IMPROVING ACCURACY OF FLUID CONTACT DETERMINATION THROUGH THE USE OF AN AUXILIARY TRANSFORM METHOD

Bambang Widarsono
Researcher at "LEMIGAS" R & D Centre for Oil and Gas Technology
Jl. Ciledug Raya, Kav. 109, Cipulir, Kebayoran Lama, P.O. Box 1089/JKT, Jakarta Selatan 12230 INDONESIA
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422, Faxsimile: 62-21-7246150

First Registered on December 16nd 2011; Received after Corection on December 27th 2011
Publication Approval on : December 30th 2011

ABSTRACT

Fluid contact(s) in reservoir sets the lower limit above which an accumulation of hydrocarbon (i.e. oil or gas) has the maximum level of mobility under a specific circumstance. This mobile hydrocarbon determines the reservoir's production feasibility. In this light, an accurate knowledge over position of fluid contact contributes to accuracy in the estimation of initial hydrocarbon in place and its corresponding reserves. Determination of fluid contact in reservoir may utilize any available sources of information but well pressure survey data is usually regarded as the primary source of information. Despite the importance, the data is sometimes not in ideal condition usually marked by absence in clear change of pressure gradient and/or data scatter for various reasons. The use of Hough transform – as introduced by Kang and Xue (2009) – for supporting fluid contact detection can solve the problem. In this study, the method that is usually used for, among others, recognizing regular shapes in images has been successfully applied for fluid contact detection. The study uses three sets of data with different level of difficulty, and the technique proves to work well for the all cases. The study also shows that the Hough transform can be used reliably in a simple way without employing the full weight of it.

Keywords: *fluid contact, determination, accuracy, hough transform*

I. INTRODUCTION

All hydrocarbon traps – regardless of type, be them structural, stratigraphic, or else – must have fluid contact(s) at certain depth(s). Depending on various factors (e.g. geological setting, in situ pressure and temperature, nature of source rocks, nature and properties of the hydrocarbon, trap's size, and rock properties) a hydrocarbon reservoir may have either one or two fluid contacts. For two-fluid phase reservoirs the fluid contact takes the form of oil-water contact, OWC, for oil reservoirs or gas-water contact, GWC, for gas reservoirs. For three-fluid phase system – regardless the type of gas cap – the reservoirs would have two fluid contacts, usually in the form of one OWC and one gas-oil contact (GOC). In highly compartmentalized reservoirs multiple fluid contacts are often found.

Whenever found by well(s) penetrating a hydrocarbon reservoir fluid contacts always serve as the lowest limit of hydrocarbon of concerned, OWC for oil reservoir and GWC for gas reservoir. For a three-fluid phase reservoir, the GOC serves both as lowest limit of its gas cap and top limit of the oil in the reservoir. Therefore, fluid contacts play a very important role in the determination of original hydrocarbon in place either original oil in place (OOIP) or original gas in place (OGIP). Failure in encountering these fluid contacts reduces 'proved' OOIP and OGIP figures only to oil and gas column limited by depths termed 'lowest known oil' (LKO) and 'lowest known gas' (LKG), respectively. Oil and gas beyond these limits are usually classified at lower degree of certainty, either 'probable' or 'possible'.

There are some traditional sources of information usually used for detecting and determining fluid contacts in reservoir: log analysis, mud logging, oil show on core samples, and formation tester. Information from all these sources of information is combined for the best possible determination of fluid contacts. However, all of these sources appear to have their own respective shortcomings. Log analysis with all of the potential bias factors provided by rock formation and borehole environment often results in unclear fluid contacts and transition zone. Mud logging always has problem with depth accuracy, and core samples are often affected by mud invasion. This is not to mention that core samples are more often than not taken from depths far away from the suspected depth(s) of the fluid contacts. The formation tester – usually RFT (repeat formation tester) and/or MDT (modular dynamic tester) – with its capacity to directly measure pressure and pressure gradient is often regarded as the primary tool for fluid contact detection. Abrupt change in the pressure gradient is an indication of the depth of the contact.

Despite a primary source of information, the formation tester is often not without problem. Apart from tool problem and unfavorable testing environment such as deep mud invasion, difficulties can still be encountered in interpreting the formation tester data. In reservoirs with thick transition zone and/or similar pressure in its water and hydrocarbon phases (e.g. water and oil with similar density values) sharp fluid contact is difficult to detect. A supporting method of analysis is therefore required.

Kang and Xue (2009) used a transform – the Hough transform – to calculate and interpret pressure data gradient. In their work they managed to use the transform to determine pressure gradient from which the fluid contact was yielded. However, as to be shown in this paper, the transform/method can be used in a simpler way and for cases more difficult than the examples they used in their work. Two data sets from two wells, each from western and eastern Indonesia, plus an additional hypothetical set of data are used in this study.

II. HOUGH TRANSFORM

Hough transform (Hough, 1962; as quoted in Kang and Xue, 2009) is basically a method for recognizing features with regular shapes such as lines, curves, circles, and ellipse among an abundant quantity of various other features with different shapes. Practically, this transform is often used for imagery purposes such as sharpening a rather blurred edge of an object within an image (e.g. Xu et al, 1990 and Casasent and Krisnapuram, 1987). Another example is to enhance and indicate some anomaly within a human internal organ in an analysis using x-ray images. Any other purposes can also surely be served as long as the object within the image that needs to be detected has regular shape.

The very basic of Hough transform is to transform a point (or pixel) in an x-y cartesian image – with a coordinate of (x,y) – into a curve in an r-θ system through

$$r = x\cos\theta + y\sin\theta \qquad \text{..........} \ (1)$$

Equation 1 transforms the point into a sinusoidal curve. When there are a series of points expressed in the form of a line the equation transforms the points into a set of curves with r is the length of a normal from the point of origin and is the orientation of r with respect to the x-axis (Figure 1). A number of n points in the x-y system would be transformed to n sinusoidal curves in the r-θ system. If the points are within a regular shape (e.g. a line) then the set of sinusoidal curves would cross at some common points (i.e. crossing points). Suppose that there is a set of points falling within a straight line (Figure 2), for $0^o \leq \theta \leq 360^o$ the points are transformed through Equation 1 into a set of sinusoidal curves (Figure 3) having some common crossing points. Figure 3 shows the curves with obvious common crossing points.

