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Expert System for Supporting the Construction of Three-Dimensional Models of Objects by the Photogrammetry Method

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ABSTRACT The task of building high-quality three-dimensional (3D) models of objects is relevant, since such 3D models are widely used in various fields of science, technology and medicine. In this work, the construction of 3D models is performed by the photogrammetry method, which consists in the construction of a 3D model of an object based on a series of its photographs. The advantages of the photogrammetry method are low hardware requirements and relatively high accuracy. To build 3D models of objects by photogrammetry, the 3DF Zephyr program was used, which contains a set of tools for pre-processing images, reconstructing 3D models, editing and measuring the dimensions of 3D models, and exporting the obtained models. The principles of building three-dimensional models of objects by the method of photogrammetry based on initial images are considered. The main stages of building 3D models are described: calculation of sparse point cloud, key points, dense point cloud, polygon grid, texture grid. Model parameters are also edited and analyzed. An expert system was developed in the CLIPS environment to select the correct modes for building a 3D model. The knowledge base of the expert system contains production rules that allow you to establish the correct modes of building a 3D model based on the initial facts. 30 facts-conditions have been developed that describe the conditions for building a three-dimensional model. 20 facts-consequences and 15 facts-recommendations for building a 3D model have been developed. Using the developed rules, 36 production rules were built. Experimental verification of the developed system was carried out. Three-dimensional models of objects were built using the 3DF Zephyr program. After entering the facts that describe the process of obtaining the model into the expert system, a number of recommendations were obtained, in particular, to increase the area of textured surfaces and use uniform lighting of objects. After following these recommendations, the model was built with satisfactory accuracy.

KEYWORDS expert system, CLIPS, 3D model, photogrammetry, 3DF Zephyr.

I. INTRODUCTION

Three-dimensional (3D) models of objects are currently widely used in various fields of science, technology and medicine [1-2]. For example, 3D models of buildings, architectural monuments and landscapes are used in architecture and construction. Digital terrain models are used in geography and cartography. 3D models are built using laser scanners (LIDAR) or photogrammetry based on a series of photographs. Laser scanners (rangefinders) create models with high accuracy, but their disadvantage is significant cost. The advantages of the photogrammetry method are low hardware requirements and relatively high accuracy [2]. One of the effective programs for building 3D models of objects using the photogrammetry method is 3DF Zephyr. 3DF Zephyr contains a set of tools for pre-processing images (masking), reconstruction of 3D models, editing and measuring the dimensions of 3D models, exporting the received models in specified formats, etc. The problem is that accurate models can be obtained using the photogrammetry method only with the correct selection of the object angles, positions and orientation of video cameras, as well as with optimal lighting conditions and construction of a 3D model. Therefore, the goal of the work, which consists in the development of an expert system to support the construction of 3D models of objects by the photogrammetry method, is relevant. Due to the recommendations of the expert system, it is possible to eliminate shortcomings in the construction of 3D models of objects and improve their quality.

II. PRINCIPLES OF BUILDING THREE-DIMENSIONAL MODELS OF OBJECTS USING PHOTOGRAMMETRY

The method of photogrammetry consists in determining the shape, size and position of objects in space by measuring and analyzing their photographic images [2, 3]. In the photogrammetry method, images of the same object are obtained from different angles using two or more cameras (Fig. 1). On the received images (I1, I2), the positions of special or key points (for example, object boundaries) are determined by software. After that, the key points of one image are combined with the key points of another, for example, each key point abcd (Fig. 1) is matched with the key point a'b'c'd' of another image. Therefore, knowing the position and orientation of the cameras, it is possible to determine the geometric coordinates of the points ABCD of the object as intersections of the corresponding lines.

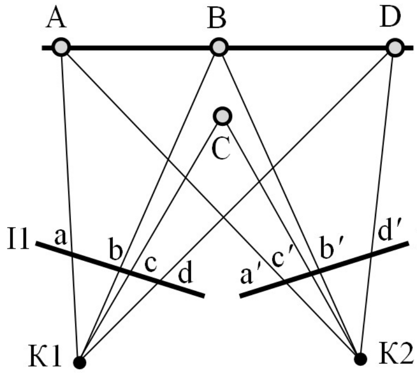

FIG. 1. Obtaining images of object ABCD using cameras K1 and K2.

