Ultrasound Needle Point Guidance using Active Echo and Mobile Imaging

Project Checkpoint

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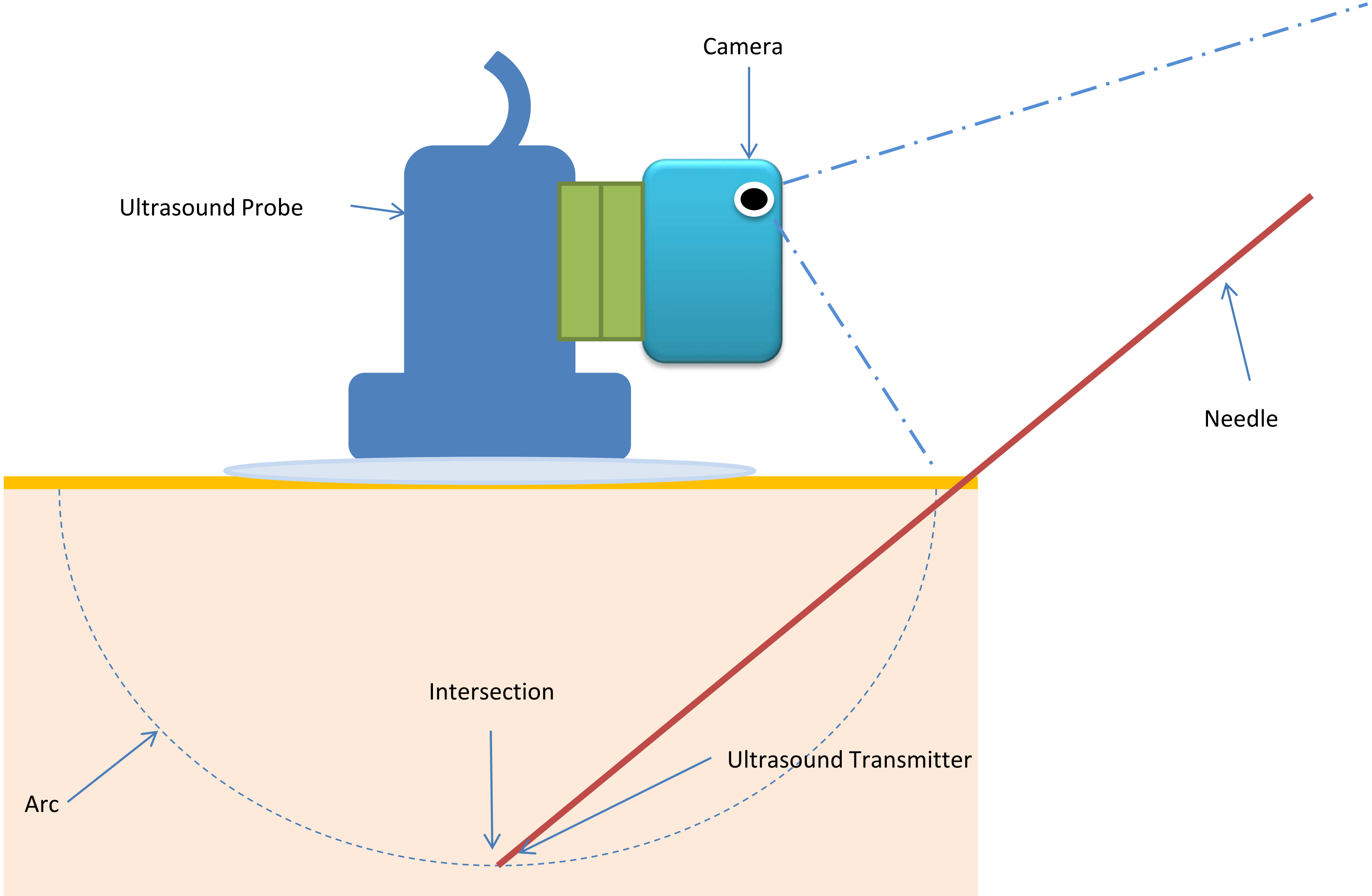
Overview