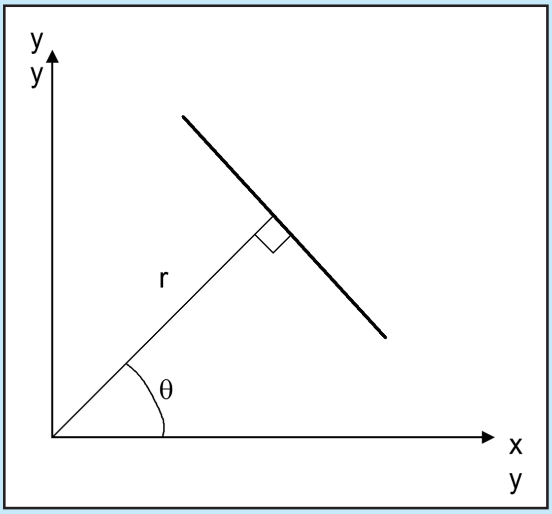

Figure 1
Illustration of how a point in a line is transformed into r-θ system

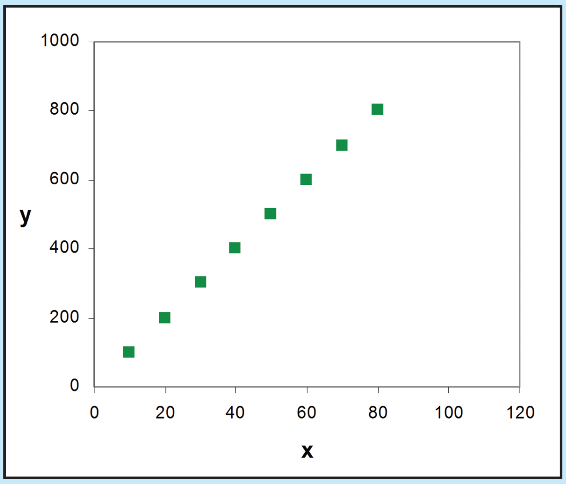

Figure 2
A set of data points falling in a straight line

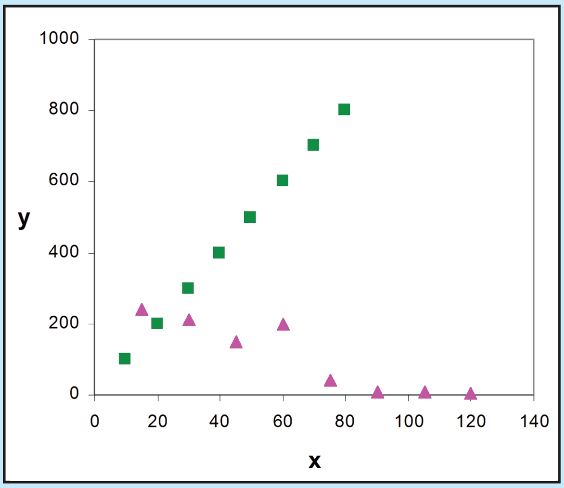

Figure 4
Two sets of data points with different orientations and levels of regularity

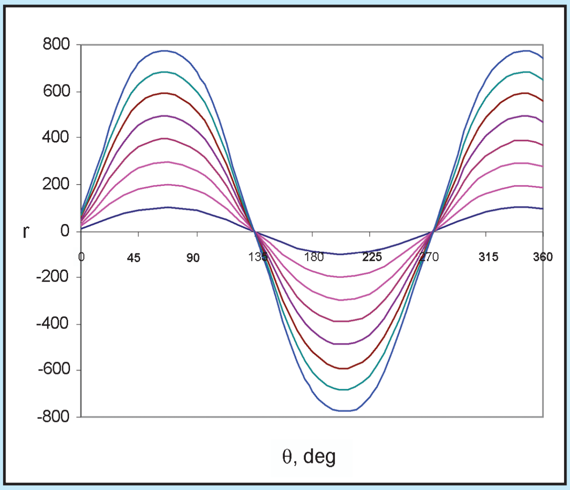

Figure 3
Sinusoidal curves as the result of transformation. The curves have common crossing points indicating that the transformed points belong to a common regular shape, a straight line in this case

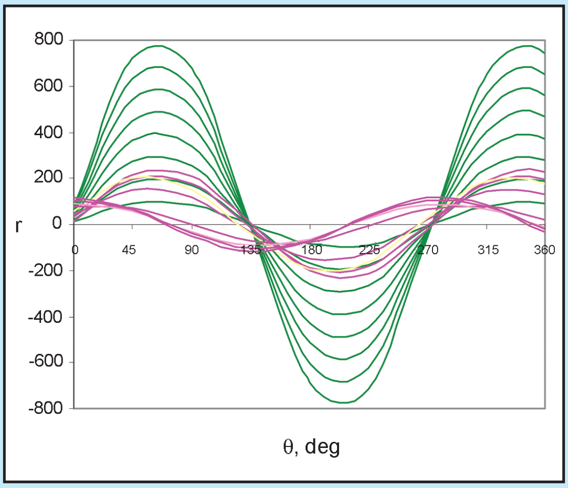

Figure 5
Two sets of sinusoidal curves as the result of transformation. The two sets have different shapes and crossing points. Notice the less regular nature of the second set due to some deviation from the basic shape (i.e. line or curve)

Figure 4 presents the original set of points – as shown in Figure 2 – but this time along with an additional set of points with apparently different orientation and level of regularity. Results of transformation are depicted in Figure 5. The r-θ plot on the figure shows the first set of curves and the second one with apparent difference in shape. The second set also has different common crossing points.

