A new method for dynamic road mapping of coronary angiography cardiac catheterization cine loops

Onsy Abdel Alim, Ibrahim Adel Ghaleb and Mohamed Shoura
Electrical Eng. Dept., Faculty of Eng., Alexandria University, Alexandria, Egypt

In this paper a new method for road mapping for cardiac catheterization cine loops was introduced. The method depends on detecting the edges of the coronary vessels after the dye injection during the Catheterization operation and drawing a road map for the vessels so that the angiographer can navigate through these drawn paths with his catheter under fluoroscopy X-ray exposure. Canny technique was used to detect the edges of these gray scale high-resolution images. It was used to detect the vessel edges due to its high level of detection for this kind of images. The method will estimate and track the heart motion during the operation and draw the road map in a real time dynamic way. The road map will be superimposed over the same fluoroscopy monitor so that the angiographer can navigate with the catheter through the detected coronary artery without any need for another monitor for road map. This method will offer X-ray dose limitation for the patient, easy manipulation in PTCA operations for inserting stents and balloons in coronary vessels.

تقدم فى هذا البحث طريقة جديدة لعمل خريطة طريق لأفلام القسطرة القلبية. تعتمد هذه الطريقة على تحديد حواف الاوعية التاجية عقب حقن الصبغة اثناء عملية القسطرة ورسم خريطة طريق لهذه الأوعية تمكن المختص من الابحار عبر المسارات المرسومة بواسطة قسطرته تحت الاشعة السينية الفلوروسكوبية. استخدمت طريقة كانــى لتحديد حواف الصور الغير ملونة العالية الدقة. استخدمت هذه الطريقة نظرا لجودتها العالية فى تحديد هذه النوعية من الصور. تتنبأ وتتتبع هذه الطريقة حركة القلب اثناء عملية القسطرة وترسم خريطة الطرق للأوعية بطريقة ديناميكية فى الوقت الحقيقى. خريطة الطريق هذه، سوف تكون متطابقة على نفس الصورة الظاهرة على شاشة الفلوروسكوبى مما يمكن طبيب القلب من الأبحار بقسطرته خلال الشريان التاجى الذى تم تحديده بدون الحاجة لشاشة أخرى لخريطة الطرق. توفر هذه الطريقة تقليل جرعة الاشعة للمريض كما تسهل المناورة عند ادخال البالونات أو الدعامات فى عمليات القسطرة العلاجية التوسيعية.

Keywords: Road map, Cardiac catch, Coronary, Stents, PTCA

1. Introduction

Coronary angiography procedures have grown into a safe and widely practiced component of cardiac catheterization. It is estimated that more than 300,000 coronary angiographic procedures are performed every year in the United States. In each procedure, the objective is to examine the entire coronary tree, recording details of the coronary anatomy, including individual variations in arterial distributions, anatomical or functional pathology (artherosclerosis, thrombosis, congenital anomalies or artery stenosis). The vessels are viewed by repeated dye injections in a series of angulated views under X-ray. The dye appears under X-ray with a dark color, so the vessels while filled with injected dye appears in a gray level darker than other parts of the image. In angiography procedures the patient has to be connected with ECG

leads and an intravenous line for administering drugs like heparin or atropine and placed on the X-ray catheterization Lab tabletop under local anesthesia. An introducing sheath is placed over a guide wire and then the catheter is advanced through this sheath. The catheterization is performed usually via femoral, brachial or auxiliary artery [1].

The catheter is advanced through the femoral artery until it reaches the coronary vessels. The catheter tip pressure should be monitored all the time during the procedure. Fall in overall catheter tip pressure indicates restriction of coronary inflow due to the insertion of the catheter tip into a proximal coronary stenosis or to an adverse catheter lie against the coronary wall. During the catheter insertion through coronary arteries under the fluoroscopy X-ray the vessels edges cannot be seen due to its radio opaque properties. This means that if the catheter tip or the guide wire

faces a bifurcation or trifurcation vessels or a vessel branches, the angiographer will not know where to direct his catheter. So for analyzing the situation further, the angiographer has to use a small dye injections through the catheter into the coronary artery followed immediately by the catheter tip. This results in a clearer image for the coronary arteries branches following the catheter tip because it is already filled with dye which is a radio opaque to X-ray, which means that it will appears in a dark gray level other than the remaining part of the image. On the other hand, this injection will result in a damped pressure waveform that may result in ischemia and arrhythmias due to the lack of oxygen delivery to the myocardium and in a direct myocardium toxicity of the hypertonic contrast agent and also the allergic reaction for some patients especially with ionic contrast agent.

