the same for the cartographers or map publishers. Cartographers are involved with the scientific, technological and artistic aspects of developing and producing maps. The emergence of the digital map publishing has forced the cartographers and map publishers to reestablish their control of copyrights. The curve of the growing popularity of the online maps has a very sharp increase within the last decade. Nonetheless, a printed map, wherefore a kind of fine arts, is still very attractive ornament that decorates people's environment. By the rapid shifting from the printed paper map to the digital media, most cartographers neglected the artistic side of the map publishing. Paper lost its popularity and interest against the digital revolution. On the other hand there is still a hope for the printing media which has one more bullet left. Holography is the subject at this point. It has the superiority of real 3D visualization that human brain is very familiar with.

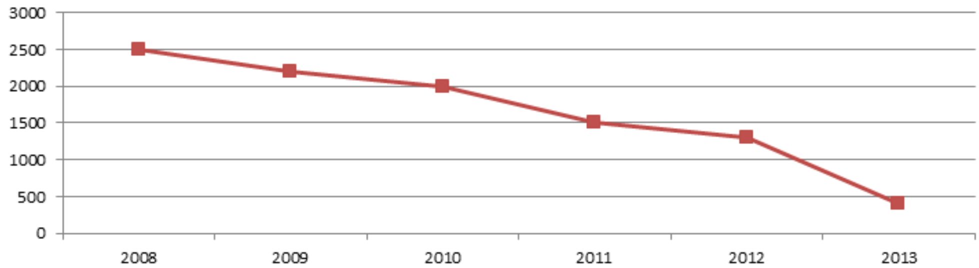


Figure 3. Price trend of holographic medium (prices are in USD).

New cartographic principles for the holographic map publishing were proposed in the article, published by Dalkiran during the Conference of International Cartography Association 2009. It was concluded that holography was a very promising technology, besides its expensiveness. Also it was predicted that the cost of the holographic plates would be decreased within a few years. When we look at the price trend of the holographic films and plates, it can be said that the technology rapidly becoming affordable. Figure 3 depicts the immediate decrease on the holographic map production cost. On the contrary, quality, resolution, and diffraction efficiency of the holographic medium has been enhanced. We suppose this rapid drop of the cost related with the increased demand on the holographic productions.

The prediction of the future trend shows that it will be possible to produce a holographic map under $100 within a few years, which is affordable for any cartographer or map publisher. We can estimate that it will take a few more years for mass production of holomaps which is under $50 per piece.

The experienced cartographic experts rather see advantages for the average map user of so-called user-oriented maps and improvement through holography than for themselves (Buchroithner & Kirschenbauer 1999). The availability of state-of-the-art holographic production technique is supposed to open a new market for the map publishers and also holographic film manufacturers. Thanks to Hangyo International Co. for their invaluable endeavors to decrease the costs of manufacturing of holographic maps. They are still working hard to develop some new machinery for mass production which is essential for the map publishers.

4. Experiment: Producing a Hologram Map (Holomap)

It's been almost five years after our first holomap was produced. There have been many efforts spent on finding cost-effective and easy ways to manufacture the holomaps. In our first experiment the cost of the hologram was so high. We used the state-of-art technology which was Computer Generated Holography (CGH) to expose our first map on a hologram film by using Geola's digital hologram printer. The result was acceptable, but not satisfactory.

In our latest experiment we changed our direction to the old friend, analog holography. By the support of **Hangyo International Corp**. (HIC) (R&D Center - Seoul, Korea) we finally achieved good results with the affordable prices. In this section we'll share our experiment and the result of the hologram map, so-called holomap.

The first stage of the production of holomap was to prepare a 3D physical representation of a map. To achieve this goal we had to produce a raised relief map by using plastic thermoforming technique. The simple demonstration (Figure 4) of the PRM production system has five steps. 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 CTP 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 for CNC Machine, TNC software is used for sending ASCII Codes to the milling head. The CNC machine carves the Midform block, a special soft and durable material, by using 3D coordinates received from the computer. (D) The preparation of 3D Midform block, a vacuum forming machine is used for molding the Plastic Map Sheet. (E) The final PRM product of the topographic map.

