X-ray tube and wireless detector alignment using Ultra-wideband and Inertial Motion Unit sensor

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***Abstract*—In advanced mobile X-ray machines also referred to as 'radiology room on wheels', the traditional cassettes have been replaced by modern wireless detectors.These detectors are randomly placed behind the patients. The misaligned placement of detector w.r.t X-ray tube can cause reshoots due to missing anatomies. Considering ALARA, this paper provides a novel method of alignment technique by combining the incoming real-time data from the Ultrawideband sensor and Inertial Motion Unit sensor to calculate a very accurate position of the detector using tri-alteration algorithm and orientation w.r.t X-ray tube. It will reduce the time required for the X-ray tube repositioning and realignment, resulting in smooth user experience. The alignment is done by referring to the GUI provided and the coordinates can be read from LCD continuously.**

***Index Terms*—Ultrawide band, Inertial Motion Unit sensor, Trialteration, Indoor positioning system,NLOS, X-ray machine**

I. Introduction

With a rise in aging population as well as obesity rates in today's world calls for the need for bedside monitoring. This also increases the demand in better bedside imaging. Mobile X-ray are designed to be just such a solution – specifically for use when it is not safe or practical to move a patient from his or her bed to the radiology department. Emergency Departments have augmented their mobile X-ray use by 100 percent in some instances, and Intensive Care Units and Operation Rooms report up to 89 percent and 60 percent respectively. With time to meet specialized radiographic needs of patients there has been development like wireless technology in detector.

Technologists no longer have to watch out for the various cords that once tethered from detectors to the X-ray machine or have to take cassettes to be developed in a dark room and then wait for them to be read by a radiologist. Wireless, portable battery operated detectors claim to provide high quality image at lower dosage. These detectors are placed behind the patient and are not visible to the technician as the patient is lying over it while exposures are being taken. The technologist approximately positions the X-ray tube head over the patient quite unsure whether the emitted X-ray will fall on the region of interest or not. The final X-ray images may have some anatomies cut off or some images might be very blurred due to scattering due to low energy radiations. In such cases, retakes are taken because of poor radiographic quality of images. 80 percent of the retakes that happen in procedure are due to misalignment of the detector and X-ray tube. These retakes not only increase the exposure of patient to X-rays but also affect the radiology workflow.

The no. of retakes can be reduced by determining the exact real time location and orientation of the detector plate. Real Time Location Systems (RTLS) is a class of system that provides information in real time about the location of objects .Indoor positioning systems (IPS) [1]are used to locate the objects inside buildings and closed areas where there is high chance of attenuation from surroundings. Most recent advancement in the IPS is Ultra wideband which has a very high position accuracy.[12] UWB is a RF signal having huge frequency band of 3.1 to 10.6 Ghz. UWB can be used for positioning by utilizing the time of arrival (TOA) of the RF signals to obtain the distance between the reference point and the target. The signal generated by UWB antenna is high amplitude instantaneous burst signal of few angstrom second which is suitable for the localization and detection in the medical applications.

The CARESTREAM Tube and Grid Alignment System proposed the use of spinning permanent magnet transmitters and receivers installed around detector grid holder. The receiver senses intensity of spinning magnetic field and phase to generate unique sine waves which helped in determining the X-ray source position.see [2]

Gauntt, D.M. and Barnes, G.T., [3] proposed a method that include an optical target arm attached to the grid tunnel, a video camera attached to the collimator and motion control system to position the X-ray focal spot to the center of the grid focal axis.

Kuhn, M. and et al., [4][5]proposed real-time UWB positioning system having dynamic 3-D accuracy of better than 6 mm and static 3-D accuracy of 3-4 mm allows various new applications for indoor wireless positioning like robot tracking, patient monitoring, and tracking during computer assisted surgeries.

Schwarz, V. and et al,[6] studied the effect of disturbances like human torso or hand blocking antenna placed in between the line of sight path between the located tag and the receiving sensors on the accuracy of the tracking system.

