Instruction and documentation

For

Code for recognition of the liquid surface and the liquid level in image of liquid in transparent vessel. For surfaces between liquid and air and between phase separating liquids

Base on paper

Computer vision-based recognition of liquid surfaces and phase boundaries in transparent vessels, with emphasis on chemistry applications

This document contains description of the source code for recognition of liquid surface and levels in an image of liquid in transparent containers. The method described in the paper "Computer vision-based recognition of liquid surfaces and phase boundaries in transparent vessels, with emphasis on chemistry applications" available at arxiv: http://arxiv.org/abs/1404.7174.

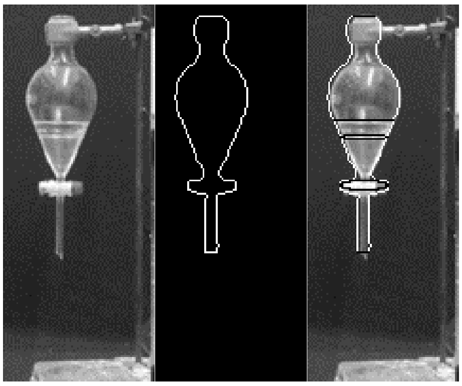

Figure S1. Input and output for the *Liquid_Surface_Line_Recognition* function. Left: Liquid container image. Center: container boundaries binary image. Right: the results of the phase boundaries recognition marked on the image.

The source code itself contain embedded explanation and documentation. This document could be used in addition. The main function responsible for the liquid surface recognition is Liquid_Surface_Line_Recognition (Is,Iborder,outname….). This function recognizes liquid surfaces and levels in an image of liquid container Is (Figure S1 left). Where the boundaries/contour line of the vessel in the image are given in Iborder (Figure S1 Center). See code for finding vessel boundaries to see how Iborder could be created:
http://www.mathworks.com/matlabcentral/fileexchange/46887-find-boundary-of-symmetric-object-in-image
or
http://www.mathworks.com/matlabcentral/fileexchange/46907-find-object-boundaries-in-image-using-template--variable-image-to-template-size-ratio-
The first parameter Is is a color image of the vessel containing liquid (Figure S1 Left). The second parameter Iborder is binary image that contain the contour of the vessel in the image Is (Figure S1 Center). The in pixels Iborder corresponding to the vessel contour are marked as one (white) the rest of the pixels marked as zero (black, Figure S1 Center). If Is and Iborder are not in the same size Is will be resized to the size of Iborder. The rest of the parameters of this function are all optional (could be left blank) and discussed in last section of this document (Also discussed the paper and in the function explanation embedded in the source code). As output Liquid_Surface_Line_Recognition function write the image Is with the all the boundaries of the liquid surfaces recognized marked in black (Figure S1 Right), in directory and file name given by string in outname (For example "C:\image"). All recognition methods discussed in the paper used Liquid_Surface_Line_Recognition function as the main function (The code in this function explained in section 2 of the paper). The difference between Entries/methods for recognition of liquid surface is the method for rating of the curve (Section 2.2, 3 of the paper). The rating of curve in the Liquid_Surface_Line_Recognition function is done by functions MatchEllipse… in line 124(probably) of the Liquid_Surface_Line_Recognition function. There various of such functions which use different methods to rate the curve, and can receive different inputs. The Connection between the function used to rate curve and the Entries in table 1-2 of the paper is given in table S1-S4 below (it is also given in the code documentation). Description of all main functions appear in the last section of this paper.
See the directory "EXAMPLE IMAGES" located in the source code directory for examples input and output images.

