SwisTrack Manual - for real-time tracking of fish:

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SwisTrack Manual –

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Initiated by D. G. Cook during the Fish Swimming Course @ University of Washington Friday Harbor Laboratories, WA, USA in 2009 and since gradually updated by H. Bergsson and J. F. Steffensen.

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Version 1

General Introduction

SwisTrack 4 is powerful free software for tracking robots, humans, animals and objects using a camera or a recorded video as input source. It uses Intel's OpenCV library for fast image processing and contains interfaces for USB and FireWire cameras, as well as AVI files.
The **main and most important benefit is that it can track one or more objects in real-time**, making it possible to make a feed-back on the object.

SwisTrack uses a list of so-called **components** to process images. Each component is in charge of a specific processing step, e.g. image acquisition, background subtraction, thresholding, or blob detection. Getting the right result is a matter of putting the right components together - in the right order, of course. Each component can be configured, and SwisTrack provides a great interface to do this in real time, while showing all intermediate processing results.

SwisTrack was made as a Tracking Tool for Multi-Unit Robotoc and Biological systems around 2005 by Ecole Polytechnique Federale Lausanne (EPLC), and since it was a tool created by researchers for researchers, it was continuously developed and there was no fixed release cycle. Unfortunately however it hasn’t been updated since about 2010 with version 4.1.

If you wish to have the compiled version 4.01 of SwisTrack, it is available on Sourceforge.net, however it does not include all components available.
https://sourceforge.net/projects/swistrack/

If you plan on using video files, you may also want to install the K-Lite Codec Pack, but several other free programs can analyze post experiment..

The newest version 4.1 was released in 2010 but is difficult to find. It can however be downloaded from here: http://bioold.science.ku.dk/jfsteffensen/SwisTrack/SwisTrack-windows.zip - unzip the file, delete the entire Component directory in the SwisTrack directory, and replace it with the Component directory in the zip-file. Then replace the swistrack.exe file and finally download the file ml100.dll from: http://bioold.science.ku.dk/jfsteffensen/SwisTrack/ml100.dll - and copy the file to the same directory as swistrack.exe

SwisTrack References:

SwisTrack description on Wikipedia

SwisTrack manual on WikiBooks

SwisTrack: A Tracking Tool for Multi-Unit Robotic and Biological Systems

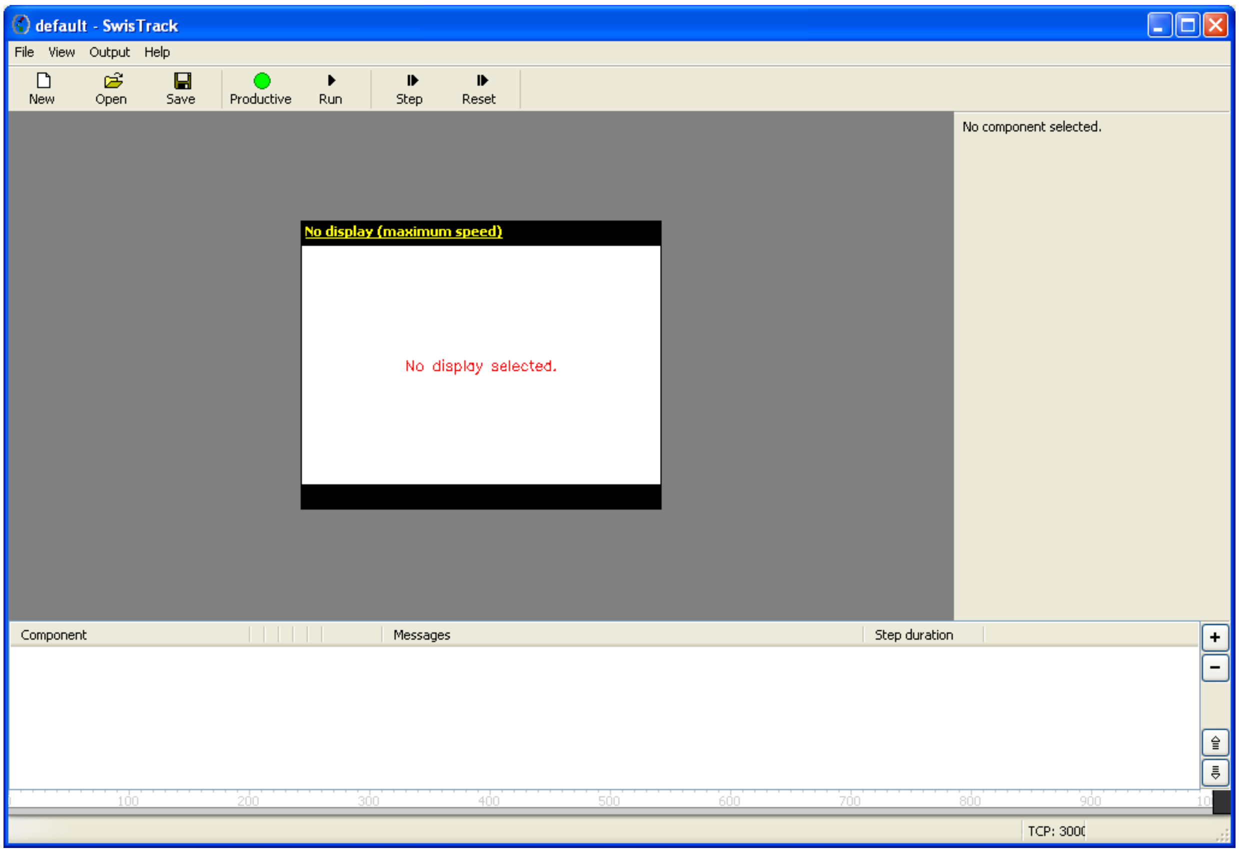
SwisTrack - A Flexible Open Source Tracking Software for Multi-Agent Systems

