Lytro Remote Shutter User Manual

1 Acknowledgements

This software package utilises software from a range of sources. The remote triggering and downloading of photos from the Lytro light field camera was made possible thanks to a DLL provided by Jan Kuˇcera. More information on this software is avail-able on his website (http://optics.miloush.net/lytro/) and thesis (http://optics.miloush.net/lytro/TheResources.aspx). Calibrating the light field files and decoding them into a user-friendly format was done using the Matlab Light Field Toolbox v0.4 by Donald Dansereau (https://au.mathworks.com/matlabcentral/fileexchange/49683-light-field-toolbox-v0-4). Generating a trajectory for the UR5 and calibrating the UR5 with the Lytro was made possible thanks to Matlab code provided by a previous ANU Engineering undergraduate student, Montiel Abello. Finally, com-municating remotely with the UR5 was made possible thanks to example Matlab and Polyscope script code by Fereshteh Aalamifar (https://au.mathworks.com/matlabcentral/fileexchange/50655-ur5-control-using-matlab?s_tid=prof_contriblnk) and Long Qian (https://github.com/qian256/ur5_setup).

2 Overview

This software has been compiled into a Windows Executable using Visual Studio. It is written in C#, but also includes a range of Matlab functions and a Ploysscope program to be run on a UR5 robot arm. The software is capable of several triggering configurations, and also provides downloading and processing functionality. These functions are briefly explained below.

2.1 Triggering Options

The software allows for three methods of triggering the Lytro. Option 1 will triggering the camera every 1.5 seconds for a time period that is specified by the user in the `config.txt` file. Option 2 allows the user to trigger the shutter remotely by pressing `SPACEBAR`. Option 3 will trigger the camera while simultaneously moving a UR5 robot arm through a predetermined range of motion. Section 3.8 outlines how the trajectory implemented by the UR5 can be set up.

2.2 Downloading

Once all photos are taken, the photos are downloaded from the Lytro to the user's computer via wi-fi. The location of the downloaded files is explained in Section 6. There are a range of photo file formats that are available to choose from, and any combination of these can be downloaded by using the appropriate combination of keywords in the `config.txt` file. These file options are detailed in Section 6. As each photo completes downloading, it is deleted from the camera. This is done to ensure that the correct photos are downloaded if consecutive runs are undertaken.

2.3 Processing

Once all the photos have been downloaded to the user's computer, instructions are sent to Matlab's command line to run the Light Field Toolbox mentioned in Section 1. This process accesses the downloaded files, decodes them, calibrates the Lytro using the white image data discussed further in Section 3.2, then rectifies the decoded images using this calibration data. This process, along with the location of all the relevant files is outlined in Section 7.

2.4 Results

Upon completion, the user will have access to the original and decoded light field files. All the photos will have been deleted from the camera, allowing for the software to be re-run immediately.

3 Before Running This Software

3.1 Physical Setup

For full functionality of this software, the user requires a PC, a UR5 robot arm and a first generation Lytro light field camera. The PC and Lytro need to be connected via wi-fi, and the PC and UR5 need to be connected via Ethernet. For the PC and UR5 to communicate, it must be ensured that they are within the same IP subnet mask.

3.2 Download Lytro Desktop

Download and install Lytro Desktop. Lytro Desktop will back up your files and download the white image files that are used by this program to calibrate the light field images. In order for these files to be downloaded, you only need to plug the Lytro into your PC via USB while Lytro Desktop is installed. No further steps are required.

3.3 Download Matlab

Matlab is required in order to decode and calibrate the light field images, and communicate with the UR5. If you do not have a Matlab licence and wish to skip the UR5 communication, decoding and calibration steps, this can be done using the `config.txt` file discussed in Section 3.9.