- Project Overview
- Current Progress
- Deliverables
- Updated Timeline
- Dependencies

Project Overview

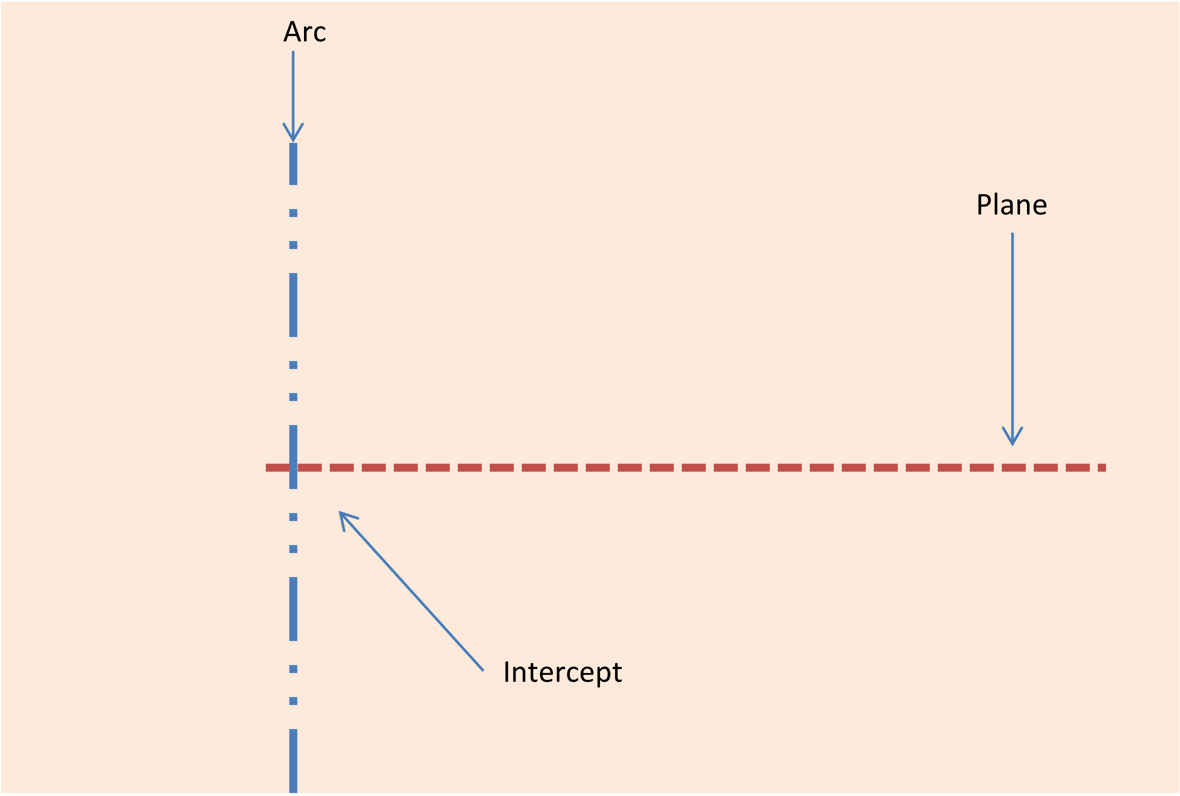
- Project Goal: Use an ultrasound emitting needle, an ultrasound probe (as receiver) and images to track the location of the needle inside a body

