C-arm Fluoroscopy Target Reconstruction for Liver RFA

We are about to perform radio-frequency ablation (RFA) of a recurrent liver tumor under C-arm fluoroscopy guidance (Fig 1). We have treated the site earlier. During that procedure, we implanted a small tantalum metal marker (surgical clip) at the tumor bed, to mark the most likely location of a local recurrence of the tumor. The the tumor has indeed recurred and now we must treat the exact same location again. We will use the clip to guide the ablator into the tumor under C-arm fluoroscope imaging. The tumor is not visible in fluoroscopy, but the implanted metal clip leaves a visible mark in the X-ray images. We want to use an image guided robot to insert the ablator into the liver. The robot has been registered and calibrated to the coordinate system of the C-arm, meaning the robot control computer understands the target coordinates expressed in the coordinate system of the C-arm. Your task is to determine the location of the target in the coordinate system of the C-arm, so that the surgical robot can use those coordinates for targeting and entering the needle into the body.

The ablator looks like a thick needle that we insert into the tumor through the skin and chest wall and open the prongs inside the tumor (Fig 2) . The diameter of the ablator needle is ~3 mm. In pre-operative CT imaging, we have determined the following: (1) the marker is in the approximate center of the recurrent tumor volume, (2) the largest diameter of the tumor is 3.0 cm, (3) the shape of the tumor is nearly spherical. We need to coagulate liver tissue with leaving at least 0.5 cm margin everywhere around the tumor, in order to kill all microscopic disease. We have an ablator that can coagulate a sphere of 5.0 cm diameter.

In our C-arm, the source-detector distance is SDD=150 cm, the source-axis distance is SAD=75 cm, and the axis-detector distance is ADD=75 cm. (Fig. 3 and 4.)

We will only use 2 images: one from anterior-posterior (top-down) and one on left-right lateral pose.

Fig 1.

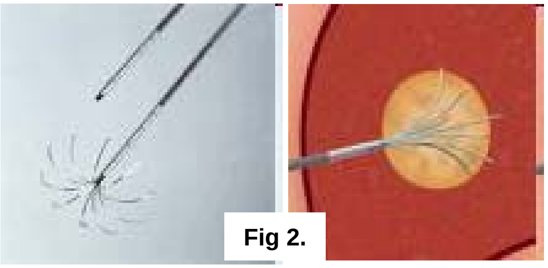


Fig 2.

Fig 3.

