Fire ROS Calculator's Manual

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Camera Calibration

The camera calibration is made by using the Computer Vision System Toolbox™ calibration algorithm which uses the camera model proposed by Jean-Yves Bouguet. The main item on the calibrate process is the calibration object, where this object will be captured by the camera in several positions. These captured images (normal digital images) will be used to calibrate the camera by getting its extrinsic, intrinsic and lens distortion parameters. Where the extrinsic and intrinsic parameters are for detecting the camera position on the space and the lens distortion parameters are for correcting this distortion, especially for the wide-angle lenses.

In a case that the camera will be used for recording the fire propagation can't take digital images (an IR camera for example). There will be a need to use another digital camera. So, if two cameras will be used, these considerations must be accounted:

- Place the digital camera as near as possible from the IR camera (or the camera the is being used to record the fire) and make sure that the two camera plans are parallel to each other (i.e. the deference in position can be corrected by translating one of them along the three axes (x y z) without any rotation)
- Adjust the zoom of the digital camera where the captured frame on the other camera will be within its frame (i.e. lower zoom than the IR camera)
- Before starting the analysis, the taken images of the calibration object by the digital camera must be cropped and rescaled to match the Images that will be taken form the recording of the fire. You may use the provided tool by the Fire ROS Calculator, the "Match Images" tool. Its guide is on the user's guide part of this manual, section 3.

On the following we will discuss the calibration object and the procure of capturing it by the camera along with some considerations.

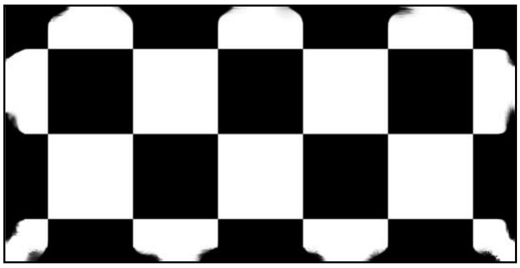
Calibration object

The calibration object is a checkerboard pattern. Where it constructs from black and white squares have the same size and distributed in a check pattern. This pattern will be printed on a board and used to calibrate the camera. The Fire ROS Calculator's user may find a group of checkboard patterns with different sizes ready to be printed from here:

https://github.com/AAbouali/Fire_ROS_Calculator/raw/0f15eeef92f857431374cf3d4646c5384a713388/calibration%20objects.rar

Considerations:

- The checkboard must have an even number of squares along one side (x) and an odd number along the other side (y) or vice versa.
- The checkerboard printout needs to be attached to a flat surface. Imperfections on the surface flatness can affect the accuracy of the calibration.
- We noticed that it's recommended to blur or smudge the last corners of the checkboard that's attached to the edges of the board or otherwise an error might happen on the detection process of the checkboard done by the program. However, the provided patterns by us have this smudginess at the corners (Fig. 1).



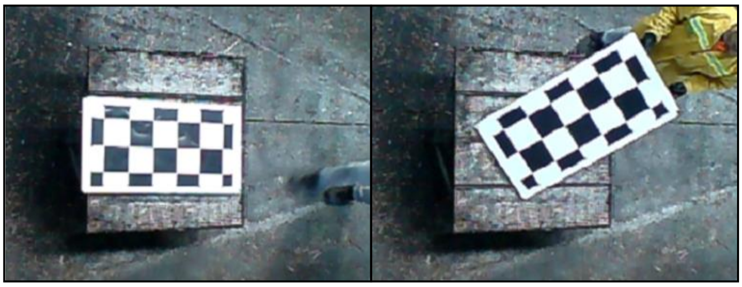


Fig. 1 Two different position where the calibration object where captured on. On the left, the board is place over the fire surface to get the Bed Surface Reference image. On the right, just a random position

Capturing the calibration object

To calibrate the camera, the calibration object must be captured by the camera from 15 to 25 times where the object (the checkboard) will be in different position each time on the space around the fuel bed where the fire test will take place.