A further investigation is made on the second set over which a separate plot has been made (Figure 6). A more careful examination over the sinusoidal curves has revealed that the curves are actually made of two groups with different and less sharp crossing points. This occurrence indicates that there are at least two groups of points with different orientations, as also obviously shown in Figure 4. The second set's less sharp crossing points also reflect the less regular

Table 1
Pressure survey data of SS-X well

Sample No.	Depth (m, TVDSS)	Pressure (psia)
1	1474	2215
2	1476	2244
3	1482	2217
4	1483	2217.5
5	1490	2218
6	1494	2218
7	1495	2219
8	1500	2220
9	1501	2230
10	1503	2220
11	1503	2238
12	1512	2224
13	1519	2232
14	1526	2243
15	1539	2269
16	1541	2264
17	1550	2278
18	1570	2320

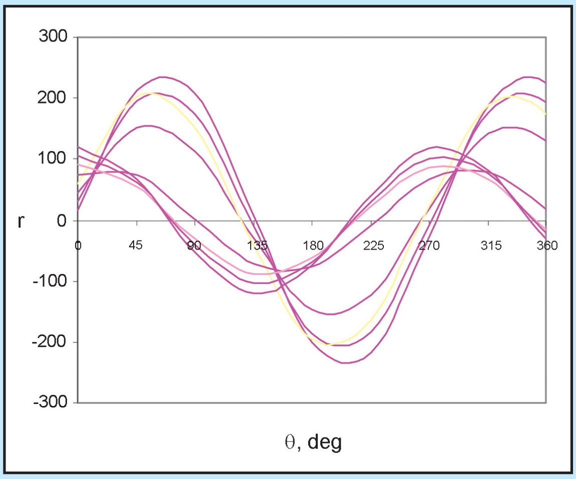

Figure 6
A closer look on the second set of curves shown on Figure 5. Two groups of curves are obvious

increments between neighboring points. Comparison between the first and second sets of points has shown to us the first step to understanding the use of Hough transform.

III. CASE TRIAL

For application of the transform for assisting the determination of fluid contacts, two cases have been used. The first is taken from a well in South Sumatera (SS-X), which well log information surrounding the fluid contact (gas – water) is exhibited on Figure 7. The most important supporting information for the well is the available MDT data. The MDT data for the SS-X well (Figure 8 and Table 1) can actually be

Table 2
Pressure survey data of EI-X well

Sample no.	Depth (m, TVDSS)	Pressure (psia)
1	3848	5585
2	3850	5585
3	3851	5588
4	3860	5593
5	3865	5610
6	3870	5600
7	3890	5615
8	3900	5630
9	3905	5624
10	3905	5600
11	3910	5620
12	3912	5623
13	3914	5620
14	3920	5643
15	3950	5680
16	3980	5720
17	4010	5760
19	4053	5810
20	4071	5840
21	4080	5885
22	4170	5980
23	4180	5977
24	4190	5990

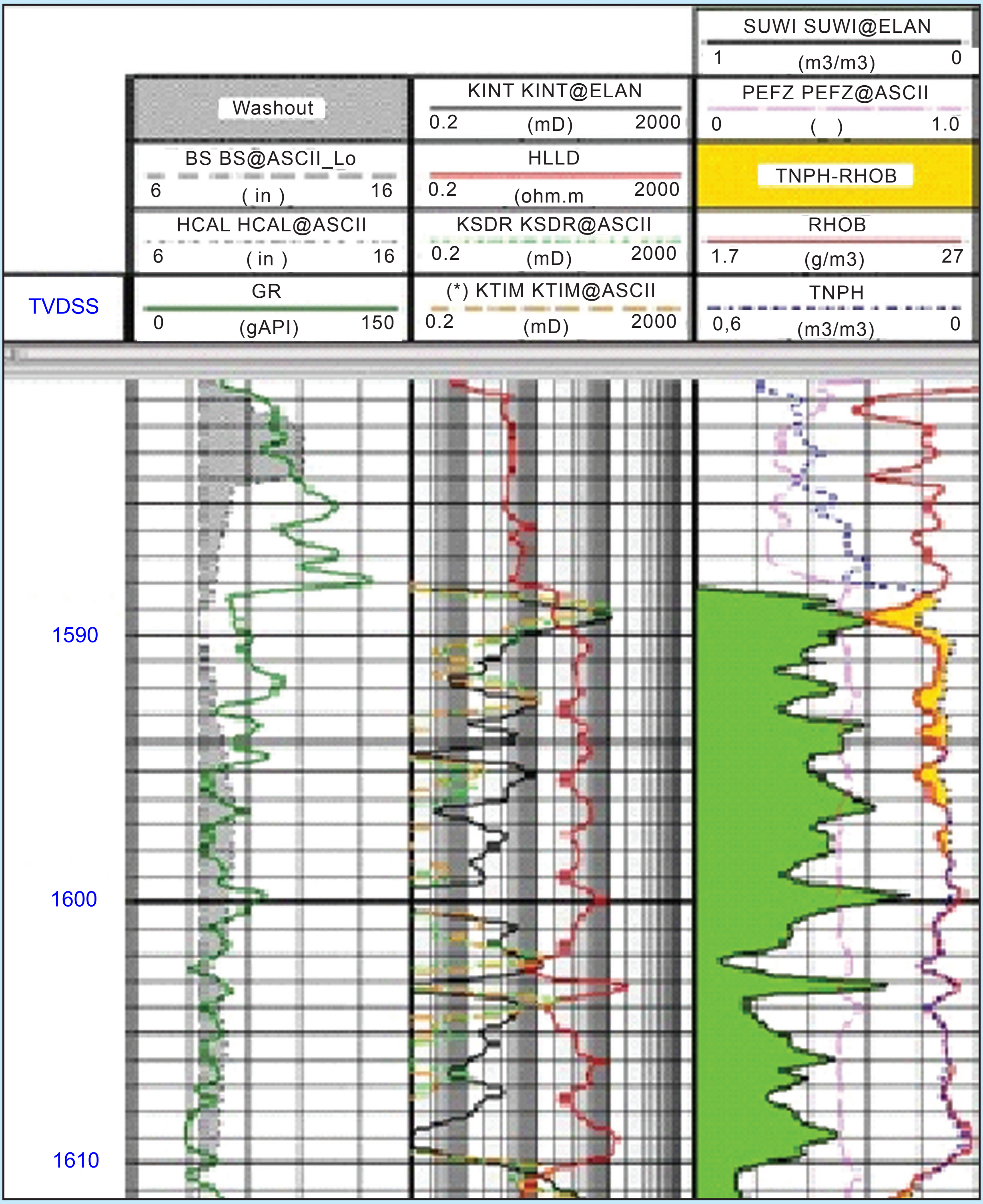

Figure 7
Well logging data and some of its log analysis results of SS-X well. Laterolog curves of the middle column (red curve) and the interpreted water saturation result on the right column (green area) both show no sharp fluid contact. The true depth of gas – water contact (GWC) may be somewhere between 1495 and 1510 m TVDSS

