

**ECBA -16****3D Mapping of an Environment around a River Using Image Processing of Photo Images Captured by a Multi-Rotor Drone and 3D Map Modeling Using a 3D Printer**Akhmad Taufik<sup>1</sup>, Shingo Okamoto<sup>2</sup>, Jae Hoon Lee<sup>3</sup><sup>1, 2, 3</sup>*Ehime University, Japan, <sup>1</sup>State Polytechnic of Ujung Pandang, Indonesia*

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**Abstract**

The purposes of this research are to make a 3D map data of an environment around a river using image processing of photo images captured by a multi-rotor drone and a 3D map model using a 3D printer. In the present research, Parrot Bebop Drone was used as the multi-rotor drone. Then, Agisoft PhotoScan Professional (Ver.1.1) was used as the photogrammetric image processing software. IRIS 3D printer was used as the 3D printer. Firstly, photo images of an environment around a river were captured by the fisheye-lens camera installed on the Parrot Bebop Drone flight-controlled manually. Then, the image processing consisting of five main steps was performed using the Agisoft PhotoScan. In the first step, the captured photo images were loaded to the workspace pane of the Agisoft PhotoScan. In the second step, the photo images were aligned in order to find matching points between overlapping images. The positions and orientations of the photo images were estimated and a sparse point cloud was built by the Agisoft PhotoScan based on the matching points. In the third step, a dense point cloud was built using the estimated positions and orientations and the sparse point cloud. In the fourth step, a polygonal mesh was built using the dense point cloud. In the fifth step, a 3D textured map was built using the polygonal mesh. The 3D textured map was thickened using the Blender software. Then, the thickened 3D map was exported to an OBJ file. Finally, the 3D map model of the environment around the river was produced by the IRIS 3D printer using the OBJ file.

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*Keywords*— 3D Mapping, 3D Modeling, Image Processing, Multi-Rotor Drone

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**Introduction**

In recent years, the 3D mapping and modeling of environments have become more important for various applications, such as area mapping on archaeology or a disaster, building modeling, road inspection, and city planning. The production of the 3D mapping and modeling is supported by the advance of technologies to process digital data such as, photogrammetric image processing softwares and 3D printing.

In the last decade, a number of studies on 3D modeling of environments based on photogrammetry have been carried out [1] – [14]. In most of them reported, photo images of the environments were captured with conventional-lens cameras installed on Unmanned Aerial Vehicles (UAVs) [1] – [7]. In a few studies of them reported, fisheye-lens cameras installed on UAVs were used to capture photo images of the environments [8] – [10]. Then, all of them used photogrammetric image processing softwares to reconstruct the photo images into digital 3D data representing the environments. 3D models in reports on digital 3D data were produced with 3D printers [11] – [14]. However, there is no report in which a 3D map model of an environment around a river was produced using the method proposed by the authors in this paper.

The authors reported on an autonomous flight along a river performed by a multi-rotor drone installing a single-lens camera and image processing [15] - [16]. In the present research, the method on 3D mapping and 3D modeling of an environment around a river, where a multi-rotor drone with a fisheye-lens camera, image processing, and a 3D printer were used, was proposed.

The authors firstly performed the experiments to capture movies of the environment around the river using the fisheye-lens camera mounted on the multi-rotor drone (Parrot Bebop Drone). Then, the 3D mapping was performed by image processing of the captured movies using a photogrammetric image processing software (Agisoft PhotoScan Professional ver.1.1.). Finally, the 3D map model of the environment around the river was produced using a full-color 3D printer (IRIS 3D printer).

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\*All correspondence related to this article should be directed to Akhmad Taufik from Ehime University, Japan & State Polytechnic of Ujung Pandang, Indonesia

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Photo Images Captured by a Multi-Rotor Drone

Experimental Method

Figure 1 shows the multi-rotor drone (Parrot Bebop Drone) with a fisheye-lens camera in the present research. The multi-rotor drone equips with a fisheye-lens camera, a memory card, and a GPS. Photo images of an environment around a river are captured by the fisheye-lens camera mounted in the front side of the drone and stored in the memory card mounted inside the drone. In addition, 3D coordinates of the drone’s positions when capturing the photo images are measured by the GPS mounted inside the drone.

