System Requirements for MSKCC Robot

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1. Objective

This document defines the requirements for the robot system being developed for rodent experiments at the Memorial Sloan Kettering Cancer Center (MSKCC).

The robot system is intended to: (1) achieve highly accurate placement of thin flexible measurement probes in in-vivo animal (rodent) tissue and provide systematic measurement in a predefined pattern of about 1 mm granularity, (2) perform biopsy of in vivo animal tissue with the same spatial accuracy, and (3) inject an adenoviral vector (in the form of an aqueous suspension) into a predefined pattern of about 1 mm granularity. These procedures require different imaging modalities, such as PET, SPECT, CT and MRI, to identify the target regions.

2. References

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3. System Overview

The initial plan was to physically attach the robot system to the scanner platform and perform the procedure in the scanner. This would have provided simple and efficient solutions for registering the scanner coordinate system to the robot coordinate system (for example, the robot can hold a calibration object in the scanner field of view). We could not, however, pursue this strategy because the research micro-scanners are too small to accommodate both the rodent and the robot (see Design Constraints).

We therefore had to consider a design where the robot is physically detached from the scanner. The procedure is performed as follows: a) place anesthetized rodent in a specially-constructed fixture (rodent bed) that contains fiducial markers; b) place rodent bed in scanner and obtain image data; c) move rodent bed to robot system with anesthetized rodent

remaining in place; d) load image data into computer workstation and identify target regions; d) register image data to robot by locating fiducials in each coordinate system; e) command robot to move to target positions.

4. Functional Requirements

4.1. Fiducial Marker System

4.1.1. The fiducial marker system shall be visible in all imaging systems being considered (PET, CT, MRI).

4.1.2. The robot shall be able to locate the fiducial markers by physical probing.

4.1.3. There shall be enough fiducials to obtain a 3 dimensional transformation between imaging coordinate and the robot coordinates.

4.1.4. The fiducials probed by the robot may be installed at different locations from the fiducials used for imaging, provided that the displacements are known.

4.2. Rodent Bed

4.2.1. The rodent bed shall be based on the current MSKCC design.

4.2.2. The rodent bed shall include the fiducial marker system.

4.2.3. The rodent bed shall be compatible with the different imaging modalities (CT, MRI, PET).

4.2.4. The rodent bed shall be capable of being firmly attached to the different scanner beds.

4.2.5. The fiducial markers shall fit within the scanner field of view (e.g., for the PET scanner, no more than 8 cm apart in the axial direction).

4.3. Robot Hardware

4.3.1. Rodent Bed Mount

4.3.1.1. The robot system shall contain a mechanism for mounting the rodent bed within the workspace.

4.3.2. End-Effector Tooling

4.3.2.1. The robot end-effector shall contain a clamp for mounting a cannula of diameter TBD-TBD through which needles and probes can be inserted.

4.3.2.2. The robot end-effector shall be capable of driving needles/probes into the target anatomy.

4.3.2.3. The robot shall contain a registration probe that can be used to physically probe the fiducial markers. This probe is only required to be attached when the markers are being located.

4.3.3. Degrees of Freedom

4.3.3.1. The robot system shall contain 3 degrees of freedom (X, Y and Z).

4.3.3.2. There shall be redundancy in the Z motion (i.e., one Z axis to move the cannula and another Z axis to move the needle/probe with respect to cannula).

4.3.4. Physical Construction

4.3.4.1. The robot system can be partitioned into more than one component (i.e., some axes to move the rodent bed and other axes to move the tooling).

4.3.4.2. The robot should be able to fit on a table or on top of a mobile cart (e.g., on top of a 19 inch rackmount cabinet).

4.3.5. Position Determination

4.3.5.1. The robot system shall be capable of determining the position of the end-effector tooling (registration probe, cannula, needle/probe tip) in X,Y,Z coordinates.