Project Overview

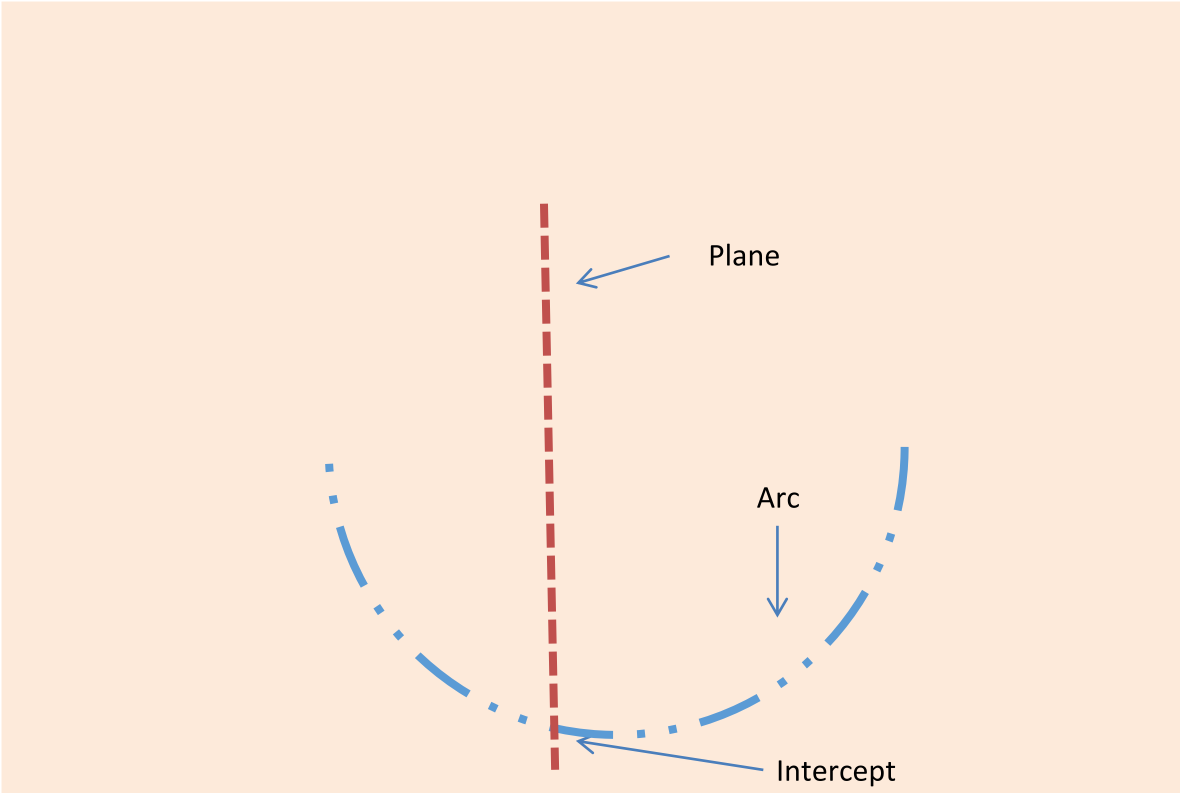


Project Overview

Top View



Front View



Edge Detection (Prewitt operator)

$$\mathbf{G_x} = \begin{bmatrix} -1 & 0 & +1 \\ -1 & 0 & +1 \\ -1 & 0 & +1 \end{bmatrix} * \mathbf{A} \quad \text{and} \quad \mathbf{G_y} = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ +1 & +1 & +1 \end{bmatrix} * \mathbf{A}$$

where $*$ here denotes the 2-dimensional convolution operation.