The Graphical Interface

The main window of SwisTrack consists of three parts:

- The **main display** in the center shows the current frame that is being processed. The frame can be displayed at (almost) all processing steps.
- The **component list** at the bottom shows the currently selected components and their status. At the right of this list, you'll find two buttons to add or remove components, and two buttons to change the order of the components.
- The **configuration panel** at the right allows you to configure the selected component.

In addition, SwisTrack shows a timeline at the very bottom of the window.



No component selected.

No display selected.

Editing the Component List

To add a component, click the **plus (+)** button on the right of the component list. A dialog will appear and allow you to select a component. Note that the available components are grouped by their category, and you'll often need a component of each category, in the order the categories are listed here.

Components are added to the end of your component list. To move them up and down, use the arrow buttons on the right side. To remove the selected component, simply click on the **minus (-)** button.

The component list consists of several columns which indicate the type and the state of the component. Next to the name of the component, a few columns are filled with *W*'s, *E*'s and *R*'s. Each of these columns corresponds to a **channel** (or a data structure), and the letters have the following meaning:

- *W*: The component is writing to this channel.
- *E*: The component is modifying (reading, then writing) this channel.
- *R*: The component reads from this channel, but doesn't change anything there.

Obviously, you first have to write something to a channel before you can read or modify it. Hence, if you look through each columns, all *E*'s and *R*'s should be below the *W*'s. If this isn't the case, then you either forgot to add a component or placed the components in the wrong order.

In the column right after the component name, you may also see some *T*'s. These components include a trigger mechanism (which may be active or not), i.e. they tell SwisTrack when to process the next frame. A setup must have at least one trigger.

Configuring and Testing your Setup

Once your component list contains a valid setup, you can process one frame by pressing the **Step** button in the toolbar. This invokes each component in the order they are listed and displays the selected image (i.e. the output of the selected component). Once the frame is processed, the component list indicates the duration of each component, and perhaps error messages. (If you just added some components, it is quite likely that one or the other component will raise an error. You may have to configure them first.) Whenever an error occurs, SwisTrack stops the execution of the frame at that point and doesn't call the subsequent components.

When clicking on a component, SwisTrack displays its configuration panel on the right side of the window. You can now modify the settings and watch how this affects the image. Whenever you change a value, SwisTrack automatically performs a step - hence your modification becomes immediately visible on the screen.

As an advice, start at the top of your component list and configure the components in the order of execution. As the configuration heavily depends on component itself, refer to the online component documentation (link on the top of the configuration panel) for the meaning of each parameter.

While the **Step** button processes one frame, the **Run** button processes frames continously. In i>run mode, the trigger components (those with a *T* next to their name) say when the next frame shall be processed. If you don't have any trigger component in your setup, add a *Timer Trigger* component to configure the processing speed.

Finally, the **Reset** button allows you to reset all components. Most of the time, SwisTrack finds out automatically when the setup must be restarted (especially when you change the configuration of a component), but there are cases where you want to that explicitely. When you hit the **Reset** button, all components are adviced to completely reset their internal state and reload the configuration. This zeroes the frame counter and deletes the track history, for example.

Running an Experiment

Once your setup is properly configured and working, you probably want to use it for your experiments. This is where the **Productive** button becomes important.

Before you start your experiment, activate the **Production** button. This resets all components and starts them in productive mode. At the end of your experiment, simply hit the **Production** button again to release it and switch back to testing mode. **Production** mode sends the output as designated. When testing outside of production mode no file will be saved

Productive mode has two main differences as compared to testing mode:

- In productive mode, SwisTrack *never resets the components automatically*. Therefore, only a subset of the configuration parameters are available any more, namely those which do not change the processing completely. For example, you can still adjust the exposure time of a camera, but you cannot change from color to grayscale mode. In addition, it is not possible to add, remove or reorder components in productive mode.
- Output components only write data to the file during productive mode. Hence, your the files contain the data of your experiments only. (Some other components also make slight differences between testing and productive mode. Refer to the component documentation for details.)

The Timeline

At at the bottom of the main window, SwisTrack displays a timeline with an evolution of its state (running, not running, productive mode, normal mode) and the frame processing steps. This not only allows you to see at a glance what Swistrack is doing, but also to find out where your CPU power is burnt.

By default, SwisTrack records all important events for approximately one second, and displays them afterwards. Hence, what you see in the timeline corresponds to what SwisTrack was doing *one second ago*.