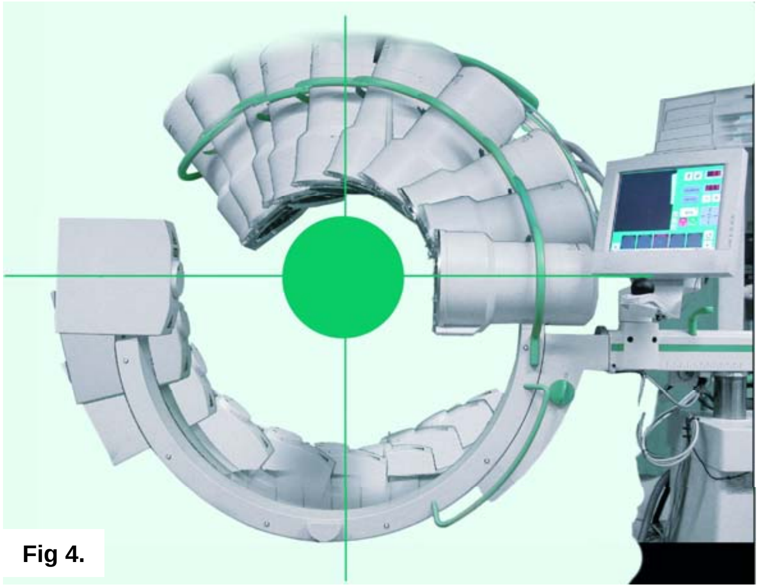
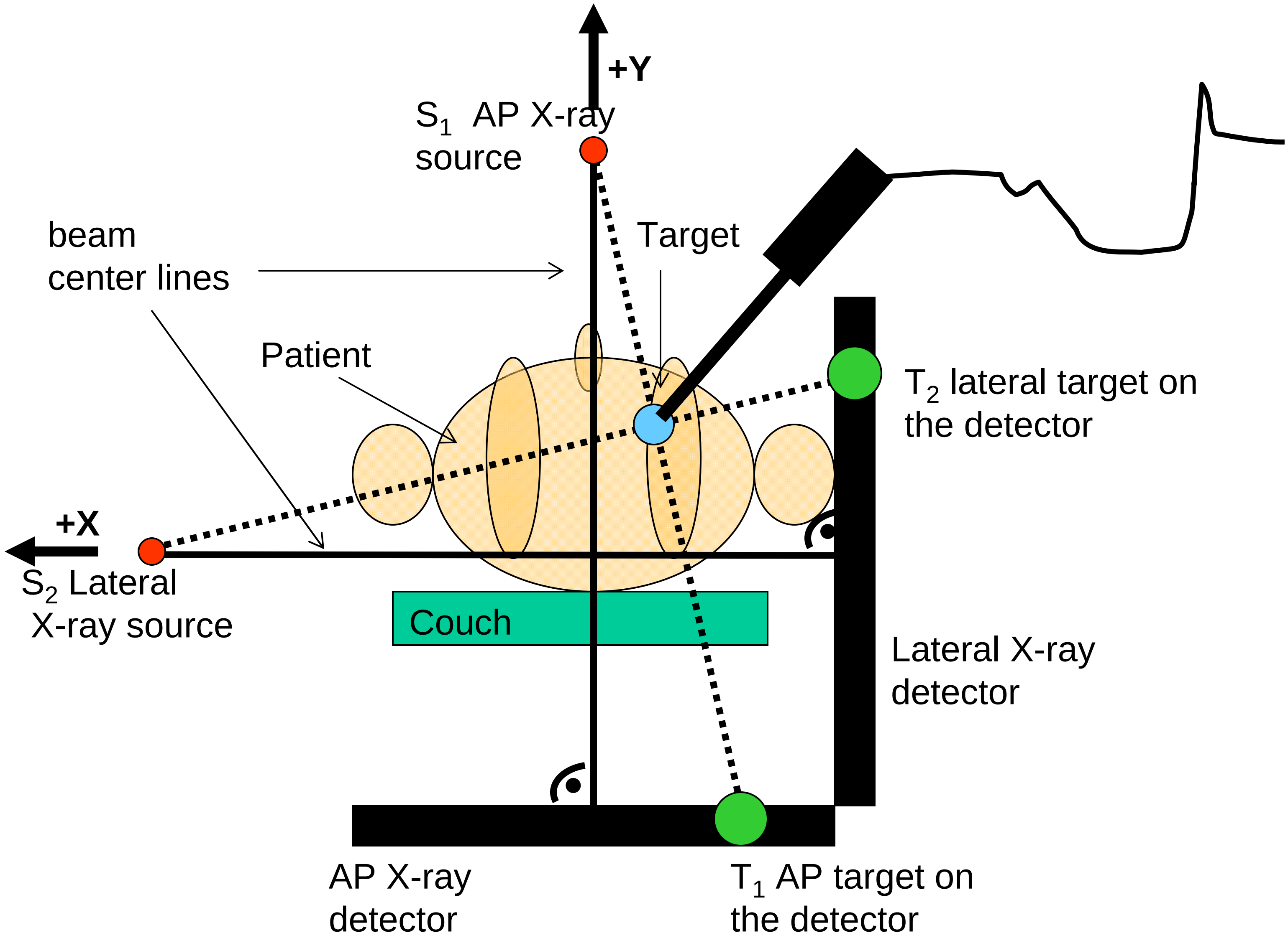


