Draksler, A., 2013. Izdelava lentikularne karte dela Julijskih Alp. Diplomska naloga. Ljubljana, Univerza v Ljubljani, Fakulteta za gradbeništvo in geodezijo. (mentor Petrovič, D., somentorica Bruhm, K.): 46 str.

Draksler, A., 2013. Izdelava lentikularne karte dela Julijskih Alp. B.Sc. Thesis. Ljubljana, University of Ljubljana, Faculty of civil and geodetic engineering. (supervisor Petrovič, D., co-supervisor Bruhm, K.): 46 pp.

Univerza
v Ljubljani
*Fakulteta za
gradbeništvo in
geodezijo*

*Jamova 2
1000 Ljubljana, Slovenija
telefon (01) 47 68 500
faks (01) 42 50 681
fgg@fgg.uni-lj.si*

**VISOKOŠOLSKI ŠTUDIJ
PRVE STOPNJE
TEHNIČNEGA
UPRAVLJANJA
NEPREMIČNIN**

Kandidatka:

ALEKSANDRA DRAKSLER

IZDELAVA LENTIKULARNE KARTE DELA JULIJSKIH ALP

Diplomska naloga št.: 16/TUN

CREATION OF LENTICULAR FOIL DISPLAY OF CENTRAL JULIAN ALPS

Graduation thesis No.: 16/TUN

Mentor:
doc. dr. Dušan Petrovič

Predsednik komisije:
viš. pred. mag. Samo Drobne

Somentorica:
Katarina Bruhm

Član komisije:
prof. dr. Bojan Stopar

Ljubljana, 27. 06. 2013

IZJAVA O AVTORSTVU

Podpisana Aleksandra Draksler izjavljam, da sem avtorica diplomskega dela z naslovom »Izdelava lentikularne karte centralnega dela Julijskih Alp«.

Izjavljam, da je elektronska različica v vsem enaka tiskani različici.

Izjavljam, da dovoljujem objavo elektronske različice v repozitoriju UL FGG.

Ljubljana, 18.6.2013 Aleksandra Draksler

ERRATA

Page	Line	Error	Correction

BIBLIOGRAPHIC-DOCUMENTALISTIC INFORMATION AND ABSTRACT

UDC: 528.9(234.323.6)(043.2)
Author: Aleksandra Draksler
Supervisor: Assist. Prof. Dušan Petrovič, Ph.D.
Co-advisor: Dipl. -Ing. Katharina Bruhm, TU Dresden
Title: Creation of Lenticular Foil Display of the Central Julian Alps
Notes: 46 p., 11 tab., 11 fig., 7 equ., 1 ann.
Key words: Lenticular technology, lenticular foil display, 3D visualisation, lenticular map

Abstract

In the last years three dimensional visualisations have become commonly used in education, science, show business and very recently also in advertising. Spatial representations of various scenes have been applied to both softcopy and hardcopy displays. Due to the ineptitude of the map users to spontaneously derive relief information out of 2D maps, auto-stereoscopic, true-3D, lenticular foil displays were implemented into cartographic visualisations mostly of mountainous terrains. Perceiving depth out of lenticular foil display without the use of additional viewing aids gives lenticular technology a huge potential in the future.

This thesis describes creation of the lenticular foil display of the mountainous area in the surrounding of the Slovenian highest mountain Triglav. The project comprises the geo-data preparation, 3D modelling and partial images generation done by the means of different software packages. As the created lenticular foil display was printed, the interlacing of partial images and the printing procedure are presented. The lenticular foil display was created on the basis of the theoretical background of the lenticular technology introduced at the beginning of this thesis. The essential part of the process was defining the recording geometry and parameters for the subimages generation based on the lenticular foil characteristics and object parameters.

BIBLIOGRAFSKO-DOKUMENTACIJSKA STRAN IN IZVLEČEK

UDK:	528.9(234.323.6)(043.2)
Avtor:	Aleksandra Draksler
Mentor:	doc. dr. Dušan Petrovič
Somentorica:	Dipl. -Ing. Katharina Bruhm, TU Dresden
Naslov:	Izdelava lentikularne karte osrednjega dela Julijskih Alp
Obseg in oprema:	46 str., 11 pregl., 11 sl., 7 en., 1 pril.
Ključne besede:	Lentikularna tehnika, lentikularni prikaz, 3D vizualizacija, lentikularna karta

Izvleček

Trirazsežnostne predstavitve so v zadnjih letih postale vse pogostejše, predvsem na področju izobraževanja, znanosti, zabavne industrije in od pred kratkim tudi v oglaševanju. Prostorske predstavitve različnih prizorov se uveljavljajo tako v digitalnih oblikah kot tudi v analognih. Nezmožnost prepoznavanja reliefnih značilnosti s strani uporabnikov dvorazsežnostnih kart je eden izmed glavnih vzrokov za začetek uporabe avtostereoskopskih, resničnih 3D lentikularnih prikazov za namene kartografske vizualizacije, predvsem goratih območij. Nadaljnji razvoj in uporaba lentikularnih prikazov imata v prihodnosti velik potencial predvsem zaradi zmožnosti prostorske zaznave uporabnika brez uporabe dodatnih pripomočkov (npr. očal).

Diplomsko delo opisuje izdelavo lentikularne karte gorskega območja v okolici najvišje slovenske gore Triglav. Projekt je obsegal pripravo in obdelavo potrebnih kartografskih podatkov, 3D modeliranje in generiranje delnih slik s pomočjo različnih programskih paketov. Ker je bila izdelana letnikularna karta natisnjena, diplomska naloga obsega tudi opis postopka razdelitve delnih slik na trakove in njihovo prepletanje ter tiskanje. Lentikularna karta je bila izdelana na podlagi teorije lentikularne tehnologije, predstavljene na začetku diplomskega dela. Najpomembnejši del izdelave lentikularne karte sta predstavljala postopka določitve geometrije in parametrov zajema stereoparov na podlagi ustvarjenega 3D modela. Geometrija in parametri zajema delnih slik so odvisni predvsem od značilnosti lentikularne folije in parametrov objekta.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Assist. Prof. Dr. Dušan Petrovič for the academic support and all the help with organising my exchange study. Most of all, I would like to thank my co-advisor Dipl. -Ing. Katharina Bruhm for all the help, explanations and advice with the practical and written part of my thesis. I would also like to thank Prof. Manfred F. Buchroithner for giving me the opportunity to make my thesis at Institute for Cartography, Technical University Dresden; to Ph.D. student Claudia Knust for the constructive remarks and help with Cinema 4D software. I sincerely thank my parents, especially my father, for the guidance through the geodetic practice and for encouraging me to find answers on my own when I had questions; and Aljoša for supporting me.

ZAHVALA

Zahvaljujem se mentorju doc. dr. Dušanu Petroviču za strokovno podporo in pomoč pri organizaciji študija v tujini. Posebna zahvala somentorici Dipl. -Ing. Katharini Bruhm za vso pomoč, razlage in nasvete pri izdelavi praktičnega in pisnega dela diplomske naloge. Zahvala gre tudi Prof. Manfredu F. Buchroithnerju za priložnost opravljanja diplomske naloge na Inštitutu za kartografijo na Tehnični univerzi Dresden. Hvala doktorski študentki Claudi Knust za konstruktivne nasvete in pomoč s programom Cinema 4D. Iskrena hvala mojim staršem, še podebej mojemu očetu za vodenje skozi geodetsko prakso in vzpodbudo za iskanje lastnih odgovorov na zastavljena vprašanja. Hvala Aljoši za vso podporo.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

2D	Two-dimension(al)
3D	Three-dimension(al)
DEM	Digital elevation model
DTK50	National topographic map 1 : 50 000 (Državna topografska karta)
DTM	Digital terrain model
GKB25	Generalised cartographic database 1 : 25 000 (Generalizirana kartografska baza)
LPI	Lenses per inch
PPI	Pixels per inch

1 INTRODUCTION

1.1 Motivation

In the last few years three dimensional visualisations have become widely applied in the movies, television, animations and different image representations. Both hardcopy and softcopy like displays have been used for spatial representations of different scenes. Due to the viewer's capability of perceiving depth information by applying stereoscopic vision the implementation of the three dimensional visualisation in cartography was self-evident. Based on past studies, deriving relief information spontaneously out of the traditional 2D maps is considered troublesome for average map users [1]. Therefore, autostereoscopic, lenticular foil display visualisations, suitable mostly for mountainous relief depictions, have become one of the feasible substitute of the traditional 2D maps. Moreover, no additional viewing aids are necessary to perceive depth information out of lenticular foil display and in contrast to other three dimensional representations, lenticular technique is not tiring for the viewer's eyes. Lenticular displays are appropriate for the outdoor usage as they are easily transportable and they do not need any electric or light source. With the usage of various stereomates lenticular displays provide numerous possible parallaxes and therefore user's ability to perceive depth from different positions and angles. Along with others, multi user capability and stable spatial geometry are other advantages of lenticular foil technique. Consequently, the application of lenticular foil displays for different cartographic visualisations has a huge potential in the future.

Institute for Cartography at Technical University Dresden, Germany, has a leading role in lenticular foil display development for cartographic visualisations. In the last decade one of the most important published lenticular foil display projects have been: True-3D visualisation of the Granatspitz Massif in Austria [2, 3], Multiscale hardcopy depiction of the Mars surface [4] and True-3D visualisation of glacier retreat in the Dachstein Massif, Austria [5]. The first lenticular foil display visualisation uses only true-3D effect and the other two combinations of 2D and 3D effects, flip and true-3D effects.

The main aim of this thesis is creating the first lenticular foil display of the Central Julian Alps. Since the area is an attractive tourist place mostly for hiking, depicted hiking trails and huts along them represent the main map content. The input for the essential part of lenticular map creation, 3D modelling, were the DTM raster image of the representation area and the texture including map information (roads, water bodies, hiking trails) generated from the data provided by the Surveying and Mapping Authority of Slovenia. By the means of Esri's ArcGIS 10.1 [6], Adobe Illustrator CS3 by Adobe Systems [7] and Cinema 4D release 14 by Maxon [8] software packages, the data were processed to generate the according number of subimages as an output of 3D modelling. Generated subimages were interlaced in the adequate interlacing software and printed successively. Interlacing and printing were made by the company specialised in printing lenticular foil displays.

1.2 Organisation of the thesis

This thesis consists of four main chapters. In the first chapter short introduction of the theoretical background and practical work is given. Second chapter describes the definition of 3D, principle of stereoscopic vision and the most important 3D techniques. The detailed theoretical background of the lenticular technology is given in the third chapter. Chapter four describes the practical part of this thesis. Creation of lenticular foil display includes the data preparation and processing for further 3D modelling and subimages generation. This chapter also presents the interlacing and printing procedure made by the printing company.

In the Appendix, the 2D map of the area is enclosed.

2 3D VIEWING AND 3D TECHNOLOGIES

In the following chapter, first the definition of the term 3D as used in cartography is presented. Since the depth perception derives from the stereoscopic vision, its principle is explained after. At last, the most important 3D techniques applied to cartographic visualisations are introduced. At the very end, a short overview of the most important charactheristics of 3D techniques described is given.

2.1 Definition of 3D

According to Buchroithner and Knust [1], we distinguish between terms true-3D and pseudo-3D. Depictions visualized perspective-monoscopically on flat media (paper, monitor screen) are pseudo-3D. Pseudo-3D depictions can be considered as "untrue" or "false" and therefore they are not autostereoscopic. With regard to Bektas et al., the term true 3D refers to a stereoscopic visualization [9]. Others describe true-3D as depictions where objects are represented with three independent coordinate axes [9]. True-3D can be classified regarding the 3D effect, the perception and the number of stereometes used. According to the 3D effect, true 3D visualizations can be parallax-3D or full-3D. They differ by the depth cues employed on which spatial perception is based. Parallax-3D visualisations use selected monocular and binocular depth cues but full-3D visualisations use all monocular and binocular depth cues. Considering the perception, true-3D visualisation can be non-autostereoscopic or autostereoscopic. Number of stereomates can vary from one to two or more [10]. If a scene is seen stereoscopically either by applying natural stereovision (physical models) or artificial stereovision (flat displays), it is considered true-3D as long as perception of two stereomates is possible [1]. Furthermore, according to the type of display on which the scene is depicted, stereoscopic displays are divided into two groups. They are either hardcopy displays or softcopy displays. While scenes represented on hardcopy displays are rendered on non-electronical display devices (analogue), using transmitted or reflected light, scenes depicted on softcopy displays are rendered on electronic display devices (digital) and are usually self-illuminated. Moreover, these displays can be non-autostereoscopic or autostereoscopic. Non-autostereoscopic displays require viewing aids (glasses) to perceive the depth impression. In contrast, to perceive a spatial impression by looking at a autostereoscopic display, no additional viewing aids are needed. The latter perception is also described as a spontaneous spatial perception. Moreover, above mentioned displays are either single-user or multi-user displays, according to how many users can see the depicted scene at the same time[10].

