DISPOSITION OF THE DOCTORAL DISSERTATION

1. Title

DEVELOPMENT OF TECHNOLOGICAL SOLUTION FOR TRANSFORMATION OF CLASSIC FINE ART INTO 3D DIGITAL FORMAT

RAZVOJ TEHNOLOŠKE REŠITVE ZA TRANSFORMACIJO DEL KLASIČNE UMETNOSTI V 3D DIGITALNI FORMAT

2. Doctoral dissertation scientific field

In wider sense of meaning, the proposed topic for doctoral dissertation relates to the scientific field of information and graphic arts technologies, while more precisely defined it deals with software and hardware development that will enable translation and interpretation of the related analog classical arts into 3D digital artistic works.

3. Definition of the research problem

The classical paintings cannot be the same at the canvas and in a digital representation, and contrary to digital the classical paintings have perspective, fine texture and great spectre of colour tones. The technology and tools for the transformation of classical fine art into digital format should be conceptualized to enable transfer from the analogous into digital art almost 1:1 meaning and designed for recognition of all morphological, shape and colour properties of the painting (shades, textures, thickness of the colour layers), and, nevertheless, artist`s style. When digital format is meant to be an intermediate medium, the process has to continue so that the digitally generated model can be reinterpreted again into the physical, analog form, i.e. the physical 3D interpretation of the classical piece of art that enables complete transfer of the identity of a certain painting, its augmentation and optimisation of user experience. Painters and designers often use analogous and digital techniques in their creative work applying also tools for digital production of paintings. The results of digital interpretations of paintings are usually unsatisfactory and consequently the research problem in the field is widely opened. Namely, the software and technology should offer solutions that match to the maximum possible extent a digital product with classical one. This is important not only for the users without disabilities, but also to enable blind and visually impaired people to feel all characteristics of the classical paintings. Therefore, the initial motivation for the development of the solution should be an integration of accessibility on technological, applicative and experiential level. Software program applications in modeling and concept of transfer, from 2D to 3D form is quite spread today. They are linked with fields such as architecture, video games, animation, plastic surgery, marketing, art, civil engineering, mechanics, etc., where it is necessary to use conceptualization strategies, tools and technologies that enable the optimisation of time and afford spent in working process. The basic deficiency of classical programs existing on the modeling market, such as 3ds Max or AutoCAD, is that these solutions cannot recognize entered analogous picture or photograph with its all visual characteristics imported through any .bmp, .tiff or .jpg format. On the contrary, the technology that will be developed in the presented research will be a new approach that will fully recognize entered photograph and all visual, texture, shape and stylistic characteristics of an artwork. The main problem with the modeling programs on the market is that they are not capable of transferring holistically the identity of analog artistic works in digital format. They can be categorized into 1) vector programs enabling modeling; 2) bitmap programs processing pictures or photographs using filters and other ways. Both types of software have certain disadvantages in *analog to digital* transformation approach. Except form surface filtering resulting in limited digital representation, the existing solutions cannot define optimally and comprehensively an analogous painting done by some artist and do not provide its further elaborateness.

Research problem

The technology for transformation the classical fine art into digital 3D format has to recognize an identity of a classical painting by scanning, recognising and interpreting all the properties such as hue, saturation and brightness of colours, shape, composition, texture and author’s style. The software has to be capable of fully interpret the identity in digital format and offer the optimal 3D digital interpretation that can be further again expressed in physical (3D printed) form.

Aim of doctoral dissertation

The aim of the research is to develop the workflow and technology of transferring classical art into digital one through concept creation of new PainterCad program. The program will fully transform and interpret the classical fine art into digital 3D format with the preservation of the identity of classical fine artworks.

This brings a revolutionary act into the art, introducing systematic changes into the classical art in form of 3D palpable pictures. Results, i.e. 3D digital interpretations of the analog classical paintings, will be defined and evaluated in order to validate the implemented transformation methodology from classical to digital art form through the use of PainterCad program. Evaluation of the program’ success fullness and its products in the form of 3D palpable pictures will be given by the defined target groups and users with disabilities (blind and visually

impaired people). The results will be an original scientific contribution in the field of information and graphic arts technologies, communication technologies development and 3D technology solutions that will offer understanding and guidelines for the further development of the technologies for digital documentation, presentation and interpretation of classical fine art.