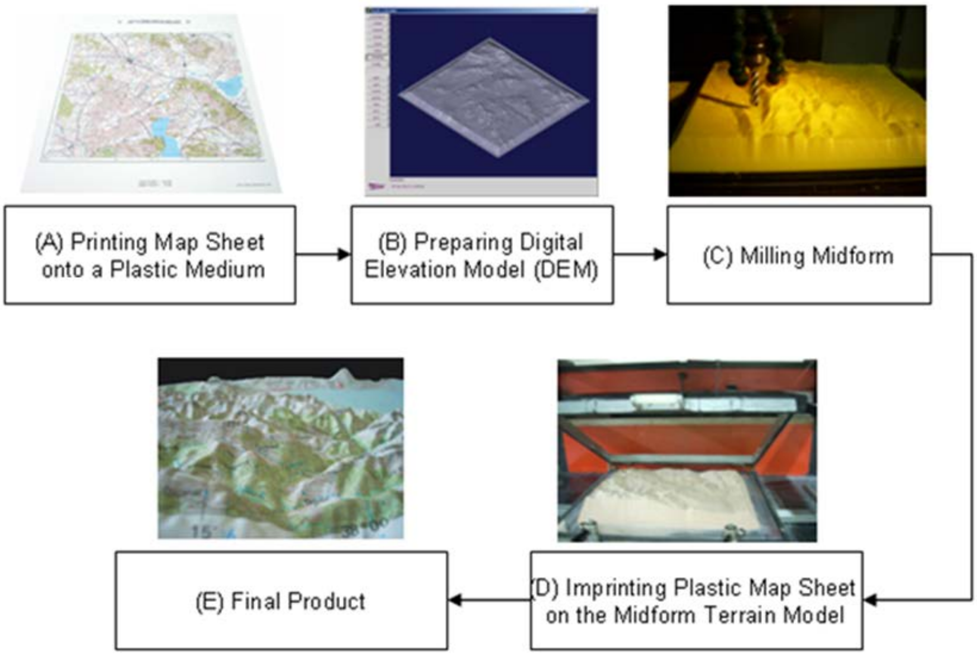


Figure 4. Workflow of Plastic Raised Relief Map.

The plastic relief map manufacturing has been a standard and ongoing production line system of General Command Mapping (GCM) (Ankara- Turkey). The next stage was converting this model to a hologram map. At this point GCM incorporated with Hangyo International Corp. which was established in 1997 and is now a major supplier of a wide range of raw material and finished products to over 30 countries including American market, European market & Asian market as well as Korean domestic market. In addition, the company is pushing forward with R&D on 3D Hologram as its future main sector. In their facility they have an R&D center and giving courses to teach holography to the individuals from all around the world.

The process of the holographic map production was very new and there had to be accomplished a trial and error stage. There had been many issues to be solved and finally we achieved very good results after 2 months trial period. Holographic map production flow chart is shown at the Figure 5.

After the first step was done by GCM, second step was the key point of the final production's quality. In order to secure color reproduction of the prepared map, measure the color natures of a reference relief map by using a 'spectrophotometer' (Figure 6a). The third step was customizing the object for hologram production. If a map is made of thin paper or thin synthetic resin, it may sway during hologram recording, which renders a hologram image to be blurred. Thus, such a map should be held up with a fixer or clay (Figure 6b).