2.2 Stereoscopic vision

For stereoscopic vision and thus depth perception, viewing with both eyes is needed. In other words, simultaneous viewing with both eyes is essential for three-dimenisonal perception of space. Human perception of space is determined by ten major parameters, called the depth cues. The depth cues are classified into two groups: physiological cues and psychological cues, as shown in Table 1. Furthermore, these depth cues can be either monocular or binocular. The group of physiological cues is the most important and directly connected to visual sensation of three-dimensional perception. Moreover, depth cues enable accurate interpretation of relative positions in space[10].

Table 1: Physiological and psychological depth cues (source: [10])

Physiological	Psychological
retinal disparity	retinal image size
convergence	linear perspective
accomodation	aerial perspective
motion parallax	overlapping/ occlusion
	shadowing (illumination)
	texture gradient

Monocular depth cues are available when looking at an object with a single eye, while binocular depth cues are only obtained using both eyes. The most essential depth cue that makes the depth perception possible is retinal disparity. Retinal disparity occurs due to the separation of the two eyes (an average is cca. 6.5 cm) and consequently our eyes see an object from two different angles. Thus, the images perceived are slightly different. Convergence causes both eyes focusing at the same point of an object and so prevents seeing the object doubled. Eye's viewing axes intersect where the object is in focus and there an angle called convergence angle is formed. The greater the distance from the viewer to the fixed point, the smaller the convergence angle is, and vice versa. Retinal disparity and convergence are binocular depth cues. All other depth cues are monocular. Accommodation is the adjustment of the focal length of the eye's lens. It is effective only in combination with other binocular cues. We can make use of motion parallax when observing the object from different positions or changing the object's location. In regard to retinal image size, we can distinguish between object sizes according to their distance from one another. Linear perspective is an effect where depth impression is achieved by reducing the object size while moving farther. Therefore, distant objects appear smaller than the near ones. Aerial perspective parameter describes an effect of decreasing haziness while increasing distance. Overlapping/occlusion refers to outlines of an object. If these outlines are not overlapped by another object, it means the object lies closer, and vice versa. The depth impression using shadowing/illumination is achieved by the distribution of light and shade in regard to the shape of an object and its position in space. The last parameter is the texture gradient which contributes to depth perception by the means of decreasing texture density and increasing distance. Psychological depth cues derive from experience, imagination and gained knowledge about the size and shape of the real objects [10], [11], [12].

Furthermore, we distinguish between natural and artificial stereoscopic vision. Stereoscopic vision with its use of both eyes is essential for perception of space. Perceived images collected by retina of an eye differ due to the spacing of our eyes. Therefore, the image seen with the left eye is perceived from a slightly different angle than the image seen with the right eye. These two images are combined into a three-dimensional perception of space by our brain. Natural stereoscopic vision is used through direct observation of objects in space. By artificial stereoscopic vision, the space is observed through spatially separated images, generated beforehand, one for the right and the other one for the left eye respectively. Using artificial stereoscopic vision, the depth impression can be increased by increasing the separation of images recording positions and therefore the convergence angle where separated images are taken from [11].

2.3 3D techniques

Cartographic data can be depicted in three dimensions by the usage of various 3D techniques. Following, the most important 3D visualisation techniques used are represented. At the end a short features overview of all described 3D visualisation techniques is given.

2.3.1 Anaglyph technique

Anaglyph technique of spatial visualisation is a three-dimensional method (also known as colorimetric method) that uses two-colour encoded stereomates, one for the left eye and the other one for the right eye respectively. Images are separated by colour filters and thus content is represented with two-colour layers. Usage of glasses is necessary to perceive depth impression. Anaglyph glasses can have red/blue, red/cyan, green/magenta or blue/yellow filters. Red/cyan and red/blue colour filters are most widely used among them [13].

Anaglyph displays are divided into two groups: grayscale anaglyph and colour anaglyph displays. They both separate an image with complementary colour filters. The left view of grayscale anaglyph image uses green and blue channel and the right view image uses red channel for filtering stereomates. Colour anaglyph uses average red and green channel for the right view image and the same one as the grayscale anaglyph for the left view image. Furthermore, display glasses with red filter for the left view and cyan filter for the right view are required for viewing either grayscale anaglyph or colour anaglyph. By using corresponding anaglyph glasses, human brain can combine perceived stereoscopic images and create three-dimensional perception. Due to the corresponding filters used, grayscale anaglyph is perceived in grayscale and colour anaglyph in colours. Anaglyph method has advantages of good image resolution, very good relief impression, multi-user capability, it offers high degree of freedom for the viewer and the usage of inexpensive anaglyph glasses. However, the technique has disadvantages of limited colour reproduction, ghosting and retinal rivalry [1].

2.3.2 Holography

Holographic three-dimensional methods are considered full-3D visualisations as they take advantage of all binocular and monocular depth cues. Therefore, holography is a method with the highest potential for creating truly three-dimensional geovisualisations [1].

During the recording process, holography uses coherent light source (laser beam) for illuminating the object and after recording a three-dimensional image of it on a flat medium. Generated image consists of numerous diffraction gratings made on a flat recording material as interference fringes. Used laser beams have a very short wavelength and therefore the resolution of histograms is very high. The laser beam from a single coherent light source is separated into two beams by a beam splitter. The coherent light from the first beam (scattered wave) is directed onto the object by a mirror and is then scattered from the object. The light from the second beam (reference wave) is reflected in a mirror. This light passes the object and therefore illuminates the medium directly. The beams interfere with each other and incident light makes adequate interference fringe pattern on the flat holographic plate that is sensitive to the light of the beam. The holographic plate is placed behind the object. From generated holograms, reconstruction of an image is possible by illuminating the hologram with monocromatic light. During the production process, objects representing the scene must be perfectly still and only small vibrations can cause mistakes. Production can be made only in a dark room and it requires holographic plates that are usually expensive. These disadvantages make holography a very expensive and complex technique of three-dimensional visualisation [12].

2.3.3 Barrier stripes technique

Barrier stripes technique is an autostereoscopic, binocular three-dimensional method of spatial visualisation. A parallax stereogram generated for perceiving depth impression consists of an image and a slit plate also called a parallax barrier placed in front of the stereoscopic image. At least two stereomates, one for the left and another for the right eye, comprise the stereoscopic image. These stereomates are combined into a stereoscopic image by interlacing. The width of an interlaced strip is the same as the slit in the parallax barrier. Due to these slits, the viewer perceives corresponding image for the left and the right eye respectively. Hence, a three-dimensional perception is achieved [12]. The principle of barrier stripes technique is shown in Figure 1.

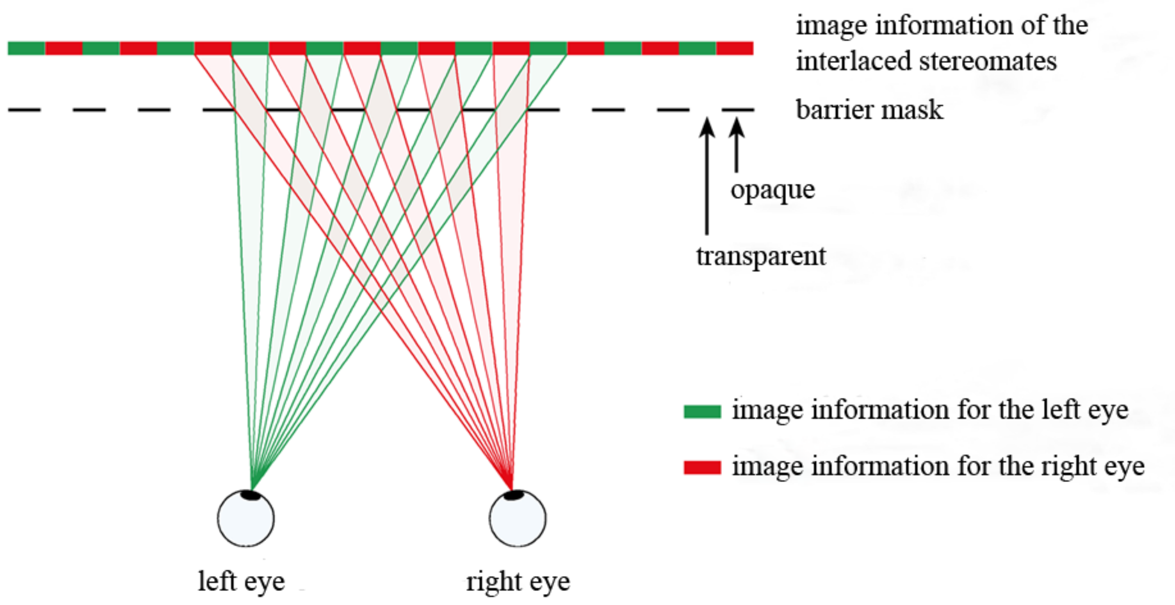


Figure 1: Principle of the barrier stripes technique (source:[14])

2.3.4 Shutter glasses

Shutter glasses is a non-autostereoscopic, softcopy technique that uses special glasses, containing liquid crystals and a polarizing filter for the three-dimensional visualisation. Shutter glasses work on the basis of synchronization of the left and the right images emitted by the screen at the high frame rate. Images are alternately shown to the adequate eye by shutting the glass of the unsuitable eye. Liquid crystal glasses prevent light from reaching viewer's right eye when the left image is illuminated and at the same time enable the light to pass through the viewer's left eye glass[15]. Synchronization between shutter glasses and the screen is achieved by infrared or radio frequency technology. The screen stores an image for the left and the right eye and then transmits the image via synchronisation signal to the corresponding glass. Therefore, the left eye sees the image meant for it and the right eye sees the image for the right eye. Afterward, two perceived images are merged by the viewer's brain to a 3D image [13].

2.3.5 Polarization technique

The polarization 3D technique is based on the application of polarised glasses with polarized filters that can block an electromagnetic wave vibrating in the opposite way to the lens filter alignment. In order to perceive separate images for the left and the right eye, the first scene has to be taken from slightly different angles and it has to be projected afterward by two (left and right) projectors. The polarizing filters placed on the projector's lenses polarize the light waves to two planes that are perpendicular to each other. Images are then projected on the same screen. Polarization glasses have two differently polarised lenses. The left lens has the same polarization filter as the left projector and the right lens the same as the right projector. Hence, the viewer sees the left image with the left eye and the right image with the right eye. Images are combined in the viewer's brain and the perception of space is achieved. By the use of polarized glasses, the perceived image appears darker than it truly is due to the less incident light reaching the viewer's eyes. Keeping the proper glasses orientation is another restriction that limits the viewer's degree of freedom [13].

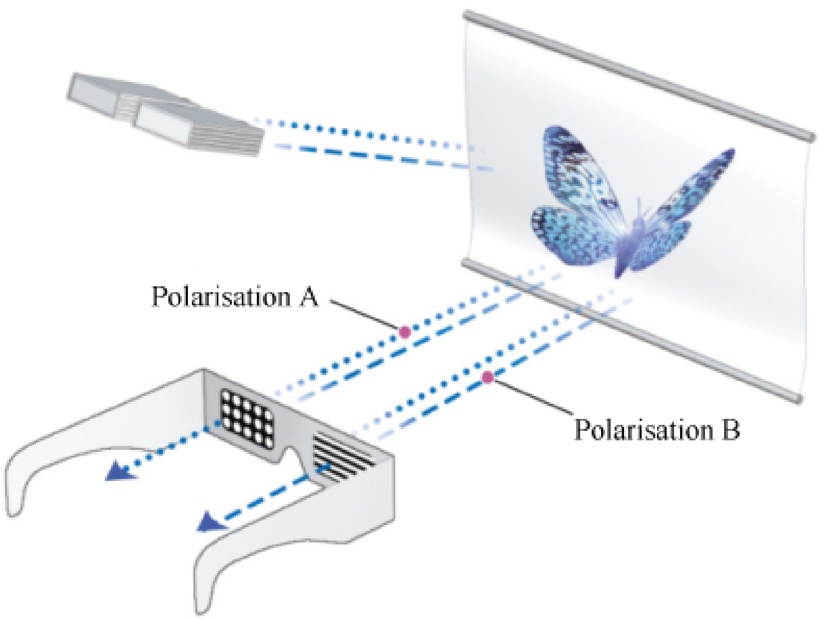


Figure 2: Principle of the polarization technique (source:[16])

2.3.6 Overview of 3D techniques

As described previously, different 3D techniques have different features. They can be either hard or softcopy, autostereoscopic or non-autostereoscopic, single or multi-user, parallax or full-3D displays. Described displays also differ in the number of stereomates used. Following, all important characteristics of a particular 3D visualization technique are summarized in Table 2.

Following, the overview table is shown in order to summarize all important characteristics of a particular 3D visualisation technique. In the table, lenticular technique described in 3 is also included.