used to convincingly determine the reservoir's GWC. Despite convincing, a trial would be performed on the data nonetheless. The second case, a more difficult one, is from a gas well in eastern Indonesia coded EI-X (Figure 9 and Table 2). Lack of obvious change in the pressure trend and presence of some scattered data points have led to difficulty in spotting the fluid contact visually. No well log data for the well is presented here, since it would not help much in the examination. Application of Hough transform is to be applied on these two cases.

Application of the basic Hough transform on SS-X well's pressure data – for $0^o \leq \theta \leq 360^o$ - results in the r-θ plot depicted on Figure 10. In the plot, it is apparently seen that there is only one curve present. In fact the apparently single curve is actually a bundle of overlapping sinusoidal curves, too small in difference to have distinctive crossing points. The cause of this occurrence is the narrow value range of both depth and pressure (Figure 8), 1470 – 1570 m and 2215 – 2325 psia, respectively. This condition is certainly not favorable for any analysis.

The situation occurring on Figure 10 is commonly dubbed as 'redundancy', in which too large Hough r-θ space is created but no identification can be made on the curves and their crossing points. As for the group of curves on Figure 10, crossing points are difficult to spot but are likely to be somewhere between $q = 80^o – 100^o$ and $\theta = 230^o – 250^o$. This redundancy can be reduced through zooming the sinusoidal group using a 'difference' method that subtracts the transform in Equation 1 by a selected value. Accordingly, the Equation 1 is re-written as

$$r = x\cos\theta + y\sin\theta - x'\cos\theta - y'\sin\theta \cdots \quad (2)$$

with x' and y' represent the chosen pressure and depth at which the zooming is to be made.

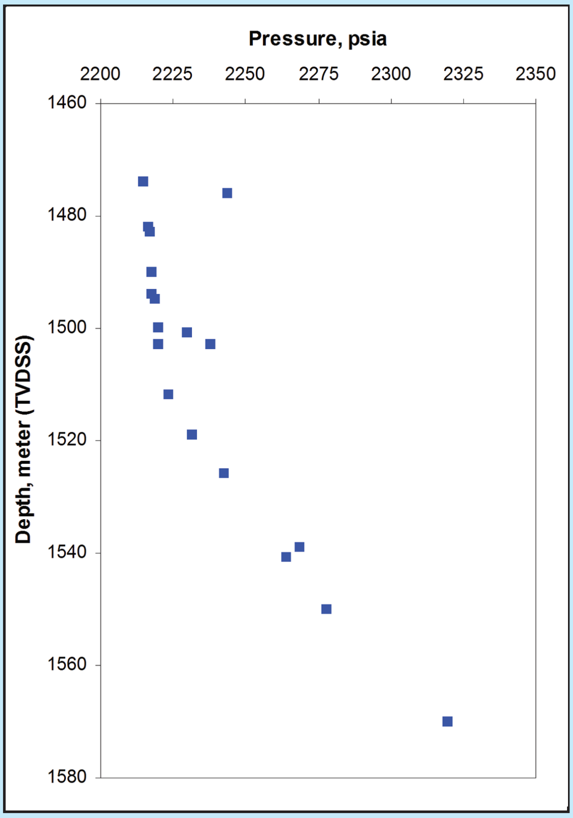

Figure 8
Pressure data for SS-X well. Although the fluid contact is apparent some scatter and deviation from the trend require a more careful examination

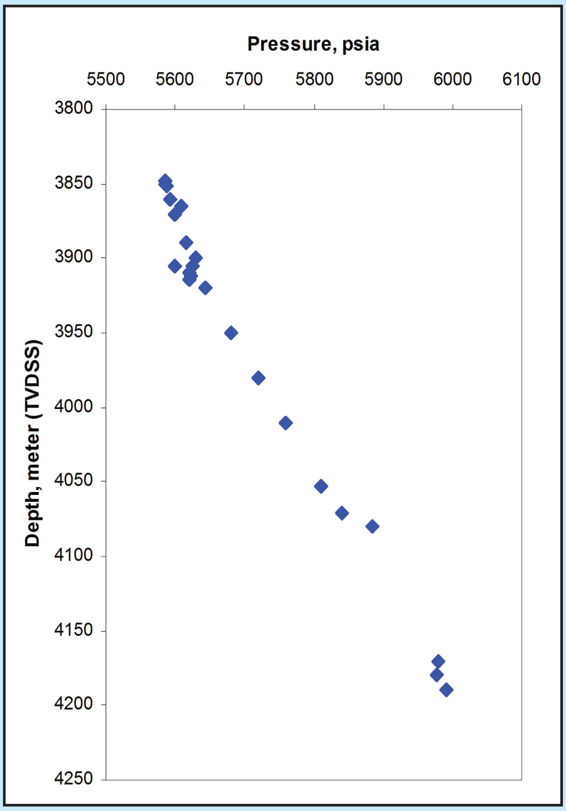

Figure 9
Pressure data for EI-X well. Absence of apparent contrast in the pressure trend (i.e. pressure gradient) and presence of some degree of scatter make visual detection over the fluid contact difficult