Elements on the Timeline

The following elements are drawn on the timeline:

- The ruler in the background indicates the milliseconds (ms) from the time recording of that particular timeline has started.
- While SwisTrack is running (*Run* button pressed), the otherwise white background changes to light gray.
- The lower third of the bar indicates whether SwisTrack is in testing mode (gray) or productive mode (green).
- The blue boxes in the middle represent the steps. Each box corresponds to the processing time of one component. The box of the selected component is highlighted in red.
- Black vertical lines indicate leap times, but only few components set leap times.

Components

The following table lists all the General components integrated into SwisTrack:

- 1) Trigger
- 2) Input
- 3) Input Conversion
- 4) Preprocessing (color)
- Preprocessing (grayscale)
- Preprocessing (binary)
- 5) Thresholding (color)
- Thresholding (gray)
- 6) Particle Detection
- 7) Calibration
- 8.) Tracking
- 9.) Output

In this manual I do not describe each of the components, only simply those that I have experience with or use in current tracking protocols.

1. Triggers

Trigger Timer: Use only when camera does not have an automatic trigger mechanism. Timer trigger processes frames (in constant intervals) at a given frame rate.

Trigger Counter: Enables stopping of processing after a certain amount of frames.

2. Input

USB Camera

SwisTrack version 4.01 and 4.1 unfortunately only work with USB cameras up to HD 720p (1280 * 720 pixels), and will downscale the image to 640 * 340 pixels, which though still is rather good. If you try using a full HD (1980 * 1080) you won't get anything but a black screen.
We suggest that you use a USB camera with zoom lens since you then can have the camera a considerable distance away from the arena, and hence minimize the problem with wide angle lenses. Please only use regular web cams (with rather wide angle view) for testing and demonstration, or for tracking animals that aren't moving in the Z-direction – as e.i. coackroaches.

Fire-wire Camera:

This component allows you to grab image from firewire cameras using the CMU driver. The output images are grayscale or color (RGB) images. As the CMU driver does only exist for Windows, this component is not cross platform. The CMU driver is available from http://www.cs.cmu.edu/~iwan/1394/. This needs to be installed as the primary Imaging Device driver on your system. Control Panel>System>Hardware>Device Manager>Imaging Devices (When camera Plugged in)>Update Driver>…

Camera Number: Allows you to select the camera if there are multiple firewire cameras connected. Typically 0.

Video Format and Mode: Video Format (0..2) and Mode (0..7) allow you to select the desired input type from the camera. Beware that a conversion is automatically done to output only grayscale or RGB images. Thus, YUV format are not really interesting, except if it allows for an increased camera frame rate.

The table contained within the appendices describes the different modes and formats. To check the available input types of you camera, you can use the 1394CameraDemo.exe that is included with the CMU driver, or check the camera datasheet.

Frame Rate: Select the camera frame rate: 1.875 fps (0), 3.75 fps (1), 7.5 fps (2),15 fps (3), 30 fps (4), 60 fps (5), 120 fps (6), 240 fps (7).

To check the available frame rates of you camera, you can use the 1394CameraDemo.exe that is shipped with the CMU driver, or check the camera datasheet.

Configuration Window: Allows you to open a configuration window to modify other camera parameters of the firewire camera, such as the white balance, saturation, gain, etc. Note that not all cameras allow you to modify all these parameters.

InputFileAVI:

This component allows you to grab an image from avi video file. The output images are gray or RGB images.

Compatible formats and codecs are numerous including Mpeg 2,3,4 avi's, and H364.avi. Many other formats are useable.

Ensure computer is updated with available codecs, The K-Lite codec pack (http://www.codecguide.com/) is invaluable when wanting to analyse avi's.

3. Input Conversion

Convert image to either grayscale or RGB. I find **Colour conversion** more effective when wanting to use a dynamic background subtraction.

4. Preproccessing

Either **Colour, Grayscale** or **Binary** depending on your input conversion. Background subtraction is for subtracting a static image in the form of a bmp file acquired from the main display of swistrack (right click image, 'save displayed image as'). Use mask component to eliminate zones of image not wanting to be tracked.

Background subtraction allows for the subtraction of a static image (i.e. an image of the tracking arena when the tank does not contain the object destined to be tracked). From the main display, left click your mouse to bring out the drop down menu, select 'save displayed image as' which will save the display image as a .bmp. Select this file as the background image in the address bar.

Mask
The mask can either be added to the colour or grayscale image (Mask Color or Mask Grayscale) prior to thresholding, or after thresholding (Mask Binary). Using the same image saved as the background, open the file in a photo editing programme and black out areas not wanting to be tracked while whiting out areas where tracking is intended. By selecting the correct mode (i.e. Black to black for the above example) you will have blacked out areas not intending to be tracked.

Dynamic Background subtraction is much better if tracking arena is likely to change, i.e. dirt particles, movement outside tank, reflections on water surface etc. I find the **Grayscale Subtraction** clunky and the modes available either produce shadows on the tracked object presenting a false centre of mass (COM) or tracking of a negative image. **Adaptive background subtraction (colour)** is more advanced, and more accurately tracks moving objects. Subtracting with **colour (median)** and **colour (mode)** appear particularly fruitful. **Background subtraction Based on Cheung and**

Kamath looks great in theory however I have not got this to work. **Colour swapper** can be helpful in cleaning up background image. Note, background subtraction (especially the mode subtraction) can require a lot of the processing requirements. Elevated requirements can cause camera capture rate to decrease below that set.

