# Validation of an Image-Guided Robot System for Measurement, Biopsy and Injection in Rodents

J.C. Li, I. Iordachita, E. Balogh, G. Fichtinger and P. Kazanzides
Johns Hopkins University, 3400 N. Charles St, Baltimore, MD 21218
Contact: P. Kazanzides, pkaz@cs.jhu.edu

*Abstract*—**We developed an image-guided robot system to achieve highly accurate placement of thin needles and probes into in-vivo rodent tumor tissue in a predefined pattern of about 1 mm granularity that is specified on a preoperative image. This development is part of a collaborative project between Johns Hopkins University (JHU) and Memorial Sloan-Kettering Cancer Center (MSKCC). This paper presents a design update and validation results for the robot system that we constructed and delivered to MSKCC.**

## I. INTRODUCTION

Last year, we presented the design of an image-guided robot system for cancer research with rodents [1]. The motivating problem was to automate and improve a tedious manual procedure used at the Memorial Sloan Kettering Cancer Center (MSKCC) to identify hypoxic (oxygen-deficient) tumor cells. Hypoxic cells are more resistant to radiation treatment, so a non-invasive identification method would allow clinicians to deliver higher radiation doses to them. MSKCC researchers are validating the efficacy of PET image data, with specific tracers, for identifying hypoxic cells by correlating multiple image data points with oxygen tension ($pO_2$) measurements obtained invasively by a manually inserted probe.

## II. SYSTEM DESIGN

The robot system consists of a mobile cart that houses the electronics, provides a table top for the four axis robot and display monitor, and contains a pull-out drawer for the keyboard and mouse (see Fig. 1). The robot design consists of an X-Y platform that moves the rodent bed and a two-axis insertion stage (Z1 and Z2). The Z1 axis is used to position a cannula near the skin surface and the Z2 axis is used to drive the needle or measurement probe to the target (see Fig. 2). The measurement procedure is physically decoupled from the imaging procedure for maximum flexibility; therefore, fiducial markers are used for the registration between image coordinates and robot coordinates. The system uses the Acustar® marker system, donated by Z-Kat Inc., for the CT, MRI and robot markers and a separate set of support tubes (offset by a known amount) for the radioactive PET markers. During the robot registration procedure, the cannula is replaced by a registration probe, which is guided to the markers using a force control mode [2]. Force control is possible because the system contains a two-axis sensor (XY) beneath the rodent bed and a single-axis sensor (Z1) near the attachment mechanism for the registration probe and cannula.

Note that the use of a single mounting point for the cannula and the registration probe differs from the design we presented in [1], which had a cross bar on which both tools were mounted. We made this change because we desired to make the registration probe and the cannula attachment mechanism as compact as possible. The more compact design provides minimal visual obstruction on the insertion target and an easier guidance by the operator.

The operation procedure is as follows: a) place anesthetized tumor-bearing rodent in rodent bed; b) place rodent bed in scanner and obtain image data; c) move rodent bed to robot system and load image data into computer; d) register image data to robot by manually guiding robot's registration probe into contact with each marker and using a semi-automatic image processing procedure to locate the corresponding image marker; e) remove registration probe from Z1 axis and attach cannula; f) attach measurement probe to Z2 axis and zero its position; g) identify target regions (sets of vertical tracks) in the image; h) command robot to move to each target position and record measurements.

## III. TEST RESULTS

We performed several tests at JHU prior to delivering the system to MSKCC in January 2005. Our in-house tests focused on the robot system because we do not have small animal imaging systems. We therefore tested the performance of each individual robot axis as well as the performance of the complete robot, including the registration procedure. The system specification, finalized with MSKCC in March 2004, requires a robot motion resolution of 0.1mm and a robot registration accuracy of ±0.25mm.


Fig 1. Robot System

### A. Repeatability and Accuracy of Individual Axes

We performed small motion repeatability and accuracy tests

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on each of the 4 axes using a dial indicator (Mitutoyo model #543-693B) with ±0.003mm accuracy and 12.7mm travel. We positioned the dial indicator in contact with the axis and moved the robot back and forth (ten times) between two positions that were 10mm apart, recording the dial indicator reading at each position. The repeatability was computed by averaging the difference between each reading and the average of all the readings. The results range from 0.001mm to 0.030 mm. The accuracy was computed by averaging the differences between the measured displacements and the specified travel of 10mm. The results range from 0.015mm to 0.075mm. Both the repeatability and the small motion accuracy are well within the 0.1mm motion resolution requirement.

