Breadboard to Schematic

Catherine Olsson
MIT
catherio@mit.edu

Michele Pratusevich
MIT
mprat@mit.edu

Abstract

TODO: Write the abstract.

1. Introduction

Breadboards are an important tool for do-it-yourself hardware designers to quickly test circuit systems. They are easy to assemble, easy to change, and easy to test, so are the tool of choice for the first prototype of many hobbyists and students. A programmatically-drawn, or more likely hand-drawn, schematic diagram is used to prototype the circuit board, but if the circuit is going to be used for high-speed, low-noise, or multiple-production applications, a printed circuit board (PCB) is much more desirable than a breadboard. However, it can be time-consuming to enter a breadboard's connection map into a programmatic language that can be used to generate a PCB. It would be faster to create a PCB-ready representation directly from the circuit-board. Even if the result had errors, these could be corrected by the user in less time than it would take to create the representation from scratch.

Our approach to solve this problem was a vision-based tool to go from a picture of a breadboard circuit to a file written in a PCB-ready format given by Eagle. Although a fully-automated tool proved to be too large a task for this project, we have successfully implemented a GUI-based tool that spans the full pipeline from bitmap image input to PCB-ready output by incorporating automated methods with input from the user.

Overall, this project was an exercise not only in computer vision methods for recognition and segmentation, but also in more general problems of visualization; modularity; and designing, manipulating, and transforming between representations on a spectrum from concrete (pixel-level) to abstract (component-level).

2. Related Work

TODO, if any

Figure 1: A breadboard oriented like those oriented in images that we can process, before any components have been added to it

3. Background

3.1. Properties of Breadboards

When solving vision-based problems, it is critical to know your system properties to better develop algorithms customized to the strengths and weaknesses of a particular application. Photos of breadboards have a number of interesting properties that can be useful in segmentation, identification, and restructuring tasks. A number of visually-interesting properties are listed here:

- A single component on a breadboard, such as a wire, LED, or chip is often a single color.
- The colors of the various components are often easily visually distinguishable.
- The breadboard is often square with the image.
- The breadboard, when not covered with components, has a black checkered pattern of holes in it.
- The breadboard color is relatively constant over the entire breadboard, except for the holes.
- Breadboards follow a specific connectivity pattern. In Figure 1, each column (not including the top two and bottom two rows) can be considered a single connection. The middle gap in the square holes is a break in the connection for each column, so there are five total holes connected to one connection in each of the columns. The top two and bottom rwo rows are connected horizontally into a single connection. Typically, one denotes a voltage of $+5$ volts and one denotes `GND`, or 0 volts.

3.2. Schematic-drawing Software

The Eagle program, developed by CADSoft, is a free schematic and PCB-drawing software that translates schematics into a PCB-ready format. The Eagle file format is a type of XML, which makes it easy to programmatically update from an image. Eagle PCB and schematic diagrams are based off of the same language, so drawing a schematic in Eagle is sufficient to computing the full PCB.

4. User Interface of our Tool

From the point of view of the user, the workflow of our tool is as follows:

1. Start the program, indicating the filename of the bitmap image containing a photograph of the breadboard.

2. Select the most important colors in the image. For example, a beige breadboard with red and green wires and a black microchip would require the user to click on examples of those four colors.

3. Confirm the selected colors to view a segmentation map of the image based on those colors.

4. Select the components in the segmentation map which should be analyzed and included in the final schematic.

5. Confirm the selected components and obtain an XML version of their connectivity.

In the following sections we will explain more about our approach to the problem, the results we obtained, and the limitations of our tool and techniques.

5. The Approach

The problem of translating information from a picture of a circuit to a PCB-friendly file format has two main steps. First, the components must be identified in the image, and second, the components must be placed in a virtual grid representation independent of their relation in the image.

For our implementation we chose to use python and it's Tkinter, PIL, SciPy, and Numpy packages for ease of implementation, user interface, and speed.

5.1. Segmentation into Circuit Components

At first we were unsure about which approach towards segmentation into image components was going to be more effective, so we tried two algorithms for detecting components.