Table 2: Overwiev of three-dimensional techniques and their type of display, need for viewing aids, multi- or single-user capability, image type, number of stereomates (source: [17])

	Anaglyph	Holography	Barrier stripes	Shutter glasses	Polarisation	Lenticular
Display type	hard and softcopy	hardcopy	hard and softcopy	softcopy	softcopy	hardcopy
Viewing aids	yes	no	no	yes	yes	no
User capability	multi	multi	multi	multi	multi	multi
Image type	parallax	full-3D	parallax	parallax	parallax	parallax
Number of stereomates	2	continuous	more than 2	2	2	more than 2

Some practical examples of 3D visualisations also applied in cartographic representations are: holographic stereogram, random-dot stereogram, single-image stereogram, single-image random-dot stereogram, prism mask/image splitter display, shutter display, head mounted display, polarisation display, pulfrich effect display, chromostereogram, rotating matrix display, rotating helix mirror and volumetric imaging[10].

3 LENTICULAR TECHNOLOGY

This chapter gives an overview of the theoretical background of the lenticular foil technology and it is divided into four parts. The first part describes the basics of the lenticular technology and structure of lenticular foil displays. In the second part, the principle of depth perception from the lenticular foil display is presented. The third part introduces the lenticular foil characteristics and the correlation between them. The last part explains the two possible types of camera arrangements and recording parameters for defining the recording geometry of the lenticular foil display.

3.1 Basics and structure

Lenticular foil technique is an autostereoscopic 3D visualisation method applied to either softcopy or hardcopy displays. It uses various images that can show different effects. Lenticular display effects can be divided into two groups: 2D and 3D effects represented in Table 3.

Table 3: Effects of lenticular displays (source: [4])

2D Effect	3D Effect	Combined Effects
Flip Morphing Zoom Animation	True-3D	All combinations of 2D and 3D effects

The alignment of lenses that comprise the lenticular display is essential to apply a certain effect. Lenses can be depending on the effect used aligned vertically or horizontally. They are running in a vertical direction if the 3D effect is used, but running horizontally if applying any of the 2D effects to the lenticular display. Therefore, both eyes perceive the same image information. The flip effect enables the viewer to see different scenes by changing the viewing direction. Usually the viewing direction is changed by tilting the display to the left or to the right side in horizontal direction. Consequently, the image content changes. Animation effect means showing images in a fast sequence that causes the animation of a scene. Zoom effect enlarges the scene and a smooth transition from one scene to another is possible with the morph effect. Displays that use combinations of 2D and 3D effects have lenses aligned vertically. Hence, the three-dimensional impression can be perceived and at the same time tilting the display enables the flip effect [11].

By looking at the lenticular display, the viewer achieves the depth perception because of the artificial stereoscopic vision application. The image separation is possible due to the structure of lenticular display and it is done by the lenticular foil. Thus, the viewer does not need any additional viewing aids in order to perceive spatial impression. Lenticular displays consist of two components shown in Figure 3:

- the lenticular image,
- the lenticular foil.

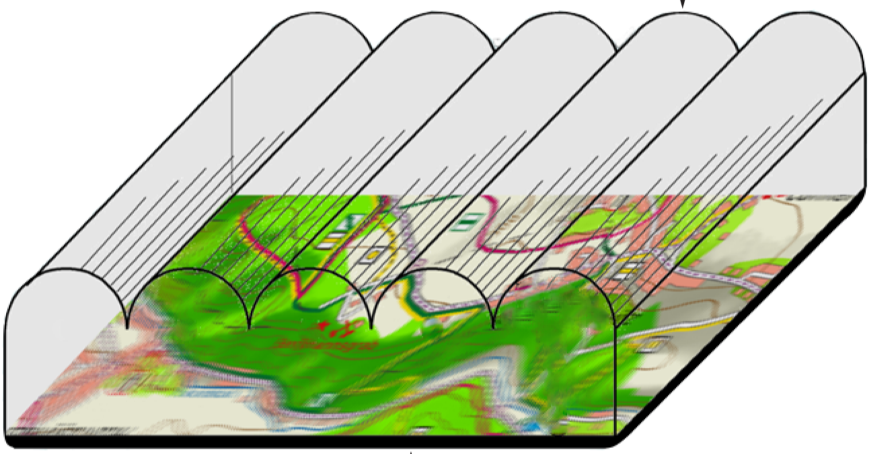


Figure 3: Structure of lenticular display (source:[10])

The upper side of the lenticular display represents lenticular foil. This transparent synthetic foil separates images to the corresponding images for the left and the right eye respectively. The lenticular foil consists of parallel semi-cylindrical micro lenses that can be aligned vertically or horizontally, depending on the effect used. On the lower (smooth and flat) side of the lenticular display the lenticular image is placed. The lenticular image is composed of interlaced strips generated from all stereomates (partial images). These stereomates are interlaced in an alternating sequence by an interlacing software[4].

3.2 Principle

In the process of interlacing, generated partial images are cut into narrow stripes and interlaced in an alternating sequence [4]. Consequently, all adequate strips of generated partial images are placed under each lenticular lens. The number of strips placed under each lens is the same as the number of stereomates. In Figure 4, an example for two generated partial images is given. The white image represents the right eye perspective image and the black image is the left eye perspective image. Both images are cut into stripes and interlaced. Therefore, the first strip of the left and the right perspective image lies under the first lens and likewise the second strip of both created subimages lies under the second lens [11].

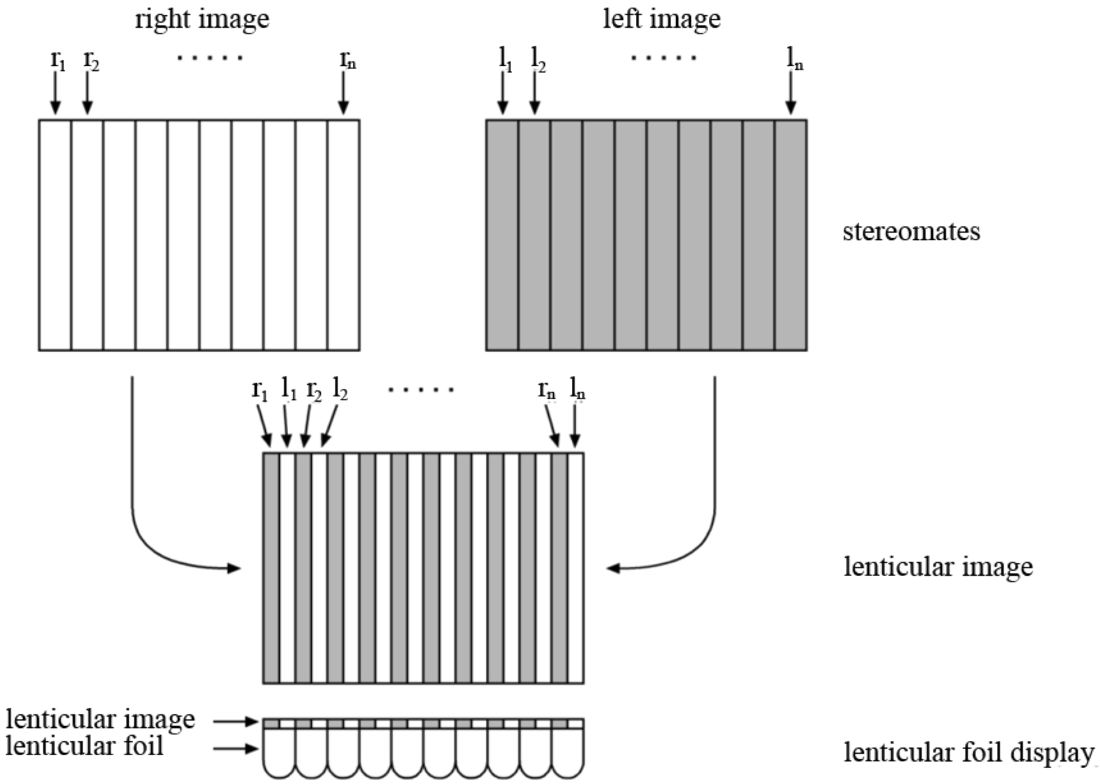


Figure 4: Interlacing of partial images and principle of lenticular foil technique (source:[11])

Optical properties of the lenticular foil enable the image separation to the adequate image for the left and the right eye. The cylindrical lenses focus the incident sight rays onto specific image strip. The change in the viewer's perspective causes that the incident rays focus onto other strips of the image. The viewer's position has to be perpendicular to the lenticular display all the time. Therefore, the separation of image information is possible from the lenticular image[4]. If the viewer's eyes are not perpendicular to the lenticular display, the depth perception is lost. Usually more than two stereomates are used in order to make the viewer's degree of freedom higher. By increasing the number of stereomates, we increase the number of possible parallaxes that enables the depth perception form various different perspectives and angles [11].

Perception of space derives from parallax. Parallax is an angle between two different lines of sight obtained while observing an object form two different directions. The depth impression depends on the value and the type of parallax. In general it is known: the larger the parallax, the larger the depth impression. However, too large parallax can cause image distortions, which is why the maximal parallax value has to be determined. Furthermore, depending where in space the incident sight rays intersect, three different types of parallaxes are known (the point of the sight rays intersection is called the virtual object point) [13]:

- Positive parallax (virtual object point lies behind the display plane),
- Zero parallax (virtual object point lies in the display plane),
- Negative parallax (virtual object point lies in front of the display plane).

In 3D depictions, object points with positive parallax are limited by the far and the zero plane, object points with the negative parallax are lying between defined zero and far plane, and zero parallax objects are placed in the zero plane. The same principle of the object distribution is to be followed by the lenticular technique.

3.3 Lenticular foil characteristics

Following the principle of stereoscopic vision, our eyes have to perceive the left and the right eye image to gain the three-dimensional vision. Hence, the lenticular image has to be separated into two suitable images. The separation is done by lenticular semi-cylindrical parallel micro lenses that construct the lenticular foil.

The lenticular foil features depend on the size and shape of lenses constructing it. The most important characteristics of the lenticular foil are:

- lens density (number of lenses per unit length) or lens width w,
- radius r,
- thickness of lenticular foil t,
- aperture angle of the lenses φ,
- refractive index n,

All the above listed parameters of the lenticular foil are shown in Figure 5.

These parameters are closely related and have to be considered before choosing the appropriate lenticular foil. The size of the final lenticular display defines the lenticular foil used to render a specific scene and the viewing distance. Typically large format displays apply the lenticular foil with lower resolution and therefore larger viewing distance than small format displays. However, displays with high resolution lenticular foil used are usually small format displays and are observed from a short distance. The resolution of the lenticular foil display applies to the lens density (number of lenses per unit) and it is defined as a number of lenses per inch (LPI). The higher the LPI value, the more lenses per inch and the smaller the width of a cylindrical lens. Inversely, the lower the LPI value, the less lenses per inch and the larger the width of a cylindrical lens. Lens density is one of the most important lenticular foil parameters and it affects other lenticular foil characteristics like: the size of the perceived pixel (resolution of the lenticular image), the width of the strip as well as the number of the subimages and the viewing distance. The number of subimages necessary for an optimal depth impression also depends on the lens density. High lens density displays render more information and thus require more stereomates. Accordingly, low lens density displays require less stereomates as they render less information [11].

Furthermore, the width of the image strip in the lenticular image has to coincide with the lens width. As described in chapter 3.1, one strip of the lenticular image is situated under each lenticular lens. The width of the individual strip influences influences the printing resolution directly. Therefore, narrow image strips require a high resolution printer, and vice versa.

Radius, refractive index and thickness of a lens are highly associated. Namely, thin lenticular foils have a small lens radius and a large viewing angle, and vice versa. The thickness of the lenticular foil is usually specified [3].

The aperture angle of the lens defines the width of the viewing zone. By increasing the viewing distance, the viewing zone becomes wider. The size of the aperture angle is determined by the radius and the refractive index of the lens. Consequently, a larger radius defines a smaller viewing zone. A narrower aperture angle is preferential (usually around 30°) to get a good 3D impression. Therefore, the risk of the motif repetition is minimised [3].