$$\mathbf{G} = \sqrt{\mathbf{G}_x{}^2 + \mathbf{G}_y{}^2}$$

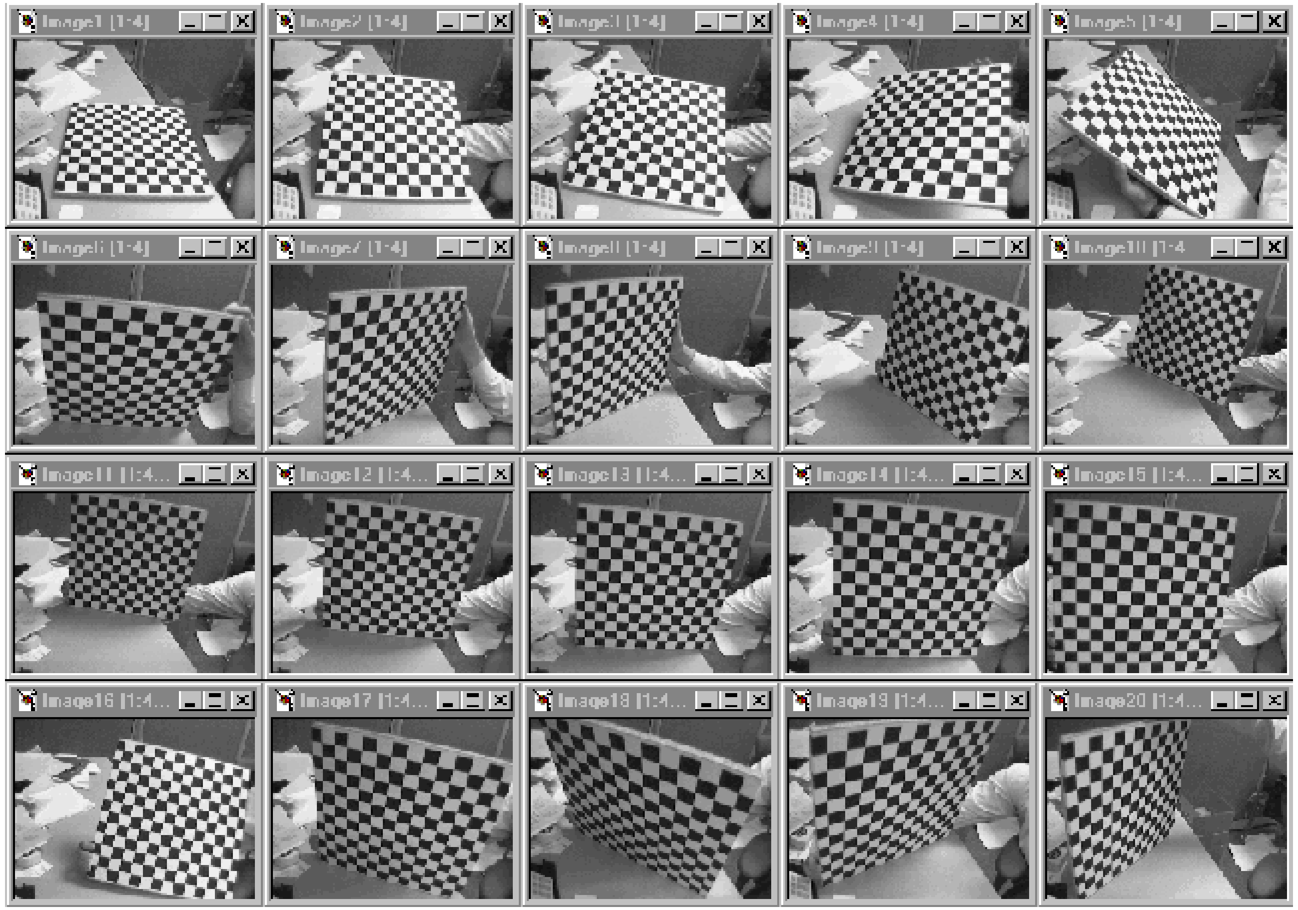
$$\mathbf{\Theta} = \operatorname{atan2}(\mathbf{G}_y, \mathbf{G}_x)$$

- A is the original image
- The operator uses two kernels to get G_x and G_y (derivative approximations)
- G is the gradient magnitude approximation
- Θ is the direction of the gradient

Hough Transform

- Used to find the straight lines in the image
- First parameterize points in terms of r, θ $r = x \cos\theta + y \sin\theta$
- Takes binary image after edge detection
- Then use a 2D array as accumulator with r, θ as dimensions for bins
- Points added to the accumulator for lines that fit into the bins
- The max valued bin represents the line from the image