4.Presentation of the researches in the field of the identified research problem

State of the art technology and methodology analysis includes the following fields:

1. Analysis of scanning, optical laser and OCR (optical character recognition) sonar approaches;
2. Analysis of the systems for image processing and face recognition;
3. Analysis of hyper-spectral camera solutions;
4. Analysis of the 3D modeling solutions;

Software is a set of computer programs and accompanying data that taken together give instructions to the computer hardware. The software is composed of all programs and data in the computer including operational content (Kiš, 2000). When developing any program, it is necessary to apply four basic phases: 1. Analysis and precise definition of the problem;2. Algorithm creation (drawing flow diagram); 3. Writing program`s code in some of the program languages; 4. Entering the program`s code into the computer, testing and errors removing (Grbovac, 2010). The program ArchiCAD applies the modeling techniques that already contains created models of the tables, chairs etc., in order to save the time with detailed design. Other analyzed program, the Revit, similarly to the AutoCAD, has different modeling approach, where two- dimension line determines a shape of certain type of selected model and allow certain freedom in the form creation of already processed models like wall, table, chair (Omura, 2017). The universal modeling program 3DsMax is done in a way that it is possible to endlessly outline all shapes including their creation. It provides additional programming and installation of supplements allowing more quality modeling in a way the user wants (Ticko, 2009).

Method and system of the colour scanner includes creation of endless scope for digital colours entering (Shiel, 2010). This discovery provides many improvements embedded in the optic laser scanning and offers small micrometer for the laser scanning for manual versions on the basis of these improvements. Moreover, the discovery relates with offering of the larger accuracy and additional characteristics for traditional existing measures of scanning while it minimizes design problems. Budelski et al. presented a scanning solution that offers dramatically increased accuracy in the measuring area that compares diameters in relation with edges (Budelski, 2014). Cossairt presented the angular scanner of electro-magnetic radiation with reduced thickness includes optical two-dimensional (2D) source of the picture and scanning set including the first optic and second optic (Cossairt, 2014). Today, on the market, is possible to find scanners for the microscope. This scanner includes a unique unit of the casing including at least one lens, one camera for the line scanning, at least one communication port, and one processor. The processor can smooth many pictorial pixels in the near-by picture at least one part of the sample executed by the web server securing operational interface through the network (Dirk, 2014). There are many scanners on the market with numerous software packages dealing with collection, processing and visualization of data, but existing knowledge are fragmented in different publications, printed or electronic. Lidar is an optical measuring instrument sending laser rays that reflect from very small particles spread in the atmosphere of the Earth (aerosol, cloud`s drops, etc.) and then register in the optical receiver inside Lidar (Carolus, 2014). Optical surface (OS) scanning is an approach that scans contours of the face of a patient in vertical position using the mobile scanner of the Artec MHT generation. This scanning is responsible for reconstruction of the 3D geometry (of face, pictures and objects) (Frey, 2018). Digital workflow and media development including 3D sculpture and 3D face reconstruction is basic problem of computer vision of extreme difficulty. Convolution neuron networks (CNN) are set of data containing 2D pictures, 3D models and scanning. CNN work with one 2D cheek of the face and can be used for reconstruction of entire 3D geometry of the face. This complex process is used by professions such as medicine, architecture, archaeology, painting (including not-visible parts of the face) (Jackson, 2017). The most recent research about perception of the face dynamics is a subject significant for the cognitive and computing sciences. The face recognition is a fundamental visual function that includes social interaction and communication (Giese, 2013). The purpose of the study in stomatology was the identification and comparison of the scanning strategy with the best accuracy in the sense of efficiency and exactness of four scanners for the impression of the entire teeth vault. The four digital scanners were applied 3D measuring software using very precise referential model obtained from the industrial scanner. This study can also be transferred to the field of art and design by scanning 3D models (Medina, 1989). Approach for the 3D objects making, with high authenticity using RGB-D scanning is one another accepted way of scanning for 3D models (Yang, 2018). In this paper, facades at the streets as a modeling method were applied. The street model is represented as a sample, as subject of the study. 3D modeling is embedded in photogrammetric in direct volume of data with combined calibration applying data of the land laser scanner in compatible way. In addition to the optic scanners that are applied for different kind of objects reconstruction, the laser scanners have important role in 3D modeling (Ergun, 2009). In order to scan very short gamma waves that cannot be visible to the eye and for authenticity and accuracy of recording of various details there was examined sensitivity of rotation-symmetric thicknesses with gamma waves recording using geometric algorithm and numerical simulations. Effect of a hole`s diameter, thickness of the rectangular part and semi-cones