Along with these images an important image must be taken where the checkboard is placed over the surface that the fire will propagate on it. For this image, which we call "Bed Surface Reference ", the board must be completely attached to the surface (Fig. 2), although the thickness of the board won't produce a high error, but it's recommended to use a board that have thickness less than 2 cm. In a case that the fire is propagating over more than a surface during the same test, the Bed Surface Reference image must be taken for all the surfaces and the fire propagation will be analyzed separately for each surface.

The other positions where the pattern will be capture on are random with accounting these considerations:

- Keep the pattern in focus, and don't change it (do not use autofocus).
- Do not change zoom settings between images.
- Use a proper calibration object size that will fill about 20% of the camera frame. The smaller size it will fill, the less accuracy the calibration will be or it will be invalid in some cases.
- Capture the images of the pattern at a distance roughly equal to the distance from your camera to the fuel bed surface. For example, if the fuel bed is at 2 meters, keep your pattern around 2 meters from the camera.
- Place the checkerboard at an angle less than 45 degrees relative to the camera plane. Also, the fire surface must have a relative angle less than 45 degrees.

- Capture enough different images of the pattern so that you have covered as much as possible all the areas appearing in the camera frame.

After finishing this calibration process, the calibrated camera must stay on the same position while performing the fire propagation tests. The process must by repeated in case of changing this position. However, if the fuel bed or the testing surface configuration have been changed. There is no need to repeat the whole process, but only the Bed Surface Reference images must be retaken for the new surface positions.

User’s Guide

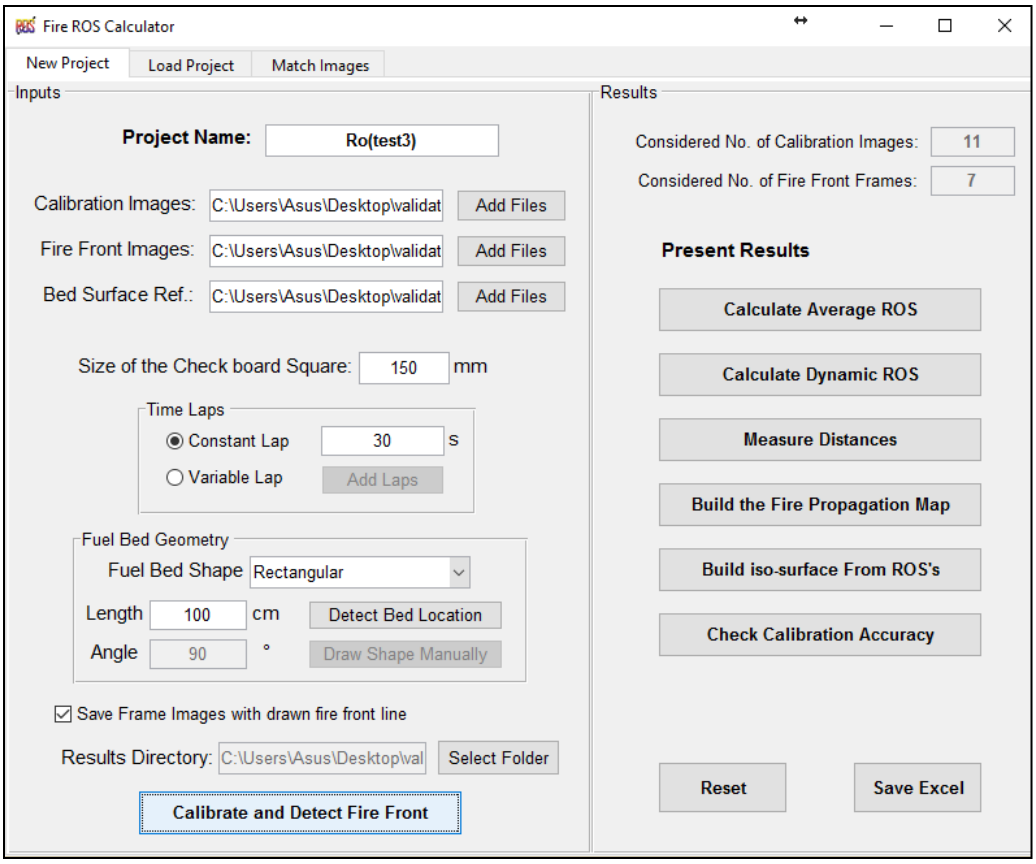
The program has a fully developed graphical user interface. By running the program, a single window will appear, on this window there are three main tabs on the top:

New Project; Which is used to start a new analysis (calculation of the ROS)

Load Project; which is used in a case that you have an old analysis and you need to for example to calculate the ROS along other directions or to get any of the provided results by the program.