Key points in real images can be determined with certain errors, especially for poorly textured images and images with repeating fragments. When analyzing a series of images of the same object, key points are determined for each image. The coordinates of all model elements are determined in a rectangular three-dimensional Cartesian xyz coordinate system.

The 3DF Zephyr program performs step-by-step construction of 3D models of objects by the photogrammetry method in the following sequence:

Stage 0. Creation of a new project: reading of initial images and their preliminary processing (masking) [4-7], auto-calibration of camera parameters. The program allows you to read initial images from individual graphic files (for example, in TIFF or JPEG formats) or from a video file.

Stage 1. Calculation based on initial images of a Sparse Point Cloud, determination of external camera parameters (position /coordinates/ and orientation), as well as internal camera parameters (focal length, distortion, etc.). For this, the program determines the keypoints of the images and the common keypoints of different images by combining them.

Stage 2. Construction of a Dense Point Cloud based on predefined camera parameters (in particular, coordinates and orientation) and initial photos. The number of points in a dense cloud is orders of magnitude greater than the number of points in a sparse cloud. In the computer world, the process of obtaining a dense point cloud is also known as Multiview Stereo technology.

Stage 3. Construction of a three-dimensional surface or a grid of polygons (Meshes) based on a Dense Point Cloud using the method of triangulation. The obtained triangulation grid of polygons (polygonal model) approximates the surface of the object under study with a set of triangles.

Stage 4. Construction of Textured Meshes for the obtained polygonal model. The texture of each triangle is read in the corresponding fragment of the image.

Stage 5. Editing parameters of the 3D model: setting the orientation of the model (for example, vertical); removal of unnecessary fragments of the model; changing the position, direction and scale of the model; changing model rendering parameters (camera position, lighting and surface appearance of the object in 3DF Zephyr).

Stage 6. Analysis of 3D model parameters: measurement of sizes, areas, volumes of model elements; determination of the number of landfills, etc.

Stage 7. Saving the created 3D model to files. The 3D model is saved in a .zep file. Polygonal mesh is saved in .ply, .Obj/Mtl, .Glb format files; and textures are saved in a .jpg file.

III. SOFTWARE IMPLEMENTATION OF AN EXPERT SYSTEM TO SUPPORT THE CONSTRUCTION OF THREE-DIMENSIONAL MODELS OF OBJECTS

An expert system (ES) was developed in the CLIPS environment (C Language Integrated Production System) to select the correct modes for building a 3D model [8-10]. The ES knowledge base contains production rules that allow to establish the correct modes of building a 3D model based on the initial facts. Rules consist of conditions (which are described by facts) and actions:

```
IF
<condition_1> and ... and <condition _N> are fulfilled,
THEN perform <action_1> and ... and <action_N>.
```

All ES facts are divided into three types:

1. Facts-conditions for building a 3D model.
2. Facts-consequences.
3. Facts-recommendations.

30 facts-conditions have been developed, in particular:

1. Low quality of dark areas of the model.
2. Average quality of light areas of the model.
3. Overlap of photos is low, less than 60%.

20 Facts-consequences were used, including:

1. Accuracy of the model is low.
3. Lighting of the model is low.
2. Number of points of the model is high.

15 facts-recommendations have been developed, in particular:

1. Place the cameras evenly in space.
2. Increase the level of lighting.
3. Increase the number of photos.

Using the developed rules, 36 production rules were built for the ES knowledge base, for example (fig. 2):

```
(defrule r5_low_lighting
 (declare (salience 100))
 (low quality of dark areas of the model)
 (average quality of light areas of the model)
  =>
   (assert (lighting of the model is low))
 )
```

FIG. 2. Rule # 5.

After inputting the initial facts, the CLIPS interpreter runs a logical inference machine that figures out which of the rules can be activated. This is done cyclically, with each cycle consisting of three steps:

- comparison of facts and rules;
- selection of the rule to be activated;
- performance of actions provided for by the rule.

At each iteration of the logic inference machine cycle, one rule must be activated. If the present facts allow the activation of more than one rule, then a conflict arises. The CLIPS language supports seven different conflict resolution strategies. By default, the depth strategy is used, according to which the newly activated rule is placed above all rules with the same priority.