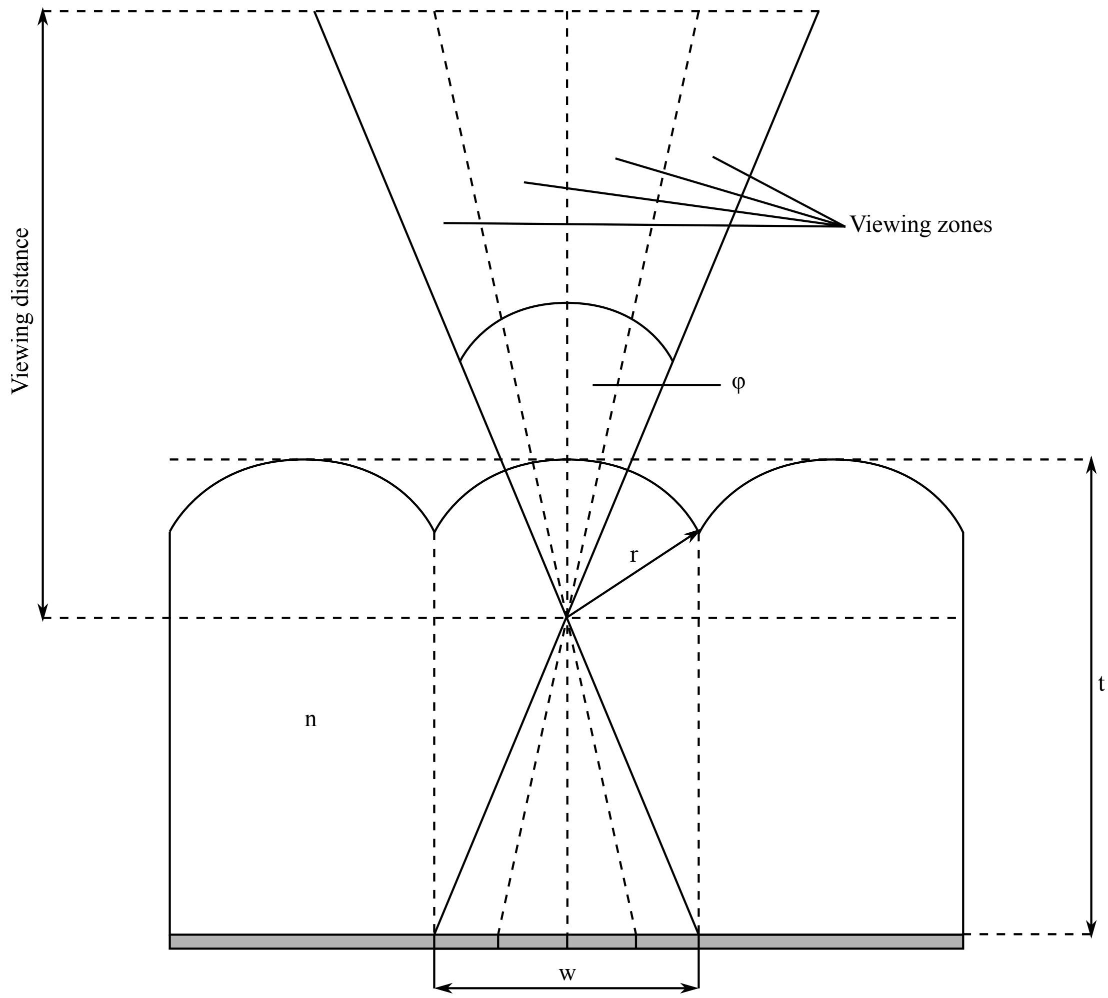


Figure 5: Parameters of the lenticular foil (source:[11])

3.4 Recording geometry and parameters

The lenticular image is the essential part of the lenticular display. The quality of its geometry consequently determines the magnitude of the depth impression and overall quality of the spatial image sensation. All parameters regarding camera geometry and its positioning are set in the according 3D modelling and visualisation software.

3.4.1 Camera arrangement

We know two basic ways to arrange the camera as shown in Figure 6:

- Convergent camera (convergent disposition) :

  Camera axes are rotated in a way that all camera axes intersect at one point. Consequently, all stereomates have a symmetric viewing pyramid. Disadvantages of this method are distortions on the edges where vertical parallax occurs [3].

- Parallel camera (parallel disposition):

  Camera axes are placed parallel. Consequently, the recording angle of the camera changes and asymmetric viewing pyramids are used. This method does not cause any distortions and with its usage we can control horizontal parallax more efficiently [3].

The number of virtual camera arrangements depends on the number of stereomates generated for a specific scene and type of display [11].

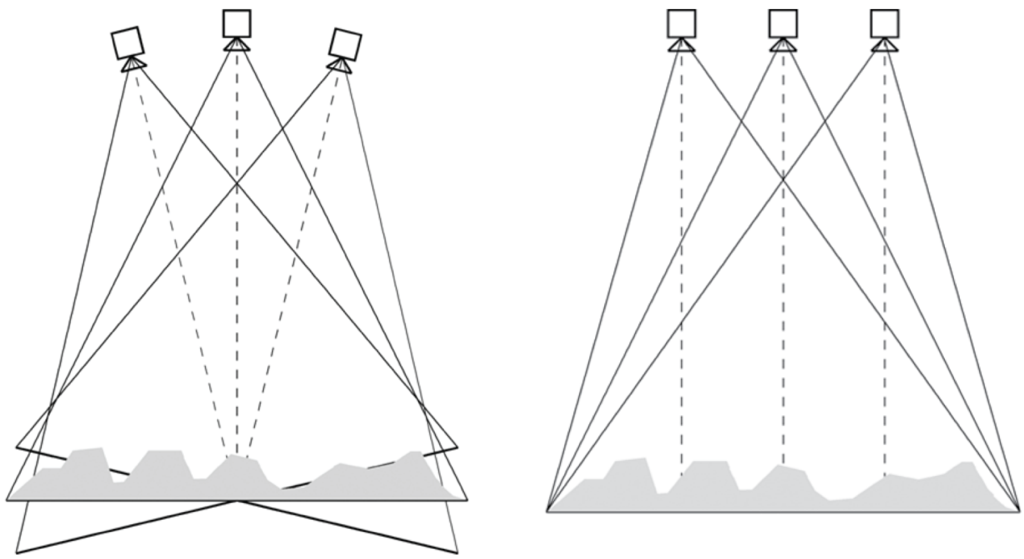


Figure 6: Convergent and parallel camera positioning (source:[11])

Images are recorded in the central perspective and therefore the principles of the central perspective are pursued. Due to the central perspective, objects in the lenticular display do not have the same scale. Higher located objects have a larger scale than objects positioned in the lower part of the lenticular image. Thus, each level of the lenticular image has a different scale [2].

3.4.2 Recording parameters

Defining recording parameters is essential in the process of stereomates generation. Recording parameters determine the geometry of the lenticular image and thus the optimal depth impression.

$$\Delta p''_{\mathrm{x-max}} = 2\,\Delta z''_{\mathrm{max}} \tan\frac{\varphi}{2}, \tag{1}$$

the maximal parallax difference in the image coordinate system $\Delta p''_{\mathrm{x-max}}$ is calculated from the maximal perceived depth $\Delta z''_{\mathrm{max}}$ on the lenticular display and the aperture angle of the lenticular foil lenses φ. When defining the maximal perceived depth $\Delta z''_{\mathrm{max}}$, the distribution of space behind and in front of the display plane has to be considered. 2/3 are to be perceived behind and 1/3 in front of the display plane for the optimal result. In this equation only the value behind the display plane has to be taken into account.

$$\Delta P_{\mathrm{X-max}} = \frac{X}{x''}\,\Delta p''_{\mathrm{x-max}}, \tag{2}$$

the maximal parallax difference in the object coordinate system $\Delta P_{\mathrm{X-max}}$ has to be specified in order to calculate other parameters. It is determined by object width X, the image width x'' and the maximal parallax difference in the image coordinate system $\Delta p''_{\mathrm{x-max}}$ that has to be calculated beforehand from equation (8).

$$Z = \frac{X}{2\tan\frac{\beta_{\mathrm{x}}}{2}}, \tag{3}$$

known values of the object width X and camera lens angle β_{x} define the shooting distance Z.

$$B_{\mathrm{max}} = \frac{\Delta P_{\mathrm{X-max}}\,(Z+\Delta Z_{\mathrm{max}})}{\Delta Z_{\mathrm{max}}}, \tag{4}$$

the maximal image recording base B_{max} is the distance between the far left and the far right camera where the far right and the far left stereomates are recorded. It is defined by the maximal parallax difference in the object coordinate system $\Delta P_{\mathrm{X-max}}$, shooting distance Z and the object maximal height difference

ΔZ_{max}.

$$B_{\mathrm{sm}} = \frac{B_{\mathrm{max}}}{N-1}, \tag{5}$$

stereomates recording base B_{sm} is the distance between adjacent (left and right) cameras. The value is the same for all stereomates and it is calculated from the maximal recording base B_{max} and the number of stereomates N used.

$$f_{\mathrm{k}} = \frac{x''}{X} Z, \tag{6}$$

focal length f_{k} is the distance between the camera lens and the sensor (film) and as seen from the equation (13), it is defined as Z times the ratio between the image width x'' and the object width X''.

$$x' = 2\, f_k \tan\frac{\beta_x}{2}, \tag{7}$$

the camera lens angle β_{x} and focal length f_{k} define the camera capture width x'. If the camera arrangement is parallel, the capture width x' of the camera is the same as the image width x''.

These recording parameters represent unknown values and to define them we need known input values. The known values depend on the scene we want to render and certain parameters of the lenticular foil used.

The change of the focal length f_k, the shooting distance Z or the stereomates recording base B_{sm} can have influence on the depth impression (parallax). The change in distance between adjacent cameras B_{sm} can cause the change of parallax (increase of B_{sm} increases the parallax and hence the spatial impression), the change of perspective and the image scale stays the same. By changing the shooting distance Z, the change in parallax and the change of the image scale appear, but there is no change in the perspective. The variation of the focal length f_k changes the parallax (increasing f_k increases the parallax) and the image scale, the perspective is not affected [2].

4 LENTICULAR FOIL DISPLAY CREATION

This chapter describes creation of the lenticular foil display of the Central Julian Alps. First, a short description of the map content and representation area is given. Next, data sources and software used for the lenticular display creation are presented. Afterward, necessary data processing for further 3D modelling done in ArcGIS and Adobe Illustrator software is described. As 3D modelling and generation of stereomates represent the essential parts of the lenticular map creation, the detailed description of them follows. Then the actual lens density test, called the pitch test, is described. At the end the short overview of the lenticular display printing techniques is given, emphasizing the printing technology applied for printing the lenticular foil display of the Central Julian Alps.

4.1 Area

Decision to select the area around Slovenian highest mountain Triglav was taken due to its popularity among domestic hikers and tourists. Since hiking is the main tourist attraction of the area, hiking trails were determined as the primary map content. The most important huts located along rendered hiking trails were also located on the map. The map is depicted on the A4 format display (210 mm x 297 mm) and it covers the area of 17.4 km x 24.7 km. The scale of the map is 1 : 83 000. The map edges coordinates in D48/GK coordinate system are represented in Table 4.

Table 4: Map edges coordinates

edge	y [m]	x [m]
top left	401590	149820
bottom left	401590	125170
top right	419020	149820
bottom right	419020	125170

The map covers the most touristic places in the central Julian Alps including all starting points for hikers going to Triglav. It encompasses the lake Bohinj in the south, a part of Pokljuka plateau in the east, Trenta in the west and Mojstrana in the north. Triglav as the essential part is positioned in the centre of the map.

4.2 Data sources

The usage of a digital terrain model (DTM) as the main data source to create the lenticular foil display is self-explanatory since 3D effect derives from multiple images based on a good quality DTM. Beside the DTM, we also used generalised cartographic database (GKB25) and the 1 : 50 000 National topographic map (DTK50) as data sources for the insertion of map information. All data were provided by Surveying and Mapping Authority of Slovenia.

Firstly, the DTM for the area was used. DTM of Slovenia comprises the data of digital elevation models (DEM) of Slovenia and its surroundings with resolution of 5 m, 12.5 m, 25 m and 100 m [18]. For the depicted area, the DTM with resolution of 12.5 m, generated as a hybrid of various data was used.

Secondly, map information (water bodies and road network) were imported in a vector format from the GKB25. The GKB25 was established in the years from 1994 to 1996. The lines were gathered from the 1 : 25 000 National topographic map. In the GKB25 four types of data with the basic attributes are included: roads, water bodies, contour lines and railways [18].

Finally, the DTK50 was used for the digitalisation of missing elements and as the control layer because GKB25 data are not up-to-date. The DTK50 consists of 58 sheets covering the whole country. All sheets are available in raster tif format with the resolution of 300 dpi, including tfw file for the raster image georeferencing [18].

4.3 Used software

Adequate software packages (shown in Figure 7) were used in the process of the lenticular foil display creation for a specific type of the data processing.