The main coronary trunks can be considered to lie in one of two orthogonal planes. The anterior descending and the posterior descending coronary arteries lie in the plane of the inter-ventricular septum, and the right and circumflex coronary trunks lie in the plane of the Atrio-Ventricular (AV) valves. In the 60-degree Left Anterior Oblique (LAO) projection, one is looking down the plane of the inter-ventricular septum, with the plane of the AV valves in the 30-degree Right Anterior Oblique (RAO) projection [2].

2. The canny edge detctor

Edge detection is the most common approach for detecting meaningful discontinuities in gray level with the use of masks. Numerous masks have been proposed over the years: Roberts [3] and Perwitt and Sobel [3], Frei and Chen [4], and Canny [5, 6]. A review article by Fram and Deutsch [7] contains numerous masks and an evaluation of their performance. Since then several studies have been done on the issue of mask performance for edge detection [8- 10].

Traditionally, edge detection is implemented by convolving the image data with some form of linear filter usually a filter that approximates a first or second derivative operator. An odd symmetric filter will approxi-

mate a first derivative, and peaks in the convolution output will correspond to edges (luminance discontinuities) in the image. An even symmetric filter will approximate a second derivative operator. Zero-crossings in the output of convolution with an even symmetric filter will correspond to edges; maxima in the output of this operator will correspond to tangent discontinuities, often referred to as *lines*, or *bars*.

In our study, we used the Canny technique [5, 6] to detect the vessel edges. The Canny edge detector is the current standard edge detection scheme widely used around the world. Canny treated edge detection as a signal-processing problem and aimed to design the `optimal' edge detector. He formally specified an objective function to be optimized and used this to design the operator [5].

The objective function has been designed to achieve the following optimization constraints:

• Maximize the signal to noise ratio to give good detection. This favors the marking of true positives.

• Achieve good localization to accurately mark edges.

• Minimize the number of responses to a single edge. This favors the identification of true negatives, that is, non-edges are not marked.

Considering the Gaussian function in one dimension, this may be expressed as:

$$G(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}} , \qquad (1)$$

and the first derivative is:

$$G'(x) = \frac{-x}{\sqrt{2\pi}\sigma^3} e^{-\frac{x^2}{2\sigma^2}} , \qquad (2)$$

and the second derivative is:

$$G''(x) = \frac{-1}{\sqrt{2\pi}\sigma^3} e^{-\frac{x^2}{2\sigma^2}} \left[1 - \frac{x^2}{\sigma^2} \right]. \qquad (3)$$

Now consider an ideal step edge. When convolved with a Gaussian function the profile looks like the leftmost sketch of fig. 2. The
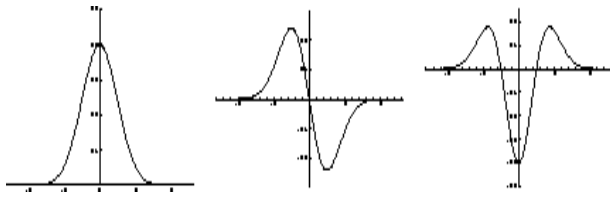
Fig. 1. The Gaussian function, first and second derivatives.
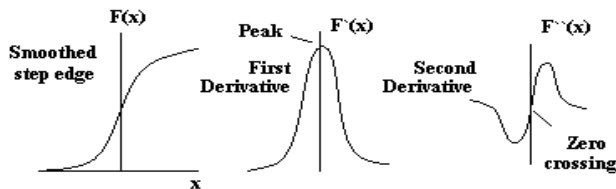

Fig. 2. First and second derivatives for an edge.

next sketches show the first and second derivatives where a peak and a zero crossing respectively mark the presence and location of the edge[6].

In fact, the first derivative of the image function convolved with a Gaussian can be written as,

$$g(x,y) = D\big[G(x,y) * f(x,y)\big], \tag{4}$$

$$g(x,y) = D\big[G(x,y)\big] * f(x,y). \tag{5}$$

Canny edge detection can be done by the following stages [5]:

Stage one - image smoothing: The image data is smoothed by a two dimensional Gaussian function of width specified by a user parameter. In practice, two dimensional convolution with large Gaussians takes a long time, so that in practice it is common to approximate this by two one dimensional Gaussians, one aligned with the x-axis, the other with the y axis. This produces two (rather than one) values at each pixel.