Image Erosion and **Image Dilation** allow you to reduce or expand the pixels that make up the tracked blob, enabling a larger blob to be tracked. Eroding particles will help to remove noise, the particle can then be dilated to make for easier tracking. However, this action may also expand noisy blobs in the thresholded image potentially adding interfering objects from the background or potentially hide the object to be tracked .

5. Thresholding

Thresholding (colour or grayscale) allows the user to pull the object intended to be tracked away from the background. By adjusting the contrast threshold, the desired object can be pulled out of the image. This moving blob upon the background will later be the blob selected for tracking.

Thresholding with Individual Threshold values is useful when pulling out objects to be tracked that are represented by a particular colour. However, the output of this thresholded colour is a binary (i.e. black/white) blob. This coloured marker, written as a binary blob, can later be the point selected for tracking. **Double thresholding** is an extension of this function whereby a range of a particular colour channel can be selected for tracking,

6. Particle Detection

Particle detection seeks out the moving image from the thresholded image. **Blob detection** will select the moving blob from the background. Maximum blobs is the no. of objects intended to be tracked. Area selection is particularly useful for separating out the image intended to be tracked from the background and any noise associated. Orientation and compactness can also be adjusted to filter out the tracked object from noise when required.
Two coloured marker detection and **red-green marker detection** functions to differentiate coloured marks (or leds) from the input image. Again number of particles is the number of marks on the image wanting to be tracked. Max distance is the separation of the two marks and is used to filter the marks from potential background noise. Output selects which of the two marks is the primary mark. Within two colored marker detection colours can be selected from entering the RGB values of the intended colour or alternatively from the palette provided within the configuration panel. Again area and compactness can be limited to reduce interference. Outputs of the 2 channel marker detection are particularly useful for determining orientations, calculated within the tracking component and outputted as radians.

Circular hough transformation can be used for tracking circular labels or objects, however, output is again binary.

7. Calibration.

No comments included, I typically convert pixels to cm within the output file using known calibration of camera within experimental setup. (i.e. cm/pixel conversion)

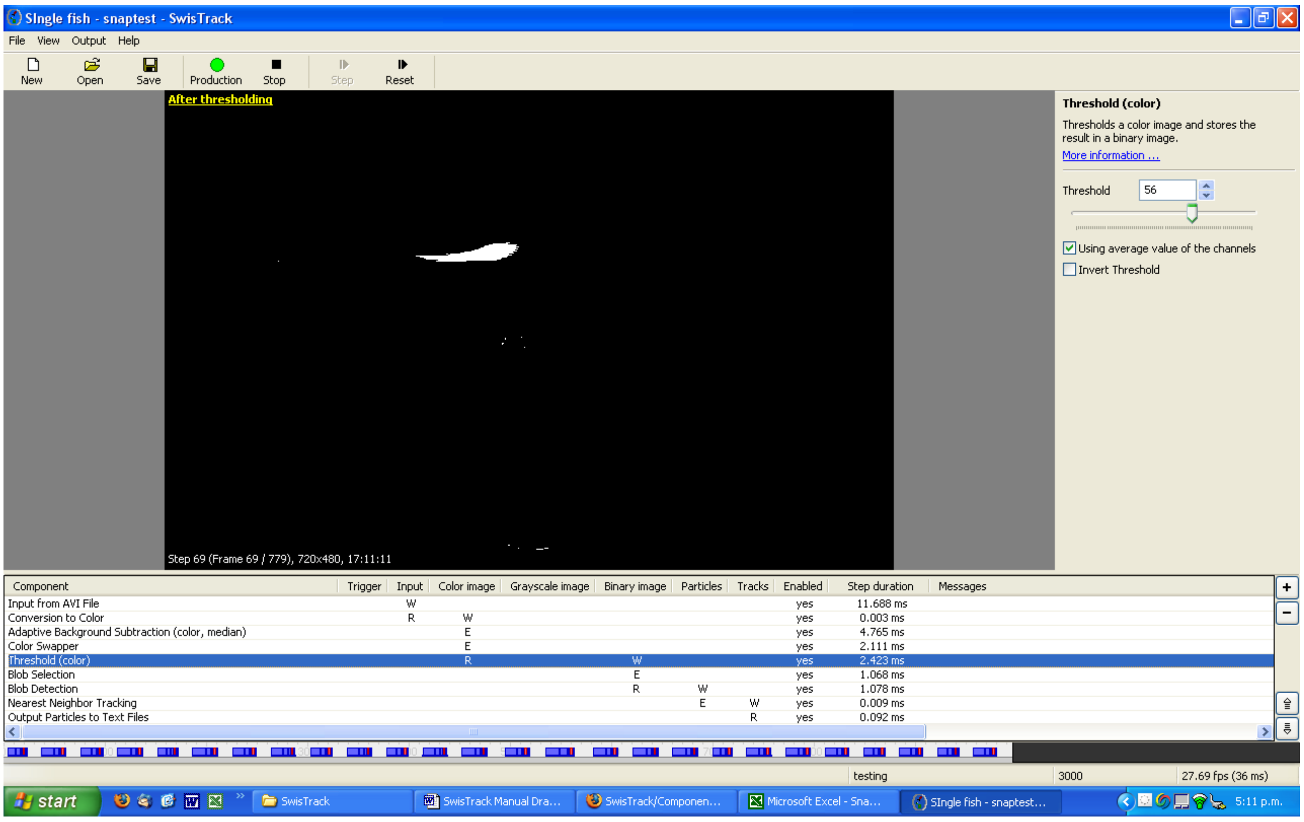
8. Tracking.