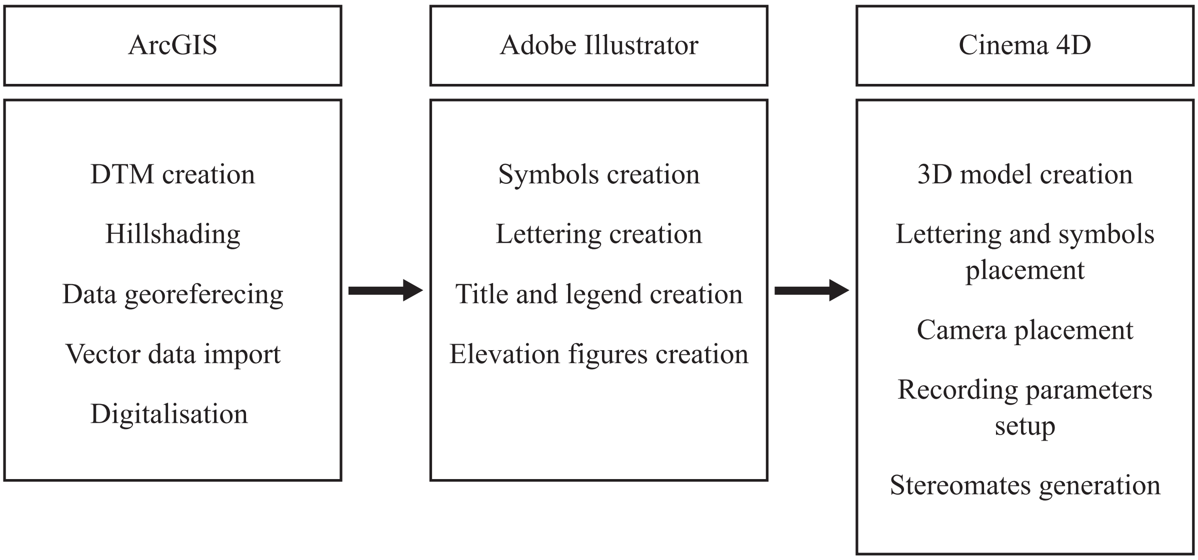


Figure 7: Type of data processing and used software

The basic data processing and preparation of the data for further 3D modelling was done by ESRIS's commercial ArcGIS software. Adobe Illustrator software was used to create map symbols and lettering. After the data were prepared, they were imported into the Maxon's 3D modelling and visualisation software Cinema 4D. In Cinema 4D, the 3D model was created and afterward the according number of stereomates was generated. The interlacing of the generated stereomates was done by the printing company in the 3DZ EXtreme V7 software by Digi Art [19].

4.4 Data preparation and processing

As for any cartographic work, geodata have to be processed and prepared in a suitable structured way also for the lenticular display creation. First, geo-data have to be processed for the later import into 3D modelling and visualisation software. In the initial part of the lenticular map creation, commercial software ArcGIS and Adobe Illustrator were used.

The basic data necessary for the lenticular display creation is a DTM. DTM raster image was processed from the data provided in an ASCII format. Because ArcMap cannot process DTM raster image directly from ASCII format, the conversion to feature class was made by ArcToolbox 3D Analyst tool. "In ArcGIS, feature classes are homogeneous collections of features with a common spatial representation and set of attributes stored in a database table" [20]. Data were assigned spatial reference properties by selecting suitable projected coordinate system D48/GK. Then points from feature class were converted to a raster image file with Conversion tool point to raster. Low elevation points were assigned dark colours and high elevation points light colours.

In order to process the material to drape it over the relief, hillshading was made. Spatial Analyst hillshade tool was used to apply hillshade from previously processed DTM raster image. "The Hillshade tool obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster. It does this by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighbouring cells" [20]. As an output we get a grayscale raster image, assigned values from 0 to 255. Zero values are assigned to cells lying in shadows of other cells, while the rest of the cells get values from 1 to 255 [20]. When applying hillshade tool, default settings were used. There were the azimuth value of 315° and altitude value of 45° . Hillshade raster was assigned 35 % transparency, resampled during display using bilinear interpolation and standard deviation stretch type. Afterwards, default Continental Europe 7 colour ramp was assigned and stretched automatically over the DTM raster image.

Following, the insertion of map information from GKB25 and DTK50 was done. Before importing vector data to ArcMap, they were geo-referenced in ArcCatalogue. Shapefiles from GKB25 were applied D48/GK coordinate system and imported to ArcMap as separate layers. GKB25 was therefore the major data source for the insertion of road network and water bodies (rivers, lakes and streams). Since level of detail in GKB25 is too high for the scale of the final lenticular map, the data were generalised where necessary. Separate lines connecting two adjacent vertices presenting the same water body or a road line were merged manually into one polyline. Meanwhile, underlying DTK50 was used as a control layer to check suitability of the GKB25 data. After merging, considering the DTK50, some missing roads were digitised and stored in a vector format. Furthermore, by digitising data for all hiking trails were gained because no other data source had been available before. Because of the high density of hiking trails in the region, only the most important ones were rendered. Based on DTK50, point features were used to determine the right position of huts, spot heights and towns. After all necessary map information had been imported and digitised, line symbols were defined as shown in Table 5. Eventually, data prepared in ArcGIS were used as primary data in 3D modelling process performed in Cinema 4D. In particular, the DTM and coloured relief with corresponding map information were exported in raster format separately.

The adequate line width is essential for good readability of the lenticular map topographic contents. The minimum width of the line segments considering the lenticular foil used has to be 1.5-2 lenses. Due to the 62 LPI resolution of the lenticular foil, suitable minimum width of the lines should be 0.6-0.8 mm

[21]. The width of line symbols used is represented in Table 5.

Point symbols, lettering and the map title with the legend were created by Adobe Illustrator commercial software. Adobe Illustrator enables complete degree of freedom in designing vector format symbols and their format compatibility with 3D modelling and visualisation software Cinema 4D. After symbols for a hut, mountain pass and spot heights were designed as shown in Table 5, the lettering for towns and mountains were created. Arial font size 12 was used for lettering. Each mountain name was exported together with its elevation figure and spot height in a separate vector file. The map title, including the legend, was placed onto the transparent grey background. The map scale and information about the author, data source, publisher and publication date were created and exported as a separate vector file from Adobe Illustrator.

Table 5: Used symbols

Object	Symbol	Width [mm]
Hiking trail	———	0.8
Road	———	1.2
River, stream	———	1 and 1.2
Hut	⌂	
Pass	)(	
Spot height	▲	
Town	⊙	

4.5 3D modelling

Multiple camera views of the scene have to be generated to attain spatial perception by the means of lenticular foil display. Therefore, a 3D model representing the scene was created. Since 3D modelling is the most significant part of the lenticular display creation, the magnitude of 3D perception is highly related to the 3D model quality. As described in 4.3, 3D modelling was done in the commercial software Cinema 4D by MAXON. Decision to use Cinema 4D was made due to the fact that students can get a free software license and university staff usage of the software.

After all necessary data for creating a 3D model had been prepared, they were imported into Cinema 4D. First, the 3D model of the representation area had to be generated by creating an object. In regard to [22], objects in Cinema 4D are parametric objects also called primitives. They are mathematical abstractions and cannot be edited. Primitives can be modified only by changing parameter values of selected primitive. Relief object was selected to create a 3D model based on the DTM raster image in Cinema 4D. Relief object uses a greyscale or colour raster image to generate the 3D relief model. Different grayscale values represent different elevations in the image. Darker pixels represent lower elevations and brighter pixels represent higher elevations [22]. Considering the values in the DTM raster image, relief object is generated as shown in Figure 8.

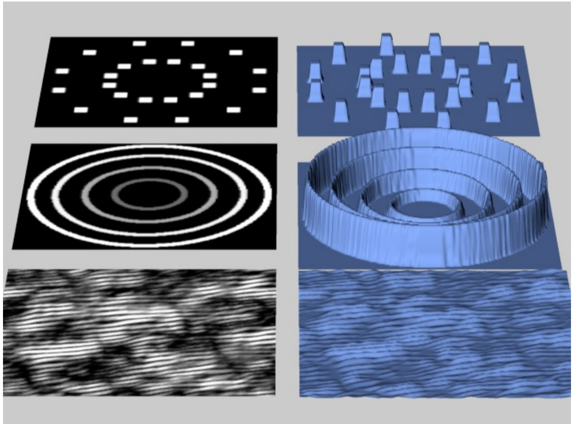


Figure 8: Grayscale image and corresponding relief object (source:[22])

To get the desired representation of the relief, it has to be texturized. Material system in Cinema 4D is based on channels which represent material properties. It is not necessary to use all channels to imitate a specific material. Only a few channels can be used to get a specific surface [22]. The coloured relief image with corresponding map information (water bodies, roads and hiking trails) was used as a texture for our model. This texture was set in the material editor and afterwards draped over previously generated 3D model. Materials were also used for texturing other plane objects created in Cinema 4D. Raster images used as textures were draped over plane objects for creating the map title, including the legend, and town symbols. These two plane objects were positioned manually on the specific position in the 3D model.

Next, the importation of lettering and hut symbols was done. As described in 4.4, the data were imported in a suitable vector format from Adobe Illustrator. Rendered lettering was divided into two groups: selection of the most important town names and mountain names with their corresponding elevations. Data import was done for each mountain separately and it included the mountain name, elevation and spot height. The lettering was assigned the same black material separately. The same procedure was used for the importation of town names and the map information (the scale, author, data source, publisher and publication date) into the model. Placement of lettering and huts symbols was done manually and separately for each one of them.

As described in 3.2, objects with zero parallax are perceived in the display plane. Objects with the same value of parallax lie on the same plane. Therefore, objects positioned in the zero plane have no parallax, which is why they are depicted sharply. Objects get blurred by moving away from the zero plane. Due to different elevations, not all objects can be placed on the zero plane and consequently rendered sharply. Hence, lettering and symbols were placed on different heights according to the relief as shown in Table 6.

Table 6: Placement of data in relation to the relief

Data	Position in realtion to the relief	Type of placement
image data	identical with the relief	automatically
roads, water bodies	identical with relief - merged with image data	automatically
huts	nearly identical with the relief	manually
mountain names and elevations	slightly above the relief	manually
town names and symbols, mountain names and elevations, map title, map information, legend	hovering above the relief - positioned in the zero plane	manually

4.6 Generation of subimages

After the model was prepared, the camera object was created. 3D stereo camera was used for the 3D visualisation of the spatial model. 3D stereo camera can be chosen as one of the default options in Cinema 4D release 14. 3D stereo camera in Cinema 4D consists of two symmetrical cameras placed at the defined distance from one another. Due to the different camera positions, images taken from slightly different angles are generated. Camera object in Cinema 4D has various different parameters that can be set as desired for a specific purpose and scene. Parameters for generation of subimages were calculated as described in section 3.4.2. The known and calculated parameters for the area are presented in Table 7.

Camera arrangement is one of the most important settings in 3D modelling process. Off axis camera arrangement was chosen for the area. In off axis mode camera arrangement is parallel and image axes intersect. The zero parallax lies where image axes intersect [22]. As described in 3.4.2 2/3 of the object have to lie spatially behind the zero plane and 1/3 in front of the zero plane. Therefore, the zero, near and far plane have to be set correctly regarding to the 3D model. While the near plane coincides with the highest point of the spatial model, the far plane coincides with the lowest point of the model. Apparently, the zero plane is positioned inside the 3D model. Final quality of the lenticular display is defined mostly by lenticular foil parameters, number of subimages and their resolution. The resolution of generated subimages was 300 pixels per inch and therefore the size of each image was 2480 x 3507 pixels. Subimages were generated in the bmp format.

Table 7: Parameters of lenticular map

	Parameter	**Cinema 4D label**	**Value**
Lenticular display parameters	map width x''	output image width	210 mm
	map height y''	output image height	297 mm
	max. perceived depth $\Delta z''_{max}$	-	12 mm
	number of subimages N	number of channels	19
	lens aperture angle of lenticular foil φ	-	42°
Object parameters	object width X	object size X	17430 m
	object height Y	object size Z	24651 m
	object max. height difference ΔZ_{max}	object size Y	1577 m
Camera parameters	camera lens angle β_x	field of view	50 °
	focal length f_k	focal length	22.517 cm
Calculated parameters of lenticular display	max. parallax difference (display) $\Delta p''_{x-max}$	-	6.14 mm
	max. parallax difference (object) ΔP_{X-max}	-	509.77 m
	shooting distance Z	object coordinate Y	18689.38 m
	maximal image recording base B_{max}	eye separation	6551.19 m
	stereomates recording base B_{sm}	-	363.955 m

Generated subimages represent the final output of 3D modelling. According to the chosen A4 format of the lenticular map, the 62 LPI lenticular foil with the 42° aperture angle of the lens was used. This resolution of lenticular foil was chosen because it gives the optimal depth impression in combination with lenticular map format and its viewing distance, number of stereomates and its width as explained in 3.3. 19 parallel perspective views were generated by the virtual stereo camera for the area.

4.7 Pitch test

Every lenticular display has a specific lenticular foil resolution defining how dense the lenses on the foil are. Due to the different effects, lens density is not always the same as specified. For example, the specified lens density is 62 LPI, but the actual lens density can vary. However, the width of every interlaced image strip has to be exactly the same as the lens width. Before starting the interlacing process, we have to make a test in order to define the actual lens density and therefore get the optimal spatial impression from an interlaced image. The test is called a pitch test. By making a pitch test we actually calibrate a printer with paper and the lenticular lens used. The pitch test has to be printed on the same paper as the interlaced image. When a printer or a paper type is changed, a new pitch test has to be made. The pitch test is (when printed) a pattern consisting of black and white strips aligned in a sequence as shown in Figure 9. Each pattern corresponds to a certain LPI value[23], [2].