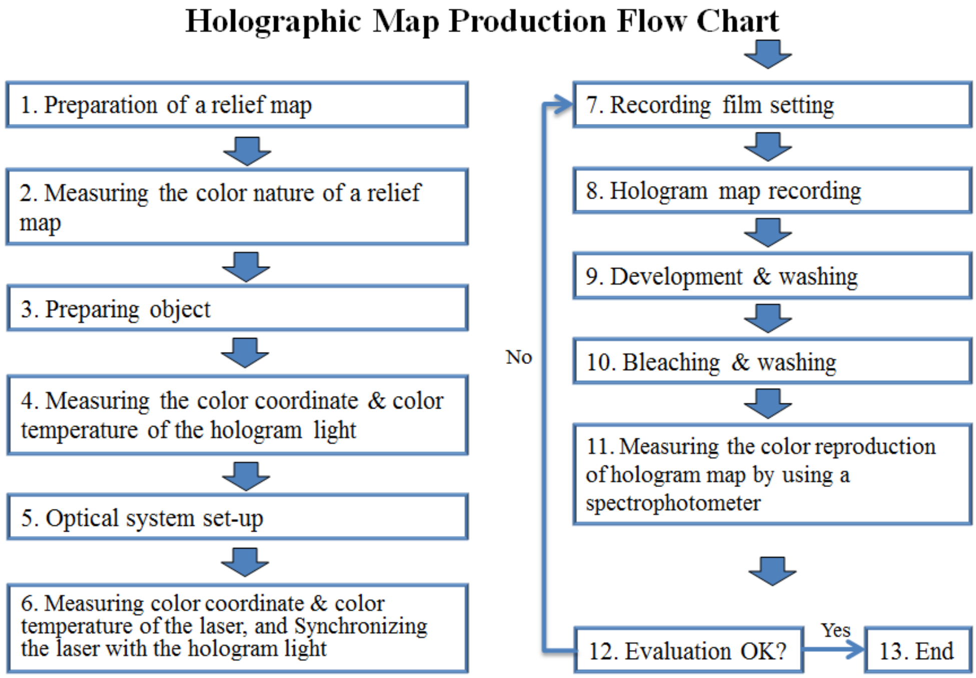


Figure 5. Holographic map production flow chart.

(a) Spectrophotometer (b) Filling gaps with clay

Figure 6. Preparation of the hologram object

In order to produce the most favorable display hologram, a light source for the hologram should be similar to a light source for a laser to be used in hologram production in terms of the color nature (step 4). Thus, measure the hologram light's color coordinate & color temperature by using an 'illuminometer' in order to secure color reproduction & color nature of a light source. In step 5, the optical system had to be set up for recording the hologram (Figure 7). After the system set-up, measure the color coordinate & color temperature of the laser that is similar to the color coordinate & color temperature of the light source of display hologram by a 'illuminometer' , then, synchronize the color nature of the laser with the color coordinate & color temperature of the reference hologram light source. In such case, the color nature can be adjustable by the output of R, G, B lasers (Figure 8).

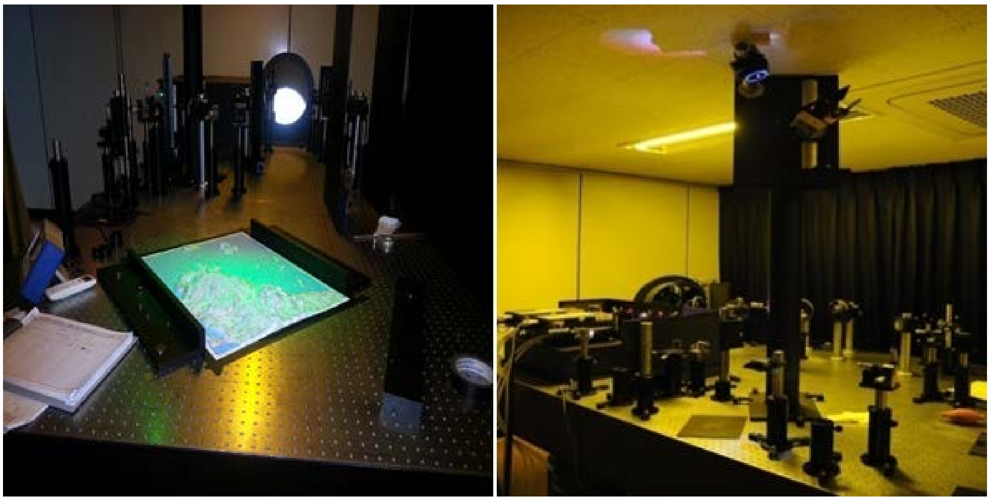


Figure 7. Optical set-up for recording hologram map

Figure 8. Measuring the color coordinate & color temperature of the laser

Cutting the recording material (Silver Halide, Photopolymer, and Photoresist) into a desirable size and attaching it to a glass plate was the step 7. In such condition that the recording material was attached to the glass plate, an interference pattern could be recorded in the material. The next step was to record an interference pattern in the recording material.

