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Abstract

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Chapter 1

Chapter Title

In this chapter there examples of various features you may want to incorporate into your document. Here's an example of a figure inserted into the text:

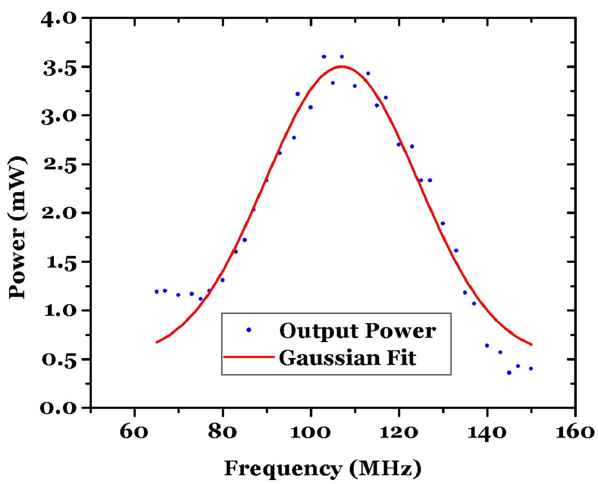

Figure 1.1: *Full caption to appear below the Figure*

See the file chapter1.tex for examples of the commands used to insert a figure or table, add a caption, etc. Here is an example of a table:

Table 1.1: *Caption to appear above the table*

Column 1 Heading	Column 2 Heading	Column 3 Heading
Col 1 Row 1	Col 2 Row 1	Col 3 Row 1
Col 1 Row 2	Col 2 Row 2	Col 3 Row 2
Col 1 Row 3	Col 2 Row 3	Col 3 Row 3

1.1 Making References to Figures or Tables

It is possible to create cross-references and hyperlinks to items or sections within your paper. For example, here is a reference to Fig. 1.1 mentioned at the beginning of this chapter and a reference to the Table 1.1.

1.2 Making a Reference to a Chapter Subsection

In this section, we refer back to text mentioned in Section 1.1 on page 2.

1.3 Making a Citation

Here's an example of a citation to a single work.[1] It's also possible to make multiple citations.[2;3]

This template uses BibTeX to manage and format citations. BibTeX is not the only way to create a bibliography within LaTeX, but it's generally considered to be the best option for long documents like a thesis or dissertation.[4] There are a few more sample citations in this paragraph so you can see examples of how in-text references are made and how the bibliography is formatted.[5] See the file "BibTeX Guide.pdf" for information on how to use BibTeX.

Chapter 2

This is Chapter 2

To refer to Chapter 1, use the slash ref command along with the ”makereference” label which was assigned back at the beginning of Chapter 1.

2.1 Page Number References

It is possible to refer to a specific page number, such as page 1. Add a slash label command and a unique name for each page to be referenced later in the text.

2.2 Referring to Sections Within Chapter 1

It is possible to refer to sections within a chapter. Add a slash label command and a unique name with the section number for each section to be referenced later in the text. Her is an example of a figure in section 1.1 and an example of a table in section 1.2. In section 1.3, we looked at examples of bibliographic citations.

Chapter 3

This is Chapter 3

Here are more examples of references to previous sections. In Chapter 1 there were several sections, including section 1.1, section 1.2, and section 1.3.

Likewise, in Chapter 2, there are sections 2.1 and 2.2.

Chapter 4

Post-Processing Pipeline

Once the images are collected they must be converted into a field map. This task is accomplished by a set of scripts that are run in a pipeline fashion, where the output of one script is used as the input to the next. This chapter provides a general overview of the pipeline followed by a detailed explanation of each script.

4.1 Pipeline Overview

In this pipeline each script is referred to as a stage, where each stage accomplished one specified task. The main reason the post-processing is split into separate stages is several stages take a significant amount of time to run, so it's beneficial to not re-run the entire pipeline when changes are made. Each stage is summarized in the following list:

Stage 0 Calculate the position and orientation (pose) of each image.

Stage 1 Find and read QR codes in each images.

Stage 2 Create the structure of the field using the QR codes.

Stage 3 Detect leaves and plant markers in each images.

Stage 4 Cluster plant parts from stage 3 into possible plants, and filter out unlikely plants.

Stage 5 Assign individual numbers to plants and save final field map to a comma separated value (CSV) file.