Camera Calibration



http://www.vision.caltech.edu/bouguetj/calib_doc/gifs/list_images.gif

Camera Calibration

$$x_n = \begin{bmatrix} X_c/Z_c \\ Y_c/Z_c \end{bmatrix} = \begin{bmatrix} x \\ y \end{bmatrix}$$

$$x_d = \begin{bmatrix} x_d(1) \\ x_d(2) \end{bmatrix} = \left(1 + kc(1)\, r^2 + kc(2)\, r^4 + kc(5)\, r^6\right) x_n + dx$$

$$KK = \begin{bmatrix} fc(1) & alpha\_c * fc(1) & cc(1) \\ 0 & fc(2) & cc(2) \\ 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} x_p \\ y_p \\ 1 \end{bmatrix} = KK \begin{bmatrix} x_d(1) \\ x_d(2) \\ 1 \end{bmatrix}$$

x_c – point in camera coordinates
x_n – normalized image projection vector
x_p – point in pixel coordinates
fc – focal length
cc – principal point
alpha_c – skew coefficient (angle between x and y pixel axes)
kc – distortion coefficients

What we want is the camera coordinates, x_n, from pixel coordinates, x_p, which can only be done numerically. Normalize(x_pixel,fc,cc,kc,alpha_c) from the Camera Calibration toolbox achieves this.

http://www.vision.caltech.edu/bouguetj/calib_doc/htmls/parameters.html

Computing Plane in Camera Coordinates

- Using the points of the line obtained from the Hough transform and the camera calibration, the plane formed from the camera origin and the needle can be computed.

x_{p1}, x_{p2}, are two points on the needle.

x_1 = [normalize(x_{p1})(x) normalize(x_{p1})(y) 1]’

x_2 = [normalize(x_{p2})(x) normalize(x_{p2})(y) 1]’

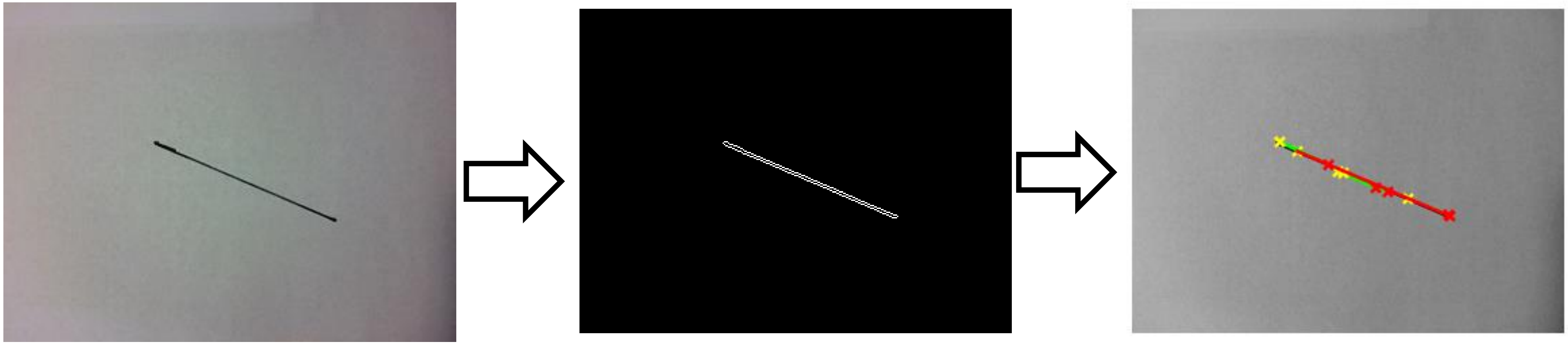
x_3 = [0 0 0]’

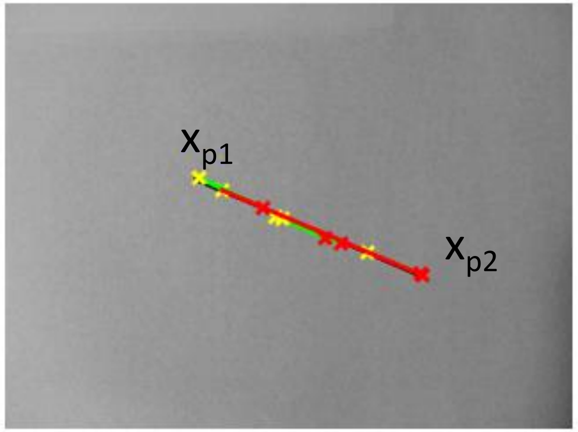
$$\begin{vmatrix} x & y & z & 1 \\ x_1 & y_1 & z_1 & 1 \\ x_2 & y_2 & z_2 & 1 \\ x_3 & y_3 & z_3 & 1 \end{vmatrix} = \begin{vmatrix} x - x_1 & y - y_1 & z - z_1 \\ x_2 - x_1 & y_2 - y_1 & z_2 - z_1 \\ x_3 - x_1 & y_3 - y_1 & z_3 - z_1 \end{vmatrix} = 0.$$