Match images; which is just an assistant tool to equalize the size of group of images to match another one, this tool will be needed if the user had used to different cameras to get the calibration and the fire images. See the calibration process part of this manual for information.

Each tab of the three runs independently from the others. On the following, a detailed guide of how to use each one of them.



1. Starting New Analysis

On the New Project tab, you can find the window is divided to two panels, one for the inputs, and another for the results that will be used after calibrating the camera and detecting the fore front.

1.1. Inputs

There are six different groups of inputs you must make sure that you have provided them before starting the process of calibration and detection of the fore front. These groups will be discussed on the following:

1.1.1. Project Name

On the field where it's written "Project Name" you need just to provide a name for this analysis where all the output results will carry this name

1.1.2. Images

Three groups of image must be provided:

<u>Calibration images:</u> which are the taken images of the calibration object (between 15 to 25 image)

<u>Fire Front images:</u> which are the taken images or frames for the propagation of the fire front over a surface.

<u>Bed Surface Reference:</u> which is the image that were took while placing the calibration object over the fire surface.

Look the Camera Calibration part for more details about how to get these images.

1.1.3. Size of the Checkboard Square

You need to provide the program on this field with the length of one square of the checkboard (the calibration object) that was used for calibration in mm.

1.1.4. Time Laps

The time lap is the time between the frames or the images of the fire front that were taken during the fire propagation. You have two options, one is the constant time lap in a case you had a fixed time step between the frames. If you have variable time steps between the frames, in that case you need to enter the time between each two frames on the field that will appear by clicking on "Add Laps". In all cases, the given time is in seconds.

1.1.5. Fuel Bed Geometry

Here you will need to provide the shape of the surface where the fire was propagating (the fuel bed). By choosing the shape of the bed the program will provide later a propagation counter map of the fire propagation enclosed inside a frame which is this shape of the bed. However, it's not necessary to choose a shape you can just choose the “Not Specified” option if you don’t need the frame. To choose a shape you have three options: Rectangular, Triangle or Draw the Shape Manually.

Rectangular: it will give a rectangular shape but you must draw one edge of the bed and provide the length of the other perpendicular edge on the rectangle.

To draw the edge, you can click on “Detect Bed Location” then you will have to choose one of the images to draw a line over one of the bed edges. You can select either one of the fire front images or the calibration images to do that. After the image will open, you can click by the mouse where the edge is starting and drag the mouse while holding to detect the other end of the edge. You can edit the location of this line by dragging its ends. After placing the line at the wanted position, you must double click over the line to end the process of detection.

Triangular: it will give a Triangular shape. You will need also to draw one edge of the triangle and provide the angle between the drawn edge and one of the other two edges of the triangle and its length. The drawing has the same process as for the rectangular shape. But you must be careful with the start and the end of the drawn line, where the provided angle and length must be for the edge that’s joining with the drawn edge at its end (last detected point).

Drawing the shape Manually: by choosing this option you can draw manually any shape with straight edges. To draw the shape, click on “Draw Shape Manually”. You will need to select an image first where you will draw the shape over it, then after it opens, you will have enter how many corners or edges does the shape has. To draw the lines (the shape edges) click a right-clicking over the image and select “Add Lines”, then draw them. When you finish placing the lines, click “OK”.

Note that once you finished placing the first line, you will be enabled automatically to place the second one and so on, only after finishing placing all of them, you can edit their location before pressing “OK” to end the process.

1.1.6. Saving

By the checking the box of “Save frame images with drawn fire front line” the program will save a copy of the fire front images where the fire front lines are drawn over these images. The option is recommended in case the fuel bed has more than one surface, which means several runs of the program, so by this option the user can use these saved images as the Fire Front Images for the next run. That will make it clear where the fire front was detected on the run before.

Finally, you will need to select a folder as a directory where all the results will be saved on.