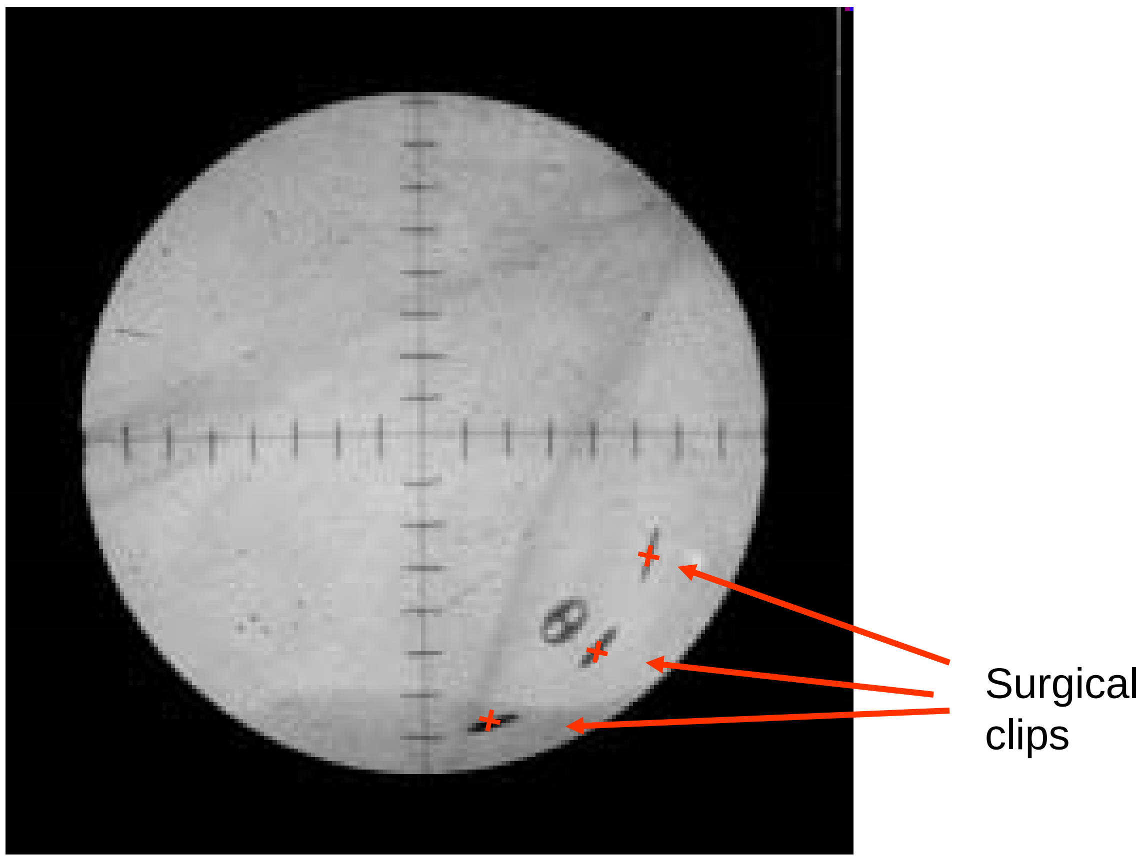
Fig 4.

Axial view

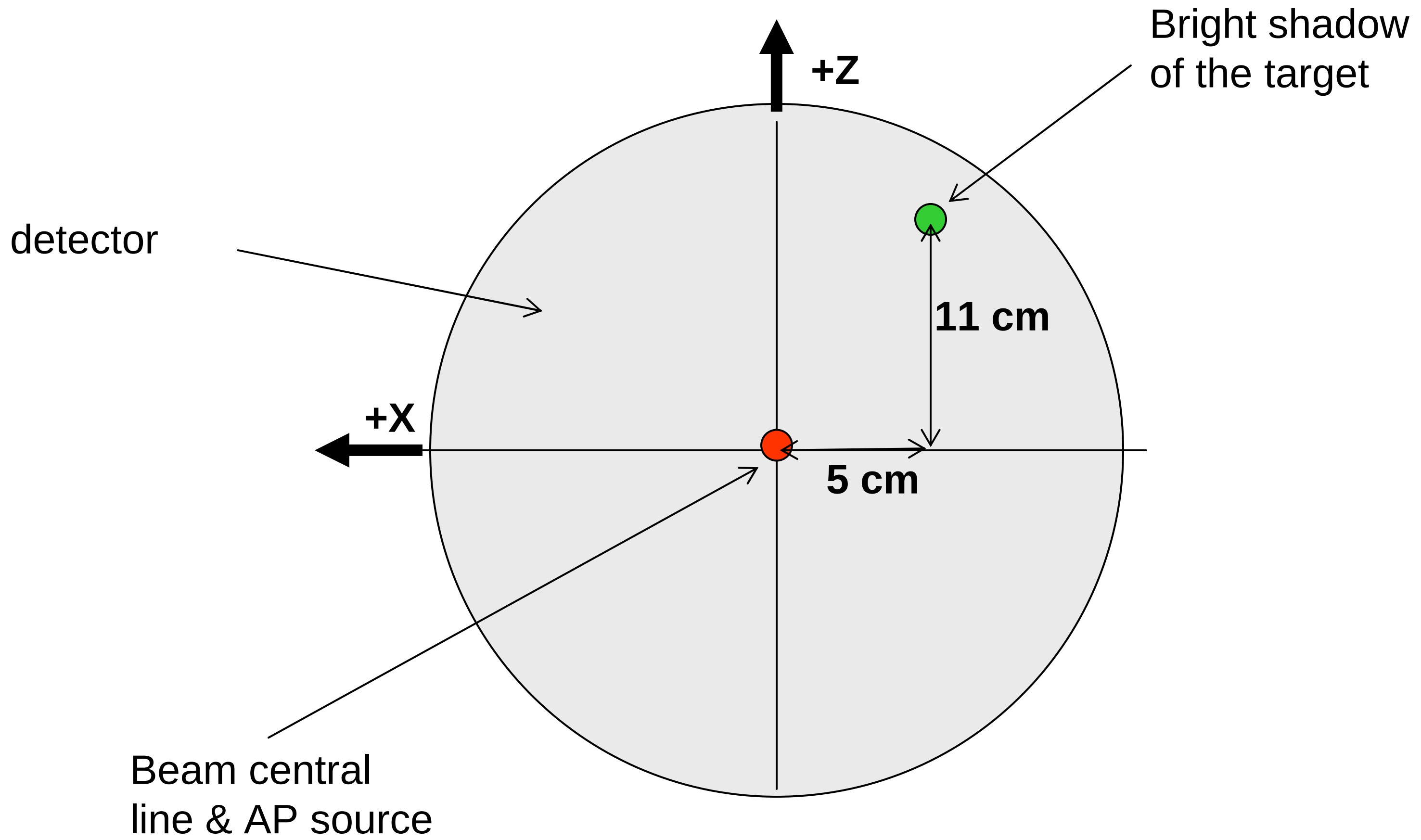
(Axial view is the scene from the negative Z axis of the biplane imager. Z axis points into the plane of the paper. We look at the patient from his/her feet.)