Entry	Indicator Description	Local score equation (Score for single curve point)	Image type (Pixel values in local score equation)	Evaluation method for curve score from local scores	Method (section 3.1)	Threshold 0.	Name of function used for curve rating (In the source code supplied)	Embedded Consistency check in the function
1	Relative intensity change normal to curve (percentile)	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Grayscale	Percentile (65%)	1	.4	*MatchEllipse11*	No
2	Relative intensity change normal to curve (average)	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Grayscale	Average	1	.4	*MatchEllipse1*	Yes
3	Intensity change normal to curve	$U-D$	Grayscale	Percentile (65%)	1	.3	*MathcEllipse12*	No
4	Global relative intensity change normal to curve[1353]	$\frac{U-D}{\mathrm{MAX}(\bar{U},\bar{D})}$	Grayscale	Average	1	.4	*MatchEllipse2*	Yes
5	Absolute intensity change normal to curve	$\lvert U-D \rvert$	Grayscale	Average	1	.4	*MatchEllipse3*	Yes
6	Absolute relative intensity change normal to curve	$\frac{\lvert U-D \rvert}{\mathrm{MAX}(U,D)}$	Grayscale	Average	1	.4	*MatchEllipse4*	Yes
7	Average intensity of pixel on curve	I	Grayscale	Average	2	.75	*MatchEllipse7*	No
8	Relative difference between average intensity above and on curve	$\frac{\lvert \bar{I}-\bar{A} \rvert}{\mathrm{MAX}(\bar{I},\bar{A})}$	Grayscale	As it is	3	.4	*MatchEllipse5b*	No
9	Normalized difference between average intensity above and on curve	$\frac{\lvert \bar{I}-\bar{A} \rvert}{\bar{I}+\bar{A}}$	Grayscale	As it is	3	.4	*MatchEllipse5*	No
10	Difference between average intensity above and on curve	$\lvert \bar{I}-\bar{A} \rvert$	Grayscale	As it is	3	.4	*MatchEllipse6*	No
11	Difference between average intensity inside and around surface curve[453436]	(Ellipse interior intensity) - (Ellipse outer curve intensity)	Grayscale	As it is	-	.4	*MatchEllipse8*	No
12	Relative edge density change normal to curve	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Edge	Average	1	.5	*MatchEllipse1*	Yes
13	Average edge density on curve	I	Edge	Average	2	.6	*MatchEllipse7*	No
14	Edge density and scalar product of gradient direction and curve normal	$I \bullet \mathrm{COS}(\theta-\phi)$	Edge	Average	2	.45	*MatchEllipse9d*	No
15	Difference between average edge density above and on curve	$\lvert \bar{I}-\bar{A} \rvert$	Edge	As it is	3	.4	*MatchEllipse6*	No
16	Score of the curve in generalized Hough transform (12 angle bins)	Hough transform curve score	Edge	Average	-	.3	*MatchEllipse15*	No
17	Change in gradient size normal to curve	$U-D$	Gradient Size	Average	1	.4	*MatchEllipse13*	No
18	Average gradient size on curve	I	Gradient Size	Average	2	.5	*MatchEllipse7*	No
19	Scalar product of gradient and curve normal	$I \bullet \mathrm{COS}(\theta-\phi)$	Gradient Size	Average	2	.5	*MatchEllipse10d*	No
20	Difference between average gradient size above and on curve	$\lvert \bar{I}-\bar{A} \rvert$	Gradient Size	As it is	3	.4	*MatchEllipse6*	No

Table S1: Relation between Entries in the paper (Tables 1-2) and functions used for curve rating in the source code. The rating of the curve is done by specific *MatchEllipse* function depends on the method use in the specific Entry(See sections 3-4 in the paper). Function name is the name of the function used for rating the curve in the code (line~124 of the *Liquid_Surface_Line_Recognition* function). Entry is the entry used in tables 1-2 of the paper. Embedded consistency check in the function, tell if the consistency check (Section 4.4.1 paper) is performed within the function or as separated function (ConsistencyFilter). If the consistency check embedded in the function it is performed by default (but could be disabled by changing the function code). The rest of the parameter's explained caption of table 2 in the Paper. All Entries in this table were run without consistency check (internal or external).

