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Research Paper

FETAL TELE-ECHOGRAPHY USING ROBOTIC ARM AND SATELLITE LINK

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This paper presents a new tele-operated robotic chain for real-time ultrasound image acquisition and medical diagnosis. This system has been developed in the frame of the Mobile Tele-Echography Using a Twisting Revolute Revolute (TRR) Robot. A light-weight six degrees-of-freedom portable robot has been specially designed for this application.

Keywords: Fetal, Tele-echography, Telemedicine, Satellite

INTRODUCTION

Telemedicine has the potential to become a powerful tool, especially in developing countries or areas with reduced medical facilities. In some African regions, for example, more than 75% of the population may be at more than a day's travel from the nearest hospital. Even in high socioeconomic countries, small medical centers do not necessarily have sonographers available 24 hour a day for initial diagnostic imaging in emergency cases. One of the major advantages of ultrasound imaging in medicine is the possibility to evaluate the degree of emergency of a patient's condition quickly and noninvasively. In a pregnant woman, even a basic fetal examination can provide valuable information. In areas with reduced medical facilities, well-trained sonographers are not available and transferring the patient to a center with good facilities may be problematic or expensive.

OBJECTIVE

- To design a robot for fetal ultrasound examination on pregnant women in isolated sites at a low cost in India.
- To carry out the modeling of the prototype using PRO-E software.
- To carry out kinematic analysis.

Concept of Tele-Echography: The TER system is a robot based Tele-echographic system that allows remote ultrasound examination. At the expert site, the expert moves the mock of the US probe and the robot

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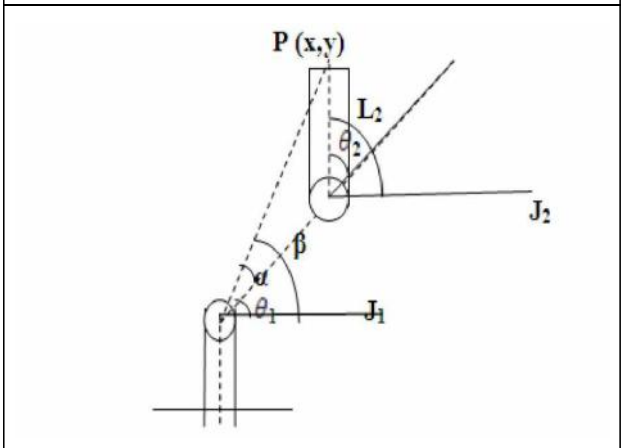
reproduces the movements of the probe which gives us back the ultrasound images and force feedback. Tele-echography is the powerful tool for conducting ultrasound examination in small health centers from isolated sites.

DESIGN CONSIDERATIONS

- Jointed arm configuration robot in x, y, z, plane relevant to human hand is selected (TRR).
- Portable and fixed robot with the the movement of 360 degrees is considered.
- For the parabolic path, the elevation of the robotic arm is considered maximum up to 60 degrees.
- To obtain a parabolic path, the movement of the probe is considered maximum up to 180 degrees.
- Length of the robotic arm is considered greater than the length of the probe (L2 > L3).
- Position of the patient is considered in the work volume of the portable fixed robot.

To obtain a desired parabolic path following kinematic calculations are carried out:

Figure 1: 2 Dimensional Robots



Forward Kinematics

For joint J1, Resolve into vector component in *x* and *y* direction

$R1 = (L_1 \cos\theta_1, L_1 \sin\theta_1)$

For Joint J_2

$R2 = L_2 \cos(\theta_1 - \theta_2, L_2 \sin(\theta_1 + \theta_2)$

$X = L_1 \cos\theta_1 + L_2 \cos(\theta_1 - \theta_2)$ --------------1

$Y = L_1 \sin\theta_1 + L_2 \sin(\theta_1 + \theta_2)$ --------------2

Inverse kinematics

$\cos(A - B) = \cos A \cos B - \sin A \sin B$

$\sin(A + B) = \sin A \cos B + \cos A \sin B$

Substituting value of $\cos(A - B)$ and $\sin(A - B)$ in equation 1 and 2

$X = L_1 \cos\theta_1 - L_2(\cos\theta_1 \cos\theta_2 - \sin\theta_1 \sin\theta_2)$ --------------3

$Y = L_1 \sin\theta_1 + L_2(\sin\theta_1 \cos\theta_2 + \cos\theta_2 \sin\theta_2)$ --------------4

Squaring both side of equation 3 and 4

$x^2 = [L_1 \cos\theta_1 + L_2 \cos(\theta_1 + \theta_2)]^2$

$= L_1^2 \cos^2\theta_1 + 2 L_1 \cos\theta_1 L_2 \cos(\theta_1 + \theta_2) + (L_2 \cos(\theta_1 + \theta_2))^2$