4.3.6. External Sensing

4.3.6.1. The robot system shall include sensors to allow it to physically locate the fiducial markers. For example, a three-axis force sensor can be used.

4.3.7. Electronics

4.3.7.1. A robot controller shall perform low-level control of the robot axes, including the power amplification.

4.3.7.2. A personal computer shall be used to run the application software and to provide the interfaces to the robot controller, Oxylite measurement system and image data (network).

4.4. Software

4.4.1. Scanner Data Interface

4.4.1.1. The software shall be capable of reading DICOM image data.

4.4.1.2. The software shall be capable of reading the proprietary data format of the microPET scanner.

4.4.1.3. The software shall be capable of handling two PET image data sets (one with fiducials and one without). It is assumed that these image data sets will have the same coordinate system.

4.4.2. Image Display

4.4.2.1. The software shall display the image data as a 3D volume and as 3 orthogonal 2D views.

4.4.2.2. The image data shall be aligned with the robot coordinate system.

4.4.2.3. The user shall be able to change the display planes and to zoom the image.

4.4.3. Robot Initialization

4.4.3.1. The software shall provide a means of initializing the robot position (e.g., a homing procedure if incremental encoders are used for feedback).

4.4.4. Robot Calibration

4.4.4.1. The software shall provide a function for calibrating the registration probe to the probe/needle and storing the calibration parameters in a file. This function may be restricted to service/maintenance mode.

4.4.4.2. The software shall read the calibration parameters from the file.

4.4.5. Robot/Image Registration

4.4.5.1. The software shall locate the fiducials in the image data. Some user assistance may be required.

4.4.5.2. The software shall move the robot to physically locate the fiducials on the rodent bed. Some user assistance may be required, such as manual guiding of the robot probe to the fiducial (or near it). This step could be eliminated if the rodent bed and fiducials are repeatably attached to the robot system.

4.4.5.3. The software shall compute the image-to-robot transformation from the positions of the fiducials in each coordinate system.

4.4.6. Interface to Oxylite System

4.4.6.1. The software shall contain an interface to the Oxylite system that allows it to obtain the Oxylite probe measurements (*not implemented for current deliverable).*

4.4.6.2. The system shall contain a window that displays a graph of the Oxylite probe measurements. This feature can be provided by an external software package.

4.4.7. Target Selection

4.4.7.1. The user shall be able to define any number of measurement tracks, where each track can be specified by a start point, end point and increment.

4.4.7.2. Alternatively, the user shall be able to define a regular grid of target points, based on the tumor boundary and specified delta-x, delta-y and delta-z values *(not implemented for current deliverable).*

4.4.7.2.1. The tumor boundary can be defined by segmenting the image data.

4.4.7.2.2. Alternatively, the tumor boundary can be defined by tracing it with the robot.

4.4.8. Installation of Probe/Needle

4.4.8.1. The system shall contain a mechanism for attaching the probe or needle to the redundant (Z) linear actuator.

4.4.8.2. The attachment procedure shall ensure that the linear actuator has sufficient travel to extend the probe/needle beyond the cannula by the required amount.

4.4.8.3. The software shall provide a means of zeroing the probe/needle position with respect to the registration probe.

4.4.9. Execution of Plan

4.4.9.1. The software shall drive the robot system so that the cannula is positioned at a safe distance above the first target point (safe distance to be defined).

4.4.9.2. The software shall allow the user to move the cannula down to the skin using manual guiding and/or control buttons on the display.

4.4.9.3. The software shall move the redundant linear actuator to its highest travel position and display a screen prompting the user to puncture the skin with a needle inserted through the cannula.

4.4.9.4. The software shall hold the cannula in place and advance the needle/probe with respect to the cannula in increments of delta-z.

4.4.9.5. The software shall provide a user control to stop needle insertion. For example, the user may stop needle insertion if he/she detects needle bending due to hitting a hard surface such as bone.