Entry	Indicator Description	Local score equation (Score for single curve point)	Image Type (Pixel values in local score equation)	Evaluation method of curve score from local scores	Method (section 3.1)	Threshold 0.	Name of function used for curve rating (In the source code supplied)	Embedded Consistency check in the function
21	Intensity change normal to curve	$U-D$	Grayscale	Average	1	.3	MatchEllipse13	Yes
22	Relative intensity change normal to curve	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Grayscale	Average	1	.4	MatchEllipse1	Yes
23	Global relative intensity change normal to curve[13,53]	$\frac{U-D}{\mathrm{MAX}(\overline{U},\overline{D})}$	Grayscale	Average	1	.4	MatchEllipse2	Yes
24	Absolute intensity change normal to curve	$\lvert U-D\rvert$	Grayscale	Average	1	.4	MatchEllipse3	Yes
25	Absolute relative intensity change normal to curve	$\frac{\lvert U-D\rvert}{\mathrm{MAX}(U,D)}$	Grayscale	Average	1	.4	MatchEllipse4	Yes
26	Relative intensity change normal to curve in 1% range (height of curve surroundings is 1% of vessel height)	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Grayscale	Average	1	.4	MatchEllipse1	Yes
27	Relative intensity change normal to curve in 2% range (height of point surroundings is 2% of vessel height)	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Grayscale	Average	1	.4	MatchEllipse1	Yes
28	Average relative intensity change normal to curve in the Red, Green, and Blue channels of the RGB color image.	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Color (R, G, B channels)	Average	1	.4	MatchEllipse1	No (consistency check is performed separately on the grey scale image
29	Edge density change normal to curve	$U-D$	Edge	Average	1	.4	MatchEllipse5b	No (disabled)
30	Average edge density on curve	I	Edge	Average	2	.45	MatchEllipse7	No
31	Edge density and scalar product gradient direction and curve normal	$I\bullet\mathrm{COS}(\theta-\phi)$	Edge	Average	2	.4	MatchEllipse9d	No
32	Difference between average edge density above and on curve	$\lvert\bar{I}-\bar{A}\rvert$	Edge	As it is	3	.4	MatchEllipse6	No
33	Scalar product gradient and curve normal	$I\bullet\mathrm{COS}(\theta-\phi)$	Gradient size	Average	2	.4	MatchEllipse10d	No
34	Difference between average gradient size above and on curve	$\lvert\bar{I}-\bar{A}\rvert$	Gradient Size	As it is	3	.32	MatchEllipse6	No
35	Relative gradient size change normal to curve	$\frac{U-D}{\mathrm{MAX}(U,D)}$	Gradient Size	Average	1	.6	MatchEllipse1	Yes

Table S2: Relation between Entries in the paper (Tables 1-2) and functions used for curve rating in the source code. The rating of the curve is done by specific *MatchEllipse* function depends on the method use in the specific Entry(See sections 3-4 in the paper). Function name is the name of the function used for rating the curve in the code (Line~ 124 of the *Liquid_Surface_Line_Recognition* function). Entry is the entry used in tables 1-2 of the paper. Embedded consistency check in the function, tell if the consistency check (Section 4.4.1 paper) is performed within the function or as separated function (ConsistencyFilter). If the consistency check embedded in the function it is performed by default (but could be disabled by changing the function code). The rest of the parameter's explained caption of table 2 in the Paper. All Entries in this table were run with consistency check (internal or external).