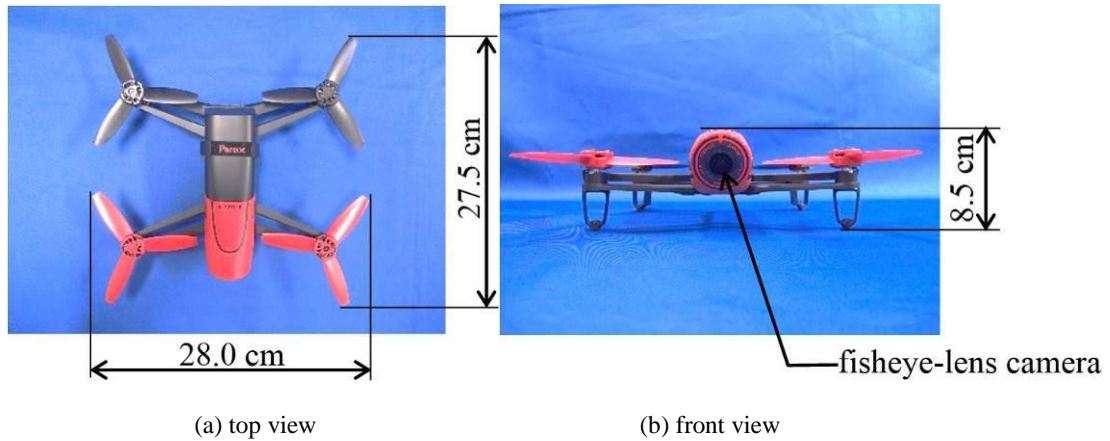


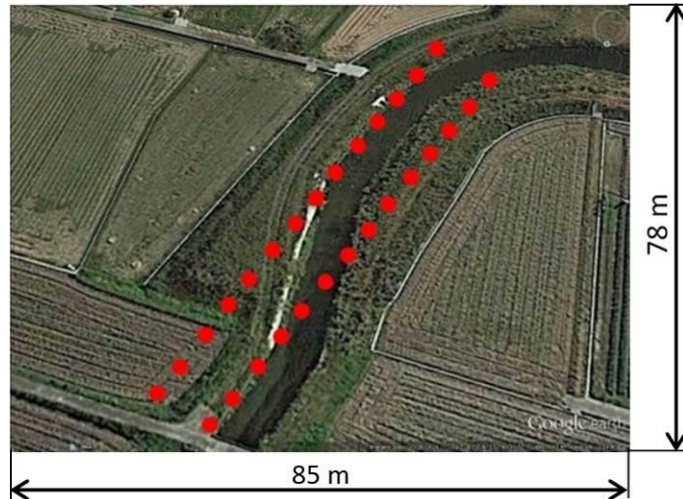
Figure 1: Multi-rotor drone (Parrot Bebop Drone) with a fisheye-lens camera

Figure 2 shows the environment around a river that is used in this research. The environment is located in a considerable distance from resident’s houses, namely around 150m. The environment used in the experiment consists of a curved river with the average width of 5m, bush and farmlands at both sides of the river. The photo images of the environment are captured using a fisheye-lens camera mounted on the multi-rotor drone with a resolution of 14Mpx and a field of view of 180°.



Figure 2: Environment around a river that is used in the current research

Figure 3 shows the positions where photo images of the environment around the river are captured by the fisheye-lens camera mounted on the multi-rotor drone. Each photo image is overlapping by 80% with the adjacent photo image. The photo images of the environment were captured in two straight lines. The drone firstly performed a flight to capture photo images in the first line. After finishing the flight in the first line, the drone repeated the flight in the second line which parallels to the first one. The 3D coordinates data of positions to capture the photo images were measured by the GPS and saved in the memory card mounted inside the multi-rotor drone.



●:Positions to capture photo images

Fig. 3: Positions where photo images were captured by the fisheye-lens camera mounted on the multi-rotor drone