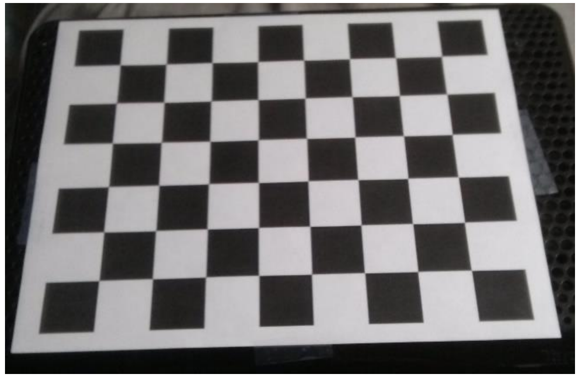
Despite the depth of the needle being unknown, the normalized points will give us the same plane.

Current Progress

- Sample Image

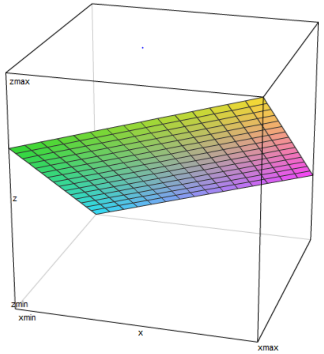






cc, cc, alpha_c, kc

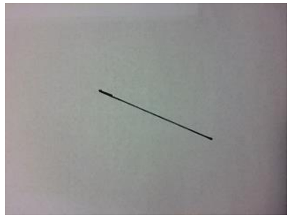
x_1, x_2, x_3

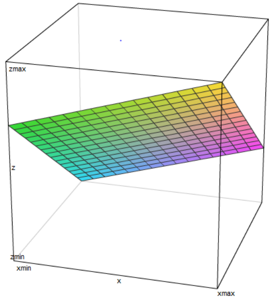


$$z = 1.3647x – 3.0604y + 1.-72e-16$$

Next steps

- Ultrasound calibration and calculation of needle point
- Analysis using UR5 robot via measuring changes in position of the needle using UR5 movement as ground truth