Stage two – differentiation: Assuming two-dimensional convolution at stage1, the smoothed image data is differentiated with respect to the x and y directions. It is possible to compute the gradient of the smooth surface of the convolved image function in any direction from the known gradient in any two directions.

Assuming the one dimensional approximation at stage one, then the values in the x-

smoothed image array are convolved with a first derivative of a one dimensional Gaussian of identical σ aligned with y. Similarly, values in the y-smoothed image array are convolved with a first derivative of a one dimensional Gaussian of identical σ aligned with x.

From the computed x and y gradient values, the magnitude and angle of the slope can be calculated from the hypotenuse and arctangent in a similar manner to the Sobel operator.

Stage three - non-maximum suppression: Having found the rate of intensity change at each point in the image, edges must now be placed at the points of maxima; or rather non-maxima must be suppressed. A local maximum occurs at a peak in the gradient function, or alternatively where the derivative of the gradient function is set to zero. However, in this case the suppression of non-maxima points perpendicular to the edge direction, rather than parallel to (along) the edge direction will be the target, since continuity of edge strength along an extended contour is expected [3].

Rather than perform an explicit differentiation perpendicular to each edge, another approximation is often used. Each pixel in turn forms the center of a nine-pixel neighborhood. By interpolation of the surrounding discrete grid values, the gradient magnitudes are calculated at the neighborhood boundary in both directions perpendicular to the center pixel. If the pixel under consideration is not greater than these two values (i.e. non-maximum), it is suppressed.

Stage four - edge thresholding: The thresholder used in the Canny operator uses a method called "hysteresis" [5]. Most thresholders used a single threshold limit, which means if the edge values fluctuate above and below this value the line will appear broken (commonly referred to as ``streaking''). Hysteresis counters streaking by setting an upper and lower edge value limit. Considering a line segment, if a value lies above the upper threshold limit it is immediately accepted. If the value lies below the low threshold it is immediately rejected. Points that lie between the two limits are accepted if they are connected to pixels that exhibit strong response. The likelihood of streaking is reduced drasti-

cally since the line segment points must fluctuate above the upper limit and below the lower limit for streaking to occur. Canny recommends the ratio of high to low limit be in the range 2:1 or 3:1, based on predicted signal-to-noise ratios. Canny edge detection method was used in our model to detect the edges of the coronary vessels due to its high degree of edge definition and low streaking effects. Fig. 3 shows the edge detection of coronary arteries.

3. Road mapping model

3.1. Conventional road mapping

The angiographer in PTCA operations have to navigate with the guide wire and catheter through the coronary tree inside the patient heart until he reaches the lesion that he wants to target in order to insert a balloon or a stent for angioplasty. Since the vessels in the X-ray images cannot appear without dye injection inside it, the angiographer has to inject repeated injections to view the way of the catheter that he routes.
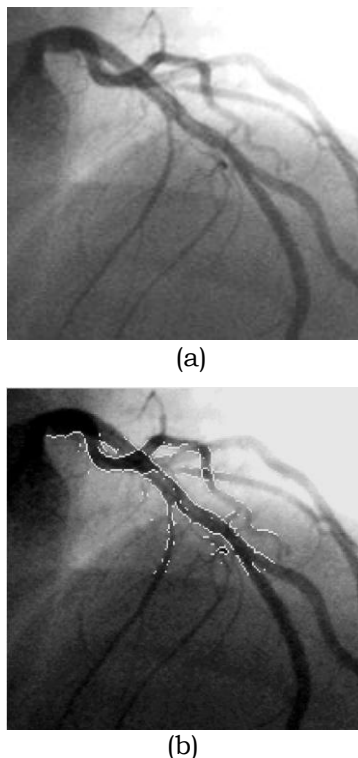

(a)

(b)

Fig. 3. A coronary map image with canny edge detected vessels (a) original image, (b) image with edge detection.

The dye injected acts as the light that guides the angiographer to view his road. Once the dye is injected the road map begins to be clear and the angiographer moves his set. The main problem is that the dye effect cannot last for a long time since the dye fades quickly after the start of injection. Vessels filled with dye more than a few seconds can lead to asystole or cardiac arrest since the dye replaces the blood inside the vessels.