5.1.1 Color Following

As a first step to tackling the component segmentation problem, we took advantage of the natural segmentation in a breadboard picture according to color. Components on a breadboard are different colors that are localized in one location, so to take advantage of this, we developed an algorithm that "grows" a component based on a given color pixel. A seed color is given to the algorithm and added to an active set of pixels. For each neighbor of each pixel in the active set, the decision is made whether that pixel is in the component if the pixel does not change the running RGB color-average of all the pixels current in the component. If a pixel is added to a component, it is then also added to the active set and the algorithm continues.

The main problem with this algorithm is that it is highly dependent on the seed pixel to the image. If a pixel is chosen that is too dark for example, the running average that the algorithm will calculate will be off from the actual running average of the color of the component, so the algorithm will return incorrect results.

5.1.2 Segmentation by Nearest Color

Idea is to segment on color by quantizing the color of the image and finding connected components in the quantized color space.

Overall algorithm:

1. Use a 3D clustering algorithm to find representative colors. We wanted to use k-means, but it didn't work. The user picks these.

2. Map colors to the nearest representative color- ie, divide up the colorspace into Voronoi regions with Euclidean distance in RGB-space.

3. Find connected components of each color. Standard algorithms work on binary masks, so run each color independently

4. (Optional) Eliminate small connected components using binary erosion/propagation. We got this part working, but it is not needed in the current user-assisted workflow.

Shows some problems, but generally works well enough for this application.

5.2. Occlusion Handling

A problem with breadboard circuits is often that components (most often wires) are occluded from each other. This is a critical issue that in any finalized version of a product like this needs to be addressed. Because we ran into other issues with our approach, we were not able to effectively solve the occlusion problem.

5.3. Virtual Grid Representation

The next component of the project involved translating the component data into a schematic. Knowing all the pixel locations that make up a component, we calculate the end pixel positions of each component rounded to the nearest 10. Because components are aligned to the hole-grid that is present on the breadboard, the calculated endpoints of the components can be used to place components on a grid in the schematic. The rounded values for the x and y coordinates are used to place the components into their XML representations into the schematic.

After all components are identified and represented in their XML formats, a new file is constructed with the proper sschematic-XML information.

6. Results

6.1. The Full Spectrum

Running our system using the nearest-color algorithm for segmentation yielded very positive results. Figure 2a shows the original image operated under, and Figure 2b shows the image after segmentation. The final schematic result (opened as a file in Eagle) is shown in Figure 2c.

Notice how the schematic figure is upside down of the original image and it's segmentation; this is a result of the difference in indexing conventions between PIL, numpy, and Eagle.

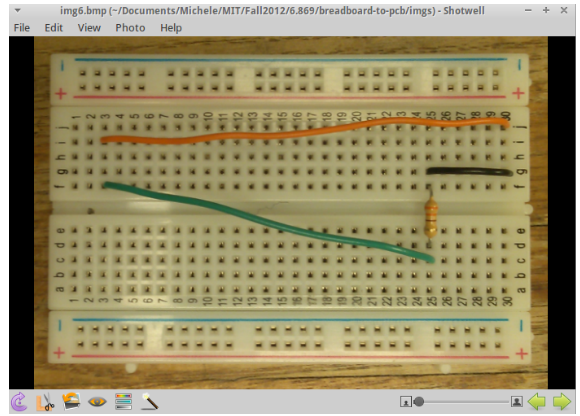
6.2. Comparing Color-following and Segmentation by Nearest Color

The color-following and nearest-color algorithms solve somewhat different problems. The color-following algorithm assumes a seed pixel (whether given programmatically or by a user) and constructs a component from that seed pixel, while the nearest-color algorithm separates the image into sections based on colors found in the entire image. In both bases, if the same component is found, it should be found correctly. Given that the exact parameters for both algorithms were not perfectly tuned, these results are a comparison of the current implementations of the algorithms as we have them.

