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Dynamic Projection Mapping on Living Things

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Abstract

In this study, we propose a tracking method for dynamic projection mapping (DPM) on living things. We also aim to report the creation of a video artwork with projection mapping silkworms, hedgehogs, and mushrooms as projection objects in this paper. In most of the previous researches and works on DPM for non-human deformable objects, the 3D shape of the projected object was input in advance or markers for tracking were attached to the projected object. In addition, there are no studies of DPM for animals and plants. In this method, we apply a common tracking method to silkworms and hedgehogs by tracking their end points. In addition, we propose an effect animation based on the shape of each object with the concept of bioluminescence.

1. Introduction

Recently, there has been an increasing number of examples of dynamic projection mapping (DPM) applied to plants and animals. However, objects such as animals and plants are deformable, and it is difficult to obtain their shape or attach markers in advance; thus, these objects present a problem for DPM. Here, we propose an automatic generation method of DPM specially designed for silkworms and hedgehogs. In addition, the system automatically generates visual-effect animations based on the shape of the silkworm, hedgehog, and mushrooms. Using this system, we conducted an experiment of projection on those real living things.

Projections in the Forest [1] is one example of a work in which PM is applied to plants and animals. In this previous work, static projection mapping was performed for plants and animals of the forest. Image registration for the mapping was performed manually by the artists, which required a substantial amount of time. Also, aesthetically, our research is inspired by this artwork. Leaves, a worm, mushrooms, small needle grasses, and so on appeared in this work, and we aim to generate DPM on targets related to them. Another reason to target the hedgehog is that we would like to widen the range of target objects to animals more.

For plant leaves with individual motion, a method of DPM that considers the occlusion of the projection area by the viewer has been proposed [2]. This method automatically generates effects that match the shape of the plant. However, leaves exhibit small deformations, and it is difficult to obtain corresponding large deformations using this method. Then we proposed the way to track silkworms to generate DPM with effect animations on silkworms [3]. A method for applying DPM to human faces has also been proposed [4]. This method can track the movement of a face without the need for markers. However, this method requires 3D face data with various expressions to be input in advance. OpenPose [5], which uses deep learning to detect skeletal structures from an input image of a human obtained via a monocular camera, has been proposed. This approach is marker-less, requiring only the input image. However, the detection target is human-based, and non-human skeleton detection is not supported.

2. Related Works

In this section, we introduce existing method for DMP and tracking method with pose estimation from input images to describe the difference with our method.

2.1 Works for DPM

The study [6] realized DPM on dynamic and variable objects such as cloth, fluid, and hands without prior shape input or tracking markers. Using three infrared cameras to obtain the normal on the surface can deal with the significant texture and shape change. However, this research requires expensive equipment such as an expensive 1000 fps projector and three 500 fps high-speed cameras, which is not practical, nor does it create video effects that match the object's shape. Therefore, we aim to perform DPM with equipment in the range of relatively inexpensive equipment and create video effects that match the object's shape.

The method [7] enables projection on deforming objects such as clay.

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Invisible markers on the projection surface allow detecting the projection surface distortion. And DPM is performed by distorting the projected image. The projection target of this method does not retain its original shape, like clay. Our approach targets the projection objects which deform mainly by their joints. Therefore, it can return to its original condition. Also, our method does not require markers to track things.

A method for DPM [8] applies a depth camera to create a 3d model. This method samples the projected object in a low-density point cloud and can track the motion of movement and rotation in real-time. Furthermore, it also supports impainting of shielding. The method targets rigid objects with complex shapes.

Capturing 3D objects in real-time, a DPM method [9] calculates ray tracing and projects it onto the object at high speed, considering the shape. Using noisy results at low resolution at high-speed, this method performs a high-speed projection of 947 fps. A noisy image is perceptually integrated, resulting in a clear projection result. This method requires special equipment: a camera at 500 fps and a projector at 947 fps. It also allows changing the object's texture but is not good at attaching uv textures.