The two stages that take the most time are 1 and 3 as they both deal with opening each image and searching through it. Even though these stages are similar, they are kept separate because having access to the field structure can significantly speed up the clustering step in 4.6

Conceptually the output of each intermediate stage consists of objects which directly relate to the field, for example QR codes, plants or rows. In reality the output is a single file containing the serialized representation of each object. This makes it trivial to pass these objects from one script to another.

The location of the code is listed in Appendix A. TODO include ref.

4.2 Stage 0 - Calculating Camera Pose

4.3 Stage 1 - Extracting QR Codes

The first goal after calculating the position and orientation of each image is to find and read all QR codes in the image set. This process involves four steps which are applied to every image.

The first step is converting the image from the default Blue Green Red (BGR) color space to the Hue Saturation Value (HSV) color space. As can be seen in figure TODO, this is a cylindrical coordinate system which separates image intensity from the color information which makes it more robust to changes in lighting. This color space is also more aligned to how humans think about color TODO insert reference.

TODO insert figure of HSV color space

The second step is to separate the white QR codes from the rest of the image. This is accomplished by applying a range threshold for each of the HSV components as described below dst(I)=lowerb(I)0src(I)0upperb(I)0lowerb(I)1src(I)1upperb(I)1

This results in a binary image where pixels that are mostly white are 1 (all white) and everything else is 0 (all black).

The third step is finding the set of external contours, or outermost edges, of each object in the binary image. Each set of contours is then assigned a bounding box, which is the smallest rotated rectangle that encompasses all of the object's contours. These bounding box's are filtered to remove one's that are either too small or too large to be QR codes.

The final step is to use these bounding box's to extract parts of the original to run through QR reading program. From the researcher's experience the ZBar open-source program provided the best results.

TODO could talk about adaptive thresholding.

The data returned by the ZBar library is used to determine if the code corresponds to a plant group or to the start/end of a row. If no data, or bad data, is returned by the ZBar library the extracted image is saved for the operator to review after the stage has completed.

TODO

4.4 Stage 2 - Creating Field Structure

The second stage of the pipeline involves assigned row numbers to each QR code and then creating plant groups that can span multiple rows.

As an optional input to this stage, the user can specify a file containing any QR codes from the previous stage that weren't automatically detected.

The first step of this stage is to pair the start and end QR code associated with each row. Since the locations of the codes are known the average row heading can be calculated as shown in figure TODO. This row heading is used to transform the world frame into a what is referred to as the field frame which has the y axis running along the rows. The origin of the field frame is defined such that all the QR codes have a positive position in both the x and y axes. If not specified any future algorithms in the pipeline use these field coordinates rather than world coordinates.

The next step is to assign each group QR code to a specific based only it's location. As some rows can span several hundred meters it's not always possible to assign a QR code to the nearest row defined as a vector between the row start and end codes. Instead a sweeping algorithm is used which is described in the following steps:

The idea is to sweep across the field, from left to right and incrementally add QR codes to each row. Once a code is added to a row it splits that row into smaller segments. Each new code computes the shortest distance to the existing row segments.

The group QR codes are sorted in order of increasing x-field coordinates. For each code find the lateral distance to the nearest row segment, where a segment is defined

It's possible that when the transplanter reaches the end of a row the current plant group isn't finished and continues into the next pass. A pass refers to the transplanter driving once down the field, so a 2-row transplanter would have a pass containing 2 rows. The di

4.5 Stage 3 - Extracting Plant Parts

Similar to the process of extracting QR codes, this stage converts each image to the HSV color space, applies a range threshold, and filters the objects based on size. Since this stage is looking for plant leaves and plant markers it uses different ranges for the HSV components which are shown below.

TODO show range values for filter

Similar to the QR codes these values are set based on experimentation.

Besides the difference in range values this stage also adds an extra step after the threshold and before finding the contours in the image. Then step applies two filters, the first being erosion and the second dilation. The erosion filter removes noise from the image and the then the dilation step connects adjacent contours. These effects can be seen in figure TODO. The reason this step isn't used for the

TODO maybe explain why connecting contours is a good thing.

The reason why this extra step isn't used in stage 1 is that step is already more robust based on the selected HSV range and the square nature of the QR codes doesn't benefit from connecting contours.

4.6 Stage 4 - Locating Plants

One of the most

4.7 Stage 5 - Saving Field Map

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Appendix A

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Appendix B

Title for This Appendix

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