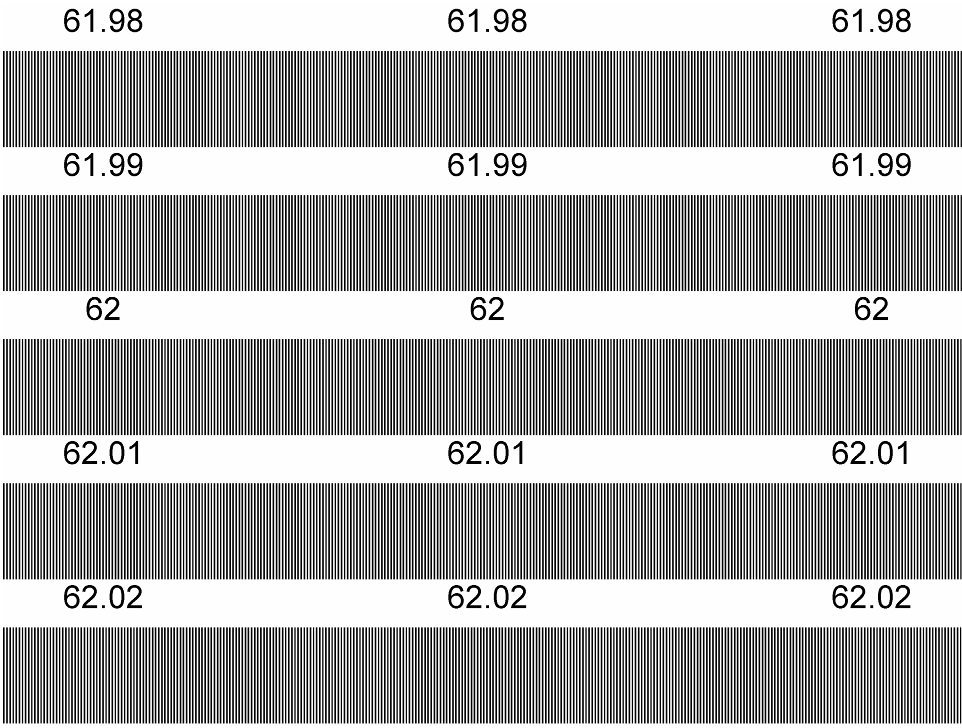


Figure 9: Pitch test made by the free lenticular interlacing software SuperFlip

4.8 Interlacing

Generated subimages are the final output of 3D modelling made in Cinema 4D. In order to create the lenticular image, the interlacing of generated 19 subimages had to be done. Based on the principle described in 3.1, the interlacing has to be done in an adequate interlacing software. As interlacing is closely related to the printing procedure, it was made by the company that printed the final hardcopies of the lenticular map. The 3DZ EXtreme V7 lenticular interlacing software was used for the interlacing. The interlacing process was done by Elmar Spreer from Digi Art company.

3DZ EXtreme V7 lenticular interlacing software enables the interlacing of unlimited number of stereo-mates for all types of lenticular foils, sizes, production techniques and effects. It supports various input and output format types. The software gives the ability of different previews on the monitor screen (animated gif, red/cyan anaglyph, barrier screen for LCD monitor, lenticular for LCD monitor). In the interlacing software, the exact LPI value specified according to the previously made pitch test, aperture angle of the lenticular foil lens, number of frames, the printer resolution (PPI), image width and height, and lenses alignment (vertical or horizontal) have to be defined. 3DZ EXtreme V7 software enables to set the border around the whole image that helps to place the lenticular foil onto the lenticular image accurately. When all necessary parameters are determined, the interlaced image can be generated and afterward printed directly from the interlacing software[24].

4.9 Printing

Printing the lenticular foil display is the main goal of the lenticular foil display creation. After generating the lenticular image by interlacing partial images, the lenticular image is prepared to be printed. In the process of lenticular printing the interlaced image is joined with the lenticular foil. Two different approaches can be used for the printing:

- direct offset printing,
- printing onto special substrate.

With the direct offset printing, the lenticular image is printed directly onto the back, smooth side of the lenticular foil. This printing procedure is suitable for a high number of copies and it enables accurate fitting of the single lens with the underlying image strip as distortions caused by the temperature variation during the printing procedure are minimised. The limited thickness of the lenticular foil used for printing is the biggest restriction of the direct offset printing. Therefore, only foils with high lens resolution (higher than 50 LPI) that are thin enough can be used. Offset printed lenticular foil displays need either a scratch resistant laminator or protective lacquer added on the back side of the lenticular display to prevent the damage of the lenticular image[25].

If the interlaced image is printed onto the special printing substrate, it has to be laminated subsequently. By laminating, the lenticular image and the lenticular foil are permanently mounted together. The lenticular image and the lenticular foil can be glued together by a special adhesive applied onto lenticular foil or by the double-sided special-adhesive foil. This type of printing is used for the lower lens density foils (less than 50 LPI) and for small number of copies. In order to diminish the temperature and humidity effects on the printing substrate, the lenticular image is normally printed on special plastic materials [25].

The company producing the maps used the Inkjet printer with the resolution of 1200 PPI for printing lenticular images for this project. Since the lenticular image has to be printed extremely accurately especially in the direction of interlacing, the lenticular image was printed onto a polyester printing substrate. This material is not affected by the heat and humidity and therefore the change of the printing substrate dimensions are tolerable. If the printing substrate deforms during the printing, the width of the interlaced strip does not match the width of the lenticular lens. Consequently the 3D effect can be lost. After the image is printed, it has to be glued together with the lenticular foil. The double-sided self-adhesive foil was used for the lenticular map of the central Julian Alps [21]. This kind of printing approach was used due to the small number of copies. However, offset printing would have been used for a high number of copies. Final printing of the lenticular maps was done by Digi Art company.

5 CONCLUSION

Created lenticular foil display of the central Julian Alps is the first lenticular map of the area depicted in bigger scale. The final map was printed by a German company Digi Art (Elmar Spreer) in cooperation with Chilean company 3D Facts (Betty Wander), both specialised in printing lenticular displays. The map was printed in 60 copies.

Sharpness of objects constructing the lenticular image and the magnitude of the 3D effect perceived are closely correlated. Finding the right ratio between the 3D effect and the sharpness of the objects in the lenticular display is of the major importance. While increasing the 3D effect, the objects placed out of the zero plane appear blurred. The placement of the zero plane has to be thoroughly considered in order to ensure readability of the lettering that cannot be positioned in the zero plane due to the relief characteristics.

Even though the space in the 3D model was distributed as optimally as possible, the very bottom and the very top objects were still not depicted completely sharp. With the 1/3 of the model distributed in front of the display plane and 2/3 behind it the optimal readability was provided. Nevertheless, the final result was not completely perfect.

This deviation occurs because of optical features of the virtual camera and it remains the biggest disadvantage of the lenticular foil display visualisations. Along with a large number of advantages offered by these autostereoscopic hardcopy displays, the lenticular foil technology still provides highly satisfactory depth impression compared to the relatively small blur of the bottom and top objects. Furthermore, lenticular displays enable depictions of different contents out of only one lenticular image. Changing lettering and changes occuring through time can be shown by using 2D flip effect. However, the content change is limited to two distinct scenes in order to retain the 3D effect at the same time. Yet, 3D effect was used for the project only.

6 RAZŠIRJENI POVZETEK DIPLOMSKE NALOGE V SLOVENSKEM JEZIKU

P.6.1 Uvod

V zadnjih letih je postala uporaba različnih 3D prikazov v filmski in televizijski industriji, animacijah in najrazličnejših slikovnih predstavitvah vse pogostejša. Prikazi na zaslonu in papirju se uporabljajo za prostorske prikaze različnih vsebin. Lentikularni prikaz omogoča prostorsko zaznavo brez dodatnih pripomočkov (npr. očal) in v primerjavi z drugimi tehnikami 3D upodobitev ni utrujajoč za oči uporabnika. Lentikularni prikazi so primerni za uporabo na prostem predvsem zaradi enostavnega transporta in zato, ker za svoje delovanje ne potrebujejo električnega napajanja. Zaradi uporabe večjega števila stereoparov lentikularni prikaz omogoča prostorsko zaznavo z različnih kotov in položajev. Glede na našteto ima uporaba lentikularnih kart za namene kartografske upodobitve v prihodnosti velik potencial.

Glavni namen diplomske naloge je izdelava lentikularne karte osrednjega dela Julijskih Alp. Glavno vsebino lentikularne karte predstavljajo najpomembnejše planinske poti in planinske koče ob njih. Vsi prostorski podatki, uporabljeni za izdelavo lentikularne karte, so bili priskrbljeni s strani Geodetske uprave Republike Slovenije. Ključni postopek izdelave lentikularne karte je 3D modeliranje, ki je bilo izvedeno s pomočjo programskega paketa Cinema 4D, izdaje 14, podjetja Maxon [8]. Obdelava podatkov, potrebna za nadaljnje 3D modeliranje, je bila izvedena s pomočjo programskih paketov ArcGIS 10.1 podjetja Esri [6]in Adobe Illustrator CS3 podjetja Adobe Systems [7]. Končni produkt 3D modeliranja so zajete delne slike (stereopari), ki se v posebnem postopku (angl. interlacing) razdelijo na ozke trakove in ustrezno prepletejo. Rezultat tega postopka je ustrezna slika, ki jo je natisnilo podjetje, specializirano za lentikularni tisk.

P.6.2 Lentikularni prikaz

P.6.2.1 Osnove in zgradba

Lentikularna tehnika je avtostereoskopska metoda 3D vizualizacije, ki se uporablja za prikaze tako na papirju kot zaslonu. S pomočjo večjega števila slik je možna uporaba različnih efektov, ki so razdeljeni v dve skupini: 2D in 3D efekti, prikazani v tabeli 8.

Tabela 8: Efekti lentikularnega prikaza (Vir: [4])

2D efekt	3D efekt	Kombinacija efektov
Nagib	Pravi 3D	Vse kombinacije 2D in 3D efektov
Prehod med prikazi		
Povečava		
Animacija		

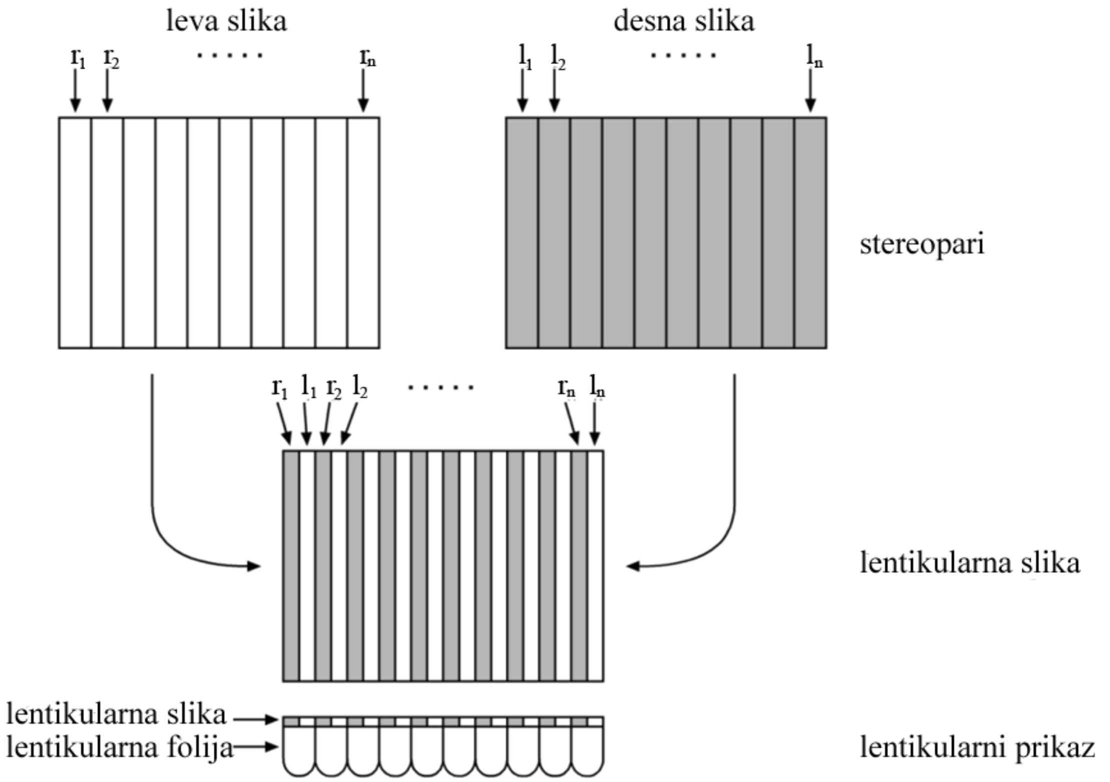
Prostorski vtis, pridobljen iz lentikularnega prikaza, je mogoč zaradi uporabe stereoskopskega vida. Zgradba lentikularnega prikaza omogoča ločitev slik na ustrezni sliki za levo in desno oko. Prostorsko ločitev slik omogoča lentikularna folija. V primeru upodobitve z lentikularnim prikazom opazovalec za pridobitev prostorskega vtisa ne potrebuje dodatnih pripomočkov. Lentikularni prikaz je sestavljen iz dveh komponent:

- lentikularne slike in
- lentikularne folije.