The method [10] performs DPM according to the deformation of plain paper or foam sheets to make them flexible and deformable displays. In this method, a deformed model of the projected object, a flat surface, is created in advance and matched with the projected object captured by a depth camera to handle the deformation. However, it does not support objects other than flat objects.

The automatic DPM generation methods [11][12] has similar purpose with this research against leaves and flowers. The former tracks the leaf by extracting the endpoints of the target object as the pair with the longest distance between them on the object edge. The latter tracks the object mainly with multiple sharp points. On the other hand, we track objects by their endpoints detected by using AKAZE for the silkworm and ellipse fitting for the hedgehog.

2.2 Works for Pose Estimation and Tracking

In recent years, many methods for pose estimation have been based on machine learning. For example, dense tracking, a type of OpticalFlow, is a learning-based method that tracks the entire specified pixel [13]. In addition, a method for pose estimation of nematodes [14], which is a relatively silkworm-like object, can take into account the complex movements of the nematode and the overlapping of its own body to estimate the pose. However, it is difficult for these methods to perform pose estimation at enough high speed for DPM. As a real-time pose estimation method, estimating 2D poses of multiple people [15] is markerless, does not require special equipment, and impaint shielded areas. However, the detection target is a human, and the pose estimation of animals is not supported. The method [16] can estimate the pose of various living creatures in real-time. It requires manually labeling the images in advance to create supervisory data so that it can follow the user's favorite part. However, it requires high machine specifications to perform estimation in real-time [17].

We describe a tracking method that does not use machine learning. The hand tracking method [18], which considers complex hand-to-hand contact and shielding, captures the hand motion from multiple viewpoints. Image tracking techniques are combined with physics-based deformation models in this method. Similarly, in 3D pose estimation and reconstruction of hands from RGB images [19], fitting is done with input images and pre-prepared hand models. These require a prior input of the target model, and the target is the hand. Another method for real-time tracking on mobile devices [20] allows fast-tracking even on mobile devices such as smartphones by using only the inside of specific feature points. However, pose estimation is not performed, and ingenuity is required to utilize it for DPM.

3. Our Method

3.1 System Configuration

The system configuration of our method follows existing work [21]. A camera and projector are located as close to each other as possible. They are placed directly above the projection target, and the infrared illumination is positioned so that the light reaches the projection target (Fig. 1abc). Then, the projected area and captured area are matched using a homography transformation (Fig. 1de).

3.2 Our Method Overview

We summerize our tracking method overview of silkworms and hedgehogs as the below reffering Fig. 2.

1. In each infrared image containing the silkworm (a), the region of the silkworm is obtained by binarization (b).
2. The tracking area is then manually specified by clicking the mouse on the binarized image if it is the first frame. After the first frame, the selected area is found by the distance between centers of the area between current and previous frames.
3. A contour line is obtained from this region, and two end points are detected from its vertices (c).
4. Based on the end points, the contour is resampled to create meshes again (d).
5. Next, the effect is generated, and texture mapping is performed (e,f).

Thus, DPM is automatically performed by tracking the contour points by repeating the above. The main difference in the tracking methods is that the silkworm uses axis extraction, and the hedgehog uses ellipse fitting to detect endpoints. Mushrooms are assumed to be motionless, so there is no tracking.

3.3 Corresponding Contour Points for Silkworms

Using our method, we tracked a silkworm that flexibly deforms by extracting its axis. After the axis was extracted, we detected four points on the contour, and the remaining vertex coordinates were determined by equal sampling among the four points.

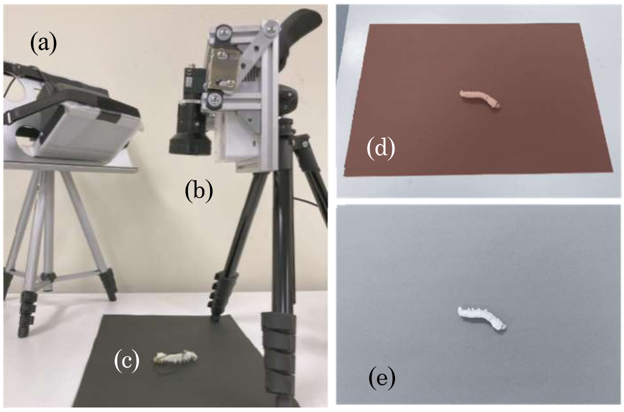


Figure 1. Our system layout (left) and homography transformation (right). (a) infrared light, (b) projector + infrared camera, (c) object, (d) obtained image, (e) image after the transformation.