Nearest Neighbour tracker is the most basic of the components used for tracking the moving object(s). Number of objects is the intended number of blobs (objects to be tracked) – This must be the same value as above in **Particle detection**. The maximum value slide is a limiter of the expected number of pixels the tracked object will move between frames. This value needs to be high enough to enable tracking of moving objects. By selecting an appropriate limitation on the tracked image it will help prevent track-exchange with other particles on the input.
Other tracking components, filters and smoothers are not typically used when tracking fish

9. Output.

x,y coordinates, area, orientation and compactness as well as a timestamp (ms) can be output as **either** a tab delimited .txt file **or** alternatively sent across a TCP server (port 3000 by default)
The **TCP output** can be used for analysis in **realtime** following building of a VI in Labview or within Matlab.
The .txt file can also be used in real time in programs like Labtech Notebook, DaisyLab, LabView etc. If tracking just one object the file will contain 9 colums withtime, x- and y- cooridnates in the first, second and third column.
Finally the .txt file can be used for post analysis in Microsoft Excel. .txt files will save in a timestamped (ms) folder contained within the same folder that your tracking protocol is saved within.
If a file is not being saved it is likely the **Production** button was not pressed while tracking.

10. Appendicies



Step 69 (Frame 69 / 779), 720x480, 17:11:11

Threshold (color)

Thresholds a color image and stores the result in a binary image.

More information ...

Threshold: 56

☑ Using average value of the channels

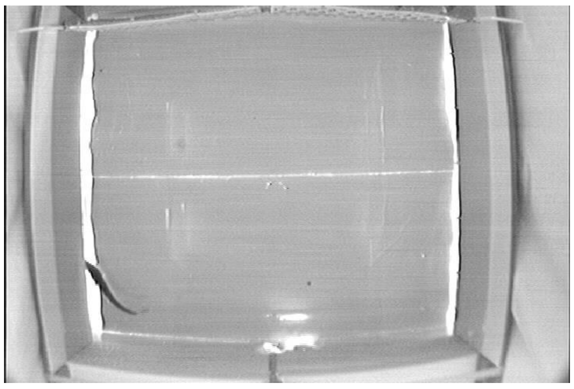
☐ Invert Threshold

Component	Trigger	Input	Color image	Grayscale image	Binary image	Particles	Tracks	Enabled	Step duration	Messages
Input from AVI File		W						yes	11.688 ms	
Conversion to Color		R	W					yes	0.003 ms	
Adaptive Background Subtraction (color, median)			E					yes	4.765 ms	
Color Swapper			E					yes	2.111 ms	
Threshold (color)			R		W			yes	2.423 ms	
Blob Selection					E			yes	1.068 ms	
Blob Detection					R	W		yes	1.078 ms	
Nearest Neighbor Tracking						E	W	yes	0.009 ms	
Output Particles to Text Files							R	yes	0.092 ms	

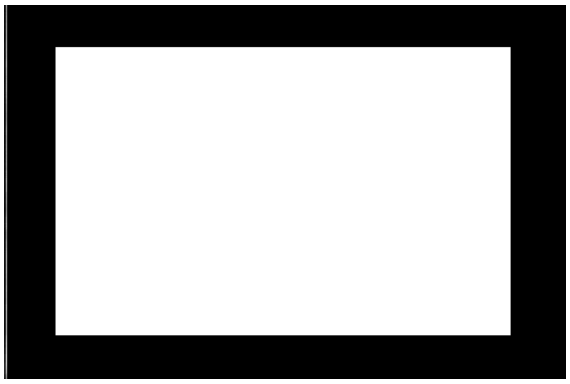
testing | 3000 | 27.69 fps (36 ms)

Figure 1: Screen dump of Swistrack showing the thresholding step of a single fish from the background. Note the pipeline created at bottom of screen. Main display shows thresholded image of tracked fish while production mode is not running

(i)



(ii)



(iii)