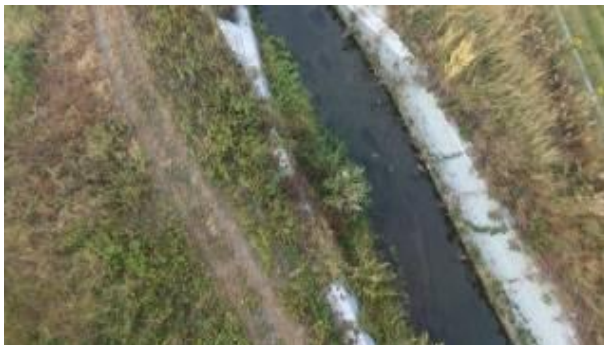
Figure 4 shows the scene in which photo images of the environment around the river captured by the fisheye-lens camera installed on the Parrot Bebop Drone flight-controlled manually was carried out. The tablet computer to control the drone communicated with the multi-rotor drone through a wireless connection (Wi-Fi). The maximum distance that the Wi-Fi can reach is 150m. Firstly, the multi-rotor drone took off the ground at the river side. Then, the altitude of the multi-rotor drone was increased until 15m. At the altitude, the drone had carried out a hovering for several seconds. After that, the drone had performed the flights to capture the photo images of the environment around the river.



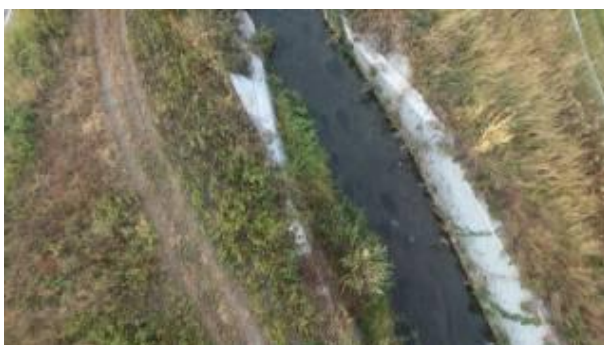
Figure 4: Scene in which photo images of the environment around the river were captured by the fisheye-lens camera installed on the Parrot Bebop Drone flight-controlled manually

*Photo Images of an Environment Around a River*

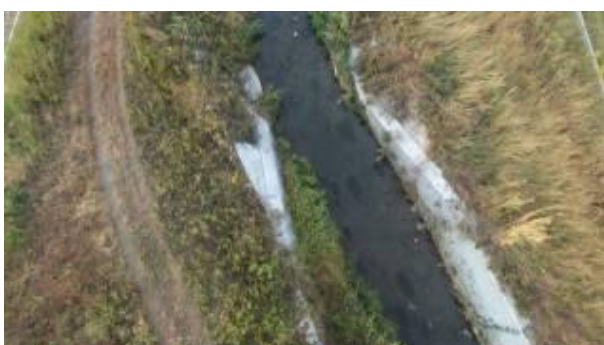
Figure 5 shows the examples of overlapping photo images of the environment around the river captured in every 6s by the fisheye-lens camera mounted on the multi-rotor drone. Forty-five overlapping photo images were captured in the experiment. Then, those photo images were saved in the memory card mounted inside the drone in JPEG format. The length and the width of the photo images are 1,920 pixels and 1,088 pixels respectively.



(a) Photo image ( $t = 13s$ )



(b) Photo image ( $t = 19s$ )



(c) Photo image ( $t = 25s$ )



(d) Photo image ( $t = 31s$ )

*Figure 5:* Examples of overlapping photo images of the environment around the river captured by the fisheye-lens camera mounted on the multi-rotor drone

### 3D Mapping Using Image Processing

In order to build a 3D map data of the environment around the river, the captured photo images were processed using the Agisoft PhotoScan Professional (Ver.1.1). There are five consecutive processes in the 3D mapping, namely loading and aligning the photo images, and building the dense point cloud, the polygonal mesh, and the 3D textured map. The image processing were performed using the commands in the workflow menu of the Agisoft.

#### Loading Photo Images

Firstly, the forty-five overlapping photo images of the environment around the river were loaded to the workspace pane of the Agisoft. The 3D coordinates of the multi-rotor drone’s positions when capturing the forty-five photo images measured by the GPS were detected by the Agisoft. Figure 6 shows the positions of the multi-rotor drone when capturing the forty-five photo images displayed in two lines in the model pane of the Agisoft. Based on those positions, eighteen photo images having no overlapping area with the photo images in the other line were removed from the workspace pane.