3.3.1 EXTRACTION OF THE MEDIAL AXIS

The medial axis is extracted as the concatenation of the midpoints of the edges of the mesh, except on the contour lines. First, the extracted contours are resampled at equal intervals. To perform sampling at a sufficiently narrow interval with respect to the process described in 3.3.2, sampling was conducted for every 4 pixel in this paper. Next, a mesh is created based on those points by Delaunay triangulation. The midpoints of the created edges of meshes except for contour edges are used as the axis points (Fig. 2d).

3.3.2 END POINT DETECTION BY AKAZE

The axis points extracted in 3.3.1 are drawn as filled circles whose radii are equal to half of the resampling interval so that the drawing areas are connected. In this paper, the radius is 2 pixels. The AKAZE detector [22] is used to detect the blob feature points. Points whose feature value is greater than the threshold value (0.02) are detected. If only two points are detected, these two points are defined as the end points. If more than two feature points are detected (Fig. 3a), the axis image is subjected to a dilation process. Subsequently, the feature detection process is performed again. We then determine the regions in which the density of the feature points is high (Fig. 3b circles), and the feature points extracted for the first time (Fig. 3a) within that region are defined as end points (Fig. 3c). If there are fewer than two feature points, the point on the axis closest to the end point of the previous frame is defined as the end point.

3.3.3 DETERMINATION OF CONTOUR POINTS

The end points e^1 and e^2 calculated in 3.3.2 are the midpoints of the contour points A, B and C, D (Fig. 4). Using A, B, C, and D, the contour is divided into four parts. Each of the divided contour lines is sampled at equal intervals. In this paper, the long contour lines (green and purple lines in Fig. 4a) are divided into 30 parts, and the short contour lines (red and yellow lines in Fig 4a) are divided into 2 parts.

Using the above method, the locations of all contour points can be determined by tracking the two end points. The end points are tracked by comparing the distance between $e_{t-1}^1 - e_t^1$ and $e_{t-1}^1 - e_t^2$ and selecting the closer point as e_t^1 and the other as e_t^2. Finally, a Kalman filter is applied to all of the detected contour points to smooth the motion. In addition, the target area is slightly reduced to prevent the end point from becoming undetectable when the head and tail of the silkworm overlap. This step reduces the final projected area; however, the effects of this step are usually negligible. By our method, silkworms can be tracked such as in the Fig. 4b.

3.4. Corresponding Contour Points for Hedgehog

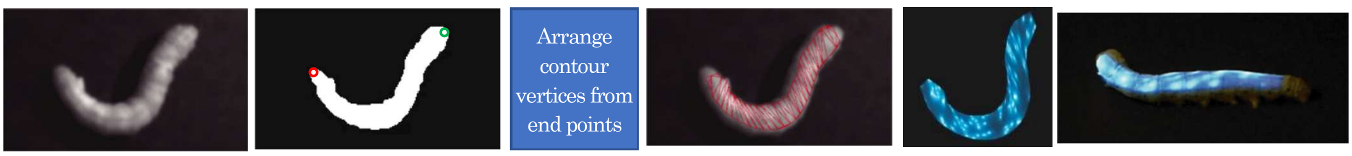
As in the silkworm, we extract the contour line of the object in every frame, find the endpoints of the head and buttocks, and correspond the points between frames by determining other contour points relative to the endpoints. We applied a more straightforward ellipse fitting to detect the endpoints since the hedgehog did not change its shape as much as the silkworm. In the case of hedgehogs, the shape is close to an ellipse, so ellipse fitting is used to detect endpoints. After binarization of the input image, a morphological transformation is performed to find the contour points so that the movements of the limbs do not affect the detection.