3.4 Loading `Lytro.urp` on the UR5

In order for the UR5 to respond to movement commands from this software package, the file `Lytro.urp` must be loaded on to the UR5 Polyscope. This can be done by saving the file to a USB and inserting the USB into the UR5 Polyscope device. The user can then choose the 'Load Program' option, navigate to the file on the USB, and open it. If you receive a warning that the software was written for an earlier version of Polyscope, accept this and continue.

3.5 IP Subnet

For communication between the user's PC and the UR5 to be successful, these devices must be within the same IP subnet mask. To check the IP address of the UR5, navigate to 'Setup Robot', 'Network Settings', then choose 'Static Address' and enter the address and subnet.

The addresses used in the initial setup were: PC IP: 192.168.100.2, PC Subnet: 255.255.255.0 PC port: 30000, UR5 IP: 192.168.100.2, UR5 subnet: 255.255.255.0 UR5 port: 30000.

Note that the user will need to update the IP address within the `Lytro.urp` file (see Section 3.4) if they wish to use a PC IP address other than the above. Fur-thermore, if the user wishes to use a different port, they will need to change this both within the `config.txt` file, and the `Lytro.urp` file.

3.6 Calibrate the Lytro

In order to determine the Lytros intrinsic matrix and allow for the rectification of images [78], the Lytro camera used with this software should be calibrated. This can be done using the Light Field Toolbox v0.4. This calibration process requires a set of images of a calibration checkerboard. This set should contain at least 10 images in a range of diverse poses, that all contain the whole checkerboard, and maintain the same zoom and focus settings. To perform this calibration, the user needs to undertake the following steps.

1. print off a checkerboard (high density, such as 19x19 squares will yield better results).
2. Measure the length and width of the checkerboard squares.
3. Ensure that Option 1 in the `calib.txt` file is set to '1 or 2', and that Option 2 is set to 'Y'.
4. Ensure that Option 7 is set to 'Y,[x,y],[x1,y2]', where [x,y] refers to the number of corners on the checkerboard (length$\times$width), and [x1,y1] refers to the length and width of the checkerboard squares.
5. Take at least 10 images of a checkerboard with known dimensions. Ensure that the entire checkerboard is visible in all images.

Upon performing the steps outlined above, 10 images will be saved to the directory \<pwd>\LFToolbox0.4\LFToolbox0.3_Samples1\Cameras\<Camera-Serial-Number\01

Lytro Remote Shutter requires access to the Lytro cameras white image files in order to perform the calibration. These are automatically downloaded when the Lytro is connected to a PC via USB. Therefore, before running this calibration routine, the user must first connect their camera to a PC and allow these files to download. Lytro Remote Shutter searches for these files when it runs this routine.

3.7 Calibrate Lytro and UR5

The Light Field toolbox and the UR5 pose data give us two different sets of 3D spacial coordinates. We need a set of coordinates that represents the position of the optical centre of the Lytro with respect to some fixed reference point. This would be possible just with the Light field toolbox if we were only using this software to measure planar checkerboards. This is because the toolbox provides us with coordinates relative to this checkerboard, and if we want to measure any other type of object the spacial coordinates calculated by the Toolbox would not be accurate.

To overcome this issue, the Lytro can first be attached to the UR5, and used to measure a planar checkerboard. This set up provided both sets of coordinates: a set corresponding to the position of the UR5 gripper with respect to the UR5 base, and a set corresponding to the position of the Lytro's optical centre with respect to the checkerboard. By following the process outlined in Section 3.3 of this thesis, these sets of images can be used to determine the offset vector between these two reference frames.

As the external camera parameters that we need are the relative rotation and translation between images, we can do the following. Set the initial gripper position as the reference point. Calculate the rotation and translation of each subsequent image relative to this reference point.

3.8 UR5 Trajectory

Note: If you do not wish to change the trajectory of the UR5 from the default (see Figure 1), this Section can be skipped.