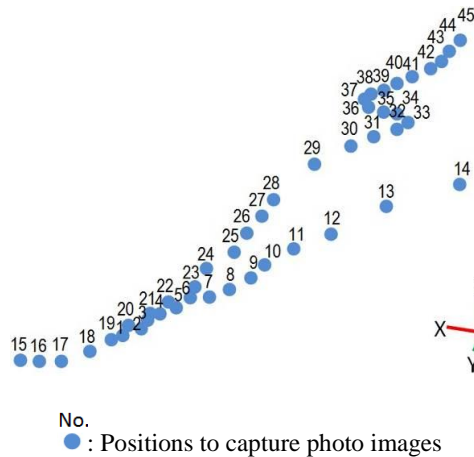


Figure 6: Positions of the multi-rotor drone when capturing the forty-five photo images displayed in two lines in the model pane of the Agisoft

#### Aligning Photo Images

In the second process, the points data of each photo image were firstly detected by the Agisoft. Then, the points data of each photo image were compared to their adjacent ones in order to detect matching points between the two photo images. Furthermore, the matching points were used to estimate the position and the orientation of each photo image and to build a sparse point cloud as an initial data for the 3D map of the environment around the river. Figure 7 shows the estimated positions and orientations of the twenty-seven photo images shown by the squares and the sparse point cloud below the positions displayed in the model pane of the Agisoft.

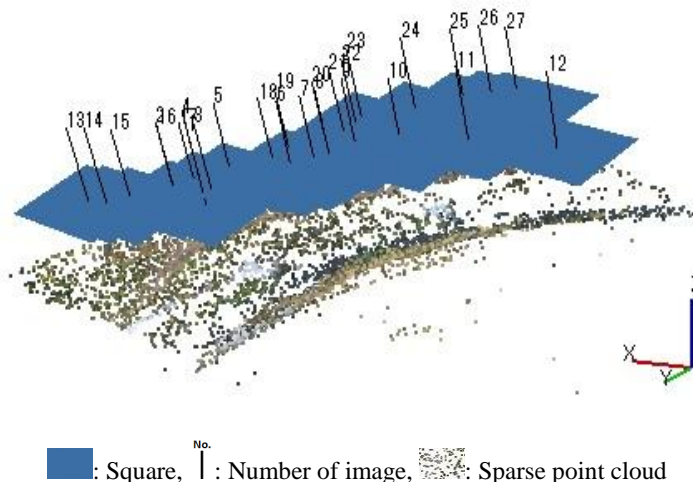


Figure 7: Estimated positions and orientations of the twenty-seven photo images shown by the squares and the sparse point cloud below the positions displayed in the model pane of the Agisoft

*Building Dense Point Cloud*

In the third process, the estimated positions and orientations of the twenty-seven photo images and the sparse point cloud were used to build a dense point cloud. There are five quality parameters to build the dense point cloud, namely ultra high, high, medium, low and lowest. The higher the quality becomes, the more complex the resulting dense point cloud will become. Therefore, the dense point cloud was built with the medium quality in order to reduce the complexity of the dense point cloud. Figure 8 shows the dense point cloud built from the estimated positions and orientations of the twenty-seven photo images and the sparse point cloud.

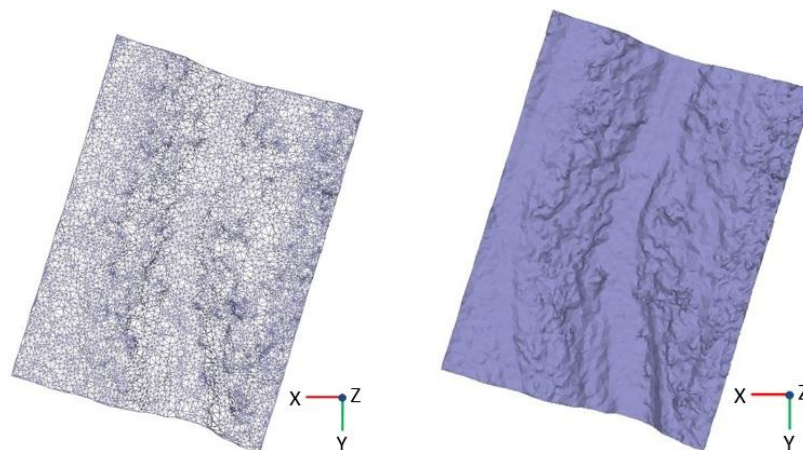


Figure 8: Dense point cloud built from the estimated positions and orientations of the twenty-seven photo images and the sparse point cloud

*Building Polygonal Mesh*

In the fourth process, a polygonal mesh was built by using the dense point cloud. Only areas selected in the dense point cloud determined using a bounding box in the model pane of the Agisoft were used to build the polygonal mesh.