1.1.7. Calibration and Detection of the fire front

After finishing entering all the inputs you can now click on "Calibrate and detect fire front", the program will do the calibration and then will ask you to start detecting the location of the fire front on each frame manually. The program will open the fire front images automatically one by one, where it will be ordered by the name in ascending order, so the user must make sure before selecting the fire front images as an input that their names are ordered as the same as their timing order. The fire front can be detected by drawing small line segments which will be defined by detecting the starting and ending points of these line segments. Every ending point will be considered the starting point of the next line automatically. On the following are some instructions to draw the lines:

- To add a point; click a left-mouse-click to determine a new point
- To delete the last detected point; press the "Backspace" key.
- To finish the detection for the image; click double clicks by the mouse while detecting the last point, or simply you can press "Enter".

After finishing Entering all the inputs and detecting the fire front. The results options on the Results panel will be enabled so the user can now get any required result. Also, the program will give the considered number of calibration images, which is the number that the calibration has been made from. The program sometimes will drop some of the inputted images automatically as the calibration object is not clear on them. The user must insure that the number of the considered calibration images is higher than 10, so accuracy of the results will be acceptable.

Once the user has finished the process of calibration and fire front detection, the program will save a file with extension: (*.mat). That file has all the necessary data to load the project and get any other results later. The process is explained on section 2.

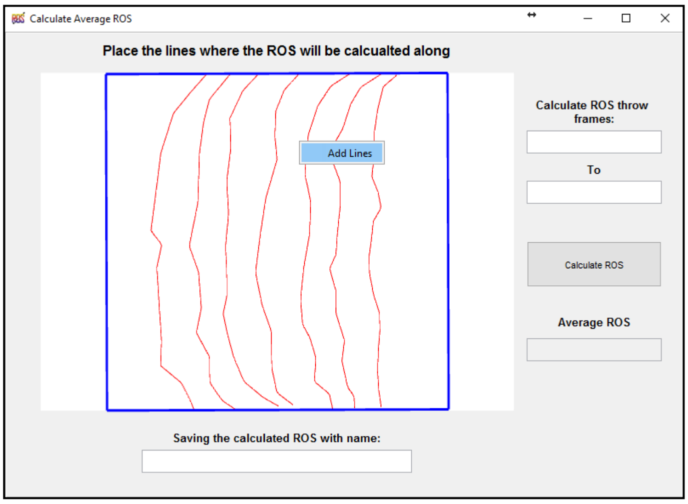
1.2. Results

On the results panel, there are different options that will help the user to understand more the fire behavior and its associated ROS's. On the following we will discuss the purpose of each option and how to use it.

Please notice that all the results that you will calculate from these options will be saved into an Excel sheet. <u>It's very important to press the bottom "Save Excel"</u> after you finish form the analysis and before you exit or reset, as the Excel sheet will be written at that moment, during the program run it's only saved on the computer memory. For some result options, not all the results that you suppose to get will be displayed on the program but it's saved into the excel sheet.

1.2.1. Calculate Average ROS

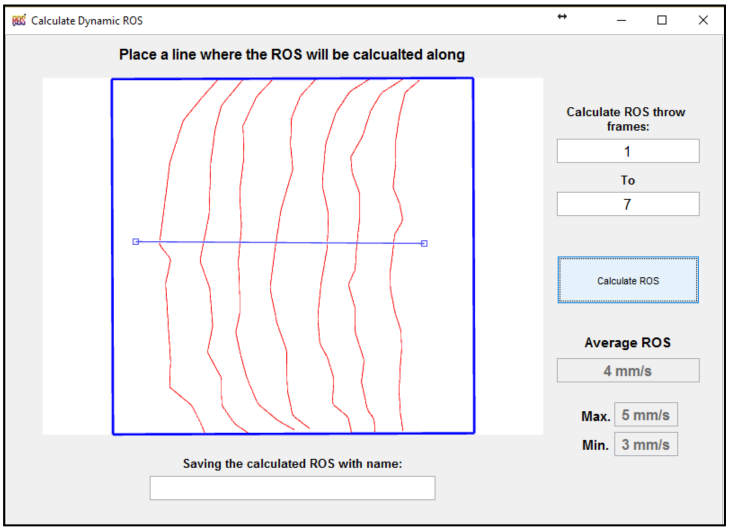
We define the average rate of spread (ROS) of a fire along a prescribed direction as the slope of a linear fit of the function: *D(t)*, where *D* is the distance passed by the fire along a predefined direction during a time (t). We are following on this Viegas 2004. However, This simplification to calculate the average ROS is only acceptable if there are no consistent variations of the rate of spread (ROS) and it implies that the fire is spreading in a quasi-steady-state, which may not be valid in all cases (Viegas 2004). In case there is consistent variations, we recommend to use also the "Calculate Dynamic ROS" option. For calculating the average ROS, the program gives you the ability to add several lines where it will provide you the average ROS for each one of them and also the average of all of them, the user may use several adjacent lines to avoid local effects and variations on the fire spread behavior on that direction.