Capture images of needle that is protruding from the skin

Segment needle to find plane in camera frame coordinates

Ultrasound calibration using active echo from the tip of needle to find shell

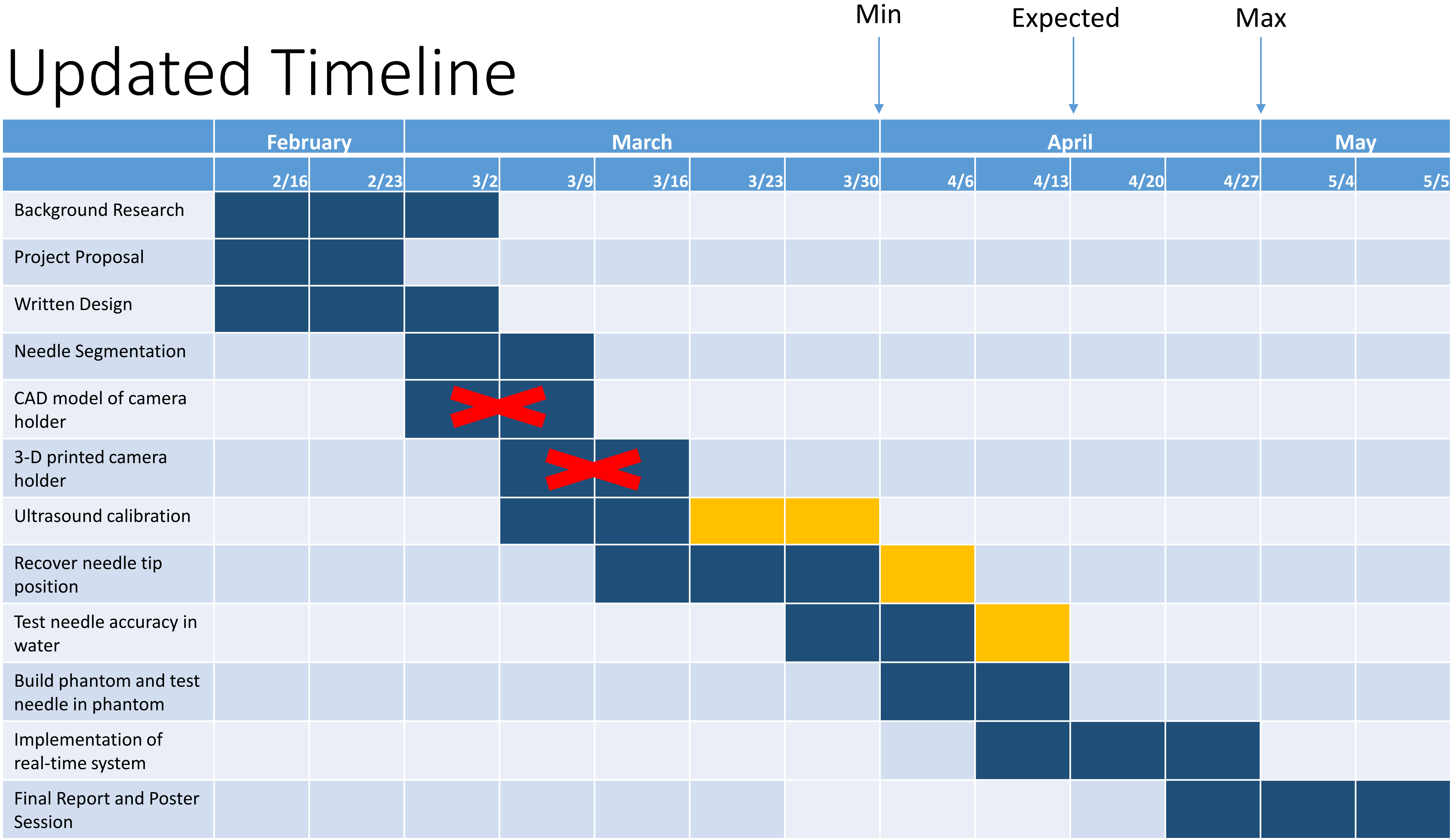
Frame transform into same coordinate system

Locate needle tip with intersection of shell (arc) and plane

Deliverables

- **Minimum:** (**NOW** Expected by April 4, 2015)
- 3D position of probe-tip offline, more specifically
  - Segmentation of needle in images taken from webcam/iPhone (Done)
  - iPhone mount to ultrasound probe (Solved with Lego attachment to iPhone case)
  - Camera calibration (Done)
  - Ultrasound calibration
  - Recover needle-point position using US and iPhone images
- **Expected:** (**NOW** Expected by April 11, 2015)
  - Analysis and validation of technique (perform in water so visual measurements can be taken)
- **Maximum:** (Expected by May 2, 2015)
  - Real-time 3D position of probe-tip using live-feed from iPhone camera and US machine

Updated Timeline



Dependencies

- Wyman 3D printer access
  - No longer needed – will use a Lego block attached to iPhone case instead
- Ultrasound machine tutorial
  - Meeting with Alexis for this on 3/26/15
  - Reschedule meeting or contact Dr. Boctor for other options if not met
  - Deadline for Resolving: 3/27/15
- UR5 use tutorial
  - Need to set up meeting time with Alexis
  - Contact Dr. Boctor for other options if not met
  - Deadline for Resolving: 4/3/15