Entry	Indicator Description	Embedded Consistency check in the function	Implementation of curve rating in *Liquid_Surface_Line_Recognition* function	Consistency check applied?	External consistency check applied
1	Relative intensity change normal to curve (percentile)	No	MatchEllipse11(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
2	Relative intensity change normal to curve (average)	Yes	MatchEllipse1(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
3	Intensity change normal to curve	No	MatchEllipse12(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
4	Global relative intensity change normal to curve	Yes	MatchEllipse2(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
5	Absolute intensity change normal to curve	Yes	MatchEllipse3(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
6	Absolute relative intensity change normal to curve	Yes	MatchEllipse4(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
7	Average intensity of pixel on curve	No	MatchEllipse7(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
8	Relative difference between average intensity above and on curve	No	MatchEllipse5b(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
9	Normalized difference between average intensity above and on curve	No	MatchEllipse5(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
10	Difference between average intensity above and on curve	No	MatchEllipse6(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
11	Difference between average intensity inside and around surface curve[453436]	No	MatchEllipse8(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
12	Relative edge density change normal to curve	Yes	MatchEllipse1(Icanny,Iellipse,Resl,y(f),Iinterior)	No	No
13	Average edge density on curve	No	MatchEllipse7(Icanny,Iellipse,Resl,y(f),Iinterior)	No	No
14	Edge density and scalar product of gradient direction and curve normal	No	MatchEllipse9d(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
15	Difference between average edge density above and on curve	No	MatchEllipse6(Icanny,Iellipse,Resl,y(f),Iinterior)	No	No
16	Score of the curve in generalized Hough transform (12 angle bins)	No	MatchEllipse15(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
17	Change in gradient size normal to curve	No	MatchEllipse13(Igradient,Iellipse,Resl,y(f),Iinterior)	No	No
18	Average gradient size on curve	No	MatchEllipse7(Igradient,Iellipse,Resl,y(f),Iinterior)	No	No
19	Scalar product of gradient and curve normal	No	MatchEllipse10d(Igr,Iellipse,Resl,y(f),Iinterior)	No	No
20	Difference between average gradient size above and on curve	No	MatchEllipse6(Igradient,Iellipse,Resl,y(f),Iinterior)	No	No

Table S3: Relation between Entries in paper (Table 1-2) and functions used for curve rating the source code. The rating on of the curve is done by specific *MatchEllipse* function depending on the method used in the Entry (See section 3-4 paper). "Implementation of curve rating *in Liquid_Surface_Line_Recognition function* Column give the function (*MatchEllipse*) used for calculating the curve score and its input parameters, used to rating the curve in the code (Line~ 124 of the *Liquid_Surface_Line_Recognition* function). The input parameters for the *MatchEllipse* functions are: *Igr* is the greyscale image of the liquid vessel. *Igradient* is the sobel gradient map of *Igr*. Icanny is the canny edge image of *Igr*. *Iellipse* is binary image of the curve to be rated, in this case some kind of horizontal ellipse (*Iellipse* is Given as binary image of the ellipse where the pixels of the curve are marked 1. The size of *Iellipse* is the same as the size of *Igr/Icanny/Igradient* image). *Resl* is the resolution of the scan, the number of pixels above and below the curve used in evaluating the curve score. Value of 1 for *Resl* give best results for most cases (Resolution discussed in section 4.5 of the paper) . *y(f)* is the Y axis vertical coordinates of the line examine in the image (*Igr*) coordinates, basically the Y values of the the ellipse center in *Iellipse*. *Iinterior* give the area of the vessel in the image (*Igr*). *Iinterior* is a binary image in the size of *Igr/Icanny* with pixels corresponding to the vessel interior in the marked as one and the rest zero. "Embedded consistency check in the function" column, tell if the consistency check (Section 4.4.1 paper) is performed within the function or as separated function (*ConsistencyFilter*). If the consistency check embedded in the function it is applied by default (but could be remove by changing the code). "External consistency check applied" column, say if consistency check is applied in the scan using external function to *matchellipse* (*ConsistencyFilter*). Entry column is the entry used in tables 1-2 of the paper. The rest of the parameter's explained caption of table 2 in the Paper. All Entries in this table were run without consistency check.