To measure the average ROS, you need to place a line by left-mouse-clicking over the showed fire propagation contour map and select "Add Line", then you can place the lines over the map after entering how many lines you would like to add. The user can detect also the area of interest by adding two frame ranks (from … to…) which the ROS will be calculate through them considering the first number (from) as the first frame and the second number (To) as the last frame. Once the ROS's were calculated the program saves an image on the results directory of the fire propagation map and the lines placed on it. Please notice the following:

- Once you finished placing a line you will be enabled to place the next one and so on, only after finishing placing all of them on the map, you can edit their location before pressing "Calculate ROS" to get their locations and calculate the ROS's along them.
- The user must insure that the placed lines are intersection with the all fire front lines, because in a case that it didn't, it will give a wrong value of the ROS. Also, it's recommended to make more than one measurement on the same direction with changing slightly the position of the line to see if there will be big difference which means one of them has an error.

1.2.2. Calculate Dynamic ROS



We define the dynamic ROS simply as the passed distance divided by the consumed time to pass it (ΔD/ Δt) along a predefine direction. Or in other sense, it's the slope of line joining two following points on the D(t) plot. So, by calculating this ROS you will have the ROS that the fire translated with between two frames.

To measure the dynamic ROS, you will need to place a line by left-mouse-clicking over the showed fire propagation contour map and select "Add Line". This line is where the ROS will be calculated along it. The user can detect the area of interest by determining the first and the last frame where the ROS will be calculated as on the Calculating Average ROS.

The obtained result here is the passed distances between the frames and the ROS that the fire passed them with it, along also with the average ROS. Once the ROS was calculated the program saves an image on the results directory of the fire propagation map and the line placed over it. Please notice the same remarks on the calculation of the average ROS about placing the line on the map and the intersections between the line and the fire front lines.

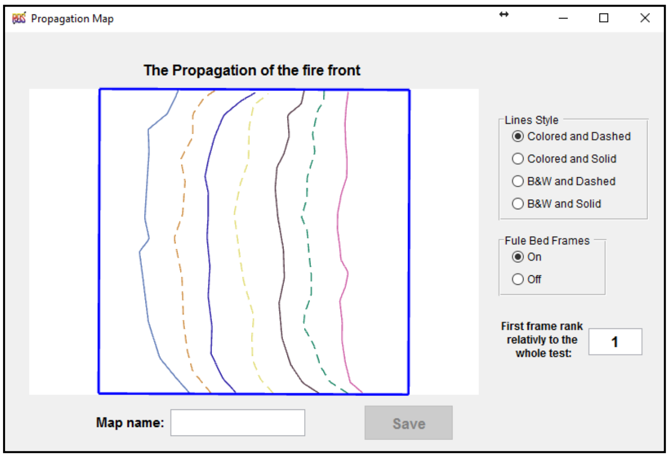
1.2.3. Measuring distances

By this option you can measure any distance over the fuel bed surface either by detecting it on the propagation map or from an image that the user would choose.

To measure the distance, you can just place a line or more depends on how many distances you like to measure. Adding the lines is with the same method that was explained for calculating the average ROS on section 1.2.1.

The obtained results from this option is the measured distances and the average of them in a case there were more than one.