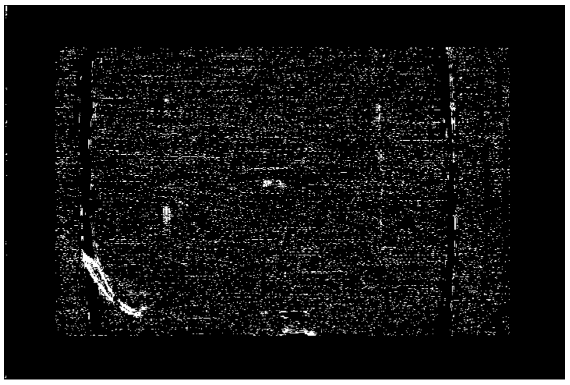
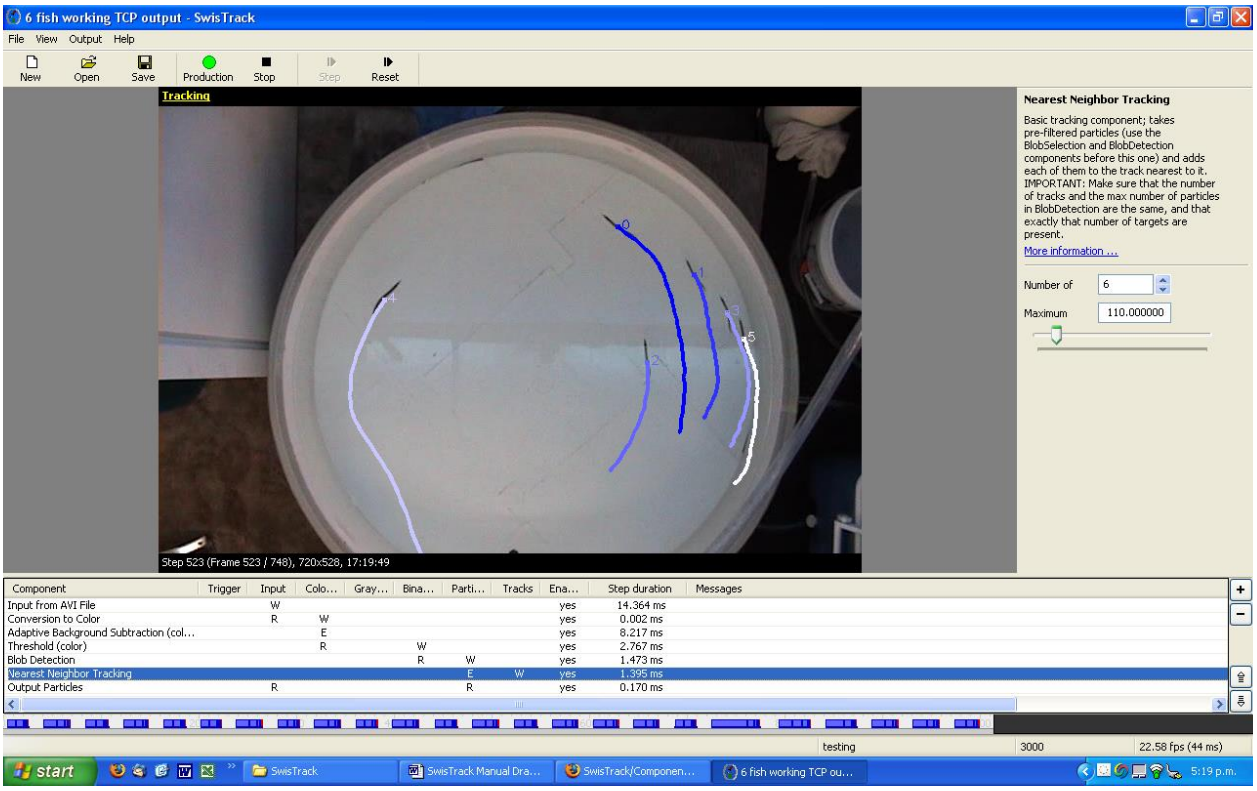


Figure 2: Steps towards masking a static background. (i) .bmp image of tracking arena. (ii) Blacked out zone not wanting to be tracked (iii) Superimposed masked area on a (poorly) thresholded input image



Nearest Neighbor Tracking

Basic tracking component; takes pre-filtered particles (use the BlobSelection and BlobDetection components before this one) and adds each of them to the track nearest to it. IMPORTANT: Make sure that the number of tracks and the max number of particles in BlobDetection are the same, and that exactly that number of targets are present.

More information ...

Number of: 6

Maximum: 110.000000

Component	Trigger	Input	Colo...	Gray...	Bina...	Parti...	Tracks	Ena...	Step duration	Messages
Input from AVI File		W						yes	14.364 ms	
Conversion to Color		R	W					yes	0.002 ms	
Adaptive Background Subtraction (col...			E					yes	8.217 ms	
Threshold (color)			R		W			yes	2.767 ms	
Blob Detection					R	W		yes	1.473 ms	
Nearest Neighbor Tracking						E	W	yes	1.395 ms	
Output Particles		R				R		yes	0.170 ms	