Entry	Indicator Description	Embedded Consistency check in the function	Implementation of curve rating in Liquid_Surface_Line_Recognition function	External Consistency check applied
21	Intensity change normal to curve	Yes	MatchEllipse13(Igr,Iellipse,Resl,y(f),Iinterior)	No
22	Relative intensity change normal to curve	Yes	MatchEllipse1(Igr,Iellipse,Resl,y(f),Iinterior)	No
23	Global relative intensity change normal to curve[13,53]	Yes	MatchEllipse2(Igr,Iellipse,Resl,y(f),Iinterior)	No
24	Absolute intensity change normal to curve	Yes	MatchEllipse3(Igr,Iellipse,Resl,y(f),Iinterior)	No
25	Absolute relative intensity change normal to curve	Yes	MatchEllipse4(Igr,Iellipse,Resl,y(f),Iinterior)	No
26	Relative intensity change normal to curve in 1% range (height of curve surroundings is 1% of vessel height)	Yes	MatchEllipse1(Igr,Iellipse,Resl,y(f),Iinterior)	No
27	Relative intensity change normal to curve in 2% range (height of point surroundings is 2% of vessel height)	Yes	MatchEllipse1(Igr,Iellipse,Resl,y(f),Iinterior)	No
28	Average relative intensity change normal to curve in the Red, Green, and Blue channels of the RGB color image.	No (consistency check is performed separately on the grey scale image	MatchEllipse1(Rchannel,Iellipse,Resl,y(f),Iinterior)+MatchEllipse1(Bchannel,Iellipse,Resl,y(f),Iinterior)+MatchEllipse1(Gchannel,Iellipse,Resl,y(f),Iinterior)	Yes
29	Edge density change normal to curve	No (disabled)	MatchEllipse13(Icanny,Iellipse,Resl,y(f),Iinterior)	Yes
30	Average edge density on curve	No	MatchEllipse7(Icanny,Iellipse,Resl,y(f),Iinterior)	Yes
31	Edge density and scalar product gradient direction and curve normal	No	MatchEllipse9d(Igr,Iellipse,Resl,y(f),Iinterior)	Yes
32	Difference between average edge density above and on curve	No	MatchEllipse6(Icanny,Iellipse,Resl,y(f),Iinterior)	Yes
33	Scalar product gradient and curve normal	No	MatchEllipse10d(Igr,Iellipse,Resl,y(f),Iinterior))	Yes
34	Difference between average gradient size above and on curve	No	MatchEllipse6(Igradient,Iellipse,Resl,y(f),Iinterior)	Yes
35	Relative gradient size change normal to curve	Yes	MatchEllipse1(Igradient,Iellipse,Resl,y(f),Iinterior)	No

Table S4: Relation between Entries in paper (Table 1-2) and functions used for curve rating the source code. The rating on of the curve is done by specific *MatchEllipse* function depending on the method used in the Entry (See section 3-4 paper). "Implementation of curve rating *in Liquid_Surface_Line_Recognition function* Column give the function (*MatchEllipse*) used for calculating the curve score and its input parameters, used to rating the curve in the code (Line~ 124 of the *Liquid_Surface_Line_Recognition* function). The input parameters for the *MatchEllipse* functions are: *Igr* is the greyscale image of the liquid vessel. *Igradient* is the sobel gradient map of *Igr*. Icanny is the canny edge image of *Igr*. *Iellipse* is binary image of the curve to be rated, in this case some kind of horizontal ellipse (*Iellipse* is Given as binary image of the ellipse where the pixels of the curve are marked 1. The size of *Iellipse* is the same as the size of *Igr/Icanny/Igradient* image). *Resl* is the resolution of the scan, the number of pixels above and below the curve used in evaluating the curve score. Value of 1 for *Resl* give best results for most cases (Resolution discussed in section 4.5 of the paper) . *y(f)* is the Y axis vertical coordinates of the line examine in the image (*Igr*) coordinates, basically the Y values of the the ellipse center in *Iellipse*. *Iinterior* give the area of the vessel in the image (*Igr*). *Iinterior* is a binary image in the size of *Igr/Icanny* with pixels corresponding to the vessel interior in the marked as one and the rest zero. "Embedded consistency check in the function" column, tell if the consistency check (Section 4.4.1 paper) is performed within the function or as separated function (*ConsistencyFilter*). If the consistency check embedded in the function it is applied by default (but could be remove by changing the code). "External consistency check applied" column, say if consistency check is applied in the scan using external function to *matchellipse* (*ConsistencyFilter*). Entry column is the entry used in tables 1-2 of the paper. The rest of the parameter's explained caption of table 2 in the Paper. All Entries in this table were run with consistency check.