4.4.9.6. Oxylite probe actions

4.4.9.6.1. The software shall be configurable to either automatically acquire the probe reading or to prompt the user to manually enter the value. *(current deliverable will only support manual entry)*

4.4.9.6.2. If configured for automatic acquisition, the software shall monitor the probe value and take a reading when it has stabilized (the reading may be an average of several samples). *(not implemented in current deliverable)*

4.4.9.6.3. If configured for manual entry, the software shall prompt the user to enter the current probe value.

4.4.9.6.4. The software shall record the xyz position in image space, probe value, image data value and current time in a comma-separated value (CSV) file format.

4.4.9.7. Biopsy needle actions *(not implemented in current deliverable)*

4.4.9.7.1. TBD

4.4.9.8. Injector needle actions *(not implemented in current deliverable)*

4.4.9.8.1. The software shall instruct the micro-injector to inject the liquid agent.

4.4.9.9. When the needle/probe has been fully advanced (to the deepest position in the target), the software shall display a screen to allow the user to move the needle/probe deeper in order to verify that the bottom of the target has been reached or to add additional measurement/delivery points.

4.4.10. Application Shutdown

4.4.10.1. The software shall provide a means of gracefully ending the procedure and moving the robot to its “parked” position.

5. Performance Requirements

5.1. Fiducial Marker System

5.1.1. The fiducial marker system shall provide a robot registration accuracy of at least $\pm$0.25mm. This shall be verified by comparing against a "gold standard" such as a phantom that is characterized by an accurate Coordinate Measurement Machine (CMM).

5.1.2. The fiducial marker system shall provide an image registration accuracy of TBD (will depend on imaging modality). This shall be verified by comparing against a "gold standard" such as a phantom that is characterized by an accurate Coordinate Measurement Machine (CMM).

5.2. Rodent Bed

5.2.1. The rodent bed shall fit inside the smaller scanner bore, which is a 5 inch diameter.

5.3. Robot

5.3.1. The robot shall be capable of working with tumors that are 2-3 cm in diameter. Note that a larger workspace will be required to include the registration procedure (locating fiducials).

5.3.2. The robot motion resolution shall be 0.1mm or better.

5.3.3. The robot shall be capable of moving through its range of travel in no more than 15 seconds.

5.4. Software

None

6. Safety Requirements

6.1. Fiducial Marker System

6.1.1. Radioactive markers (e.g., for PET) shall be handled according to the specified safety protocol.

6.2. Rodent Bed

6.2.1. The rodent bed shall be designed to allow sanitary cleaning and, thus, reusability of the bed in subsequent scans.

6.3. Robot

6.3.1. The robot system shall include an emergency stop button that removes robot motor power.

6.3.2. The robot system shall not move more than 2mm when motor power is removed.

6.3.3. The robot system shall include axis limit or home sensors when necessary (e.g., when incremental encoders are used for feedback).

6.4. Software

6.4.1. The software shall provide controls to allow the user to stop the robot at any time.

6.4.2. The software shall perform a check of the registration check by comparing the distances between the fiducials in each coordinate system. The registration shall be rejected if this distance is greater than TBD mm.

7. Design Constraints

7.1. Scanner Dimensions

The scanner openings are too small to allow the robot system to work inside the scanner. This constrains us to perform the robot procedure outside the scanner and led to the use of fiducials for registration.

7.2. Registration

Based on consultations with others, we have constrained ourselves to use a fiducial-based registration. Another option might have been to use the imaging system alignment laser and to count on repeatable fixturing of the rodent bed to the robot.

7.3. Programming Language

The software shall be written in C++.

7.4. Visualization Software

Slicer (www.slicer.org) shall be used for the image data visualization and overall application control software.

8. Change History

Rev	Date	Description
1	1/23/04	Initial version by P. Kazanzides
2	2/13/04	Updated based on comments by J. Li.
3	3/5/04	Updated based on meeting 3/2/04 at MSKCC