Zgornjo stran lentikularnega prikaza predstavlja lentikularna folija. Lentikularna folija je sestavljena iz vzporednih polcilindričnih mikroleč, ki so lahko poravnane vertikalno ali horizontalno. Poravnava leč je odvisna od uporabljenega efekta. Spodnjo stran lentikularnega prikaza predstavlja lentikularna slika, ki je sestavljena iz ozkih trakov, generiranih iz vseh predhodno zajetih stereoparov. Lentikularna slika je izdelana s pomočjo ustrezne programske opreme [4].

P.6.2.2 Princip

V procesu, imenovanem "interlacing", so zajete delne slike, razrezane na ozke trakove in nato izmenično prepletene v ustreznem zaporedju [4]. Pod vsako lečo lentikularne folije tako ležijo vsi pripadajoči trakovi zajetih delnih slik. Na sliki 10 je podan primer razdelitve slike na trakove za dva zajeta stereopara [11].



Slika 10: Princip lentikularnega prikaza (Vir:[11])

Ločitev lentikularne slike na ustrezni sliki za levo in desno oko je mogoča zaradi optičnih značilnosti lentikularne folije. Polcilindrične mikroleče namreč izostrijo vpadne žarke na določen trak lentikularne slike v odvisnosti od položaja opazovalca. Sprememba položaja opazovalca povzroči izostritev vpadnih žarkov na druge trakove lentikularne slike. 3D zaznavanje z lentikularne slike je mogoče, če je položaj opazovalca pravokoten na lentikularno sliko [4]. Z uporabo večjega števila stereoparov se poveča število možnih paralaks, ki omogočajo prostorsko zaznavo z različnih kotov in položajev. Zato se običajno uporablja večje število stereoparov [11]. Prostorski vid je omogočen na podlagi paralakse. Prostorski učinek je odvisen od velikosti paralakse in tipa paralakse. Večja, kot je vrednost paralakse, večji je prostorski učinek [13].

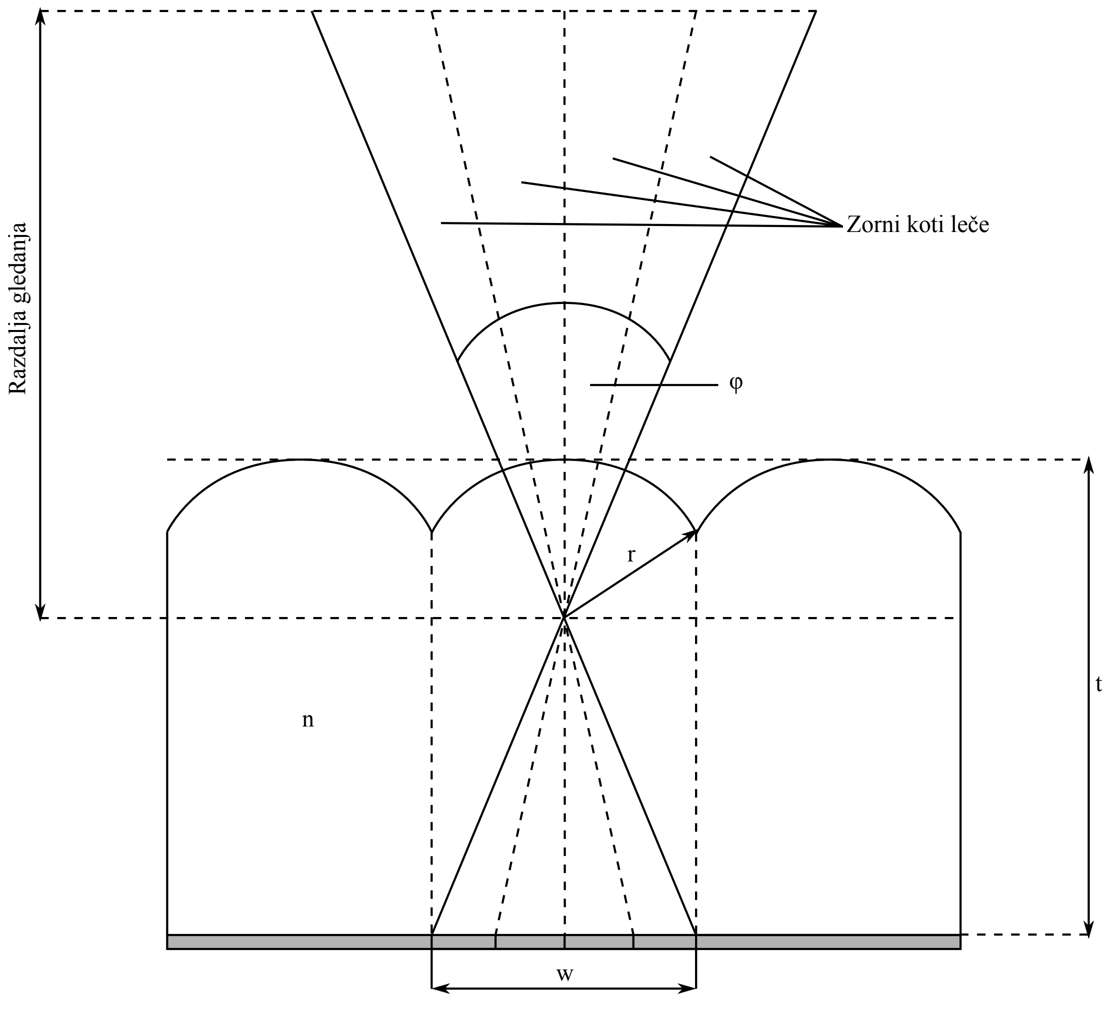
P.6.2.3 Značilnosti lentikularne folije

Zaznava leve in desne slike s pripadajočim očesom na podlagi delovanja stereoskopskega vida je mogoča zaradi vzporednih polcilindričnih mikroleč, ki sestavljajo lentikularno folijo.

Najpomembnejše karakteristike lentikularne folije so:

- gostota leč (število leč na palec) *w*,
- radij leče *r*,
- debelina lentikularne folije *t*,
- zorni kot leče φ in
- lomni količnik *n*.

Parametri lentikularne folije so predstavljeni na sliki 11.



Slika 11: Parameteri lentikularne folije (Vir:[11])

Parametri lentikularne folije so soodvisni in imajo neposreden vpliv na velikost in kvaliteto prostorskega učinka [11].

P.6.2.4 Parametri zajema in geometrije steoparov

Lentikularna slika je najpomembnejši del lentikularnega prikaza. Geometrija njenega zajema posledično določa velikost prostorskega učinka in kvaliteto zaznane slike. Parametri zajema in geometrije stereoparov so za posamezen 3D model določeni s pomočjo ustrezne programske opreme, namenjene 3D modeliranju in predstavitvi.

Poznamo dva osnovna načina postavitve virtualne kamere v 3D modelu:

- Konvergentna postavitev:
  Osi kamer so zavrtene, tako da se njihove osi sekajo v eni točki. Virtualne kamere vseh stereoparov posledično tvorijo simetrične piramide. Pri takšnem načinu postavitve prihaja do popačenj na robovih slike [3].
- Vzporedna postavitev:
  Osi kamer so vzporedne. Kot zajema posamezne virtualne kamere se posledično spremeni in tako kamere vseh stereoparov tvorijo asimetrične piramide. Pri uporabi tega načina ne prihaja do popačenja slike [3].

Najpomembnejši korak v procesu zajema stereoparov na podlagi ustvarjenega 3D modela je določitev parametrov zajema. Parametri zajema določajo geometrijo lentikularne slike in posledično optimalen prostorski učinek, dosežen z lentikularnim prikazom.

$$\Delta p''_{\mathrm{x-max}} = 2\,\Delta z''_{\mathrm{max}}\,\tan\frac{\varphi}{2}, \tag{P.1}$$

največja paralaksna razlika v slikovnem koordinatnem sistemu $\Delta p''_{\mathrm{x-max}}$ je izračunana iz največje zaznane prostorske globine $\Delta z''_{\mathrm{max}}$, iz lentikularnega prikaza in zornega kota leče lentikularne folije φ.

$$\Delta P_{\mathrm{X-max}} = \frac{X}{x''}\,\Delta p''_{\mathrm{x-max}}, \tag{P.2}$$

največjo paralaksno razliko v objektnem koordinatnem sistemu $\Delta P_{\mathrm{X-max}}$ določimo na podlagi širine objekta X, širine slike x'' in največje paralaksne razlike v slikovnem koordinatnem sistemu $\Delta p''_{\mathrm{x-max}}$.

$$Z = \frac{X}{2\,\tan\frac{\beta_{\mathrm{x}}}{2}}, \tag{P.3}$$

širina objekta X in zorni kot kamere β_{x} določata oddaljenost objekta od objektiva kamere Z.

$$B_{\mathrm{max}} = \frac{\Delta P_{\mathrm{X-max}}\,(Z + \Delta Z_{\mathrm{max}})}{\Delta Z_{\mathrm{max}}}, \tag{P.4}$$

največja bazna razdalja B_{max} med skrajno levo in skrajno desno kamero je določena z največjo paralaksno razliko v objektnem koordinatnem sistemu $\Delta P_{\mathrm{X-max}}$, oddaljenostjo objekta od objektiva kamere Z in največjo višinsko razliko objekta ΔZ_{max}.

$$B_{\mathrm{sm}} = \frac{B_{\mathrm{max}}}{N-1}, \tag{P.5}$$

bazna razdaljo stereopara določata največja bazna razdalja B_{max} in število zajetih stereoparov N.

$$f_{\mathrm{k}} = \frac{x''}{X}\,Z, \tag{P.6}$$

goriščna razdalja f_{k} je določena na podlagi oddaljenosti objekta od objektiva Z, širine slike x'' in širine objekta X''.

$$x' = 2\,f_k\,\tan\frac{\beta_x}{2}, \tag{P.7}$$

širina zajema kamere x' je določena z zornim kotom kamere β_{x} in goriščno razdaljo f_{k}.

P.6.3 Izdelava lentikularne karte

P.6.3.1 Območje, uporabljeni podatki in programska oprema

Del Julijskih Alp v bližini najvišje slovenske gore Triglav predstavlja eno izmed najbolj priljubljenih pohodniških poti med slovenskimi planinci in tudi tujimi turisti. Zaradi navedenega so bile planinske poti skupaj z najpomembnejšimi kočami ob njih izbrane za osrednjo vsebino lentikularne karte. Izdelana lentikularna karta je karta formata A4 v merilu 1 : 83 000.

Uporabljeni kartografski viri so bili: digitalni model višin s prostorsko ločljivostjo 12,5 m (DMV12,5), Državna topografska karta v merilu 1 : 50 000 in generalizirana kartografska baza v merilu 1 : 25 000 (GKB25). Vse naštete vire je posredovala Geodetska uprava Republike Slovenije.

V postopku obdelave in priprave prostorskih podatkov, 3D modeliranja in zajema stereoparov so bili uporabljeni ustrezni programski paketi. Vsak od programskih paketov je bil uporabljen za določen korak obdelave podatkov. Uporabljeni so bili programski paketi: ArcGIS, Adobe Illustrator, Cinema 4D in 3DZ EXtreme V7 [19].

P.6.3.2 Priprava in obdelava podatkov

Za pripravo in obdelavo prostorskih podatkov, ki so bili potrebni za nadaljnje 3D modeliranje in vizualizacijo, sta bila uporabljena programska paketa ArcGIS in Adobe Illustrator.

DMV predstavlja osnovni podatek za izdelavo lentikularne karte. Rastrska slika DMV-ja je bila izdelana s pomočjo programa ArcMap iz ASCII zapisa podatkov DMV-ja. Podatki so bili georeferencirani v D48/GK koordinatnem sistemu. Pridobljeni DTM je nato služil kot osnova za izdelavo senčenja. Pri izdelavi senčenja so bile uporabljene privzete nastavitve. Vrednost azimuta je bila 315° in kot osvetlitve 45°. Rezultat izdelave senčenja je rastrska slika, ki smo ji določili 35 % prosojnost. DMV-ju je bil nato določena ena izmed privzetih barvnih lestvic. Naslednji korak je predstavljal vnos topografskih podatkov (naravnih in zgrajenih elementov) iz GKB25. GKB25 je služila kot glavni vir podatkov o vodovju in komunikacijah. Zaradi neažuriranosti GKB25 je bila kot kontrolni sloj uporabljena DTK50. Manjkajoči in neustrezni podatki so bili digitalizirani in spremenjeni na podlagi DTK50. DTK50 je služila tudi kot vir za digitalizacijo planinskih poti. Zaradi velike gostote planinskih poti na prikazanem območju so bile prikazane le najpomembnejše. Na podlagi DTK50 je bil določen položaj koč, vrhov in naselij s točkovnimi znaki. V programu ArcMap so bili definirani tudi linijski simboli, kot je prikazano v tabeli 9. Generiran DTM in topografski podatki skupaj z določeno barvno lestvico so bili izvoženi v obliki rastrske slike z namenom nadaljnje obdelave v programskem paketu Cinema 4D. Točkovni znaki, napisi in naslov karte so bili oblikovani v programu Adobe Illustrator. Narejeni so bili točkovni znaki za prelaz in sedlo, planinsko kočo in višinsko točko (vrh), kot je prikazano v tabeli 9. Izdelani so bili tudi napisi imen vrhov s pripadajočo višino, imena naselij, naslov karte z legendo in podatki o avtorju, virih, izdajatelju in letnici izdaje. Vsi ti podatki so bili izvoženi v vektorski obliki.