The desired UR5 trajectory can be produced using `generateUR5Trajectory.m`. The trajectory is defined as a function within this script. Currently this function is defined as:

$$f(x) = \sqrt{0.15\cos(x)^2 - 1.5\sin(3x)^2 + 0.4\cos(2x)^2} \tag{1}$$

This function produces the trajectory illustrated in Figure 1.

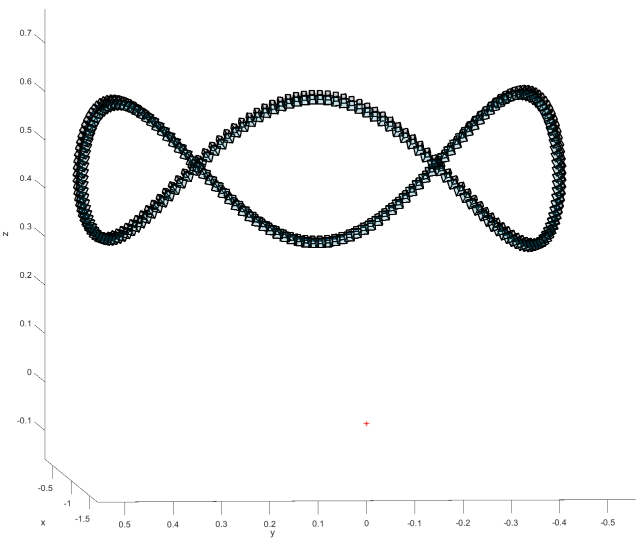

Figure 1: Example trajectory of a camera attached to a UR5, with the centre of focus illustrated as a red dot

Figure 1 is generated by the same Matlab program, and indicates the progression of the focal centre of a camera attached to the UR5 as it moves through 200 positions. The figure also shows the location of the centre of focus as a red dot.

Running this `generateUR5Trajectory.m` produces `.SCRIPT` and `.TXT` files with the positions of the UR5's joints at points along the trajectory. The `.TXT` file is read by this software package, and the joint positions are then sent to the UR5 via Ethernet.

3.9 config.txt

An example `config.txt` file is provided below:

```
Lytro Remote Shutter Configuration File.

For a description of how this file works, please see the User Manual.

1. For 0.66fps video for a duration specified below enter '1',
For photos triggered by SPACEBAR enter '2',
For autonomous photos synchronised with a UR5 enter '3'
-----------------------------------------------------------
3
-----------------------------------------------------------

2. Do you want to download the photos to this computer once finished? (Y/N)
-----------------------------------------------------------
N
-----------------------------------------------------------

3. Do you want the photos to be deleted off the camera after they are
downloaded? (Y/N)
----------------------------------------------------------
N
----------------------------------------------------------

4. What format(s) would you like your photos to be saved as?
raw sensor .jpg ('j'), raw sensor .raw (r), raw sensor metadata ('m'),
stack of raw sensor images ('s'), processed .jpg ('J'),
processed .raw ('R'), processed text file ('T'),
processed light field photo (.lfp) ('L')
----------------------------------------------------------
L
----------------------------------------------------------
```

```
5. For Option 1, how long should the video be (in seconds)?
(leave as '0' if Option 1 is set to 2 or 3)
----------------------------------------------------------
0
----------------------------------------------------------

6. Perform UR5-Lytro calibration routine? (Y/N) (Option 1 must be set to '3')
----------------------------------------------------------
N
----------------------------------------------------------

7. Perform Lytro calibration routine using (Option 1 must be set to '1 or 2')
Format: (Y/N),[x,y],[x1,y1] (see User Manual for further details)
----------------------------------------------------------
N,[21 14],[12.2 12.2]
----------------------------------------------------------
```

4 Starting the Software

This section outlines how to run the software. This process involves the following steps:

1. Ensure that both Matlab and Lytro Desktop are installed on your PC (see Sections 3.2 and 3.3).
2. Ensure that you have previously connected the Lytro to your PC so that the white image data set could be downloaded (see Section 3.2).
3. Alter and save the `config.txt` file as required (see Section 3.9).
4. Connect the PC and UR5 via Ethernet cable.
5. Turn the UR5 on.
6. Ensure that the PC and UR5 are within the same IP subnet mask (see Section 3.5).
7. Load the Polyscope program `Lytro.urp` onto the UR5 (don't run it) (see Section 3.4).
8. Turn the Lytro camera on.
9. Enable the Lytro's wifi.
10. Connect your PC to the Lytro's wi-fi.