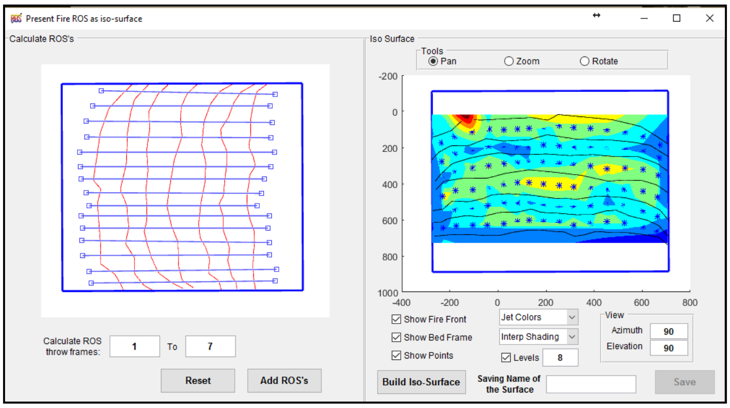
1.2.4. Build the fire propagation map

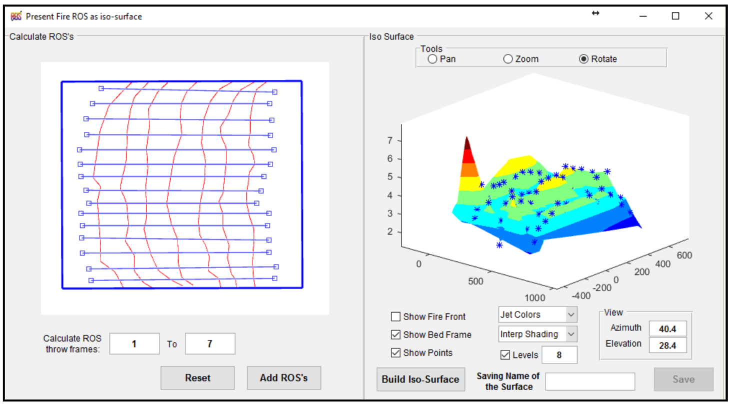


From this option, you can save the Fire propagation contour map with several options like showing or hiding the bed frame or changing the style of the lines.

There is an option that you can determine the rank of the first frame on this map relatively to the whole experiment. This option can be used if there are more than one surface that the fire is propagating on, and as it's required to do a separate analysis for each surface, this option will make a consistence of the color and style of the fire front lines of the same time step on different surfaces.

1.2.5. Build iso-surface from ROS's





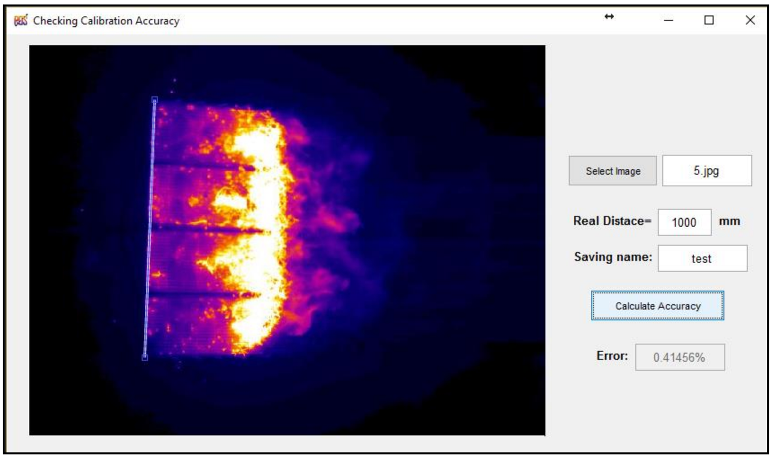
This option allows the user to do a 3D presentation of the fire ROS's based on their X-Y location over the fire surface, where the dynamic ROS will be on the Z axis. Then interpolating these values to build an iso-surface.

To get the iso-surface the user must add at least one line where the dynamic ROS will be calculated along it. However, to get a good presentation of the fire ROS values and their distribution over the surface, it's recommended to use a convenient number of fire front images, so that we will have many frames covering the whole surface with relatively small distances between the fire front lines. Also, to add as much lines as possible to cover the whole surface, so the 3D representation will have enough value points to construct an iso-surface that presents the values of the fire ROS all over the surface.