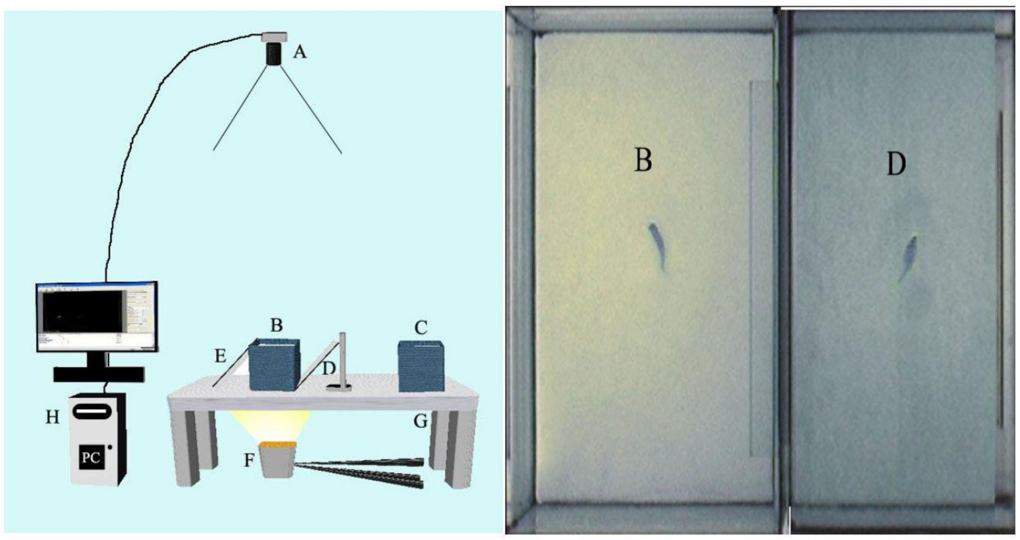
Figure 3: Screen dump of Swistrack actively tracking multiple fish. Main display shows output of tracked fish while production mode is not running. Note, multiple fish tracking by this protocol experiences track exchange when fish cross

11:
A few benefits with SwisTrack:

A: Work in real-time w inexpensive USB cameras – and make feed-back on the target possible.

B: Target strength discrimination: One very usefull and strong feature in SwisTrack is that you can selecet approximately how large (number of pixels) your target is. Hence pixel noice caused by e.i. the animal defecating during the experiment will be ingnored in the calculation of the X- Y coordinate mass midpoint.

C: 3D-tracking of one fish: Another very usefull feature in SwisTrack is that you can track e.i. a fish in 3D by having the fish in a gals aquariaum and e.i having the camera above for the X- and Y- coordinate, and a mirror at an angle of 45 Deg so the same camera in addition to the view from above will montor the aquarium from the side. By tracking the fish as two objects one rcak will be equal to the X and Y- coorinates, and the other the Z- and X- or Y coordinate.



Figur 1: Forsøgsopstilling set fra siden og billede fra kameraet. A: Firewire kamera med zoom objektiv. B: Akvarium 1. C: Akvarium 2. D: Spejl 1. E: Spejl 2. F: Halogen lampe. G: Bord med hvid plastik bordplade. H: Computer.

Fig 1.Left:
Experimental setup for 3D tracking of one zebrafish. A: camera. B: aquarium. E and D: mirrors. F. Light source. H. Computer.
Fig 1. Right:
Images of one fish – B is vertical view (X- and Y- coordinates) and D is horizontal view through mirror D.
(H. Bergsson, B. Sc.-theis unpublished).

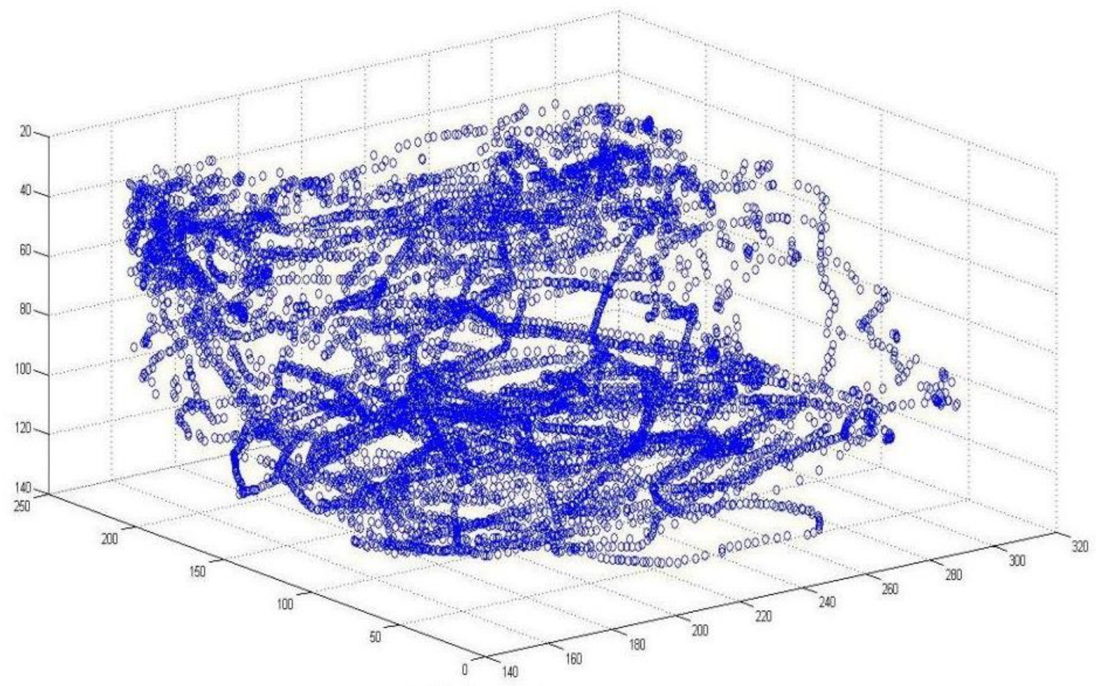


Fig. 2 SwisTrack derived 3D track of zebrafish using one camera and two mirrors. (H. Bergsson, B.Sc.-thesis unpublished).