2. Description of some other functions used in the code

The following section contains brief explanation of main functions in the code (these functions also contain documentation embedded in the code itself).

Liquid_Surface_Line_Recognition(Is,Iborder,outname,Mode,MinRes,MinWidth,MinScore, Hightd_To_Width_Ellipse_Ratio,MinFractScore)

The main liquid surfaces recognition function.
Given image *Is* of liquid in vessel (in color) and binary edge image *Iborder* in which pixels on the boundary of the vessel region in the image *Is* have value of 1.
The function recognize the borders and surfaces of each liquid surface inside the vessel, this in include the top and floor of the vessel (which are always recognise as surfaces).
As output the function write the recognised liquid-surface/phase-boundaries marked in black on the original image *Is*. It save this image as tif image in directory and name given by text sting *outname*
Other than *Is*, *Iborder*, *outname* all parameters are optional and could be left blank.
This function algorithm is explained in section 2 of the paper.

Parameters
(See section 2.1 of the paper for this parameters)

Is is the original image of the liquid container in color.

Iborder is the edge image (binary image) of the liquid container contour in image *Is*. Pixels in ***Iborder*** corresponding to the boundaries of the of the vessel in image *Is* have value of 1, and the rest of the pixels have value of zero.
(Iborder can be created as the _BORDERS.tif output of the code in:

http://www.mathworks.com/matlabcentral/fileexchange/46887-find-boundary-of-symmetric-object-in-image

or

http://www.mathworks.com/matlabcentral/fileexchange/46907-find-object-boundaries-in-image-using-template--variable-image-to-template-size-ratio-

MinFractScore is the minimal threshold score for curve to be accepted as surface compared to the best score achieve by all curves in the scan. The threshold score for accepting curve as liquid surface will be *[Threshold Score]= MinFractScore•[Best score for all curve scanned]*. See section 2.3 in the paper for more details.

MinScore is the minimum curve score needed for curve in to be accepted as liquid surface (this can used as alternative or in addition to *MinFractScore*) it could be set to zero if *MinFractScore* used. *MinScore* is basically the threshold score for accepting curve as liquid surface. All curves with score higher than *MinScore* will be accepted. See section 2.3 in the paper for more details.

MinWidth is the minimal width of image regions in the vessel that will be scanned (as fraction of the maximal width of the vessel) in the image. Areas of the vessel narrower than *MinWidth•[Maximal vessel width]* pixels will not be scanned (see section 2.1 of paper).

Width_To_Hight_Ellipse_Ratio give the maximal height of the ellipse scanned compared to the width of that line/ellipse. The larger this parameter the lower the maximum ellipse height will be in the scaned. Values between 0.2 to 0.4 are recommended, values of one is the maximal which mean all possible ellipse from line to circle will be scanned for *Width_To_Hight_Ellipse_Ratio=1*.

MinRes is the minimal resolution in which the scanning will be done. Hence the number of lines (in pixels) above and below the curve line that will be used for evaluating the curve score. Value of 1 for *MinRes* give best results for most cases.

outname is text string in which the directory and file name for the output image files are written. For example "C:\output\file1" will lead to output image C:\output\file1.tif.

Function description.

(See section 2 of paper).

General what this function do is scan line by line in the area of the image belong to the vessel (Areas in *Is* inside the contour of *Iborder*).

For each line it generated various of elliptic curves that correspond to possible shape of liquid surface centred in this line.

The curves are compared to the image to find score for its correspondence to liquid surface in the image.

The liquid surface must look like either straight horizontal line or horizontal ellipse in order to be recognised. The curves with scores that pass some threshold given by *MinFractScore* or *MinScore* are accepted and marked on the image, which is saved as TIF image in location given by *outname*.

[Score] = MatchEllipseXXX(Ir,Iellipse,Resly,Ycnt,Ierea)

Include group of functions, where *XXX* is some number correspond to the specific curve rating method.

These functions rate of the correspondence between the curve in *Iellips*e and liquid-surface/phase-boundary in image *Ir* a and return *score* belong to this correspondence (The algorithm described in section 2.2 and 3 of the paper).