For adding the lines, use the same method that on section 1.2.1. You can add more than one group of lines where every group will have different area of interest. Noticing that each group of lines must intersect with all the specified frames. After placing some group of lines, you must click "Add ROS's" before adding another group or start to build the iso-surface.

After finishing adding ROS's values you can click on "Build iso-surface" button, that will present to you the iso-surface on the other axis. The user can show or hide each of the fire front lines, the bed frame and the points where the ROS were measured and the iso-surface was built from them.

1.2.6. Checking calibration Accuracy



You can check the accuracy of the calibration by checking the accuracy of a measured distance as measuring the real distances is the main goal of the calibration and the main component on determining the ROS. So, the presented error here can be assumed as the error in all the obtained results during this analysis.

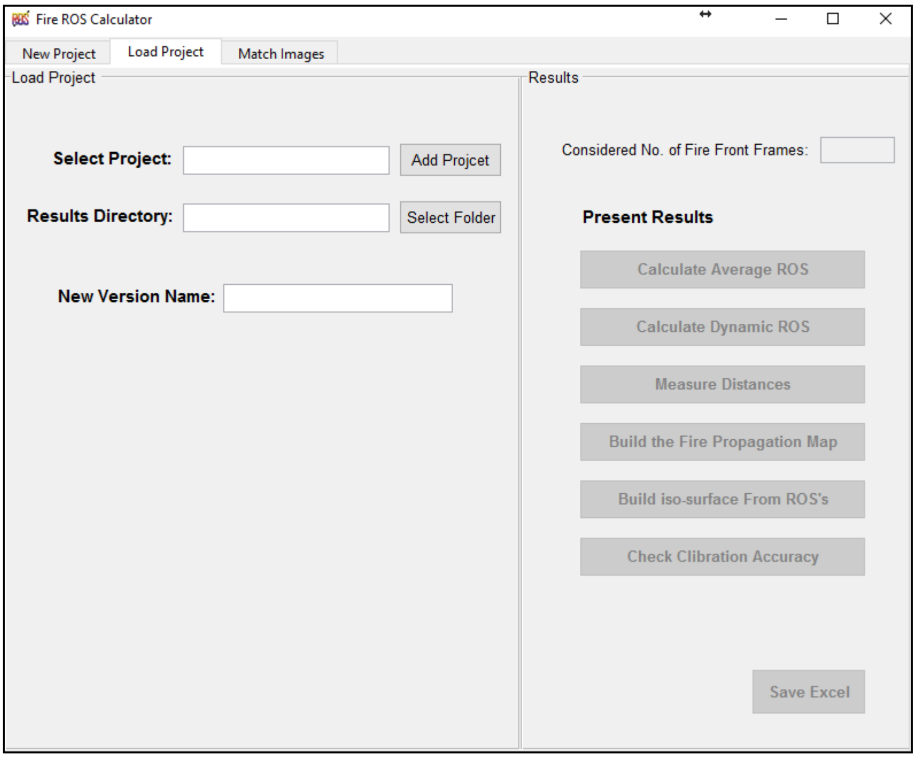
To measure the error in some distance measurement, you need to select an image where you want to measure this distance form and then place a line over it with the same way that was shown in section 1.2.1. Then enter the real distance of that measurement and the program will give you the error. However, it's recommended to take several measurements and take the average of them, as this error is including also the human error on putting the line exactly over the length that's being measured.

2. Loading Project

On this tab, the user can load an old project or analysis which is a file have the extension *.mat (a MATLAB Workspace), this file is generated automatically after performing the calibration and the fire front detection process, it contains the calibration parameters and the fire front coordinates basically with some other data. By loading the MAT file and choosing a directory and a name (the excel sheet name) for the results, the user will be able to choose any of the result options that were mentioned in section 1.2.