Table 1: Firewire camera settings when using CMU driver for selection within configuration panel of **Input from Firewire (1394) camera**

Offset	Name	Field	Bit	Description
180h	V_MODE_INQ_0	Mode_0	[0]	160 X 120 YUV(4:4:4) Mode (24bit/pixel)
	(Format_0)	Mode_1	[1]	320 X 240 YUV(4:2:2) Mode (16bit/pixel)
		Mode_2	[2]	640 X 480 YUV(4:1:1) Mode (12bit/pixel)
		Mode_3	[3]	640 X 480 YUV(4:2:2) Mode (16bit/pixel)
		Mode_4	[4]	640 X 480 RGB Mode (24bit/pixel)
		Mode_5	[5]	640 X 480 Y (Mono) Mode (8bit/pixel)
		Mode_6	[6]	640 X 480 Y (Mono16) Mode (16bit/pixel)
184h	V_MODE_INQ_1	Mode_0	[0]	800 X 600 YUV(4:2:2) Mode (16bit/pixel)
	(Format_1)	Mode_1	[1]	800 X 600 RGB Mode (24bit/pixel)
		Mode_2	[2]	800 X 600 Y (Mono) Mode (8bit/pixel)
		Mode_3	[3]	1024 X 768 YUV(4:2:2) Mode (16bit/pixel)
		Mode_4	[4]	1024 X 768 RGB Mode (24bit/pixel)
		Mode_5	[5]	1024 X 768 Y (Mono) Mode (8bit/pixel)
		Mode_6	[6]	800 X 600 Y (Mono16) Mode (16bit/pixel)
		Mode_7	[7]	1024 X 768 Y (Mono16) Mode (16bit/pixel)
188h	V_MODE_INQ_2	Mode_0	[0]	1280 X 960 YUV(4:2:2) Mode (16bit/pixel)
	(Format_2)	Mode_1	[1]	1280 X 960 RGB Mode (24bit/pixel)
		Mode_2	[2]	1280 X 960 Y (Mono) Mode (8bit/pixel)
		Mode_3	[3]	1600 X 1200 YUV(4:2:2) Mode (16bit/pixel)
		Mode_4	[4]	1600 X 1200 RGB Mode (24bit/pixel)
		Mode_5	[5]	1600 X 1200 Y (Mono) Mode (8bit/pixel)
		Mode_6	[6]	1280 X 960 Y (Mono16) Mode (16bit/pixel)
		Mode_7	[7]	1600X 1200 Y (Mono16) Mode (16bit/pixel)
18ch				
...		Reserved for other V_MODE_INQ_x for Format_x.		
198h	V_MODE_INQ_6	Mode_0	[0]	Exif format
	(Format_6)	Mode_x	[1...7]	Reserved for another Mode
		-	[8..31]	Reserved
19ch	V_MODE_INQ_7	Mode_0	[0]	Format_7 Mode_0
	(Format_7)	Mode_1	[1]	Format_7 Mode_1
		Mode_2	[2]	Format_7 Mode_2
		Mode_3	[3]	Format_7 Mode_3
		Mode_4	[4]	Format_7 Mode_4
		Mode_5	[5]	Format_7 Mode_5
		Mode_6	[6]	Format_7 Mode_6
		Mode_7	[7]	Format_7 Mode_7

References concerning SwisTrack:

Correll, N., Sempo, G., Lopez de Meneses, Y. Halloy, J., Deneubourg, J.-L. and Martinoli, A. SwisTrack: A Tracking Tool for Multi-Unit Roboticand Biological Systems.(2008). Proceedings of the 2006 IEEE/RSJInternational Conference on Intelligent Robots and SystemsOctober 9 - 15, 2006, Beijing, China

Lochmatter, T., Roduit, P., Cianci, C., Correll, N., Jacot, J. and Martinoli, A. (2008). SwisTrack - A Flexible Open Source Tracking Software for Multi-AgentSystems.IEEE/RSJ International Conference on Intelligent Robots and SystemsAcropolis Convention CenterNice, France, Sept, 22-26, 2008.

References concerning what it can be used for in biological systems:

Example of post experimental analysis:

Cook, D.G., Brown, E., Lefevre, S., Domenici, P. and Steffensen, J. F. (2014). The response of striped surfperch *Embiotoca lateralis* to progressive hypoxia: Swimming activity, shoal structure, and estimated metabolic expenditure. J. Exp. Mar. Biol. Ecol. 460, 162-169

Link to Research gate project page with description of how to use Swistrack in a temperature shuttlebox system:
"Steffensen" shuttle box for temperature preference - how to build and run it:

originally described in:

Schurmann, H., Steffensen, J. F., Lomholt, J. P. (1991). The influence of hypoxia on the preferred temperature of rainbow-trout, *Oncorhyncus mykiss*. J. exp. Biol. 157: 75-86.

Schurmann, H. & Steffensen, J. F. (1992). Lethal oxygen levels at different temperatures and the preferred temperature during hypoxia of the Atlantic cod, *Gadus morhua*. J. Fish. Biology, 41;927-934.

Schurmann, H. & Steffensen, J. F. (1994). Spontaneous activity of Atlantic cod, *Gadus morhua*, exposed to graded hypoxia at three different temperatures. J. exp. Biol. 197; 129-142.