There are two types of surfaces on the parameters to build the polygonal mesh, namely the options of “arbitrary” and “height field”. The option of “arbitrary” is used for the surfaces of isolated objects and the option of “height field” is used for the surfaces of terrains. Then, the polygonal mesh was built with the option of “height field”. Figure 9 shows the polygonal mesh displayed as a wireframe of the selected area in the dense point cloud and the solid model built from the wireframe.



(a) Wireframe of the selected area

(b) Solid model built from the wireframe

Figure 9: Wireframe of the selected area in the dense point cloud and solid model built from the wireframe

*Building 3D Textured Map*

In the fifth process, a 3D textured map was built by texturing the solid model of the selected areas in the dense point cloud. The texture data of the selected areas were firstly read by the Agisoft. However, some parts on the selected areas don't have texture data. Then, new texture data calculated using the existing ones were generated by the Agisoft for the parts without texture data. Furthermore, a 3D textured map was built by texturing the solid model using the existing and new texture data.

The 3D textured map represents the geometry and the texture of the environment around the river. The length and the width of the map representing the environment correspond to 27m and 20m, respectively for the actual one. Figure 10 shows the 3D textured map built from the solid model showing the geometry and the texture of the environment around the river.



Figure 10: 3D textured map built from the solid model showing the geometry and the texture of the environment around the river

3D Modeling Using a 3D Printer

In order to obtain a real 3D visualization of the environment around the river, a 3D map model was built by using a 3D printer. In this 3D modeling, the 3D textured map was thickened by using the Blender (Ver.2.7.6b) that is an open software of 3D computer graphics. Then, the 3D map model was built by using the thickened 3D map and the 3D printer.

*Exporting 3D Textured Map*

In this stage, a thickened 3D map was built for a 3D printing. The 3D textured map was firstly exported to an OBJ file by using the Agisoft PhotoScan software. The OBJ file contains the 3D geometry data of the 3D map, namely the 3D coordinates of each point in the 3D map. Both a JPG file containing the texture data of the 3D map and an MTL file containing the parameters to map the texture data were generated by the Agisoft in order to keep the texture of the 3D map. Then, the 3D textured map in the OBJ file was thickened by using the Blender. The length, the width, and the height of the thickened 3D map are 21.5cm, 15.5cm, and 3.0cm respectively. The scale ratio of the thickened 3D map is 1:126. Figure 11 shows the thickened 3D map built from the OBJ file of the 3D textured map.

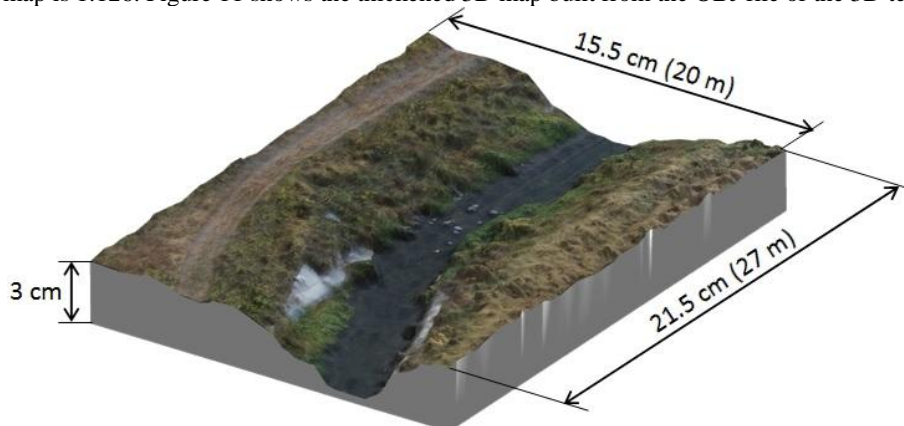


Figure 11: Thickened 3D map (scale ratio of 1:126) built from the OBJ file of the 3D textured map which was exported using the Agisoft PhotoScan software

*Preparation of Material and 3D Printer*

A color 3D printer, here the IRIS 3D printer was used to build the 3D map model of the environment around the river. Figure 12 shows both the IRIS 3D printer connected to a PC installing the SliceIT and the A4 size papers used for building the 3D map model. The SliceIT (Ver.6.1.5) is the IRIS 3D printer’s software. Then, A4 size papers were used as the materials to build the 3D map model.