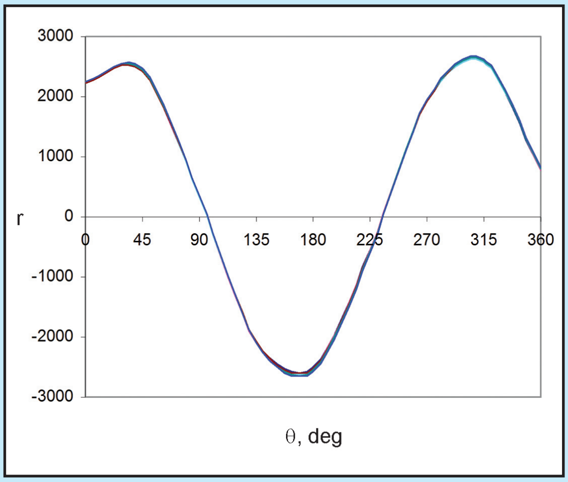

Figure 10
Transformed data of SS-X well.
The apparently single sinusoidal curve is actually made of all the sinusoidal curves that overlap to each other

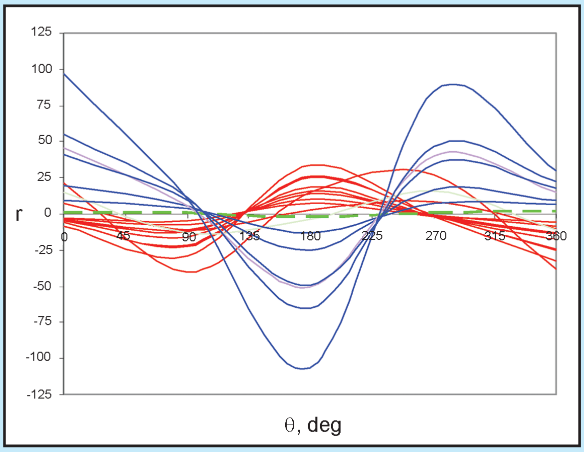

Figure 11
Zoomed data of SS-X well at around p = 2223 psia and depth = 1510 m. The separation of the two groups of curves are now apparent with blue curves (larger r values) belonging to water and red curves (smaler r values) representing gas. This separation clearly identifies the data point that devides the two groups – green dashed curve – and therefore is representing the gas-water contact depth

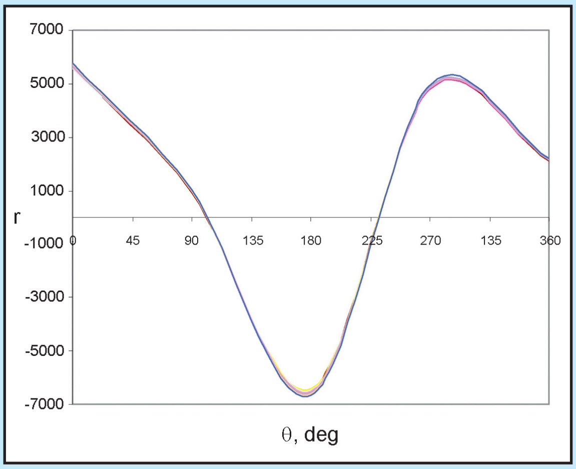

Figure 12
Transformed data of El-X well.
Same occurrence as in the case of SS-X well data also takes place

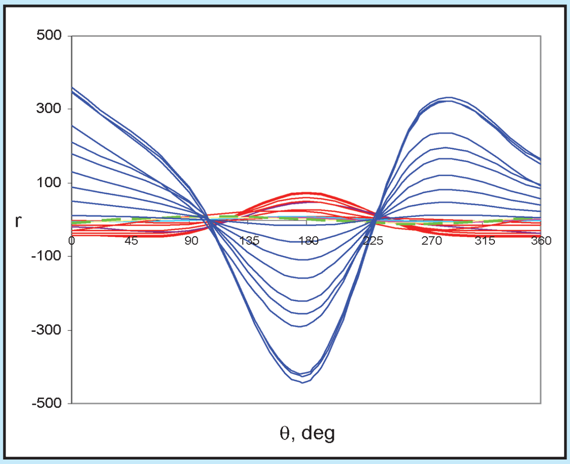

Figure 13
Zoomed data of El-X well at around p = 5630 psia and depth = 3910 m. Like in the case of SS-X well data separation between the two groups is obvious with blue curves (larger r values) belonging to water and red curves (smaler r values) representing gas. The zooming manages to indicate GWC depth at 3900 m represented by the green dashed curve between the two groups

For the same range of θ, and x' = 2223 psia and y' = 1510 m, a zoomed Hough r-θ space is created (Figure 11). The zoomed plot of the SS-X pressure data has apparently enabled the differentiation between the two sinusoidal curve bands. This zooming also enables the identification of data that is very likely to belong to the GWC at depth of 1512 m (sample #12 in Table 1). When this depth is added to the log data on Figure 7, a reasonably clearer picture is now obtained below the depth water saturation increases rapidly towards 100% marking an obvious and typical transition zone below a GWC. It is also worth noting that some sinusoidal curves belonging to the gas stray out from the group marking the scattered points shown on Figure 8.

For the second case, the more difficult EI-X data (Figure 9), same procedure is applied with un-zoomed transformation is presented on Figure 12 and the zoomed results are exhibited on Figure 13 (x' = 5630 psia and y' = 3910 m). The zooming has resulted in a clear indication over the data point that represents the reservoir's GWC at 3900 m (sample #8 in Table 2). This GWC depth is confirmed by a more conclusive set of MDT data from other wells in the same field.

IV. FURTHER TESTS

In the zooming of Hough transform, a pair of x' and y' values have to be assigned for the use of Equation 2. Users, especially in the case of fluid contact detection, may have some indication or approximation over the location of the fluid contact, and therefore can choose an appropriate pair of values to focus on. Question may arise, however, in the case of no indication or clue over x' and y' values to zoom at. To investigate this matter a further series of tests have been performed using rather arbitrary pair of x' and y' values.