angle have been analyzed. It has been showed that spot source was substitution for homogenous plane through theoretical deduction, numerical calculations and experimental measuring of sensitivity depending on the angle. Small quasi-point source was founded on the basis of 10K source level 60Co gamma rays in the experimental measuring of the sensitivity dependable on the angle (Zhang, 2018). With one realization of the discovery it is used the process of scanning-updating in order to compress unknown cardinality into the meter value that counts binary number in bitmap vector (Aiyou, 2015). In order to transform the analog art into digital one, it is necessary to scan analogous works, what is possible with the use of the scanners such as optical laser, OCR, sonar (sound navigation ranging), or microscopes. In order to provide detailed and accurate recognition of defined object or picture, sensor set or optic colour scanner is applied that possesses three different lines of optic sensors. Two of three sensor lines have colour filters and one is not-filtered. The optional filter of white channel secures accuracy if the light source has significant wave lengths out of the human visual scope; in other words, this way enables recognition of endless number of colour shades (Wayne,1998).

In addition to scanning having important role of transformation from one to another media, the transformation can be done using hyper-spectral recording. The spectral and hyper-spectral imaging are used in processing due to examination of historical inscriptions and texts, manuscripts analysis, ink identification and segmentation of given text in order to preserve the heritage (Karning, 2012). The hyper-spectral cameras were recently developed and aimed the production of spectral photometers for recording reflexive specters on the individual locations of pixels. In the process, the computational comparisons of linearized RGB in hyper-spectral camera, conditions of their individual capacities to discriminate targeted colours of different perceptual colours that are similar are performed in order to remedy errors (Jair, 2016). Segmentation of the hyper-spectral medicinal images is one of the many segmentation method approaches requesting profiling. This profiling means either adjusting the existing well-known methods of image segmentation or new method proposal of image hyper-spectral segmentation (Koprowski, 2016).

The spectral recording is also in use with microscopes when examining pathological samples (Fong, 2018).

In medicine diagnosis (abdomen cancer) the system of endoscopic light for recording stereoscopic images is applied and the light system includes the light source from several spectral lights. Besides in medicine, this recording lighting system is also used in the field of digital art. The first and second path of the light are configured for the multi-layered light transfer with digital sequence of mirrors (DMA) accepting and directing multi-spectral light (Hohman, 2016). In the field, a hybrid method was introduced for fast measuring of technical data, three-dimension (3D) geometry of buildings providing a virtual presentations of energy performances of existing objects (Vang, 2013). Clinton et al. presented the discovery that relates to the image processing technique that is used on the monitor screen or printer from documents. Data about documents the software executes for the text or application processing are embedded in the expression for drawing with sequence of commanding data including at least one of the pictures and images (Clinton, 2014). Image processing system for generating control signals for printing means, from source image data from an image source, comprising a raster image processing and layout module configured to convert said source image data into a first lane bitmap element and a second lane bitmap element. The incentives of one photo are converted into several types of data (RGB, RAW..) (Jurgen, 2015). The process of joining many digital pictures includes extraction of details from digital pictures combining values of pixels by many digital pictures for generation of combined digital pictures (Jinghong, 2014). In the field of optic recognition of the character (also optic reader of the character, OCR), a solution Orthophone should be mentioned, developed by Edmund Fournier d`Albe. Orthophoneisa manual scanner that produces sound when cross over the page, and such tones match specific letters or images. (Monga, 2013). Computer readable medium for recoding keeps control program of the printer that causes the computer functioning as: unit for PDL conversion and configured in a way to transfer data about any drawing received from the application in PDL data; rasterization unit configured in a way to transfer at least one textual object and vector objects in raster of objects when drawing`s data are transferred into PDL data; and control unit for communication configured for the PDL data transfer into device for the picture formulation (Yoshiyuki, 2014). The power of algorithms requests research to examine if they can work on not-structured data. All that contains text in any format used presently, PDF, table, data file, picture, and video can be converted into the format that API can use (Copyright Hewlett Packard Enterprise Development LP, 2019). Author Tomohiro presents a patent where an image forming apparatus includes a reading unit that reads image data. This apparatus includes a drawing data storage unit that stores object data comprising the read image data so as to allow the stored object data to be distinguished between a vector object and a raster object, a vector gray determination unit that determines whether each of stored vector objects is formed of an achromatic colour, a raster gray determination unit that determines whether each of stored raster objects is formed of an achromatic colour, and an output data creation unit that converts the stored object data into multi-colour when the stored object data includes a chromatic colour and converts the stored object data into monochrome when the stored object data is formed only of achromatic colours. This patent has a close connection with program PainerCad in identifying object (Tomohiro, 2014). Authors Gerritset al developed a device for the picture creation including a unit for reading that can read data about such picture, unit for saving data about drawing that saves data about object containing data for reading the picture in order to enable differentiation of data about saved objects between vector and raster of the object (Gerrits,2014). Current solutions are directed to colour systems and methodologies for printing, presenting and especially the colour characterization. In the present-day business and scientific world, the colour has become