When the guide wire reaches the area of interest, a view with injected dye should be recorded on the memory of the cath lab machine as a still image. This road map image is displayed on a second monitor called roadmap monitor. This road map image will be the guide for the angiographer in order to insert his guide wire exactly inside the diseased vessel where he views the online insertion of the guide wire on the main screen while viewing the road map on the road map monitor.

This conventional technique has the following disadvantages:
1. A lot of dye injections to view the road map.
2. Difficult navigation.
3. The angiographer has to view two monitors.
4. Time Consuming procedure.

3.2. Online road mapping model

In this system a medical grade frame grabber PCI card is used(Imagraph I-series from Forsight imaging) to record the image sequences from the cath lab machine.

With 512x512 image size and 25 frame/sec. The image sequences or cine loops are grabbed from the video signal supplied to the main monitor to a P4 1.6 GHz 512 RAM Compaq EVO.

The cath lab machine used to grab the cine loops is a Toshiba Infinix CX machine. The studies are recorded online with the X-ray exposure by using a TTL trigger to control the beginning and the end of the cine loop recording.

An ECG module (Mindray Ltd.) is used to monitor the ECG for the patient linked with the road map system. Heart motion during recording affects the cine loops behavior where the vessels move along with the heart contraction in a cyclic motion repeated every cardiac cycle. The system begins with recording the

cine loop when receiving the cine trigger from the cath lab at t_{dn} at the moment the angiographer approach the area of interest with the guide wire.

The right image in fig. 4 shows the complete filling of the coronaries with the dye where a stenotic lesion appears in the middle that has to be cured by inserting a stent inside this lesion to clear this stenosis and represents the conventional road map image that should be viewed on the road map monitor to be a guide for the angiographer to insert the stent inside the lesion.

The system begins to draw road map edge detected views for all the frames starting from the first complete dye filled frame i_{d0} till at least a complete cardiac cycle keeping that the last frame i_{dn} should be also completely filled. The detection is done as stated before by using Canny edge detector with low threshold of 0.012 and high threshold of 0.12 and $\sigma = 1$ for the smoothing Gaussian filter.

n is the number of complete dye filled frames,

t_{d0} is the time of first dye filled recorded frame,

t_{dn} is the time of last dye filled recorded frame, and

T is the cardiac cycle time.

Once the detected frames (roadmap) that have been calculated in m cardiac cycles, we begin to display this road map in a light white color superimposed over the main monitor of the cath machine with the ability to fade the road map color to allow a clearer view for the original diseased coronaries.

The main problem is how to synchronize the display of the detected road map with the online fluoroscopy screening. This is done with the aid of the ECG synchronization where the road map is super imposed at $t_{road = mT + t_{d0}}$ t_0 where m is determined according to system speed and performance. In this model m=2 is used which means that the system begins displaying the roadmap after two cardiac cycles which is enough for the system to calculate the roadmap.

The system uses another kind of trigger called injection trigger that tells the system the start time of injection t_{i0} which is exactly before the complete filling. Complete filling comes after approximately $T/3$ where:
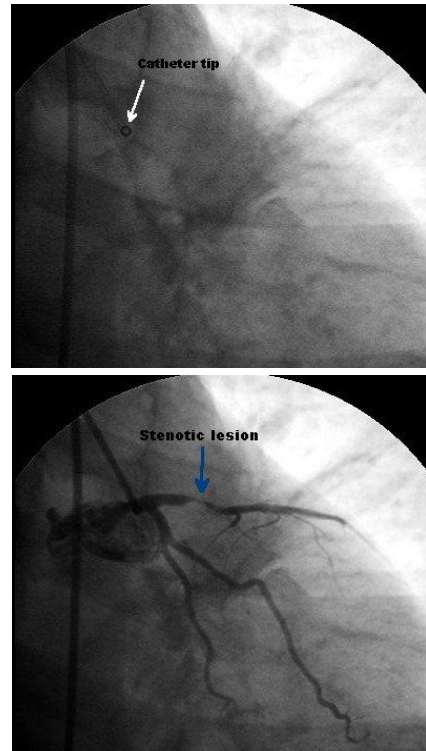

Fig. 4. The beginning of the recording at the start of injection (the catheter tip is clear) and the complete filling of coronaries with the dye.

$$t_{do} = t_{io} + \frac{T}{3}.$$

(6)

Time between t_{dn} and t_{road} is called processing time that is the time that the computer has to finish the processing to begin displaying the road map.