Using the SS-X well data trials were performed through choosing four zooming points; (2223 psia, 1520 m), (2215 psia, 1495 m), (2270 psia, 1540 m), and (2215 psia, 1475 m). Two of the points are considered as near to the original zooming point of (2223 psia, 1510 m), and the rest are for tests when the approximated zooming points fall far from the actual fluid contact. Results of the tests are presented on Figures 14 through 17.

Results of the tests have shown that the sinusoidal curves may change in shape and 'polarization' but they remain divided in two groups. Despite the straying curves, the two groups also keep their separate crossing points. No matter that the data is zoomed at points near or far from the actual fluid contact, indication over the presence of two pressure gradients remains. One of the most important notes to draw is that the sinusoidal curve belonging to data point (in this case sample #12 of SS-X well data) representing the fluid contact always cross all crossing points of the two groups. This marks evidence that such data point somehow belongs to

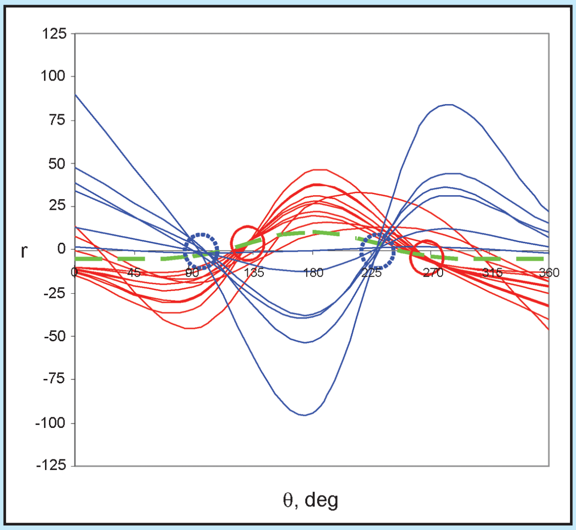

Figure 14
Zoomed data of SS-X well at around p = 2223 psia and depth = 1520 m. Crossing points for gas curves are marked by red circles whereas the ones for the water curves are indicated by blue dotted circles. The curves of the two bands are on the opposite polarization indicating the zooming point is near the actual fluid contact

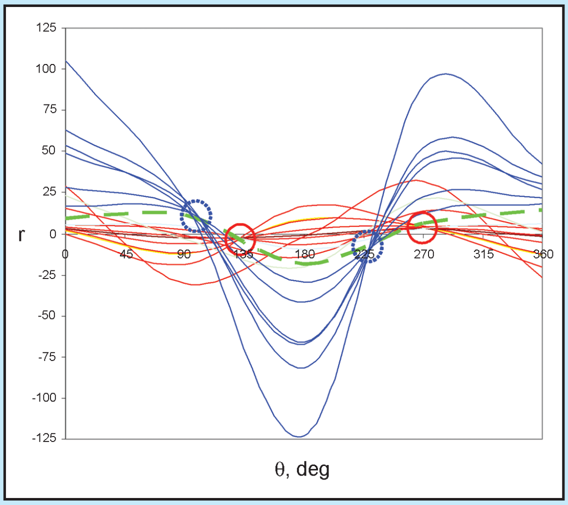

Figure 15
Zoomed data of SS-X well at around p = 2215 psia and depth = 1495 m. Crossing points for gas curves are marked by red circles whereas the ones for the water curves are indicated by blue dotted circles. The green dashed curve that represents the fluid contact crosses the four crossing points. This occurrence can be used as guidance in spotting the fluid contact

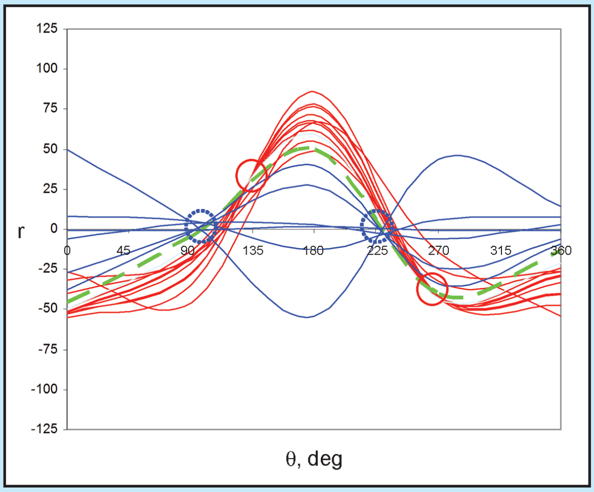

Figure 16
Zoomed data of SS-X well at around p = 2270 psia and depth = 1540 m. Crossing points for gas curves are marked by red circles whereas the ones for the water curves are indicated by blue dotted circles. Notice that some of the water curves are in the same polarization to the gas curves due to the significant distance between the zooming point and the actual fluid contact

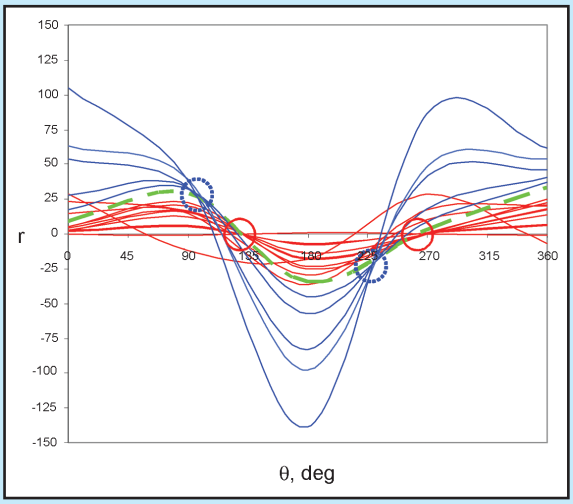

Figure 17
Zoomed data of SS-X well at around p = 2215 psia and depth = 1475 m. Crossing points for gas curves are marked by red circles whereas the ones for the water curves are indicated by blue dotted circles. Notice that all curves are in the same polarization but the green dashed curve representing the fluid contact remains crossing the four crossing points

both groups hence indicating the switch between the two groups. Concentration is therefore should be focused on spotting this kind of data point(s).