$= L_1^2 \cos^2\theta_1 + 2 L_1 \cos\theta_1 L_2 (\cos\theta_1 \cos\theta_2 - \sin\theta_1 \sin\theta_2) + L_2^2(\cos\theta_1 \cos\theta_2 - \sin\theta_1 \sin\theta_2)^2$

$= L_1^2 \cos^2\theta_1 + 2 L_1 \cos\theta_1 L_2 \cos\theta_1 \cos\theta_2 - 2 L_1 \cos\theta_1 L_2 \sin\theta_1 \sin\theta_2 + L_2^2(\cos^2\theta_1 \cos^2\theta_2 - 2 \cos\theta_1 \cos\theta_2 \sin\theta_1 \sin\theta_2 + \sin^2\theta_1 \sin^2\theta_2)$

$= L_1^2 \cos^2\theta_1 + 2 L_1 L_2 \cos^2\theta_1 \cos\theta_2 - 2 L_1 L_2 \cos\theta_1 \sin\theta_2 \sin\theta_1 + L_2^2 \cos^2\theta_1 \cos^2\theta_2 - 2 L_2^2 \cos\theta_1 \cos\theta_2 \sin\theta_1 \sin\theta_2 + L_2^2 \sin^2\theta_1 \sin^2\theta_2$

$y^2 = [L_1 \sin\theta_1 - L_2 \sin(\theta_1 + \theta_2)]^2$

$= L_1^2 \sin^2\theta_1 + 2 L_1 \sin\theta_1 L_2 \sin(\theta_1 + \theta_2) + (L_2 \cos(\theta_1 + \theta_2))^2$

$= L_1^2 \sin^2\theta_1 + 2 L_1 \sin\theta_1 L_2 (\sin\theta_1 \cos\theta_2 + \cos\theta_1 \sin\theta_2) + [L_2^2(\cos\theta_1 \cos\theta_2 - \sin\theta_1 \sin\theta_2)]^2$

$= L_1^2 \sin^2\theta_1 + 2 L_1 \sin\theta_1 L_2 \sin\theta_1 \cos\theta_2 - 2 L_1 L_1 \sin\theta_1 \cos\theta_1 \sin\theta_2 + L_2^2(\sin^2\theta_1 \cos^2\theta_2 + 2 \sin\theta_1 \cos\theta_2 \cos\theta_1 \sin\theta_2 + \cos^2\theta_1 \sin^2\theta_2)$

$= L_1^2 \sin^2\theta_1 - 2 L_1 L_2 \sin^2\theta_1 \cos\theta_2 - 2 L_1 L_2 \sin^2\theta_1 \cos\theta_1 + L_2^2 \sin^2\theta_1 \cos^2\theta_2 + 2 L_2^2 \sin\theta_1 \cos\theta_2 \cos\theta_1 \sin\theta_2 + L_2^2 \cos^2\theta_1 \sin^2\theta_2$

Now Adding:

$x^2 + y^2 = L_1^2 \cos^2\theta_1 + 2 L_1 L_2 \cos^2\theta_1 \cos\theta_2 - 2 L_1 L_2 \cos\theta_1 \sin\theta_2 \sin\theta_1 + L_2^2 \cos^2\theta_1 \cos^2\theta_2 - 2 L_2^2 \cos\theta_1 \cos\theta_2 \sin\theta_1 \sin\theta_2 + L_2^2 \sin^2\theta_1 \sin^2\theta_2 + L_1^2 \sin^2\theta_1 + 2 L_1 L_2 \sin^2\theta_1 \cos\theta_2 + 2 L_1 L_2 \sin^2\theta_1 \cos\theta_1 + L_2^2 \sin^2\theta_1 \cos^2\theta_2 + 2 L_2^2 \sin\theta_1 \cos\theta_2 \cos\theta_1 \sin\theta_2 + L_2^2 \cos^2\theta_1 \sin^2\theta_2$

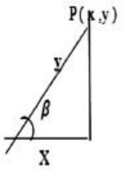
$= L_1^2 (\cos^2\theta_1 + \sin^2\theta_1) + 2 L_1 L_2 \cos\theta_2 (\cos^2\theta_1 + \sin^2\theta_2) + L_2^2 \cos^2\theta_2 (\cos^2\theta_1 + \sin^2\theta_2)$