Tabela 9: Uporabljeni znaki

Objekt	Znak	Debelina [mm]
Planinska pot	—	0.8
Cesta	—	1.2
Reka, potok	—	1 in 1.2
Planinska koča	⌂	
Prelaz	)(	
Višinska točka	▲	
Naselje	⊙	

P.6.3.3 3D modeliranje

Za zajem stereparov je potrebna izdelava 3D modela območja. 3D modeliranje je bilo izvedeno v programski opremi Cinema 4D, namenjeni 3D modeliranju in predstavitvi. 3D model je bil izdelan na podlagi črno-bele rastrske slike DMV-ja z reliefnim objektom, definiranim v Cinemi 4D. Izdelanemu 3D modelu je bila nato dodana tekstura. Teksturo je predstavljala rastrska slika z barvno lestvico in ostalimi topografskimi podatki. Naslov z legendo je bil prav tako izdelan na podlagi teksture. Napisi in topografski znaki, oblikovani s pomočjo Adobe Illustratorja, so bili uvoženi v Cinemo 4D v vektorski obliki. Napisi in topografski znaki so bili pozicionirani v 3D model posamično in ročno, kot je predstavljeno v tabeli 10.

Tabela 10: Pozicioniranje posameznih objektov glede na relief

Podatki	Položaj glede na relief	Vrsta pozicioniranja
rastrski podatki	identičen z reliefom	avtomatično
komunikacije, vodovje	identičen z reliefom - združeni z rastrskimi podatki	avtomatično
planinske koče	skoraj identičen z reliefom	ročno
imena vrhov, višinske točke	malo nad reliefom	ročno
imena naselij in simboli, imena vrhov, višinske točke, naslov, podatki, legenda	lebdeče nad reliefom - pozicionirano na goriščno ravnino	ročno

P.6.3.4 Generiranje stereoparov

Virtualna kamera omogoča zajem stereoparov izdelanega 3D modela. Za 3D upodobitev smo uporabili 3D stereo kamero, ki je ena izmed privzetih možnosti izbire kamere v programu Cinema 4D. Kamera objekti v Cinemi 4D omogočajo nastavitev različnih parametrov, ki so bili za generiran 3D model izračunani na podlagi enačb v poglavju P.6.2.4. Izračunane vrednosti parametrov za izdelan 3D model so predstavljene v tabeli 11.

Pozicioniranje virtualne kamere je pomemben korak v postopku 3D modeliranja. Za obravnavano območje je bila izbrana vzporedna postavitev virtualne kamere, pri kateri so osi kamer vzporedne. Pri nastavitvi parametrov kamere je pomembna razporeditev objekta v prostoru, ki se določi z določitvijo položaja goriščne, bližnje in oddaljene ravnine. 2/3 3D modela mora v prostoru ležati za goriščno ravnino in 1/3 modela pred njo. Končna kvaliteta lentikularnega prikaza je tako odvisna predvsem od parametrov lentikularne folije, števila stereoparov in njihove resolucije. Glede na izbran A4 format lentikularne karte je bila uporabljena lentikularna folija z resolucijo 62 leč na palec in zornim kotom leč 42°. Generiranih je bilo 19 delnih slik.

Tabela 11: Parametri lentikularne karte

Parametri lentikularne karte	
širina karte x''	210 mm
višina karte y''	297 mm
največja zaznana prostorska globina $\Delta z''_{\text{max}}$	12 mm
število stereoparov N	19
zorni kot leče φ	42°
Prametri objekta	
širina objekta X	17430 m
višina objekta Y	24651 m
največja višinska razlika objekta ΔZ_{max}	1577 m
Prametri virtualne kamere	
snemalni kot kamere β_{x}	50 °
goriščna razdalja f_{k}	22,517 cm
Izračunani parametri lentikularne karte	
največja paralaksna razlika (karta) $\Delta p''_{\text{x}-\text{max}}$	6,14 mm
največja paralaksna razlika (objekt) $\Delta P_{\text{X}-\text{max}}$	509,77 m
oddaljenost objekta od objektiva kamere Z	18689,38 m
največja bazna razdalja B_{max}	6551,19 m
bazna razdalja stereopara B_{sm}	363,955 m

P.6.3.5 Test resolucije lentikularne folije in razdelitev slik na trakove

Resolucija lentikularne folije določa gostoto lentikularnih leč na enoto. Vsaka lentikularna folija ima podano resolucijo, ki pa ni nujno, da se ujema z navedeno. Pred postopkom razdelitve slik na trakove je tako treba izvesti test resolucije lentikularne folije, imenovan "pitch test", s katerim se določi točno gostoto leč na enoto. Ko je dejanska resolucija določena, sledi razdelitev generiranih slik na trakove in njihovo prepletanje [23], [2]. Razdelitev slik na trakove je bila izvedena s programsko opremo 3DZ EXtreme V7. Ker je ta postopek predpriprava za tiskanje lentikularne slike, jo je izvedlo podjetje, ki je karto natisnilo.

P.6.3.6 Tiskanje

Tiskanje lentikularne karte je glavni cilj njene izdelave. Za tiskanje lentikularne karte je potrebno predhodno generiranje ustreznega števila stereoparov in izvedba razdelitve slik na trakove ter njihovo prepletanje. S tiskanjem lentikularne karte je dosežena združitev lentikularne slike in lentikularne folije. Za tiskanje lentikularih prikazov sta v uporabi dva načina:

- direktno offset tiskanje in
- tikanje na poseben substrat.

Za tiskanje lentikularne karte osrednjega dela Julijskih Alp je bil uporabljen način tiskanja lentikularne slike na poseben substrat. Lentikularna slika je bila natisnjena na poliesterski substrat, ki je bil izbran zato, ker vzdrži vplive vlage in toplote ter se tako med tiskanjem minimalno deformira. Deformacije natisnjene lentikularne slike ne smejo presegati omejitev, saj lahko povzročijo neujemanje lentikularne slike in lentikularne folije in posledično izgubo prostorskega učinka. Lentikularna slika je bila natisnjena z brizgalnim tiskalnikom z resolucijo 1200 PPI. Lentikularna slika in lentikularna folija sta bili združeni z lepilom, vsebovanim na dvostranski samolepilni foliji [21]. Opisani način tiskanja je bil aktualen zaradi majhnega števila izvodov karte.

P.6.4 Zaključek

Izdelana lentikularna karta osrednjega dela Julijskih Alp je prva lentikularna karta tega območja v večjem merilu. Natisnilo jo je nemško podjetje Digi Art v sodelovanju s čilskim podjetjem 3D Facts v 60 izvodih.

Ostrost objektov, ki sestavljajo lentikularno sliko, in velikost zaznanega 3D učinka sta tesno povezana. Določitev optimalnega razmerja med velikostjo 3D učinka in ostrostjo objektov je posledično najpomembnejši korak pri izdelavi lentikularne karte. Kljub najbolj optimalni razporeditvi objektov v 3D modelu, najvišje in najnižje pozicionirani objekti niso bili upodobljeni popolnoma ostro. Neostrost teh objektov, prikazanih na lentikularni karti predstavlja največjo slabost lentikularnega prikaza in je posledica optičnih značilnosti virtualne kamere. Vendar glede na ostale prednosti, ki jih njegova uporaba ima, lentikularni prikaz predstavlja zadovoljiv prostorski učinek v primerjavi z neostrostjo nekaterih objektov.

REFERENCES

[1] Buchroithner, M. F., Knust, C. 2012. True-3D in Cartography - Current Hard- and Softcopy Developments. In: Moore, A., Drecki I. (Eds.). Geospatial Visualisation, Lecture notes in geoinformation and cartography. Berlin, Germany: Springer, pp. 41-65.

[2] Gründemann, T. 2004. Herstellung einer Echt-3D-Hochgebirgskarte auf der Basis des Lentikularverfahrens. Diplomarbeit. Dresden, Technische Universität Dresden.

[3] Buchroithner, M. F., Habermann, K., Gründemann, T. 2004. True-3D visualisation of mountainous terrain by means of lenticular foil technology: proceeding of the 4th ICA Mountain Cartography Workshop, Vall de Nuria, Catalonia, Spain, 30 September-2 October 2004.

[4] Buchroithner, M. F., Gründemann, T., Randolph, K. L., Habermann, K. 2005. Three in one: Multiscale Hardcopy Depiction of the Mars Surface in True-3D. In: Photogrammetric Engineering and Remote Sensing 71, Nr. 10, pp 1105-1108.

[5] Bruhm, K., Buchroithner, M.F., Hetze, B., Gindele, M. 2012. True-3D visulaisation of glacier retreat in the Dachstein massif, Austria: Hard- and softcopy displays. In: Buchroithner M.F. (Eds.). True-3D in Cartography, Autostereoscopic and solid visualisation of geodata. Berlin, Germany: Springer, pp. 105-117.

[6] ArcGIS software. 2013.
`http://www.esri.com/software/arcgis`. (Accessed May 29, 2013.)

[7] Adobe Illustrator software. 2013.
`http://www.adobe.com/products/illustrator.html`. (Accessed May 29, 2013.)

[8] Cinema 4D software. 2013.
`http://www.maxon.net/`. (Accessed May 29, 2013.)

[9] Bektas, K., Cöltekin, A., Straumann, R. K. 2012. True-3D in Cartography - Current Hard- and Softcopy Developments. In: Buchroithner, M.F. (Eds.). True-3D in Cartography, Autostereoscopic and solid visualisation of geodata. Berlin, Germany: Springer, pp. 43-66.

[10] Buchroithner, M. F., 2012-2013. Lecture notes. True-3D Cartography. Technische Universität Dresden.

[11] Gründemann, T. 2004. Grundlagenuntersuchungen zur kartographischen Echt-3D-Visualisierung mittels des Lentikularverfahrens. TU Dresden, Studienarbeit. Dresden, Technische Universität Dresden.

[12] Okoshi, T. 2011. Three-Dimensional Imaging Techniques. Atara Press; 2nd edition.

[13] Minoli, D. 2011. 3D television (3DTV) technology, systems, and deployment : Rolling out the infrastructure for next-generation entertainment. Boca Raton [etc.]: CRC Press.

[14] Knust, C., 2007. Konzeption eines digitalen historischen Globus für den Mathematisch-Physikalischen Salon zur Visualisierung an einem 3D-Display. Studienarbeit. Dresden, Technische Universität Dresden.

[15] Bos, J. F. 1993. Liquid-Crystal Shutter Systems for Time-Multiplexed Stereoscopic Displays. In: MacAllister, D.F. (Eds.). Stereo Computer Graphics and Other True 3D Technologies. Princeton, NJ : Princeton Univ. Press, pp. 90-118.

[16] Polarisation technique. 2013. http://www.chip.de/artikel/3D-TVs-im-Technik-Duell-Polarisation-versus-Shutter-2_51183986.html. (Accessed May 2, 2013.)

[17] Buchroithner, M. F., Schenker, R., Kirschenbauer, S. 2000. 3D display techniques for cartographic purposes: Semotic aspects. In: International Archives of Photogrammetry and Remote Sensing. Vol. 33. Part B5, pp. 99-106.

[18] Surveying and mapping authority of Slovenia. 2013. http://www.e-prostor.gov.si/zbirke_prostorskih_podatkov/topografski_in_kartografski_podatki/topografski_podatki_in_karte/. (Accessed May 8, 2013.)

[19] 3DZ EXtreme V7 software. 2013. http://www.lenticularsoftware.de/beschreibungen/extreme/index.htm. (Accessed May 29, 2013.)

[20] ArcGIS help. 2013. http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html. (Accessed May 9, 2013.)

[21] Wander, B. 2013. Lenticular map. Message to: Wander, B. 13.5.2013. Personal communication.

[22] Cinema 4D R14 Student, Help, MAXON Computer GmbH, 1989-2013

[23] Pitch test. 2013.
http://www.vuethru.com/index.html. (Accessed April 30, 2013.)

[24] Digi Art. 2013.
http://www.lenticularsoftware.de/. (Accesed May 14, 2013)

[25] Gründemann T., M., Habermann, K. 2012. Autostereoscopic maps on the basis of lenticular foils. In: Buchroithner, M.F. (Eds.). True-3D in Cartography, Autostereoscopic and solid visualisation of geodata. Berlin, Germany: Springer, pp. 97-103.

APPENDICES

APPENDIX A: 2D map of the Central Julian Alps (75 % of the original size)

THIS PAGE IS INTENTIONALLY LEFT BLANK

TA STRAN JE NAMENOMA PRAZNA

APPENDIX A:

2D map of the Central Julian Alps (75 % of the original size)