essential component of communication. The colour facilitates exchange of knowledge and ideas. Companies involved in the digital systems development for painting colours permanently look for modes of improving total quality of the image of their products. One of the elements influencing the quality of the picture is possibility of consistent creation of the same quality of the picture on the printer (Mrav, 2014). Although3D printers use different materials and techniques, they share ability to turn digital data base containing three-dimensional data – regardless they were created on CAD (computer design) or CAM (computer product) programs, or 3D scanner into physical objects (Ziff, 2015).3D art and 3D objects' presentations slowly come into domination in comparison with all former disciplines in the field of art and information – communication technologies. Therefore, in the age of electronic devices and new technologies, traditional imaging is substituted by dynamics containing hyper-space, animation and more graphic interactive characteristics. Digital and interactive media differentiate in comparison with traditional, passive media especially when interaction in communication is included (Hsu, 2012). One of the experimental tools for the applicability examination of interactive 3D maps is also a solution 3DmoveR. The main aim of the tool is to record position and orientation of the camera between moves of the user inside the virtual 3D scene together with other aspects of users' interaction (Rezník, 2014).

An interesting research including 3D design and printing was presented also at student medical centre that is responsible for invention of solution for the practical problem applying technologies. This innovative laboratory works on two accessible and tactile projects applying 3D printing. The first project deals with geometry visualization, forms and measuring graph that can be a challenge for blind students. The second project is an attempt to fill the void in tactile interaction and learning from histological images. The end result of the mentioned project work is tactile libraries (Mairn, 2018).

It is a man`s need to present a product of the program through one new innovative way in third dimension and to make it accessible to the target groups such as blind and visually impaired people. In addition to this target group, the technology solutions are also intended for other target groups or individuals. After the literature examination it is obvious that domains of the technology and tools development for the transformation of classical art into digital art, and entire workflow starting with scanning, processing to the design and production of the final product, i.e. 3D product, is still quite unexplored. With the consideration of the findings from the review of the references connected with the identified research problem, it was discovered that the research topic, i.e. technology development for transformation and interpretation of classical fine art into digital form, is widely open for further consideration.

5.Research hypotheses and methods

Considering the identified research problem, the following hypotheses can be assumed:

1. Development of the new technology, i.e. PainterCad program, including adaptation of algorithms for transforming specifies and characteristics of the analog art into digital interpretations, positively affects the workflow making it accessible and more optimized, with effective results of accessible digital and 3D physical interpretations of analog artworks that will be demonstrated through the practice.
2. Newly developed technology and tools will influence the speed of modeling, its performance and on the 3D model appearance.
3. PainterCad program will enable transformation of the classical art and complex processes of appropriation (how aesthetic of the classical art is used in the digital era) through scanning analogous pictures. The results will be complex digital 3D models.
4. PainterCad will be capable to computationally reinterpret the aesthetics of materials of the analog (old) art and to present these interpretations as emancipated screen pictures. Moreover, the software will enable the preparation and optimisation for 3D printing, i.e. design of a new physical form and digital interpretation.
5. 3D model appearance as the final result of the implemented methodology for the transformation of the classical art into 3D digital reproduction positively affects users and potential buyers of the artworks on the market.
6. Existing software solutions are less optimised as the newly developed technology. They have disadvantages regarding import of the analogous formats of the artworks and implemented scanning, processing and production of the final product are more time consuming .With the newly developed PainterCad, the import of the analogous formats will be simplified, the identity of the artworks will be fully recognised and quality reproduced, first, in digital form and, second, in new physical 3D interpretation (3Dprinting).
7. Digital (3D) interpretation spaced through media (television, internet, social media) are due to their flexibility and adaptability more accessible, engaging and more available to contemporary users than analogous artwork slinked to the past time.