3.3. Condition for accurate road mapping

What makes the cardiac cath very difficult for road mapping is the complex three-dimensional deformation that occurs during the heart contraction and relaxation. In peripheral cath (Neuro-angiography or leg angiography) injected vessels are almost static and there is no motion or contractions. This makes the road mapping done by DSA (Digital subtraction angiography) where the coming frames after injection are displayed subtracted. This subtracted views let the vessels the only thing to appear in the image sequences [11].

The following should be done for more accurate road mapping:

1. Patient physical motion, coughing and up normal breathing must be avoided because it deforms the coronary views in a random way so that the detected views couldn't affected by this noise.

2. Breath hold could help a lot in obtaining an accurate road map sequence since the heart motion will be limited.

3. Dye injections should be sufficient and with enough pressure to completely fill the coronaries in a short time.

X-ray dose in the cath lab machine should be adjusted to obtain high contrast and high SNR to get an accurate edge detected sequences.

4. Results and discussion

The study has been done on a male patient in Alexandria University with total occlusion LAD 99% stenosis and having severe chest pain. A balloon and a stent have been used to open this occlusion.

A total of 113 frames have been recorded. It takes about 21 frames for the dye to fill the coronaries completely and 37 frames were already filled completely.

At frame number 83, the dye begins to fade out till frame number 113 where the dye completely disappears.
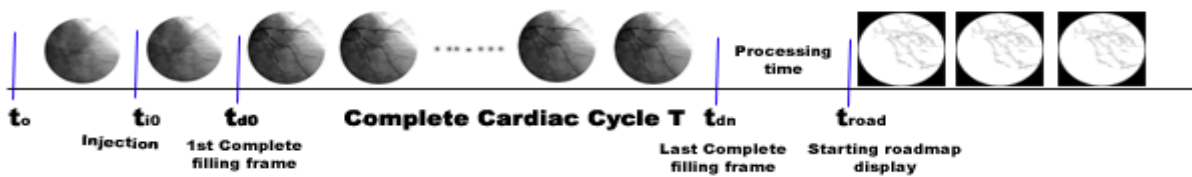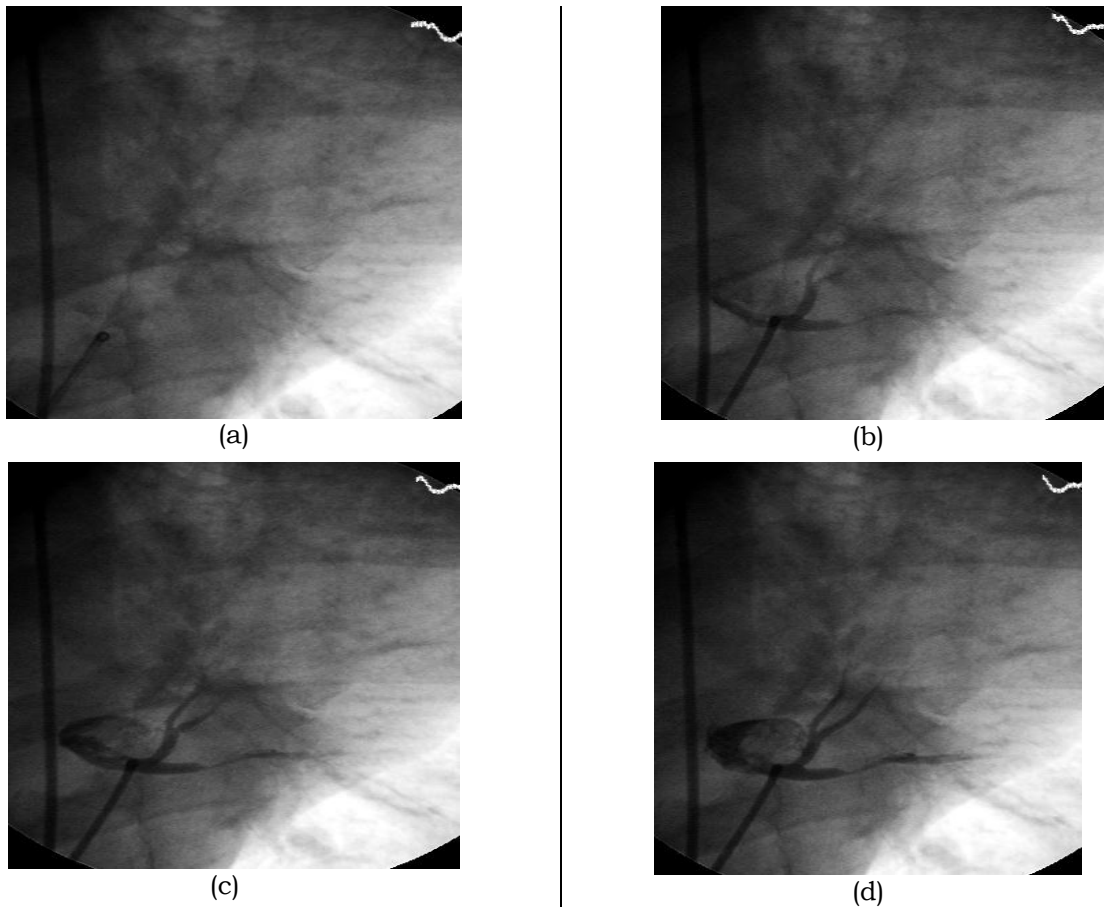