11. Start the software and follow the prompts.

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5 UR5 Communication

Communication with the UR5 is done via Ethernet cable and TCP/IP protocol. See Section 3.5 for an explanation of how this connection is set up. The communication is initiated and carried out using the Matlab functions `init()` and `moverobot()`. The Lytro Remote Shutter software calls these functions by creating a reference to the Matlab Type Library. The `init()` function opens the TCP/IP connection for the given IP address and port. The `moverobot()` function sends movement commands to the UR5 one at a time. These movement commands are extracted from the `.txt` file produced by the `generateUR5Trajectory.m` program described in Section 3.8.

There is a 2 second delay between the sending of movement commands to the UR5. Half way through this time interval, the Lytro camera is triggered, thus ensuring that the UR5 has completed it's previous movement and is stationary when triggering occurs.

6 Downloading the Files

This software package allows images to be downloaded from the Lytro over wi-fi. The images can be downloaded in the following formats: `.raw, .jpg, .txt, .LFP, .JPG, .RAW`. The first three, lower-case file options refer to raw sensor data, while the upper-case options refer to data packages. Choosing which file types to download can be done in the `config.txt` file (see Section 3.9). Any number of options can be chosen at one time. Ensure that multiple options are separated by commas in the `config.txt` file.

7 Matlab Processing

As mentioned in Section 1, the processing of the light field files is done using the Matlab Light Field Toolbox created by Donald Dansereau. The required toolbox functions are run from the Matlab command line, which receives it's instructions from the Light Field Remote Shutter software.

The procedure that these instructions follow very closely mirrors the 'Quick Tour' that is described in the Light Field Toolbox user manual. Broadly, the procedure undertakes the following steps:

1. Processing the White Images: A white image database is built using the white images specific to the Lytro camera being used. These files are loaded onto a PC when the Lytro is connected via USB. On Windows computers, these files are saved by default at the directory <drive_letter>:\Users\<username>\AppData\Local\... Lytro\cameras\sn-<serial_number>. These files are copied from this directory by this software package, and the white image database is then built using the Matlab toolbox.

2. Decoding the Light Field files: The light field images downloaded from the Lytro by this software package are decoded using the Matlab toolbox. For each image, the toolbox selects the corresponding white image, and saves the output files in the following formats: *__Decode.mat and *.png. These files are saved to the same directory that they are downloaded to.

3. Rectifying the Decoded files: In order to rectify the decoded light field files, the Lytro camera must first be calibrated. This can be done using the calibration data sets available here [80]. By default, the PlenCalCVPR2013DatasetA has been used. The result of this calibration is a CalInfo.json file, that contains information including pose, and intrinsic and distortion parameters. The lenslet grid model is also produced, an example of which is displayed below.

The decoded light field images are then rectified based on this calibration information, and the files are saved in the same location.

8 Accessing Decoded Files

The decoded and rectified light field images will be available at <pwd>\LFToolbox0.4\... LFToolbox0.3_Samples1\Image\Lytro\ once the software has finished.

9 Directory Structure

```
LytroRemoteShutter
    RunDLL
        bin
            Release
```

```
LFToolbox0.4
    LFToolbox0.3_Samples1
        Cameras
            A903200311
                01
                WhiteImages
        Images
            Lytro
    SupportFunctions
ur5_setup-master
    interface
UR5Trajectory

config.txt
Lytro Remote Shutter.exe
```