Yao, L. and et al, [7] proposed fusion of an Ultra-Wideband (UWB) sensor-based positioning solution with an Inertial Measurement Unit (IMU) sensor-based positioning solution to obtain an increased accuracy for tracking.

II. METHOD

In mobile X-ray machines, the wireless detector is not physically connected to X-ray machine. Once the detector is placed behind the patient, it is very difficult to exactly know its location and align the X-ray tube head over detector to get good radiographic image. To determine the location, UWB sensors configured as anchors are placed at various positions on the X-ray tube head. UWB sensors configured as tags are placed on the detector.UWB sensors are fused with IMU(Inertial Measurement Unit) sensor which will help in alignment of the detector. The readings from IMU mounted on both tube and detector is compared until and the X-ray tube is rotated or moved such that the X-ray tube becomes parallel to the detector plate. Once the parallel orientation is obtained, i.e the Z axis is fixed, the tube is moved in manner in left-right, forward-backward directions while checking for the display such that the alignment is obtained , i.e the X-ray tube is directly over the detector . Once accurate positioning of the X-ray tube is done, exposure will be taken. It will not only decrease the dosage of X-ray to patient as the entire process is being reduced to one shot X-ray. This will provide a hassle free radiology workflow.

A. Flow Digram

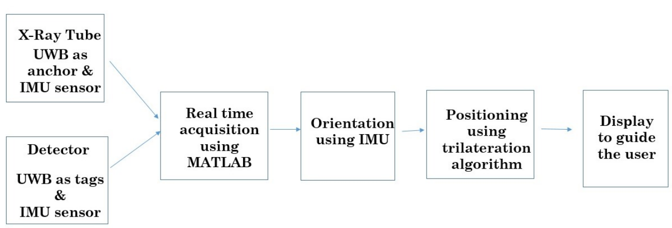

Fig. 1. Flow Diagram

B. Components

1) Ultrawideband Sensor: The operating range of decawave UWB sensor is 3.5 GHz – 10 GHz The ranging distance and accuracy is 100 m indoors and +/- 5-10 mm respectively whereas our application requires a distance of 0.70 m to 1.50 m and +/- 50 mm. Hence UWB sensor serve the purpose. As the sensor supports USB communication, they can be directly connected to the system like plug and play. It has a 500 mAh li-poly 3.7V battery (rechargeable) with standard JST connector which is swappable.see [8]Thus, the sensor are portable and can be easily installed on the X-ray tube and detector plate as anchors and tags.Also,UWB sensor can work in Non Line Of Sight(NLOS) wherein the tag and anchor cant see each other.[11]

2) Inertial Motion Sensor: The BNO055 has a triaxial 14-bit accelerometer, a triaxial 16-bit gyroscope with a range of +/- 2000 degrees per second, a triaxial geomagnetic sensor and a 32-bit cortex M0+ microcontroller running Bosch Sensortec sensor fusion software, in a single package. It has wake-on-motion interrupt for low power operation as the operating range is between 1.71 V to 3.45 V. [9]It provides high orientation accuracy of +/-0.06 deg which makes it precise for alignment.

C. Methodology

1) Orientation: The data from sensor is obtained in the form of quarternions q_1 = $cos(a/2)$, $q2$ = $sin(a/2)cosb_x$, q_3 = $sin(a/2)cosb_y$ and q_4 = $sin(a/2)cosb_z$ where a is angle of rotation and $cosb_{x,y,z}$ are direction cosines. A quaternion is a four-element vector that can be used to encode any rotation in a 3D coordinate system which composes of one real element and three complex elements. It is converted to Euler angles which describe the orientation of a rigid body in 3-dimensional Euclidean space. where α, β and γ are euler

$$\begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} arctan\frac{2(q_0q_1+q_2q_3)}{1-2(q_1^2+q_2^2)} \\ arcsin(2(q_0q_2-q_3q_1)) \\ arctan\frac{2(q_0q_3+q_2q_1)}{1-2(q_2^2+q_3^2)} \end{bmatrix}$$

angles describing rotation along x,y and z axis. There are 12 possible conventions regarding the Euler angles in use like zyx, xyz etc in which we will be using zyx convention. This euler angles are obtained in radian and are converted to degrees. The angles are calculated from both the tag as well as anchor. The angle of inclination of detector which acts as reference. The X-ray tube is adjusted to match the inclination of detector.see [10]