8. The module for 3D printing that will be implemented in the technology will be adapted to the tactile approach in the form of fine textures, shapes and artistic style and will make the 3D objects (3D interpretations of classical artworks) recognizable and understandable by the blind and the visually impaired users.The following methods will be used in this research:

1. Review and analysis of the existing software and solutions for 3D modeling and processing the pictures such as 3ds Max, AutoCAD, Photoshop andIllustrator.2. Planning, development and application of the software.

Development means the essence of the program development, its purpose and structure; the user interface design of the solution PainterCad in accordance with the defined target groups. 3. Review and analysis of the hardware to enter (importing) the classical pictures, scanner, hyper-spectral cameras, 3D scanner, sonar, and hardware for exporting digitally processed program through 3D printer, CNC, 3D robot for application of all kind of materials (e.g.apiscor). 4. Development of the hardware with the optimized import of the classical fine artworks and quality transformation of input data in 3D digitalformat.5. Development of the algorithm set and program recording process for automatic processing of imported data. Producing proposition of algorithm tools for processing imported files. 6. Producing proposition of algorithms for exporting processed data files toward external hardware for 3D printing or presentation software through user interfaces on the computer monitor, mobile devices, etc. 7. Development of the module with in the software to enable accessibility of the solution. The technology will enable the users to effectively process their own manual sketches or pictures in digital 3D format and to send them to the 3D printer for the production of 3D physical objects. In this way the technology will support target users as blind and visually impaired users and professional designers during the transformation of their sketches into the 3Dmodels. 8. Exhibition of the 3D digital interpretations in the prototype of virtual gallery and exhibition with the presentations of 3D printed interpretations of classical fine artworks. 9. Evaluation of the results of digital 3D interpretations and 3D printed objects : usability testing and the evaluation of the user experience (selected evaluation approaches: issue-based, self-reported and performance metrics).

6. Expected results and contribution to science

The result of the research will be the newly developed technology that will enable the effectively importing of any picture or drawing of classical fine art and optimal recognition of the colours, textures and surfaces of the artwork. Therefore, the identified artworks' characteristics will be transformed into grouped layers obtaining direct link between the analogous picture and its digital form.

The solution will authentically and comprehensively represent the analogous pictures to the audience in 3D form through processing that includes tools, scanners, hyper-spectral cameras, OCR devices, and similar scanning systems that will be implemented in the technology. The final product of the approach will be collection of 3D models with all compositional, textual and coloristic elements that are present on the imported and scanned analog artworks and processed by the algorithms and hardware technology.

The part of the software within the program will reinterpret the analogous picture through scanner and will fully transform the analog identity into the digital format. In the solution all possibilities of importing the processing through different types of scanners will be elaborated until getting digital database of products. In the database each art work will be registered and presented in the virtual gallery so that it will be available and accessible to the defined target groups. The time component will be important, and the optimization of the workflow will be the main contribution of the research. The newly developed technology, i.e. PainterCad, will be capable of quality, effectively and optimal recognition and transformation of imported image data and formats and will aim to 3D digitally represent and 3D print the product with detailed specifications representing classical analog painting. Consequently, the processing time of certain model will be significantly reduced.

The presented dissertation will contribute to the science particularly by deepening theoretical base and understanding scientific expertise in the field of emerging and development of the tools in the field of information and graphic arts technologies including the improved comprehension of the transformation process from 2D art into 3D art. The new solution PainterCad will represent the innovation in contemporary modelling approach. Therefore, the results will facilitate the working processes indifferent professional fields, i.e. archaeology, art history, architecture, plastic surgery, enabling to the professionals optimal user experience, saving time, efficient workflows and more quality final results.

In addition, the results of this innovative workflow will facilitate the accessibility of the technology, enable the optimal usability of the 3D presentations and improve the experience of the blind and visually impaired users.

Marija Jevtić Ljubljana, januar 2019

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