Parameters:

Ir is the image of the liquid surface which could be grayscale image, Edge image or gradient image.

Iellipse is binary image of the curve to be rated, in this case some kind of horizontal ellipse or horizontal line (*Iellipse* is Given as binary image of the ellipse where the pixels of the curve are marked 1, and all the rest of the pixels have value of 0. The size of *Iellipse* is the same as the size of *Ir*).

Resly is the resolution of the scan, the number of pixels above and below the curve used in evaluating the curve score (not all *MatchEllipse* functions can use this parameter). Value of 1 for *Resl* give best results for most cases (Resolution discussed in section 4.5 of the paper) .

Ycnt is the Y axis vertical coordinates of the center line of the curve (in *Iellipse*). Basically the Y values of the ellipse center in *Iellipse*.

Iinterior give the region of vessel in the image (*Igr*). *Iinterior* is a binary image in the size of *Ir* with all pixels corresponding to the vessel interior in the original image marked as one and the rest of the pixels marked as zero. For working mode see section 3,4 of the paper.

[Score] =ConsistencyFilter(Ir,Iellipse,Resly,Ycnt,Ierea,Fract, Thresh)
This check the consistency of the relative intensity change normal to the curve ***Iellipse*** in image ***Ir*** (mostly grayscale image). The function return 1 if more than ***Fract*** percent of the curve point show relative intensity change that pass ***Thresh*** value to the same direction (with the same sign). The rest of the parameters are the same as in *MatchEllipse*.
See section 4.4.1 of the paper.

[Iel,sumofpixels] = ELLIPSE(x1,x2,y1,y2, posdil,negdil,sizeim, PartsToDraw)

Draw specific elliptic curve in an binary image (*Iel*). Create binary image with the ellipse drawn on it.
x1,x2,y1,y2 are the leftmost rightmost top and bottom coordinates of the ellipse respectively.
Sizeim is the size of the binary image(*Iel*) in which the ellipse should be drawn (should be the same as the size of liquid container image).
posdil and ***negdil parameters*** are not being used and should be set to zero. This parameters controls the positive and negative dilation of the ellipse curve generated.
PartsToDraw again parameter that isn't being used and could be left blank. This parameter determines if to draw all the ellipse or only the top/bottom half. Draw all ellipse by default.
Iel The output binary image with the ellipse drawn. Pixel belong to ellipse line have value of 1. The rest have value of zero. The size of *Iel* image is ***Sizeim.***
Sumofpixels is the sum of all pixel in *Iel* which is basically the number of point on the ellipse drawn. This output parameter is not used.

[y,x1,x2,np]=find_binary_contour_leftright_edges(BW)
This function take the binary image ***BW*** that contain the contour of the vessel (Figure S1 center), and find the left and right edges (in image coordinates) of every line inside the contour given in *BW*.
x1[n] array that contain the left most *x* coordinate of line *n*, in the vessel region of the image.
image).
x2[n] array that contain the right most x coordinate of line *n*, in the vessel region of the image.
y[n] array that contain the y coordinate of line *n*, in the vessel region of the image.
np the number of lines in the vessel region of the image.

Directory_Liquid_Phases_Recognition.m

This script basically preform liquid surface recognition on every jpg image file in a given directory (*SystemDir*, line 24)

The directory must contain color images of the liquid containing vessel in jpg format (this format be change by changing ".jpg" in line 32)

For every color jpg image the directory most contain a binary edge images of the vessel contour in the liquid vessel.
The name of the edge file must be the same as the name of the liquid image for which this boundaries belong + _BORDERS.tif extension . For example "v1.jpg" and "v1_BORDERS.tif". Images that do not have contour files with _BORDERS extension will be ignored.
Basically the script scan for all files with color image of the system directory *SystemDir*
and find files with equivalent name which end by _Border.tif.
It then transfer this to files to the function *Liquid_Surface_Line_Recognition* which performs the recognition.

Example images

Several example input and output files are given in the directory “EXAMPLE IMAGES” in the located source code directory.