IV. EXPERIMENTAL CHECK OF THE DEVELOPED SYSTEM

Using the 3DF Zephyr program, three-dimensional models of objects were built using photogrammetry. For each object, a series of its photos (from different angles) was obtained. A sparse point cloud, a dense point cloud (Fig. 3), polygon meshes (Fig. 4) and texture meshes (Fig. 5) were constructed based on a series of photographs using the 3DF Zephyr program. With a sufficiently large number of photos of the object (up to 50 for the free version of 3DF Zephyr), different angles of the object and uniform illumination, three-dimensional models are obtained with fairly high accuracy (Fig. 5).

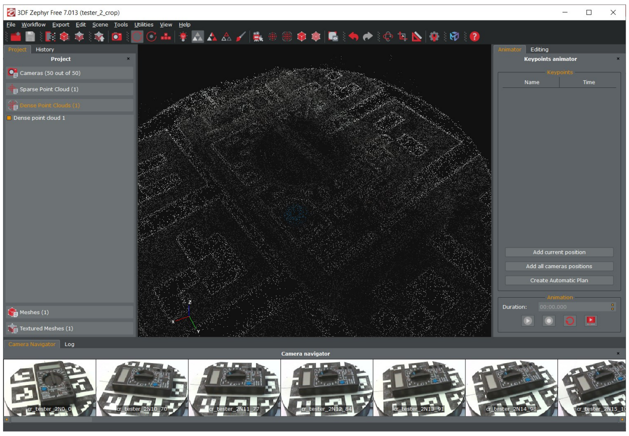

FIG. 3. Dense Point Cloud.

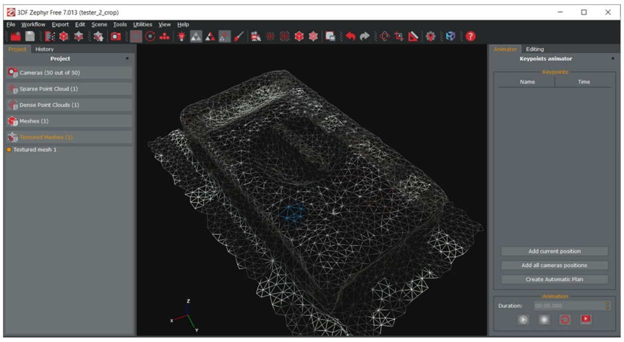

FIG. 4. Grids of polygons (Meshes) without coloring.

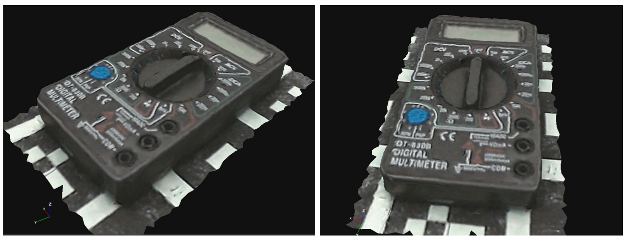

FIG. 5. Textured Meshes of the model in different angles.

However, for objects with non-textured surfaces (for example, for a laptop with the screen turned off), three-dimensional models with significant defects were obtained. After entering the facts that describe the process of obtaining the model into the expert system, a number of recommendations were obtained: increase the area of textured surfaces (display a static image on the screen), use uniform lighting to avoid glare. After following these recommendations, a model was built with average accuracy (Fig. 6). The accuracy of 3D models was assessed qualitatively (low, medium, high) and quantitatively as the number of Points and Triangles of the model. Properties of the 3D model are obtained by context menu of the Textured mesh object. For example, when building a model with the value "Default" for the "Presets" parameter of the 3DF Zephyr wizard, a low accuracy model was obtained (Points = 25571, Triangles = 31694). When building a model with the value "Deep" for the "Presets" parameter, the average accuracy of the model was obtained (Points = 91605, Triangles = 107727) (Fig. 6).