3.4.1 END POINT DETECTION BY ELLIPSE FITTING

We perform ellipse fitting on the vertices on the contour of the hedgehog to find the ellipse's two intersection points and the ellipse's major axis. The contour points closest to these intersection points are endpoints. These endpoints are assigned to which sides (head or hip) by the distance from the previous endpoints.

3.4.2 DETERMINATION OF CONTOUR POINTS

Each of the two endpoints bisecting the contour line is sampled at equal intervals to be a vertex. In this method, each line is divided into 30 equal parts. We map those vertices to the contour vertices of the previous frame according to their relative positions from the endpoints. Finally, a Kalman filter is applied to the entire detected contour points to smooth the motion. This tracking results are shown in Fig. 5.



(a) Input image (b) Contour and ends (c) Arrange (d) New meshes (e) Effect (f) Projected result

Figure 2. Overview of the system.

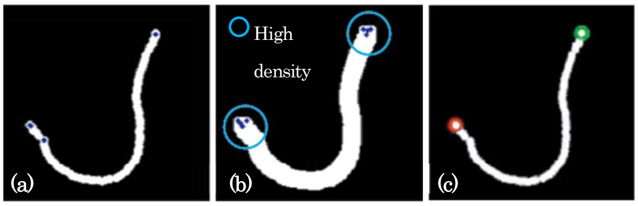


Figure 3. Detection of end points. (a) More than two feature points, (b) feature points after dilation, (c) end points.

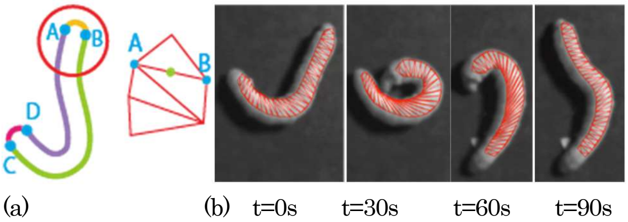


Figure 4. Division of the contour lines (a) and tracking results (b).

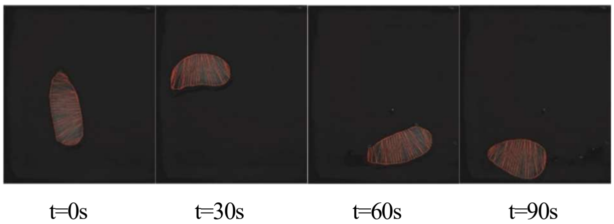


Figure 5. An experience of tracking a hedgehog.

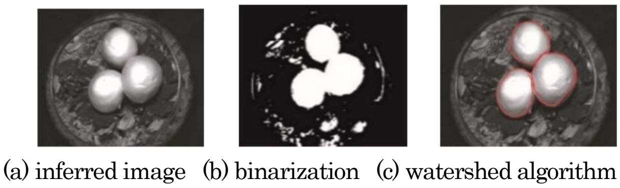


Figure 6. Extracting each object by watershed

3.5 Extraction of Contours of Mushrooms

In projection mapping on mushrooms, it is necessary to obtain the contour of each densely packed mushroom. However, detecting multiple closely spaced objects is not simple because they become a single foreground when binarized (Fig. 6). We adopt the watershed algorithm to extract the contour lines.

3.6 GENERATION OF EFFECTS

3.6.1 Effects for Silkworms

We produced three types of animation effects based on bioluminescent sea creatures (Fig. 7).

Ridge effect

The first effect represents energy propagating through the body of the silkworm along its ridgeline based on the motif of Cavernularia obesa. In the initial frame, the projection area is specified, and a path along the ridge is indicated by dragging the mouse. Thereafter, particles are gradually displayed in sequence along the vertices of the input path to represent light propagation.

Contour Effect

The second effect is an effect of light running along the contour line of a silkworm, based on the motif of Beroe abyssicola. To represent the rainbow-colored glow of fine cilia, we created a flickering light that continuously changes color.