Some processes were performed before starting the 3D printing. Firstly, the thickened 3D map was exported to a new OBJ file by using the Blender software. Both a new JPG file and a new MTL file were also generated by the Blender. Then, those three files were processed by the SliceIT. The thickened 3D map in the OBJ file was sliced into 337 colored layers by the SliceIT. After that, those layers were printed on 337 pages of A4 size papers by using an ordinary color printer. The colors printed on each page of paper describe the geometry and the texture of each layer of the thickened 3D map. Furthermore, those 337 pages of papers were loaded into the paper tray of the IRIS 3D printer. Both a knife and an adhesive glue were set inside the IRIS 3D printer for building the 3D map model of the environment around the river using the 337 pages of papers.

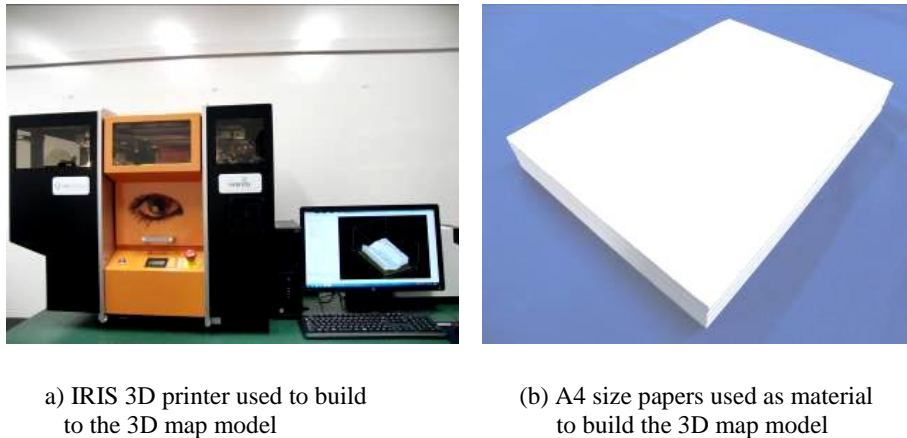


Figure 12: Both IRIS 3D printer connected to a PC installing the SliceIT and A4 size papers prepared for building the 3D map model of the environment around the river

**Result**

The 3D printing was performed after finishing the preparation of the material and the IRIS 3D printer. Firstly, the first page of papers was pulled from the paper tray and placed on a build plate inside the IRIS 3D printer. Then, the geometry data of the first layer were read by the SliceIT. After that, the commands of both cutting and applying adhesive were generated by the SliceIT based on the geometry data. The commands were sent from the PC to the IRIS 3D printer. The processes of the cutting and applying adhesive were performed by the IRIS 3D printer on the first page of papers. After finishing the processes on the first page, the second page was pulled and placed on the first page. Both pages were pressed by the heat plate inside the IRIS 3D printer. Then, the whole processes were repeated from the second page to the 337th page of papers. Furthermore, the 337 pages of papers containing the 3D map model were taken out from the IRIS 3D printer.

After finishing the 3D printing, all unnecessary parts around the 3D map model were removed from the 3D map model. Figure 13 shows the final 3D map model built by using the IRIS 3D printer. The dimensions and the scale ratio of the 3D map model are same as those of the thickened 3D map.

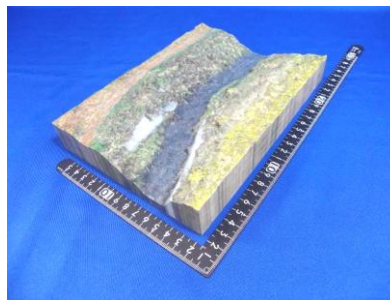


Figure 13: Final 3D map model built using the IRIS 3D printer



## Conclusion

The summary of the results is shown below.

- Firstly, the experiment to capture overlapping photo images of an environment around a river had been performed using the multi-rotor drone (Parrot Bebop Drone). The photo images were captured by the fisheye-lens camera mounted on the multi-rotor drone.
- Then, the image processing to build a 3D textured map of the environment around the river had been performed using the Agisoft PhotoScan software. Furthermore, a thickened 3D map was built by using the 3D textured map. The scale ratio of the 3D textured map to the real environment is 1:126.
- Finally, a 3D printing to build a 3D map model of the environment around the river had been performed using the IRIS 3D printer. The dimensions and the scale ratio of the 3D map model are same as those of the thickened 3D map.

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