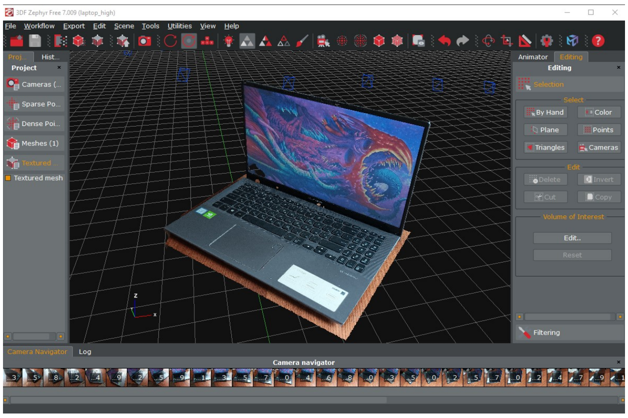

FIG. 6. Textured mesh of a 3D laptop model.

Typical ES recommendations include: increase the number of photos of the object, obtain photos of the object from all angles, place the object in the focus of the video camera, etc., which as a result ensures the construction of a high-quality 3D model.

V. CONCLUSION

An expert system has been developed to support the construction of 3D models of objects by the photogrammetry method, which consists in the construction of a model of an object based on a series of its photographs. To build 3D models of objects by photogrammetry, the 3DF Zephyr program was used.

An expert system was developed in the CLIPS environment to select the correct modes for building a 3D model. The knowledge base of the expert system contains production rules that allow to establish the correct modes of building a 3D model based on the initial facts. 30 facts-conditions, 20 facts-consequences and 15 facts-recommendations have been developed. Using the developed rules, 36 production rules were built. If necessary, the number of facts and rules can be increased. 3D models of objects were built using the 3DF Zephyr program. Due to the recommendations of the expert system, the 3D model is built with satisfactory accuracy. The resulting 3D models can be used, in particular, in Virtual and Augmented reality systems, in Internet of Things systems.

AUTHOR CONTRIBUTIONS

S.B. – conceptualization, writing-review and editing, supervision; V.V. – software, resources, writing-original draft preparation, visualization; I.F. – methodology, validation, investigation.

COMPETING INTERESTS

The authors declare no conflict of interest.

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Експертна система для підтримки побудови тривимірних моделей об'єктів методом фотограмметрії

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АНОТАЦІЯ Завдання побудови якісних тривимірних (3D) моделей об'єктів є актуальним, оскільки такі 3D моделі широко використовуються в різних сферах науки, техніки та медицини. У даній роботі побудова 3D моделей виконана методом фотограмметрії, який полягає у побудові 3D-моделі об'єкту на основі серії його фотографій. Перевагами методу фотограмметрії є низькі вимоги до апаратного забезпечення та порівняно висока точність. Для побудови 3D моделей об'єктів методом фотограмметрії використано програму 3DF Zephyr, яка містить набір інструментів для проведення попередньої обробки зображень, реконструкції 3D-моделей, редагування та вимірювання розмірів 3D-моделей, експорту отриманих моделей. Розглянуто принципи побудови тривимірних моделей об'єктів методом фотограмметрії на основі початкових зображень. Описано основні етапи побудови 3D-моделей: обчислення розрідженої хмари точок, ключових точок, щільної хмари точок, сітки полігонів, текстурної сітки. Також виконується редагування та аналіз параметрів моделі. Для вибору правильних режимів побудови 3D моделі розроблено експертну систему у середовищі CLIPS. База знань експертної системи містить продукційні правила, які дозволяють на основі початкових фактів встановити правильні режими побудови 3D моделі. Розроблено 30 фактів-умов, які описують умови побудови тривимірної моделі. Розроблено 20 фактів-наслідків та 15 фактів-рекомендацій для побудови 3D моделі. Із використанням розроблених правил побудовано 36 продукційних правил. Проведено експериментальну перевірку розробленої системи. За допомогою програми 3DF Zephyr побудовано тривимірні моделі об'єктів. Ввівши в експертну систему факти, які описують процес отримання моделі, отримано ряд рекомендацій, зокрема, збільшити площу текстурованих поверхонь та використати рівномірне освітлення об'єктів. Після виконання таких рекомендацій побудовано модель із задовільною точністю.

КЛЮЧОВІ СЛОВА експертна система, CLIPS, тривимірна модель, фотограмметрія, 3DF Zephyr.