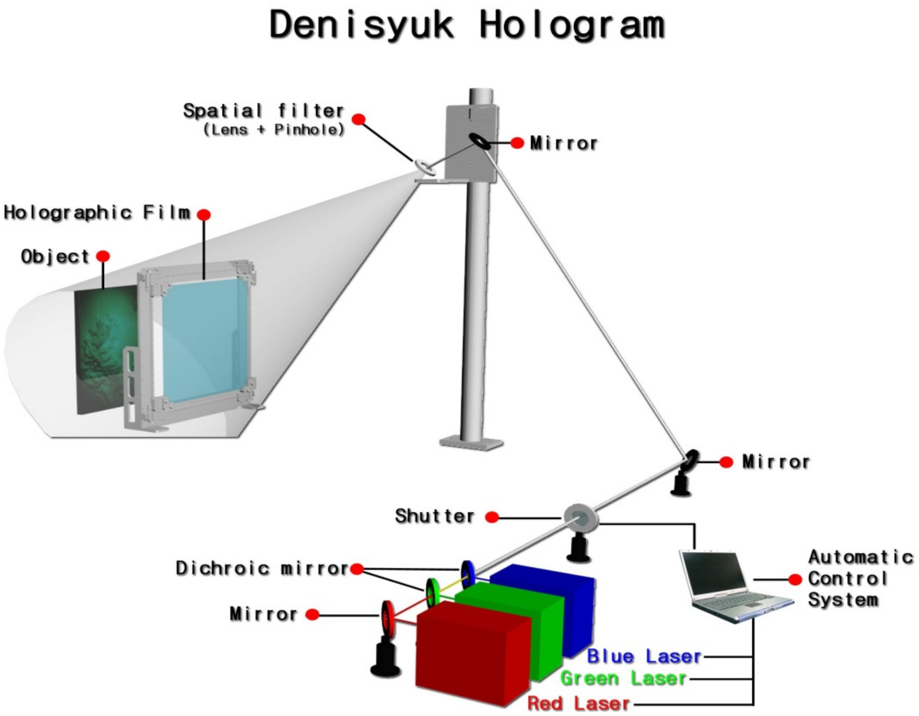
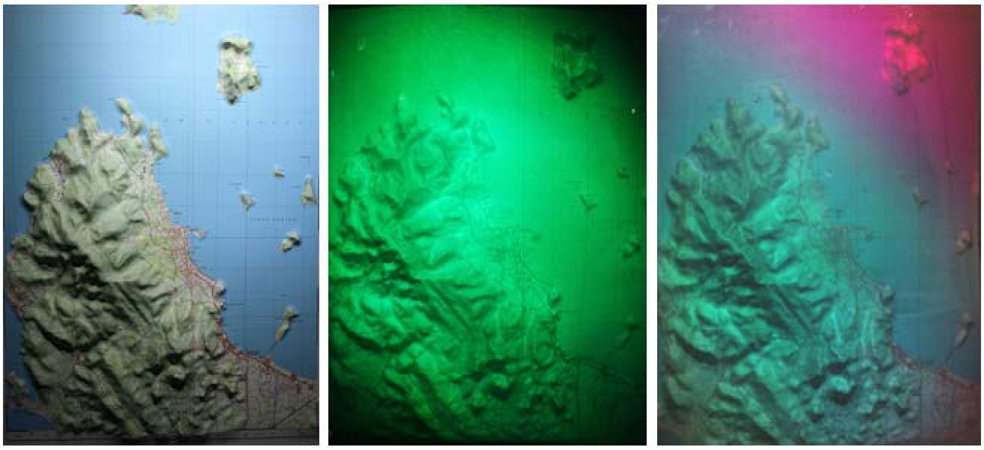


Figure 9. Exposing the hologram

The recorded film was developed with Automatic Developing Machine which is equipped with a digital LCD control system enabling the operator to adjust the developing conditions automatically. After finishing the development phase, the film was bleached with Automatic Bleaching Machine which is equipped with a digital LCD control system enabling the operator to adjust the bleaching conditions automatically. After the bleaching, the film was washed & dried automatically. Once developing and bleaching processes were done, we measured the color reproduction with the spectrophotometer whether the colors of recorded hologram map was identical to the color of an original relief map. This process was done to measure a gap between the color of the object map and the color of the recorded hologram map. After evaluating the measurement process we should checked whether the gap between the color of the object map and the color of the recorded hologram map was within tolerance range. If such a gap was within tolerance, the production will end, otherwise, we had to go back to the step 7 to restart. Figure 10 depicts the final result of the holographic map production process. The qualities of the holomaps are very good in comparison with our previous experiments. Color reproduction was very good under white light illumination. Map symbols and especially annotations could be easily read. To see the difference between the effects of depth we also produced 3 types of hologram trials.



(a) Plastic Relief Map (b) Green Colored Holomap (c) Full Colored Holomap

Figure 10. Final results of the holographic map production.

5. Investigating the Experiment

The application of holography to map production was not a common task for both of the participating sides. It was a venture to use analog holography to produce holomaps. Our previous works had been carried out by using computer generated holography and we already shared our experiences in preceding articles. In this experiment we faced with new troubles and had to solve them recursively.

To produce a hologram map for advanced military engineering, there are some indispensable requirements. Some of these are:

- The need for the high resolution of the holomap is very essential. Thus any regular user could read the holomap easily without being disturbed while focusing on 3D terrain.
- Like any other topographic map, holomap has to be full colored and the contrast between cartographic symbols should be high.
- Precision of the coordinate system of holomap must be exactly the same as the paper map.