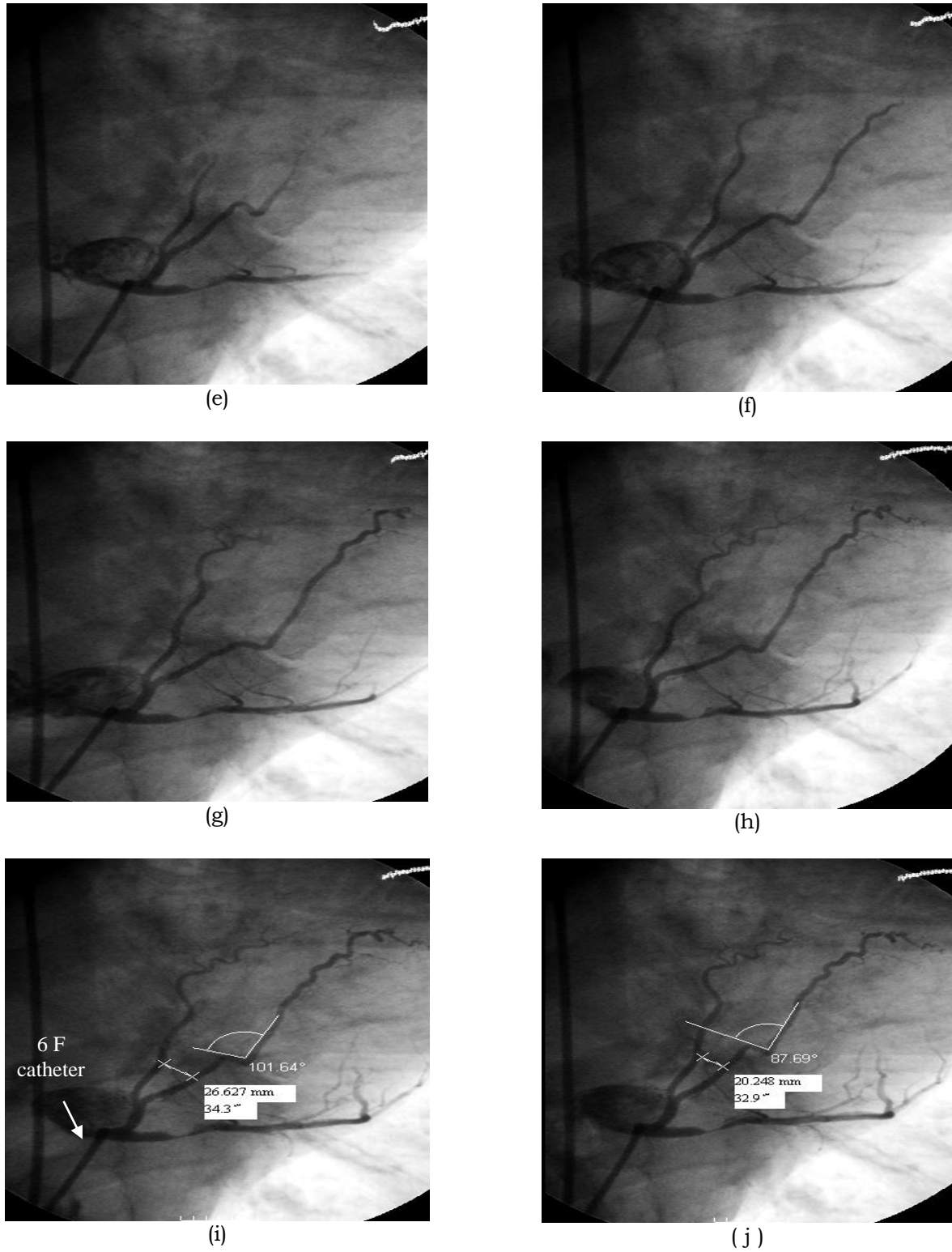Fig. 5. The timing diagram for the road mapping method.