### *B. Repeatability and Accuracy of Robot System*

For these tests, we designed a test plate with 9 target holes on a horizontal plane and 4 more at various. Four of the target holes on the horizontal plane were arranged in the same geometry as the four Acustar markers on the rodent bed. Each target hole had the same conical shape and depth that allowed the rounded registration probe tip to sit at the bottom of the cone in a repeatable manner. The test plate was 8"L x 5"W x 4.5"H in size and was machined on a CNC machine with a known accuracy of 0.0005" (0.0127mm). This plate served as the gold standard for our measurements.

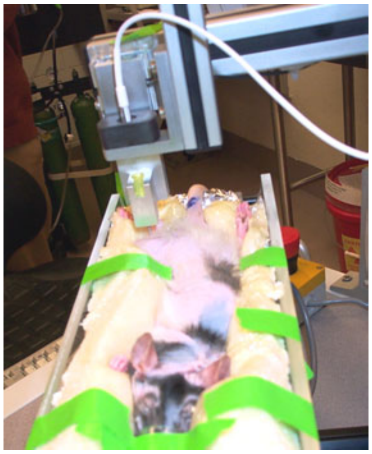

Fig. 2. Oxylite Probe Inserted in Rodent

The repeatability test was facilitated by a software program that prompted the operator to hand-guide the registration probe, in a force-feedback mode [2], to a target hole on the test plate. After seating the probe tip in the bottom of the hole, the operator pressed the Enter key to record the position. The robot automatically retracted the registration probe and moved it horizontally by a random amount. This was repeated ten times on the same hole. Four operators performed this test and the repeatability results ranged from 0.267mm to 0.389mm.

These results were not as good as desired and it was clear during the testing that the geometric design of the test plate holes made the registration procedure more difficult. We therefore performed the same repeatability test, with the same four operators, on an Acustar marker. These results ranged from 0.112mm to 0.159mm, significantly better than those obtained with the test plate.

We designed the accuracy tests to compare the position of the registration probe, measured by the robot encoders, with the known locations of the machined holes that the registration probe touches during registration. We collected three data sets and analyzed them with the following two methods:

(a) Use the four fiducials with the same geometry as the Acustar markers to register the robot coordinate system to the plate coordinate system. Transform all 13 robot points to the plate coordinate system and compute the distance between each of the 13 sets of matched points.

(b) Compute the distance between each pair of points in robot coordinates and compare that to the distance between each pair of points in plate coordinates. For example, if $R_{ab}$ is the distance between points *a* and *b* measured by the robot and $P_{ab}$ is the distance between points *a* and *b* in the CAD drawing, then the absolute distance error is $| R_{ab} – P_{ab}|$.

The combined average error using method (a) was 0.404mm, compared to 0.301mm using method (b). The better result obtained with method (b) is likely due to the fact that it is not affected by registration error. These results are not within the 0.25mm specification, but we note that the test plate repeatability was the same order of magnitude as the accuracy error. Therefore, it is reasonable to expect a better accuracy result with the Acustar markers, which produced significantly better repeatability results.

## IV. CONCLUSIONS

We completed the design and testing of an image-guided robot system to assist with cancer research and delivered it to MSKCC in January 2005. The repeatability and accuracy of the individual robot axes are well within specification. Our test of the robot system, including the registration procedure, produced promising results though it was negatively affected by the test plate design. This could be addressed by designing a better test plate (possibly attaching Acustar markers instead of machining holes) or by improving the software to enable more repeatable data collection on the machined holes. The next step is to measure the repeatability and accuracy of the entire system including the imaging device.

We believe that this robot system will improve the efficiency and accuracy of needle-based procedures for in-vivo measurement, biopsy, and injection in small animals. One notable feature is the support for a variety of imaging modalities, including CT, PET, SPECT, and MRI.

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