2) Trialteration: Trialteration uses the geometric properties of triangles to estimate the target location. It has two derivations:- lateration and angulation. Lateration estimates the position of an object by measuring its distances from multiple reference points. So, it is also called range measurement techniques. The data tha
t is obtained from the sensors is actually the ranging data i.e the distance between the each tag and anchor on the detector and X-ray tube head respectively. The UWB antenna transmit a RF wave signal from the anchor and wait for the signal to receive again. This is the known as the time of arrival (T). For each different location of the anchor and tag, there will be slightly different time of arrival. This distance is given as **d = cT/2**.
where d = ranging distance and c = 299792458 m/s which is speed of light. Once, the distance of each anchor tag pair is known, then the position of the target can also be computed by minimizing the sum of squares of a nonlinear cost function, i.e., least-squares algorithm. They are calculated by the matrix method and least square algorithm is applied to minimize the error of estimation as the estimated values may vary depending on the change in the length of ranging distance. The distance between tag and anchor can be found out using
The distance between tag and anchor can be found out using

$$d_i = \sqrt{(a_i-a)^2+(b_i-b)^2} \tag{1}$$

for i=1,2,..n ; where n= no. of anchors used in the system i.e 3 in our case which will be mounted on the X-ray tube and and b are the co-ordinates of tag mounted on the detector whose are ti be estimated or

$$d_i^2 = (a_i - a)^2 + (b_i - b)^2 \tag{2}$$

or

$$d_i^2 = a_i^2 + a^2 - 2a_i a + b_i^2 + b^2 - 2b_i b \tag{3}$$

Equation 3 is the non-linear terms a^2 and b^2 . Eliminating the non linear terms from the equation using the least square method such that equation is in terms of linear variables x and y only.

$$d_i^2 - d_n^2 = a_i^2 - a_n^2 + b_i^2 - b_n^2 - 2a(a_i - a_n) - 2b(b_i - b_n) \tag{4}$$

It can be expressed in matrix form as

$$P = A \begin{bmatrix} a \\ b \end{bmatrix}$$

$$with\ P = \begin{bmatrix} d_1^2 - a_1^2 - b_1^2 - d_n^2 + a_n^2 + b_n^2 \\ d_2^2 - a_2^2 - b_2^2 - d_n^2 + a_n^2 + b_n^2 \\ \vdots \\ d_{n-1}^2 - a_{n-1}^2 - b_{n-1}^2 - d_n^2 + a_n^2 + b_n^2 \end{bmatrix}$$

$$and\ A = -2 \begin{bmatrix} a_1 - a_n & b_1 - b_n \\ a_2 - a_n & b_2 - b_n \\ \vdots & \vdots \\ a_{n-1} - a_n & b_{n-1} - b_n \end{bmatrix}$$

Using this mathematical analysis, the co-ordinates a and b are found out co-ordinates = $A^{-1}.P$ which is the position of detector w.r.t X-ray tube.

D. Display

The display will be on a LCD screen which is connected via Arduino Uno. The developed GUI for MATLAB will show that the orientation is achieved as “tube detector alignment” and the coordinates of X-ray tube w.r.t to detector on LCD screen.