- Vertical exaggeration of the terrain is the key point of hologram map and it is expected to mimic the plastic raised relief map as is.
- The size of the holomap should meet the requirements of the military standards for topographic maps.

Once we settled our essential demands, we focused onto prospective problems and solutions. The first issue was to find the right recording material which meets the requirements above. We ordered highest quality silver halide film, with the diffraction efficiency max %95, was available in the market. In our first trail we found that the production with firstly-ordered film was not so successful (Figure 11). The diffraction efficiency of the hologram film reached only 45% level from the target value (the hologram was unclear and looked dark after being made). Doing many trials for measurement of diffraction efficiency and change of working conditions, we found that the film itself had a quality problem. After repeated discussion with our film manufacturer, the proper film to our system has been developed by change of the recipe of the emulsion.

Figure 11. (Left) improper hologram; (Right) proper hologram

Due to thin & light plastic material as 3D object, a subtle change on the surface of the map occurs during hologram exposure even under the condition of room air stabilization process and using vibration proof table. We decided to increase in weight by filling urethane foam into the holes of plastic raised map on the backside (Figure 6b). As the colors of the model were not clear, the produced hologram map doesn't look in full colors. We found that the reflection level of the plastic's surface caused this problem. Another potential reason, the color space of the standard map symbols did not match with the wavelengths of the RGB lasers. The color schema should be rectified by using the complementary colors when pressing the map on plastic medium. Existing optical setup had to be optimized to exposure the hologram for the size of 300x400mm recording material.

The font size and family used for the standard map production system were chosen for paper map publishing. Although the resolution was extremely high (10.000 lpi) on recording material some unpredictable conditions causes blur on the annotations. This issue can be overcome by using more suitable font family and size. Hand carrying and preservation of the holo-map was another issue had to be surmounted. We decided attaching a den-im textile to the back side of the film. Thus the film could be portable and protected from being twisted. Illumination of the hologram was the most essential point to reconstruct the holomap. We used Over 1300 lumen LED light with the beam angle between 30˚~40˚ (Figure 12).

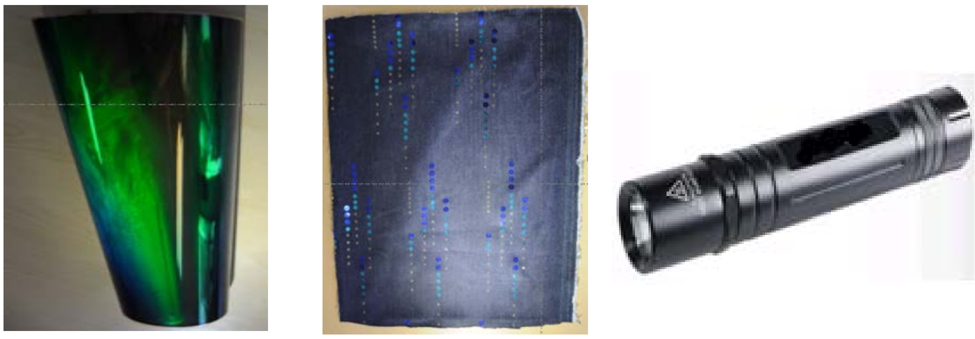


Figure 12. Application denim textile and 1300 lumen LED light.

6. Conclusion

Our previous works on holographic map production introduced a new ap-proach to the cartography what we coined as “Holographic Cartography”. We proposed some aspects for the cartographers how to implement carto-graphic rules into holography. In that experiment we used computer gener-ated holography (CGH) technique to prepare a holomap. We also analyzed the results and extrapolated the future trend of this remarkable technology. This initial work showed that the holography was too expensive for the mass production. In course of time our prediction became true. Within four years the cost of the hologram manufacturing has been decreased to the affordable prices (Figure 3). In most cases anyone who wants to implement a new technology to his/her study, focuses on the latest technology availa-ble. At first we did the same and focused on CGH, but later we found that analog holography was more feasible and affordable. After working with

Hangyo International Corp. we reached the results what we expected. Thanks to their skilled staffs and invaluable support for this project.

The technology we used in this experiment showed that analog hologram is a promising map publishing medium. In spite of digital media, defeats pressing media, there is still an opportunity for map publishers and cartographers. We propose in the near future this technology will be more common and affordable, by the availability of mass production.

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