MBR Tracking Algorithm

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1 Algorithm

1.1 Structure of a model

The main data type of the tracking algorithm is the Model. The Model stores all of the relevant information for tracking and exposing a MBR. The fundamental representation of a Model is its contour, which consists of a set of points that make up the edge of the structure. The Model implements tracking with a series of vectors that store information about the model at every frame. There are three main pieces of information to be calculated at each frame: the object's center, orientation, and the contour found in that frame.

1.2 Filtering and finding contours

The process of extracting the contours from an image is used multiple times throughout the tracking algorithm so I will describe it first here.

The first step is to remove the blue channel from the image to separate the structures from any light projected on the stage. Next the image is converted grayscale and then to a binary image using an adaptive threshold which causes any areas of rapid intensity change to be set to 1 and every other area set to 0. This effectively highlights the edges of the contour as well as any other noise in the image. The light or "on" areas are then expanded using an erode method to close any small gaps in the edges of the structures. Then the find contours method is used to extract all of the shapes present in the image. Finally the noise is filtered out by only taking contours with an enclosed area in a specified range.

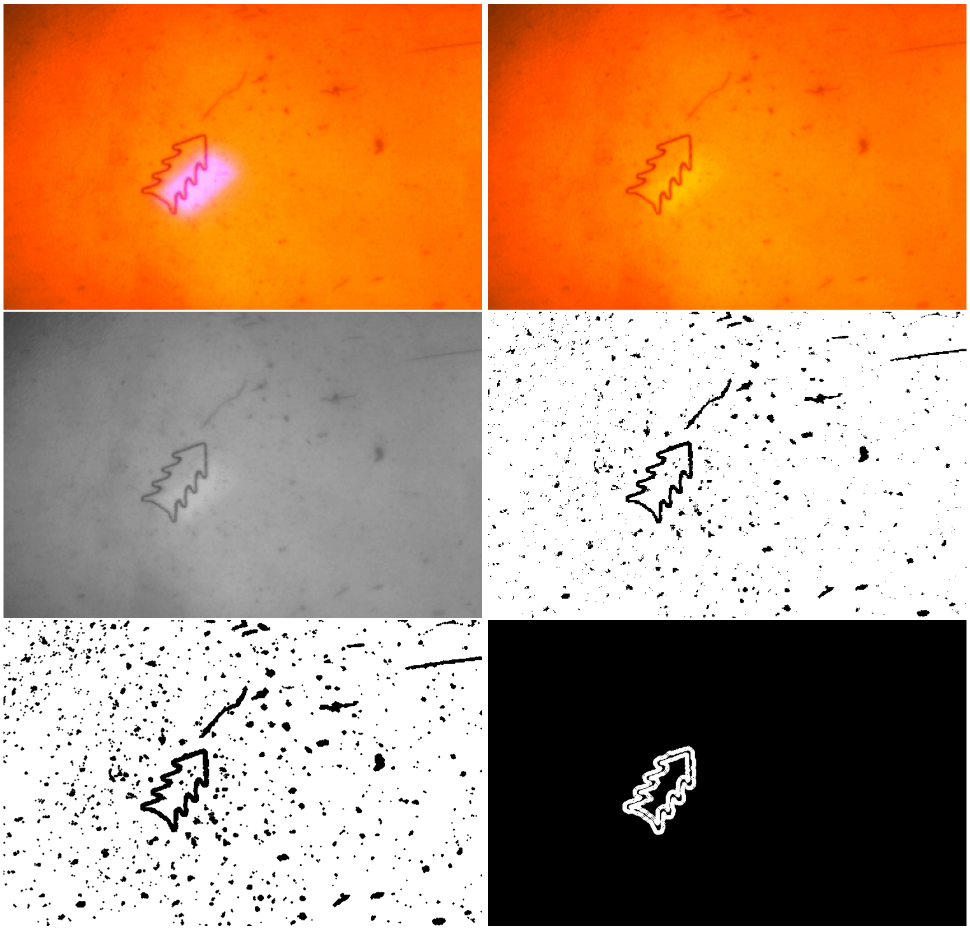

Figure 1: From left to right and top to bottom these images show each step of the contour finding algorithm.

1.3 Warping

Before tracking the Models some calibration is in order to correct for the distortion created by the projection method. To calibrate the setup the user is asked to identify the position of 3 pairs of points as they exist on both the stage and the DMD. These pairs are then used to compute an affine transformation between the two planes. From this point on any images to be projected are first run through that transformation.

1.4 Tracking

1.4.1 Generating models

The first step in tracking is to find all of the potential models. All potential contours are checked for an area inside the given range and a Model object is created with the initial information about the contour. The algorithm then begins to track all of the potential models while the user selects which models are of interest. Then the tracking is restarted using only those models. The tracking needs to start before the user selects the models since the algorithm relies on each model not moving too much between frames.

1.4.2 Updating models

The actual tracking itself is performed by capturing a frame and using it to update all of the models from the previous frame. To do this the following process is performed on each model in turn. First a small region of interest around the previous position of the model is identified and contours are extracted from it using the normal method. Then these contours are searched for the one whose area most closely matches the area of the initial model. If the two areas are close enough the model is considered to be 'found' in that frame. If the object is found the contour is then used to determine the other two pieces of tracking information, the center and the orientation.

Calculating the center is done by simply computing the center of mass of all of the contour points. Determining the orientation is more difficult since the algorithm is designed to operate on arbitrary contours which could have any amount of rotational symmetry. To simplify this issue we compute a sort of polar histogram of the contour called an orientation signal (Figure 2). The histogram has 360 slots, one for each degree. Each slot contains the average distance from the center to all points in the contour that lie in that direction. In this form a rotation of the object corresponds to a phase shift of this signal. Calculating the phase shift that gives the minimum change in angle from the previous frame then gives the new orientation provided the object can't rotate fast enough in one frame to reach a point of symmetry since in that case it would be impossible to determine the orientation. Finally the information is added to the tracking vectors of the model.

1.5 Projecting

While the tracking occurs the user is presented with a visualization of all the tracked models current state. Then the user can select which model to

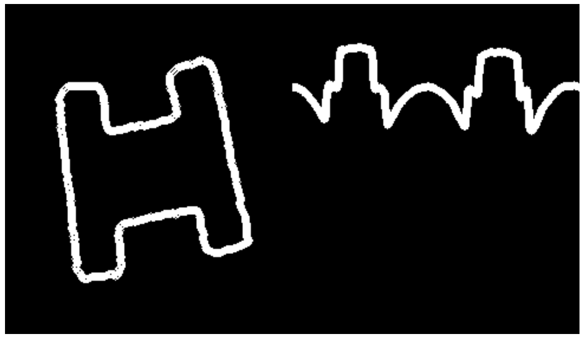

Figure 2: A model and its rotation signal

expose at any time. There are two categories of exposure to select from. Within each category the user can select different types of exposure for each model which are then toggled on off throughout the experiment. The first category is contour based. In this type of exposure the entire contour of a microrobot is exposed except for a specific region selected by the user. The second category is not contour based. In this category the user selects which regions of the robot to expose based only on the orientation of the robot without any information about the specific shape of the contour. For example the user may choose to expose a rectangle covering the top half of a robot. Both types of exposure are shown in Figure 3

Figure 3: Left: A non-contour based exposure, the contour is shown in blue but does not appear in the actual projection. Right: A contour based exposure that exposes the bottom half of the contour