Activity Effect

The third effect displays lighting points on the entire body, which change according to the magnitude of movement of the silkworm, based on the motif of the Sepioteuthis lessoniana. The Sepioteuthis lessoniana changes the color of its entire body all at once when hunting or excited. To create this effect, a blue particle is displayed when there is little movement, presenting an image of stillness, and a red particle is displayed when there is movement, presenting an image of activity.

3.6.2 Effects for Hedgehog

Two types of animation effects for hedgehogs are created by detecting and considering the flow of hedgehog hair.

Extracting the flow of hedgehog hair

The hair flow is detected only once in the initial frame. An effect created with the hair flow in mind is mapped to the target every frame.

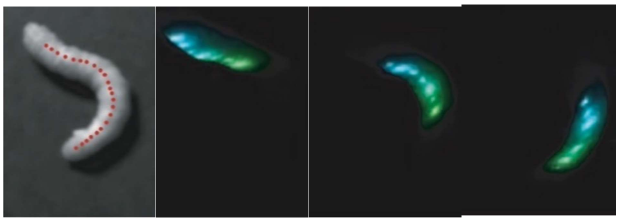
In the hair flow detection (Fig. 8), the input image is first cropped using the bounding rectangle of the target region (a). The cropped image is then subjected to edge detection using the method of Kang et al. [23] (b). This method enables edge detection by maintaining the characteristic edges of the image and orienting the less characteristic edges closer to the nearby strong edges. Next, the color inversion process is performed (c), and a mask is applied to (c) by using the shrunk image in the foreground of the binarized input image (d). The connecting information of this with the thin line processing (f) is analyzed, and the coordinates of each connected point group are obtained as an array. In this process, the array size of less than five is not saved from removing lines that are too short. The user then enters starting points of effects with a mouse click, and the order of the vertices is rearranged so that the endpoint with the closest distance to the starting point is the first in each array.

FlowEffect

Two effects of the hedgehog are shown in Fig. 9. FlowEffect is an effect in which light runs along the flow of hairs. Our method randomly selects five hairs to display the light lines. Then, we draw the particles in order, shifting the start timing for each array of hairs.

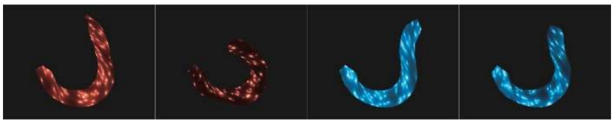
GlitterEffect

GlitterEffect is an effect that connects a line of hairs and floating particles with a straight line. It floats 1000 particles inside the bounding



Ridge effect: input ridge (red dots in the left)

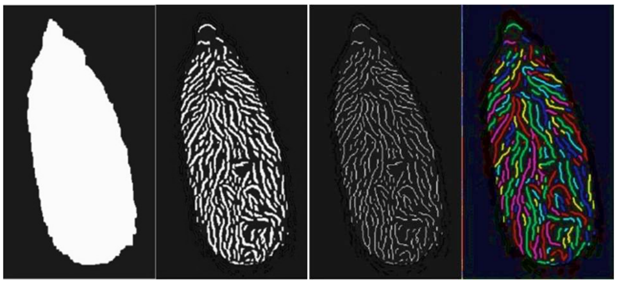
Contour effect



Activity effect : active / non-active (red / blue)

Figure 7. Effects for silkworms

(a) Input (b) Extracting the flow of hair (c) Color inversion



(d) Erosion (e) Masking (f) Thinning and labeling to visualize

Figure 8. Extracting the flow of hedgehog hair

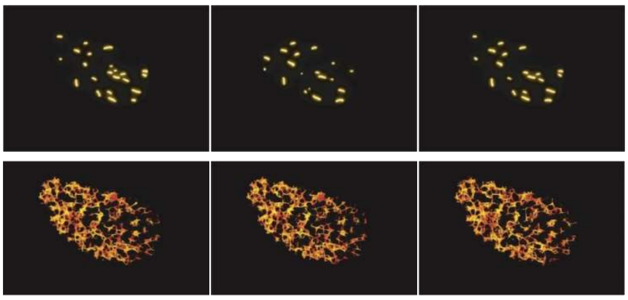


Figure 9. Effects for hedgehogs. FlowEffect (top) and GlitterEffect (bottom)

rectangle of a hedgehog and draws a straight line connecting them when the distance between each vertex of the hair and the particle is less than a certain value.

