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

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Mobile X-ray

- Need for bedside monitoring due to rise in aging population and obesity
- Mobile X-ray machines used in ICU's and OT
- Advanced technology like portable detector more efficient than former wired cassette
- Wireless battery operated detectors which reduced hassle in operation arena

Figure: Mobile X-ray

- Time for X-ray film development reduced drastically
- The wireless detector placed behind patient
- Detector in non line of sight from technician
- X-ray tube guided randomly and exposure taken
- Poor radiographic image due to scatter radiation or missing anatomies
- Increasing no. of exposures increases radiation dose. ALARA voilated

- To design a technology for alignment of digital detector with X-ray tube using Ultra-wide band Sensor and Inertial Motion Sensor.

Real Time Tracking

- Real Time Location Systems (RTLS) is a class of system that provides information in real time about the location of objects
- It helps to determine the absolute position of tag (object to be tracked) from anchor (source)
- ***Protocol***
  - T1 : The time instant at which anchor transmits a message to the tag
  - T2:The time instant at which anchor receives the reply from tag after the tag received transmitted message
  - Time difference Tr = T2 – T1 The anchor then calculates the distance 'd' between anchor and tag
    d = cTr/2, where c is the speed of light.

By calculating the distance d from a number of anchors, it is possible to detect accurate location of tag
B - Unknown position of tag
P1,P2,P3 - Position of anchors

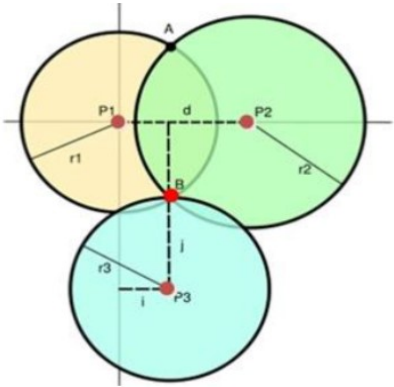


Figure: multialteration

The distance between tag and anchor can be found out using

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2} \tag{1}$$

for i=1,2,..n ; where n= no. of anchors used in the system. or

$$d_i^2 = (x_i - x)^2 + (y_i - y)^2 \tag{2}$$

or

$$d_i^2 = x_i^2 + x^2 - 2x_i x + y_i^2 + y^2 - 2y_i y \tag{3}$$

Equation 3 is the non-linear terms x^2 and y^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.

$$d_i^2 - d_n^2 = x_i^2 - x_n^2 + y_i^2 - y_n^2 - 2x(x_i - x_n) - 2y(y_i - y_n) \tag{4}$$

It can be expressed in matrix form as

$$b = A \begin{bmatrix} x \\ y \end{bmatrix}$$

$$with\ b = \begin{bmatrix} d_1^2 - x_1^2 - y_1^2 - d_n^2 + x_n^2 + y_n^2 \\ d_2^2 - x_2^2 - y_2^2 - d_n^2 + x_n^2 + y_n^2 \\ \vdots \\ d_{n-1}^2 - x_{n-1}^2 - y_{n-1}^2 - d_n^2 + x_n^2 + y_n^2 \end{bmatrix}$$

$$and\ A = -2 \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ \vdots & \vdots \\ x_{n-1} - x_n & y_{n-1} - y_n \end{bmatrix}$$

– The co-ordinates **x** and **y** are found out co-ordinates by $A^{-1}. * b$

Orientation

Quarternion values obtained from sensor will be changed to euler values using

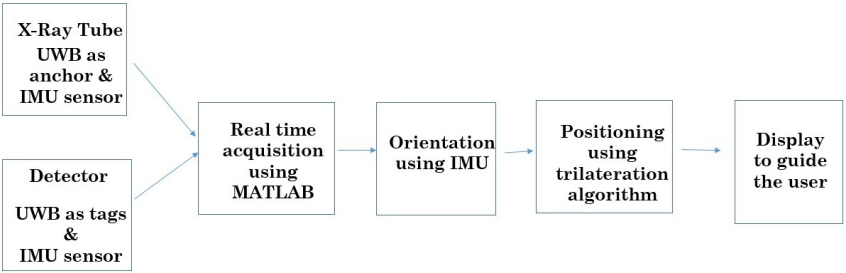
$$\begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} arctan\frac{2(q_0q_1+q_2q_3)}{1-2(q_1^2+q_2^2)} \\ arcsin(2(q_0q_2-q_3q_1)) \\ arctan\frac{2(q_0q_3+q_2q_1)}{1-2(q_2^2+q_3^2)} \end{bmatrix}$$

where α, β and γ are euler angles

	Bluetooth	**Infrared**	**Ultrasonic**	**Ultra-wide Band**
Ranging technology	Received Signal Strength	Proximity	Time of Arrival	Time of Arrival
Operating Range	10 m	100 m	5 m	100 m
Advantages	Does not require LOS	Sensitive for indoor positioning	No interference with EM waves	- No LOS required, - Sensitive to indoor positioning, - no radio frequency interference
Disadvantages	Radio frequency interference	Affected by external light source	Affected by reflected signal	High cost, susceptible to metal interference

- Ultra-wide band have operating frequency range of 3.1-10.6 Ghz.
- High penetrability , ie can pass through human body
- Ranging accuracy is 100 m indoors and +/- 5-10 mm respectively whereas application requires a distance of 0.70 m to 1.50 m and +/- 50 mm.
- Sensor supports serial communication
- UWB sensor can work in Non Line Of Sight(NLOS) wherein the tag and anchor cant see each other.

- BNO055 Bosch Sensortec from tri-axial 14- bit accelerometer, a tri-axial 16-bit gyroscope with a range of +/- 2000 degrees per second, a tri-axial geomagnetic sensor
- The operating voltage is between 1.71 V to 3.45 V
- High orientation accuracy of +/-0.06 deg



- 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

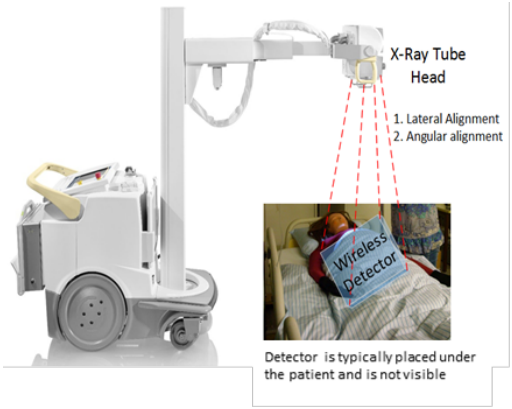


Figure: Detector Misalignment

- 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.

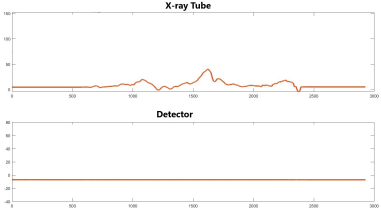


Figure: X-ray tube Detector alignment

Figure: Display

- The X-ray tube and detector lost alignment once it was placed behind patient at t = 700ms
- Position and orientation algorithm were applied to determine location
- Area from X-ray Light source (actual) and Area from detector was estimated (measured).
- Error calculated by the (Measured - Actual) / Actual = 8.8 %

* 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.
* Work can be further extended to determine the instant of exposure using UWB radar pulse and X-ray can be taken only when lungs are in expanded state.

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