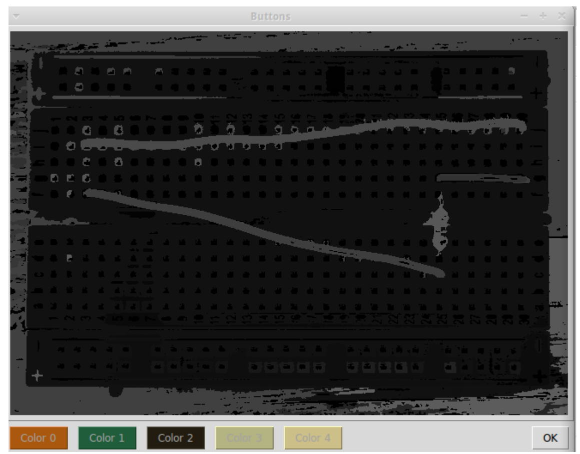
Figure 2d has the original image that we are analyzing. Figure 2e shows one wire detected by the color-following algorithm. Note how, given a particularly good seed color, it was able to only detect one of the two wires that are nearest each other. In Figure 2f, note the same wire is detected as a single wire with the wire immediately below it.

6.3. Limitations

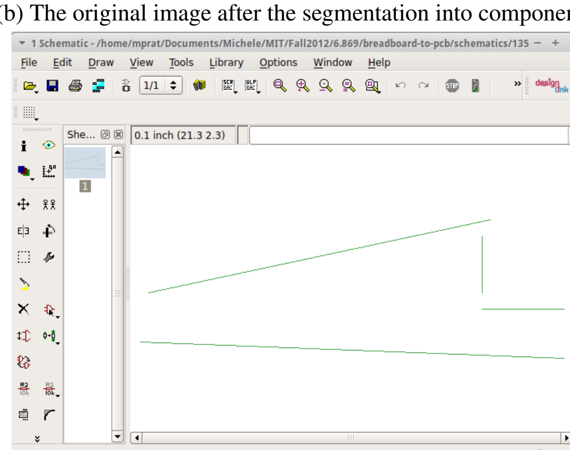
One limitation of our product as we've written it is that it can only handle breadboard circuits that are oriented horizontally as shown above in Figure 1. This is because



(a) The original image



(b) The original image after the segmentation into components

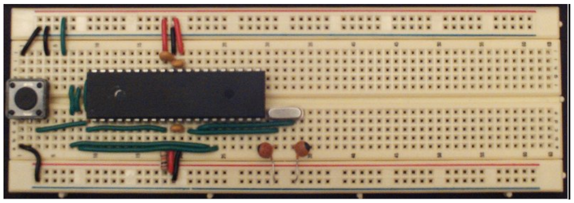


(c) The schematic computed from the original image

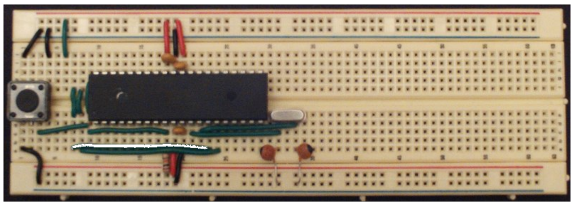
connectivity properties of the breadboard are geometry-dependent, and our program automatically assumes a particular orientation for the breadboard to infer connectivity.

7. Future Work

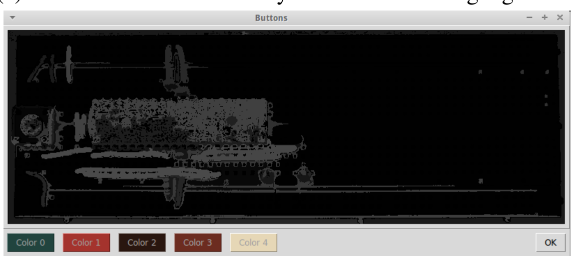
TODO: automatically identify components



(d) The original image



(e) The white wire detected by the color-following algorithm



(f) Note the same wire incorrectly detected by the closet-color algorithm

8. Conclusion

TODO