3.6.3 Effects for Mushrooms

We have created two different effects for mushrooms (Fig. 10). First, the user specifies the center of the effect by clicking the mouse. We also get the bounding rectangle of the clicked projection area and scale the effect with w being the greater of the width and height. If there are multiple projection targets, the order to start which object's effect can also be specified by the order of the user's clicks.

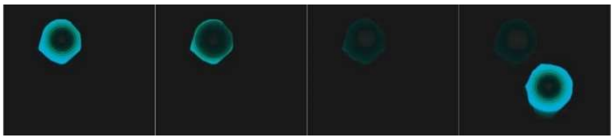
RippleEffect

The first effect is a ripple effect, where light spreads out in concentric circles from a starting point. Our system draws seven circles with a radius incremented by 0.01w and masks them at the outline of the mushroom. Then, by increasing the radius by 0.03w each frame, those circles spread.

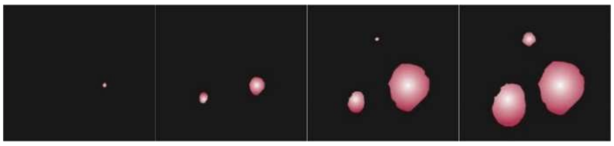
GradationEffect

The second effect is to color the mushroom with a gradient that spreads in a circle from the center. Our system draws a circular gradation from the center and masks it at the outline of the mushroom. Then scale it smoothly with the following magnification factor α. Here, t is the number of frames.

$$\alpha = \begin{cases} \sin\left(\frac{t}{20}2\pi\right) & (t < 5) \\ 1 - random(0.001, 0.002) & (otherwize) \end{cases}$$



(a) RippleEffect



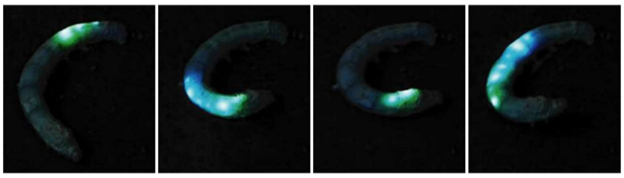
(b) GradationEffect

Figure 10. Effects of Mushrooms.

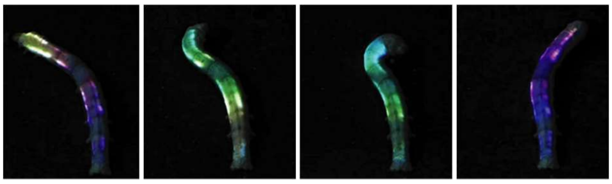
4. Results and Discussion

4.1. Effects of Projection for Animals and Plants

In our experiences, we project the LED lights of the projector onto silkworms, hedgehogs, and shiitake mushrooms. Silkworms have characteristics of running toward lights [24]. Hedgehogs are nocturnal. However, along the existing research [25], artificial light at night has little effect on European hedgehog activity, and there is a non-academic report of the observation that red light has little effect on hedgehogs [26].



Ridge effect: The motif is based on Cavernularia obesa.



Contour effect: The motif is based on Beroe abyssicola

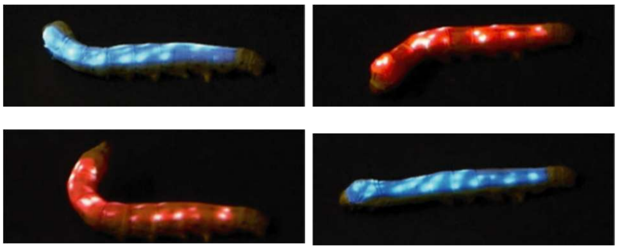
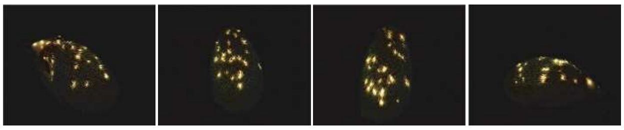
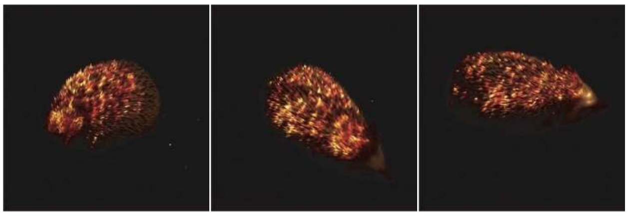