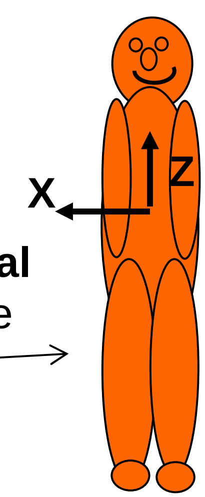


Example: C-arm fluoroscopy image w/ segmented clips



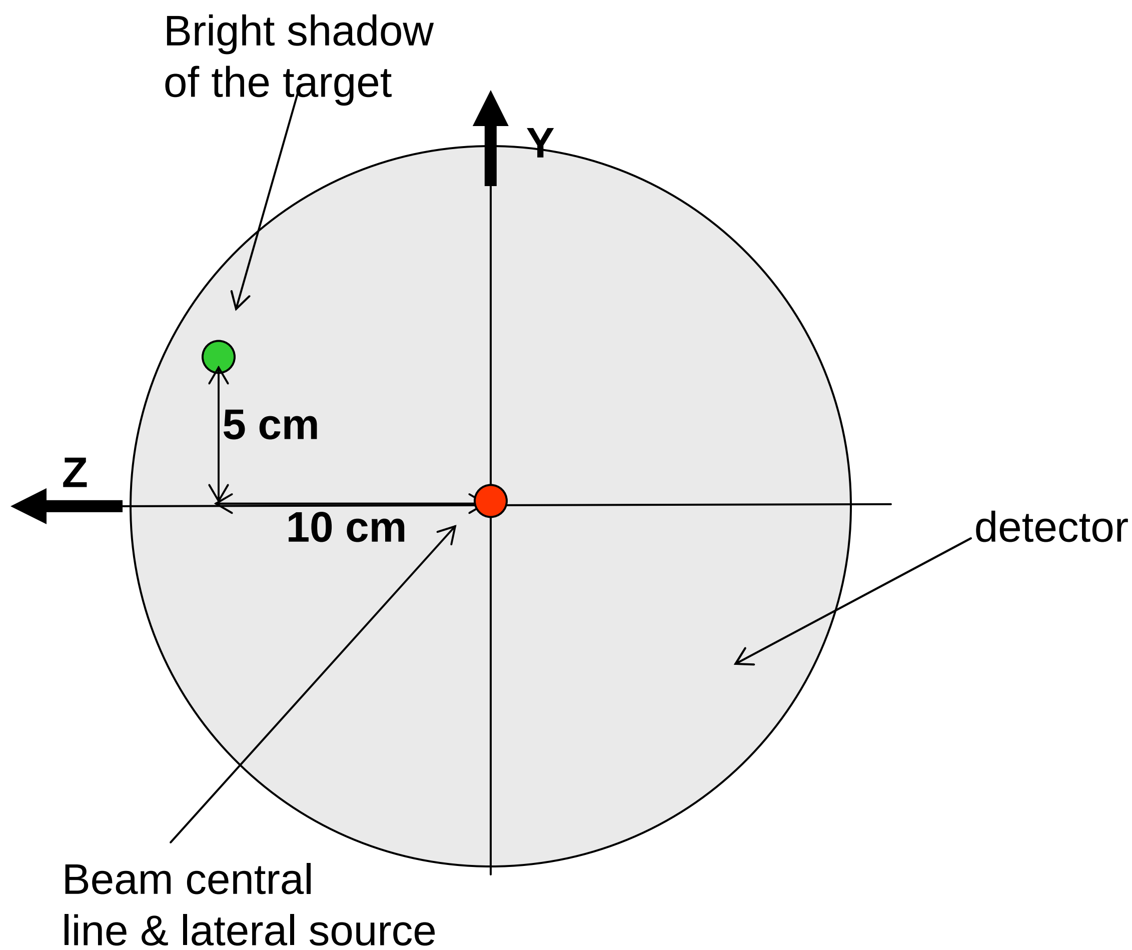
AP view



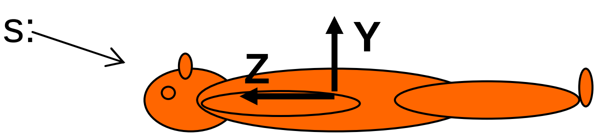


This beam's eye view **is the view from the source, along the beam's central line.** In the detector, we can see the beam central. Read out coordinates of the target, in cm. We see the patient's face, like ourselves in a mirror

Lateral view



This beam's eye view **is the view from the source, along the beam's central line**
In the detector, we can see the beam central point and read out the coordinates of the target, in cm. We see the patient from his/her right side, like this:



Questions (95 pts)

1. Explain how the coordinates of a small, point-like target can be reconstructed from the two X–ray projections. Explain how you will calculate the 3D error of your target reconstruction. Use the “axial view” figure for explanation, with marking the appropriate points, vectors, and derive the generic equations you need to solve. (You need convey solid your solid understand of the logic and math behind the method.) (15 **pts**).
2. Look at the numerical values and numbers given and produce a good ballpark estimation of the expected results. You must explain your reasoning. (**15 pts**)
3. Plug the given numerical values into your equations in question 1. Calculate the coordinates of the target (metal marker) the mean 3D error of the target reconstruction. (15 **pts)**
4. What is the minimum required 3D target reconstruction accuracy for this particular patient, assuming there is no other significant source of error in the system? Is the accuracy of your reconstruction is satisfactory? Give your reasoning in a sketch and clear sentences. (**10 pts**)
5. Explain the main sources of uncertainties and errors in C-arm target reconstruction. **(10 pts)**
6. Explain how to extend your 2-pose target reconstruction method for 3 or more fluoroscopy poses. What are the benefits and drawbacks of using many more fluoroscopy poses. (**15 pts**)
7. Explain how to extend your reconstruction method for 2 targets that look indistinguishable in the X-ray image. (We referred to this as the correspondence problem.) (15 **pts**)

Directions

- Always explain how you plan to solve the problem. Use sketches, math symbols and formulas, text, as you find them appropriate. I need to know that you <u>understand</u> what you are about to do. I must be able to follow your reasoning.

- **ALWAYS start with a general parametric solution (without specific numbers). Derive the necessary formula. Explain how/why does it work, and then plug in the actual numbers and values and calculate the numerical results.**

- Calculation errors are not serious mistakes, you can still earn 80% of the score if you produce a correct general parametric solution.

- Always verify the results by replacing the final numbers back into your equations/ formulas. Verification and analysis of the results are always mandatory.

- Type your text with large enough margin and line spacing.

- If you do not have access to a word processor, write clearly and legibly.

- Neatness reflects clarity and care. You can earn (or lose) important points.

- Number the pages and staple the sheets. Do not use paper clip! We are not responsible for losing some renegade sheets.

- **Work alone!**

- If you have questions or problems, contact the TA-s or come to office hours.

- Have fun!