This finding has lead to a need to test this technique further using an even more difficult case. For the test, a hypothetical set of data (i.e. Case 3 data) was used (Figure 18). The data set contains some scattered data points plus a depth interval with missing data points, within which the true fluid contect depth is expected to be located. Converting the x-y data into r-θ space can be done directly following the procedure has been used to process the Case 1 and Case 2 data. However, it would be much easier for the analysis when the data is sorted out first, through which 'faulty' data points were removed, and the remaining data points representing water and hydrocarbon gradients were selected. The result is presented on Figure 19. Problem remains, nonetheless, that through the use of traditional extrapolation tecnique a series of depths ranging from 1808 m to 1821 m can result. In this light, the Hough transform is used.

In the use of Hough transform, data points are always needed. Therefore, imaginary data points within the 1808 m – 1821 m depth interval were established. Three exemplary trial data points were set, (2224 psia,1808 m), (2226 psia,1815 m), and (2230 psia, 1821 m), and the zoomed results are shown on Figure 20. On the r-θ space on the figure the three curves appear to cross all the four crossing points. However, with some magnification (Figure 21) it is obvious that the (2224 psia, 1808 m) data point is better positioned when compared to the other two. The (2224 psia, 1808 m) curve mostly crosses the crossing points at their centers. It is confirmed then that the fluid contact depth for this hypothetical set of data is at 1808 m, and with theoretical measured pressure of 2224 psia.

The application of Hough transform has shown that even for a difficult case such as the Case 3 data the method remains robust for separating different shapes or trends. The zooming of Hough space has further strengthened the understanding over the use of Hough transform to separate certain regular shapes from 'noise' in the background. As shown by Kang and Xue (2009), the identified shapes can be further converted into other forms of information – in their work, the data is converted into formation fluid

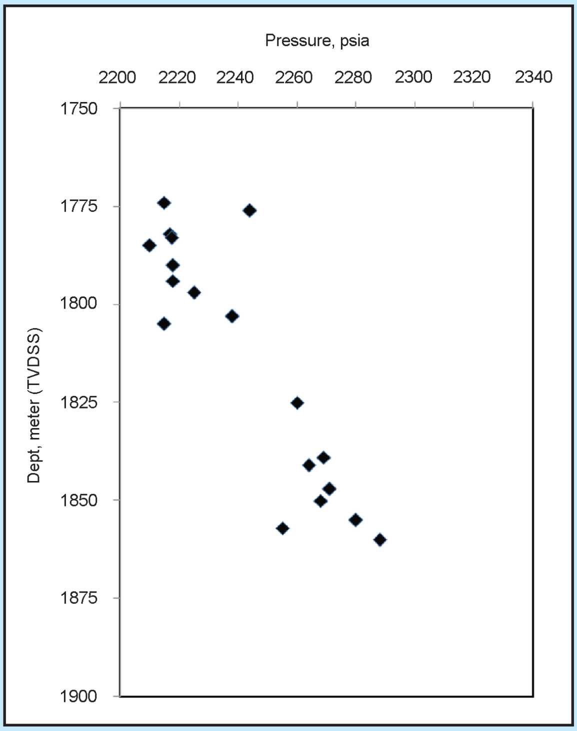

Figure 18
A hypothetical data set for Case 3, in which a more difficult situation is found marked by some scatter of data and data missing for depths expected to be around the fluid contact depth

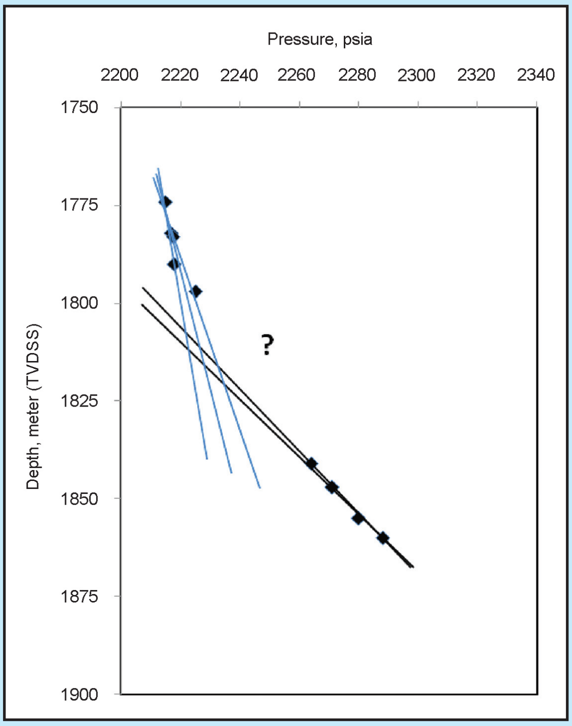

Figure 19
After removing the 'faulty' data points – a process that cannot be avoided nevertheless – two groups of data points representing hydrocarbon and water bearing intervals emerge. However, determination of fluid contact depth using the traditional interpolation technique may produce several ambiguous fluid contact depths ranging from 1808 m to 1821 m (TVDSS)

density versus depth and pressure – or 'de-Houghed' into the original form or data.

V. FURTHER DISCUSSION

The application on two data sets with different level of difficulty has shown that the Hough transform can provide a useful support to the determination of fluid contact(s) in reservoir. Kang and Xue (2009) in their work proceeded far into determining density profile in order to spot the fluid contact. In this study, with a more complex example than the ones being used in their study, it is shown that just by examining the sinusoidal curves the wanted fluid contact can be detected. Being a transition between gas and water zones the pertinent MDT pressure sample(s) should read between the two trends, and this is clearly exhibited by the sinusoidal curve that crosses all crossing points in a manner shown on Figures 14 through 17. Provided the data is sufficient this serves as a powerful tool for fluid contact detection.

Considering the sensitivity of the method to distinguish shape or trends it would be beneficial to deploy the technique to study fluid contacts in complex reservoir system. In reservoir system that is heavily compartmentalized and layered an attempt to determine fluid contacts is indeed challenging. A well penetrating this kind of system is likely to provide confusing pressure survey data due to presence of multiple fluid contacts in the system. The utilization of the Hough transform is likely to help much in the analysis.