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

6 F
catheter

101.64°

26.627 mm
34.3⁚

(i)

87.69°

20.248 mm
32.9⁚

(j)

Fig. 6. The angiogram sequence used in the model.

Timing variable for the model was as follows:

$T_{road}= 2T + t_{d0}$ = 2.9 Sec, t_{d0} = 1.26Sec t_{dn} = 2.32 Sec, T=0.82 Sec (Average Heart rate= 73 pulse/min).

28 frames which form a complete synchronized cardiac cycle with completely filled dye were used to calculate the roadmap sequence by Canny method as stated before.

A number of ten frames shown in fig. 6 to show different situations of the injected dye from the start of injection as in (a) and (b) till the complete filling in (g) through (j).

The last four frames show the deformations that occur in the coronary tree due to heart contraction and relaxation.

Fig. 6-i, 6-j show the deformations where the angle of a kinky point in the LAD changed from 87 deg to 101 deg and the distance from a fixed point between the LAD and CX arteries changed from 20.2 mm to 26.6 mm.

All the measurements done were calibrated by using the length of the catheter that have the length of 6 French (2 mm) and was used as a reference to all the measurements.

The road map calculated will be displayed at:

$$T_{road}= 2T + t_{d0} = 2.9 \text{ Sec}$$

5. Conclusions

In this paper a model for dynamic road mapping was described, the model draws virtual walls for the coronary arteries being catheterized where the angiographer has to navigate with the guide wire inside the boundaries of these walls. These walls mark the edges of the boundaries of the vessels. This model is very useful since it shortens the cath operation and reduces X-ray dose and dye injections.

The system also reduces guide wire collisions with the artery wall and dissections that may be caused by these collisions.

References

[1] A. Guyton, M.D., "Textbook of Medical Physiology", Chapter 25, W.B. SAUNDERS, (1980).

[2] W. Grossman, M.D., "Cardiac Catheterization and Angiography", LEA&FEBIGER Philadelphia (1986).

[3] R.C. Gonzalez and R.E. Woods. Digital Image Processing. Prentice-Hall Publishing Company (2002).

[4] W. Frei, and C. Chen, "Fast Boundary Detection: A Generalization and a New Algorithm", IEEE Trans. Computers, Vol. C-26 (10), pp. 988-998 (1977).

[5] J. Canny, "A Computational Approach to Edge Detection", IEEE Trans. on Pattern Analysis and Machine Intelligence, Vol. 8 (6), pp. 679- 698 (1986).

[6] J.F. Canny, 'Finding edges and lines in images' Master's thesis, MIT. AI Lab. TR-720, (1983).

[7] J. Fram, and E. Deutsch, "On the Quantitative Evaluation of Edge Detection Schemes and Their Comparison with Human Performance", IEEE Trans. Computers., Vol. C-24 (6), pp. 616-628 (1975).

[8] R. Qian, and T. Huang "Optimal Edge Detection in Two-Dimensional Images", IEEE Trans. Image Processing, Vol. 5 (7), pp. 1215-1220 (1996).

[9] Z. Wang, K. Rao, and J. Ben-Arie, "Optimal Ramp Edge Detection Using Expansion Matching", IEEE Trans. Pattern Analysis and Machine Intelligence, Vol. 18 (11), pp. 1586-1592 (1996).

[10] S. Ando, "Consistent Gradient Operators", IEEE Trans. Pattern Analysis and Machine Intelligence, Vol. 22 (3), pp. 252-265 (2000).

[11] S. Malassiotis, "Tracking LV in Echocardiographic Images by Learning Heart Dynamics", IEEE Trans. On Medical Imaging Vol. 18 (3) (1999).