Figure 11. Projection onto real silkworms.

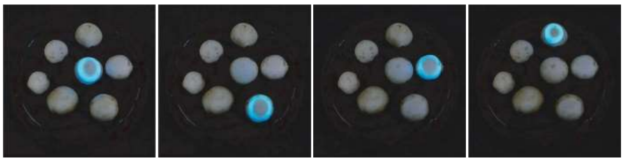


A projected FlowEffect.

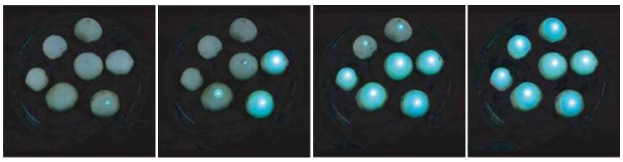


A projected GlitterEffect.

Figure 12. Projection onto real hedgehogs.



RippleEffect



GradationEffect

Figure 13. Projection onto real mushrooms.

So, we mainly use reddish color for hedgehog's effect animations. Also, we avoid projection around the eyes. We use the blue light effect for Shiitake mushrooms because they are grown rapidly in blue lights [27].

4.2. Common Property

We took videos of the experiments in a dark room with infrared light, projection targets, and an infrared camera. The projector was a Taxan KG-PL081W with 1280×720 resolution, the infrared illuminator was an S8100-IR, and the camera was an STC-MBCM200U3V-NIR with 2048×1088 resolution and 169 fps frame rate.

In this experiment, we used a Windows PC (AMD Ryzen 7 3700X 8-Core Processor 3.59GHz) with 32GB of memory. We develop the system by C++, OpenFrameworks, OpenCV, etc. We also used the glsl shader for all rendering except the Glitter effect.

We tested the tracking method in an experimental video of approximately 2 minutes. Fig. 4,5 show the results obtained for every 30 seconds. These results show that the system can track the large deformations of the silkworm and hedgehog without losing its shape. The frame rates, including tracking and drawing, are shown in the Table 1. Although we do not measure the exact time for tracking and drawing, most of the computation time is spent on tracking in the case of silkworms and on drawing in the case of hedgehogs.

Table 1. Framerate.

	Effect	The number	Framerate	Shader	Tracking
silkworm	All	1	13 fps	O	O
hedgehog	Flow	1	60 fps	O	O
hedgehog	Glitter	1	30 fps	-	O
mushroom	All	1	30 fps	O	-
mushroom	All	3	12 fps	O	-

4.3. Silkworm

As shown in Fig. 11, we projected three types of effects onto real silkworms. Overall, the tracking was good. In rare cases, there were gaps between the real and tracked contours and flickering in the image.

In this paper, we proposed an automatic tracking method for DPM for silkworms and applied this method to real silkworms. By extracting the axis, we created corresponding local deformations and reduced the number of points to be tracked. However, the frame rate of this method was approximately 13 fps, and the behavior of the silkworms was generally fine. In the future, it may be possible to apply DPM to multiple objects by increasing the speed.

4.4. Hedgehoge

Two types of effects were projected on a real hedgehog (Fig. 12). The projected image sometimes collapsed when the hedgehog tried to climb a wall. But it continued to follow after the hedgehog returned to level ground. The speed of the process is 60 fps, which can handle the quick movements of hedgehogs.

4.5. Mushroom

Two effects were projected using seven mushrooms (Fig. 13). From the results of the projection experiment, we can see that the video projection is smooth according to the shape. The frame rate dropped below 12 fps when using many mushrooms, but this was not a problem because the mushrooms did not track.