Fig. 2. Display

III. Experimental Setup

Image Courtesy: Philips HIC,India

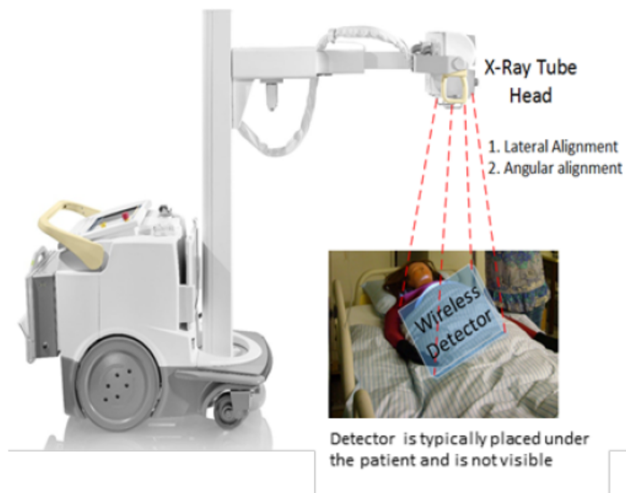

Fig. 3. Experimental Setup

IV. Experimental Procedure

- The sensors are mounted on pre-located areas on X-ray tube and detector. i.e on the edges of tube and mid of detector edges.
- The detector is placed behind patient such that the technologist cant locate the detector.
- The main anchor labeled A1 is connected to the system via a mini USB cable and the code for serial communication is executed.This will provide information about the angle of orientation of detector , X-ray tube and the ranging distances between them.
- Each data string will be stored in separate variables for quarternion for orientation, ranging distances for positioning.
- The data will be continuously processed to calculate the orientation and location of the X-ray tube w.r.t to detector.
- Move the X-ray tube until the GUI displays that the orientation is achieved. Once the orientation is achieved, move the X-ray tube until the tags and anchors communicate to determine the location of detector and indicates that the plate are aligned when both tag and detector results are as shown below.
- The GUI will guide the user to move in left , right back front direction.

V. Results And Discussion

As seen in Figure 4, the X-ray tube and detector were aligned earlier in line of sight operation. Once the detector was placed behind the patient, the alignment was lost.Hence the computation of orientation and positioning was applied to realign the X-ray tube. The results were validated by finding the accuracy of the experiment.The X-ray machine has a light source which determines the actual area wherein the X-ray will fall. After determining the location of detector, the area of detector was mapped which is the measured area. Both the areas were compared on plot and the difference between the readings were found.This showed an error of 8.8 percent. The results were tested on phantoms of various widths considering patients of various tissue thickness. The accuracy of UWB sensor reading is affected by the presence of human body or metal bed, the deviation being 7.8 cm and 4.5 cm respectively as from experimental results. The time required to adjust the X-ray tube with detector has highly decreased from 5 mins to less than 2.5 minutes. Thus, this implementation will help to improve radiology workflow making it more streamlined.

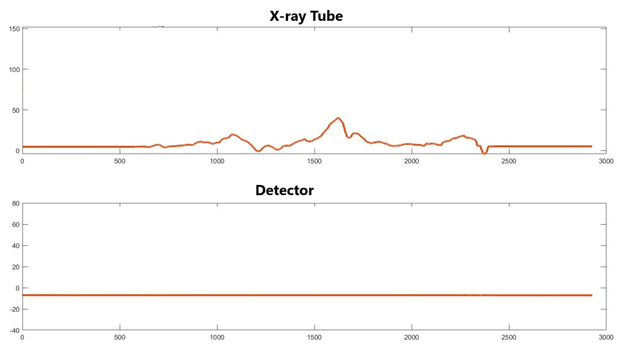

Fig. 4. Result

VI. Conclusion

The alignment between detector and X-ray tube can be obtained with help of IMU and UWB sensor. Currently the movement of X-ray tube after determining in which direction to move is done manually. Further work can be done to control the X-ray tube movement using motors and controller. The accuracy of sensor can also be improved by other means like TDOA(time difference of arrival) or applying digital filter while collecting ranging data.

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