$= L_1^2 + 2 L_1 L_2 \cos\theta_2 + L_2^2(\cos^2\theta_1 + \sin^2\theta_2)$

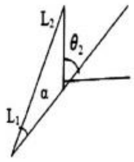
$= L_1^2 + L_2^2 + 2 L_1 L_2 \cos\theta_2$

$$\cos\theta_2 = \frac{x^2 + y^2 - L_1^2 - L_2^2}{2 L_1 L_2}$$

Consider a triangle :



$$\tan\beta = \frac{y}{x}$$



$$\tan\alpha = \frac{L_2 \sin\theta_2}{L_2 \cos\theta_2 + L_1}$$

$$\tan(\beta - \alpha) = \frac{\tan\beta - \tan\alpha}{1 + \tan\beta \tan\alpha}$$

$$= \frac{\frac{y}{x} - \frac{L_2 \sin\theta_2}{L_2 \cos\theta_2 + L_1}}{1 + \frac{y}{X}\frac{L_2 \sin\theta_2}{L_2 \cos\theta_2 + L_1}}$$

$$\tan\theta_1 = \frac{y(L_2 \cos\theta_2 + L_1) - x(L_2 \sin\theta_2)}{x(L_2 \cos\theta_2 + L_1) + y(L_2 \sin\theta_2)}$$

ROBOTIC DESIGN

To design a portable and handy light weight Robot, aluminum sheet is used as a material. The complete base rotation of 360 degrees is obtained with the help of DC motor of speed 5 rpm and torque 10 kN. The movement of the robotic arm is possible with the help of 2nd DC motor of speed 5 rpm and torque 10 kNThe sensitive probe attached to the robotic arm moves about 180 degrees with the help of servomotor.

Figure 2: TRR Robot

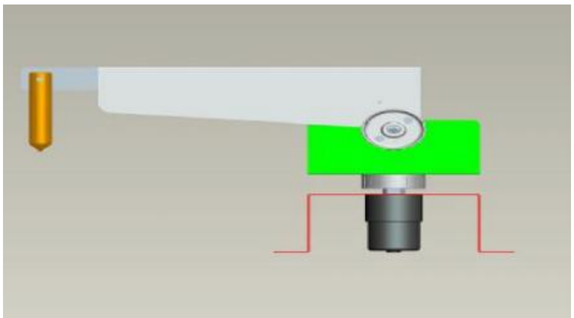


Figure 3: TRR Robot

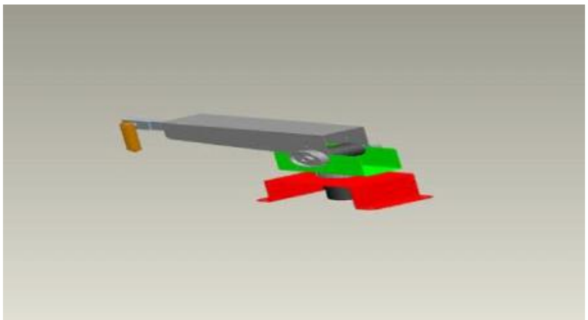


Table 1: Length of Linkages

Linkages	Base (L1) cm	Arm (L2) cm	Probe (L3) cm
Lengths	5	10	6

Table 2: Inclination of Linkages

Motor	(Degrees)
DC (J1)	360
DC (J2)	60
Servomotor (J3)	180

ROBOTIC PERFORMANCE

The robotic arm consists of sensitive ultrasound probe which is able to orient the probe on the patients skin surface in all directions until an appropriate view of the organ under investigation is found out. At the patient site (isolated site) the robotic arm holding the ultrasound probe is handled by the non sonographer. At the expert site the sonographer moves the ultrasound probe connected to video calling mobile say M1. It sends the coordinate changes induced by the probe to the another video calling mobile say M2 located at the patients site via satellite link. The robotic arm reproduces the exact movements of the sonographers hand who guides the examination at the expert center and assistant present at the patients site moves the probe based on the vocal instructions given by the experts using video controls.

COMMUNICATION

The video exchanged between the two sites, the dynamic ultrasound images sent from the patients site to experts site and the command orders sent from the expert site to the patients site for activating the robotic movement are transmitted through the satellite.

WORKING

This work is based on Robot Arm controlled through Mobile phone using video calling. The hardware consists of:

- DTMF decoder which receives mobile's Keypad tone (DTMF) and convert it to 4 bit Binary equivalent data like:
- key 1 -> 0001
- key 2 -> 0010
- key 3 -> 0011
- key 4 -> 0100
- key 5 -> 0101
- key 6 -> 0110
- key 7 -> 0111
- key 8 -> 1000
- key 9 -> 1001
- key 0 -> 1010
- key * -> 1011
- key # -> 1100

All above data is received by the microcontroller and process it according to algorithm written inside the microcontroller. Further the microcontroler sends this data to the Motor Driver to drive the motors of Robotic Arm to get linear and non linear motions.

RESULTS

The jointed arm configuration Robot which is portable, fixed and handy to use, is designed in the x, y, z, plane for conducting fetal ultrasound examination on pregnant woman in isolated hospital sites using Tele-echography.

CONCLUSION

The objective of various profile curves needed for fetal ultrasound examination of pregnant woman is successfully achieved by the prototype that is designed.

FUTHER WORK

Actual model can be fabricated from this prototype which can be handy to use at all medical centers especially in remote areas at the cheap level as compared to other existing systems. Dynamic analysis will be carried out.

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