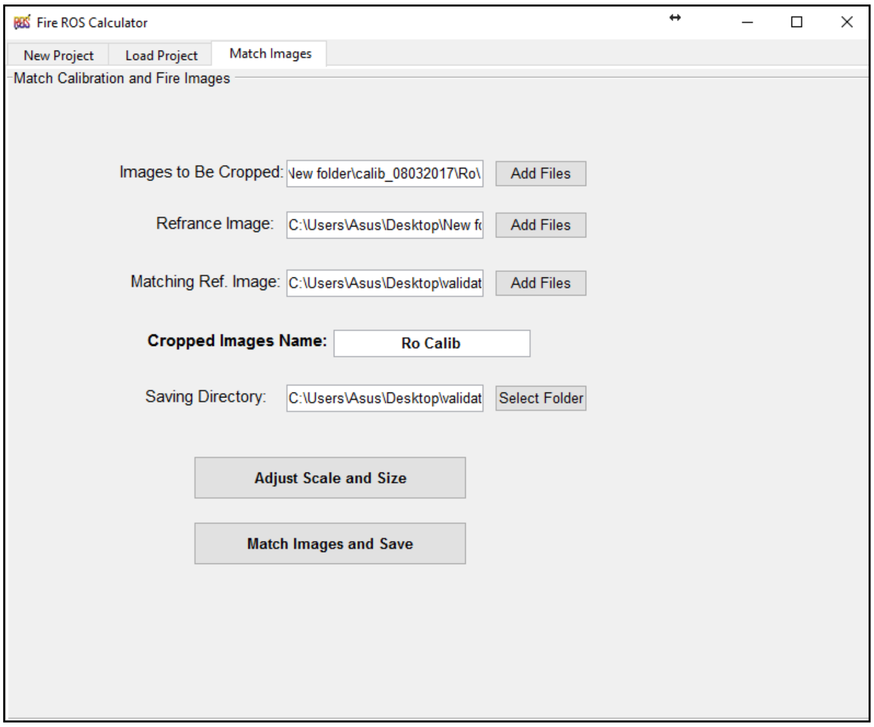
Note that in a case of choosing the same results directory as before, if the program found a file with the same name that's being saved with now, it will overwrite it.

None of the results will be saved in the MAT file, so in a case the user closed the program without saving the Excel file, the results will be lost and the user must repeat calculating them.



3. Match Images

On this tab, there is an assessing tool in a case that the fire images had a different size than the calibration images or vice versa. As mentioned on the calibration process part of this manual, the calibration and fire images must match, which means the same size, scale and frame. This matching can be made by this tool in a case of using two different cameras for the calibration and fire images.



3.1. Inputs

Three groups of images must be added, first group, “images to be cropped”, which is the images that have a bigger frame than the other group, whether it’s the calibration or the fire images. Or in other sense, the images that have a lower zoom. Second and third groups, are a reference image and a matching reference image respectively. The reference image is one of the chosen images to be cropped. The matching reference images is an image that you want to match the selected images on the first group to it (the image with the higher zoom or bigger frame).

The user then needs to provide a name for the images that will be cropped to be saved with and a directory where to save them, the name will be just prefix and the images will have numbers.

3.2. Matching the images

Unfortunately, we don’t have an automatic detection of how much the images size should be reduced or from where it will be cropped. However, the detection is being made by the user through detecting some points on the reference image and the matching reference image.

When clicking over “Adjust Scale and Size”, the program will open first the matching reference image where the user must detect two point over the image. These two points will be detected also on the reference image after that, so they must be appearing on both images clearly. The two points must be detected as accurate as possible since it will affect the matching accuracy. (example: detect the two corners of the fuel bed on both images). After detecting these two points, the scale now has been adjusted, i.e. the number of pixels between the two points is the same on both images. Then, the program will open again the matching reference image asking the user to detect a point from the image, this point must be a clear point appearing on both images also. After detecting this point on both images which will be used to detect the frame borders where the image needs to be cropped.

After finishing adjusting the scale and the size, the user can now match the images and save them by clicking on “Match images and Save” where it will be saved on the chosen directory.

Refrances

Bouguet, J. Y. "Camera Calibration Toolbox for Matlab." Computational Vision at the California Institute of Technology.

Viegas, Domingos X. (2004). “Slope and Wind Effects on Fire Propagation.” International Journal of Wildland Fire 13 (2): 143–56. doi:10.1071/WF03046.

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