In accordance with the common use of the Hough transform, the technique requires continuous pressure data in order to spot the fluid contact. Real data from the field does not always meet this condition. Data missing due to disrupted survey or inconclusive evaluation certainly cause problem especially when this takes place at depths expected to be the location of the fluid contact. Data scatter due to occassional gauge problem may also create difficulty since this can be interpreted as presence of multiple fluid contacts. In these situations a careful analysis on input data using all other available source of information is still needed. Nevertheless, as has been shown in the test on Case 3 data, the technique can still be use satisfactorily with some improvisation.

VI. CONCLUSIONS

The study on the use of Hough transform to assist detection of fluid contact has produced some main conclusions:

- Hough transform is a useful and powerful technique to detect fluid contact(s) in reservoir. The technique can spot data transition from water to hydrocarbon (especially gas) that cannot be seen visually.
- Pressure data that marks the change in the pressure trends always cross all of the crossing points of the sinusoidal curves belonging to both water and hydrocarbon groups regardless at what depth the zooming is made.

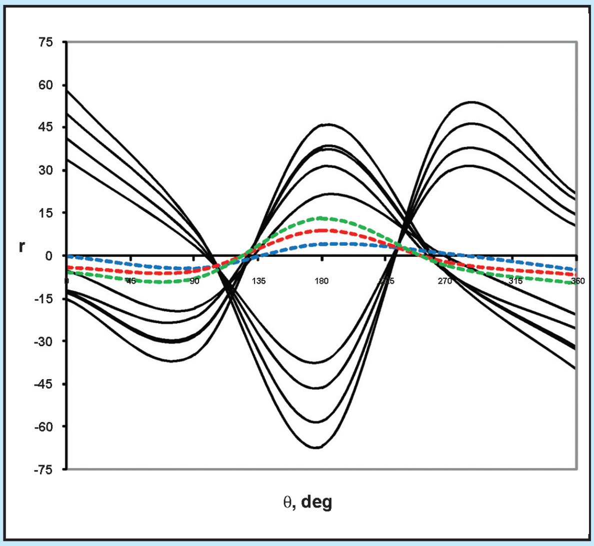

Figure 20
Zoomed Case 3 data (after removal of 'faulty' data points) at p = 2230 psia and depth = 1830 m. Three trial data points of (2224 psia, 1808 m), (2226 psia,1815 m), and (2230 psia, 1821 m) are used represented by the green, red, and blue dashed curve, respectively

- Data deviation in the pressure data is significantly enhanced through the use of the transform hence providing a larger opportunity to analysis.
- The technique requires continuous pressure data at least at depths expected to be the fluid contact depth(s). In the occurrence of missing data application of the technique may face difficulties. However, with careful data selection the technique can still provide conclusive, unique, and satisfactory result.

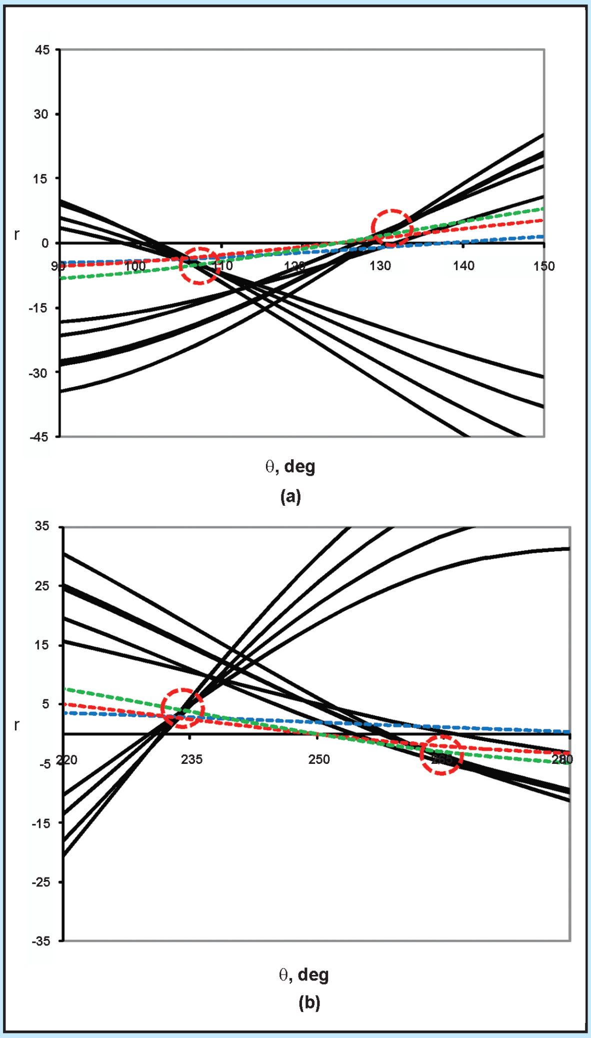

Figure 21
Magnification of the left (a) and right (b) crossing points of the curves presented on Figure 16. The crossing points are marked by the dashed red circles. The green dashed curve representing (2224 psia, 1808 m) appears to cross all of the crossing points better than the other two confirming the fluid contact depth is around 1808 m and with theoretical measured pressure of 2224 psia

REFERENCES

1. **Hough, P.V.C.** (1962). A method and means for recognizing complex patterns: US Patent 3,069,654.
2. **Kang, X.Q**. and **Xue, Y.J.** (2009). An improved plot for wireline pressure data gradient interpretation. Petrophysics, vol. 50, No. 3, June, pp. 226 – 236.
3. **Casasent, D.** and **Krishnapuram, R.** (1987). Curved object location by Hough transformations and inversions. Pattern Recognition, vol 20 no. 2, p.181 – 188.
4. **Xu, L., Oja, E.,** and **Kultanen, P.** (1990). A new curve detection method: randomized Hough transform (rht). Pattern Recognition Letters, vol. 11, no.5, p. 331 – 338.