4.6. Creation of the Work "bioluminescent life"

Using this system, we have created a video work, "bioluminescent life." The story and structure of the work are as follows.

Story: Soon, some plants and animals will evolve so that living creatures can express their emotions through bioluminescence. Bioluminescence is a phenomenon in which living things produce and radiate light, as seen in fireflies and jellyfish. There are many reasons for bioluminescence, such as courtship, predation, survival strategies, etc. Here, humans raise such animals and plants as pets and ornamental plants, and their fantastic beauty of light gives people comfort.

Scenes:

1. A person is taking care of a pet hedgehog.
2. A person puts her hand near a mushroom in a dark room, and the mushroom glows.
3. The silkworm and hedgehog glow.
4. After thoroughly enjoying the light, the room lights are turned on.

The hedgehog, silkworm, mushroom, and person's hand were created mainly by synthesizing images.

Some of the viewers who saw the images said they felt like they were emitting light. The interaction between the mushrooms and the person was created by synthesizing videos of each one, but it can be easily realized by using sensors and other devices. The produced video was shared online [28] and was generally well-received.

Activity effect: The motif is based on the Sepioteuthis lessoniana.

4.7. Discussion and Future Works

We tracked two kinds of animals, a silkworm and a hedgehog, and both objects shared the idea of tracking two endpoints from the shape and determining the remaining contour points based on the endpoints. We believe that we can apply this idea to contour tracking of other objects. For example, our silkworm tracking method might be applied to worms, cats, dogs, and slim pigs, which are thin from the top view. Our hedgehog tracking method might be applied for hamsters and frogs. Fishes can be tracked as either. However, the projected image sometimes collapsed or shifted when the target objects deform significantly or move in a high-speed (Fig. 15). Because we use an infrared camera, it is sometimes difficult to adjust light conditions intuitively.

We can apply our methods to multiple silkworms and hedgehogs if each object is detected without occlusions.

For the ProCam system, it is possible not to use a homography transformation for faster calculation if we manually register the areas of a camera and projector. To improve the speed of tracking silkworms, it

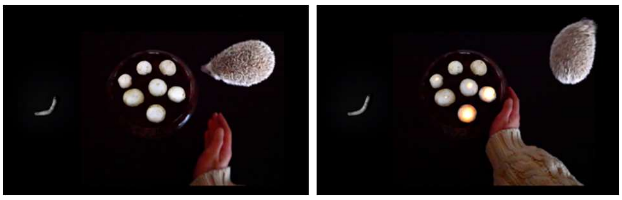
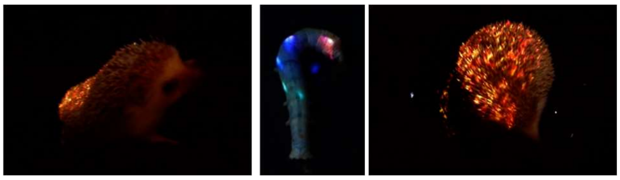


Figure 14. bioluminescent life



(a) A collapsed effect (b) Shifted effects

Figure 15: Collapsed or shifted effects on objects

might be better to detect endpoints by simple geometrical process instead of AKAZE and its preprocess.

We think our extraction with a single axis or ellipse cannot deal with skeletal animals because they are complicated to track by two points. It would be future issues for tracking targets.

We need a system with linked multiple cameras and projectors to deal with more large projection areas for big animals and plants. In addition, DPM has been applied only to single objects, such as hedgehogs and silkworms in this case. When applying DPM to multiple objects, it is necessary to consider collisions and overlaps between objects and improve the tracking speed.

5. Conclusion

This paper proposed a DPM system for silkworms and hedgehogs as DPM for living things. In addition, we performed projection mapping on mushrooms, and we integrated the results of each projection to create video work. It would be possible to apply this DPM method to various animals and plants by tracking two points on the target. Furthermore, by adding interaction elements, we hope it can function as an interface between plants and people in the future.

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