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SHORT COMMUNICATION

Update: Toward image-guided robotic surgery: determining the intrinsic accuracy of the daVinci-S robot

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Abstract Early in 2006, Intuitive Surgical (Sunnyvale, CA, USA) released their next generation robotic surgery system, the daVinci-S. While the S is an update on the daVinci surgical system it has significantly different structures. This led to the belief that there might be differences in the accuracy and precision of the daVinci-S as compared to the daVinci "classic". In a previous study, we measured the accuracy of the daVinci "classic" to be 1.02 mm throughout its work volume (Kwartowitz et al. in Int J Comput Assist Radiol Surg 1:159–165, 2006) In this study we evaluated the accuracy of the daVinci-S using the same protocol as was used for the daVinci "classic". The localization error is found to be 1.05 mm, which is essentially the same as the measured error for the daVinci "classic". It is concluded that the daVinci-S is an appropriate localizer for a robotic image guided surgery (RIGS) system.

Keywords Robot · Image-guided surgery · Image registration · Surgery · Robotic assisted surgery

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Introduction

This technical note is a continuation of work which was previously presented in this journal [1].

Use of robotics in surgery continues to increase, due in part to the improvements in dexterity and tremor reduction over traditional laparoscopy [2]. The dominant system used for these robotic procedures is the daVinci™ surgical system (Intuitive Surgical, Sunnyvale, CA, USA). In response to the continued popularity of the daVinci system, a next generation daVinci system was released by Intuitive Surgical in early 2006. The new system, called the daVinci Streamlined (daVinci-S™), has a number of differences from the daVinci "classic" system. These differences are implemented to improve surgeon experience as well as system flexability. The primary difference affecting operation is an increase in tool lengths allowing for an increased range of motion. The architecture of both daVinci surgical systems is that of a master-slave system, where the surgeon sits at a console and directly instructs the system's movement [3]. Feedback is provided to the surgeon through use of a laparoscopic camera which allows for visualization of the tips of the tools being manipulated. The camera can be moved throughout the procedure changing the surgeon's reference and the perceived tool positions, as the tool positions are relative to the camera position. In its standard usage, the daVinci system does not provide the surgeon with subsurface information such as vessel, critical structure, or tumor margin position.

Design of a robotic image guided surgery (RIGS) system, using the daVinci "classic" system was previously proposed [1]. Assessment of the system accuracy and precision gave an assessment as to the applicability of the "daVinci classic" system in a RIGS system. Kinematic differences in the daVinci-S surgical system allow for potential differences in intrinsic accuracy and precision.

As the proliferation of daVinci-S systems continues, implementation of a daVinci-S based RIGS system becomes more desirable. In this study we will assess the accuracy and precision of the daVinci S surgical system using a standardized protocol used for the "daVinci classic."

Methods

To assess the accuracy and precision of the daVinci-S surgical system a series of phantom experiments were performed. In these phantom experiments an 11 target rigid localization phantom was used (Fig. 1). The design of this phantom was such that the targets were scattered throughout the work volume of a single patient side manipulator (PSM) with its setup joints fixed. The targets were scattered such that the effect of position on accuracy and precision could be assessed.

Each of the points on the phantom were localized 10 times using an Optotrak 3020 (Northern Digital Instruments, Waterloo, ON, Canada) with a 24 infrared light-emitting diode (IRED) pen probe. The Optotrak 3,020 has a National Institute of Standards and Technology (NIST) traceable accuracy of 0.1 mm for a single IRED over the work volume and a 0.25 mm accuracy when localizing a 24 IRED helical pen probe [4]. The mean target location for each of the 11 targets was taken as a gold standard of target position.

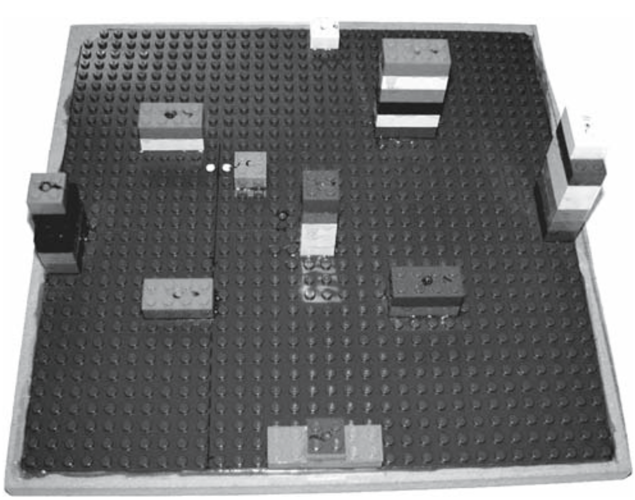

Fig. 1 Image of 11 target rigid localization phantom

A module for the operating room image oriented navigation (ORION) system was authored for recording the tip positions of the daVinci-S system [1,4]. This module acquired joint positions through a proprietary communications protocol and preformed forward kinematics to determine tip position. The daVinci-S localizations were performed using a large needle driver (LND) tool for both consistency between the "daVinci classic" and the daVinci-S, and phantom design.

The targets were then localized ten times each with the daVinci-S surgical system. The daVinci-S data was then compared to itself and to the Optotrak data.

In comparison of the daVinci-S data to itself, first the centroid of each target was computed from the daVinci-S acquisitions. These centroids were assumed to be the actual location of the targets. The deviation in location of each measured point from its assumed actual location was then calculated and called the localization error (ϵ).

The trials were then tested for independance. The correlation matrices were computed for the inter-target and inter-trial cases. The inter-target correlation matrix was valued from 0.02 to 0.8 with a mean value of 0.38. A small number of excursions acted to skew the mean and allowed the assumption of independence to remain. The inter-trial correlation matrix was valued from 0.01 to 0.76 with a mean value of 0.25, thus demonstrated inter-trial independence.

The distribution of the errors was computed using a quantile–quantile (QQ) plot [5]. In the QQ plot the quantiles for a Maxwell–Boltzmann distribution were used as the tested hypothesis. The Maxwell–Boltzmann distribution is defined by Gaussian distributions in three normal dimensions. As localization error can occur in a three dimensional sense, a three dimensional distribution was required. The QQ plot showed that the errors fit a Maxwell–Boltzmann distribution with 99% significance.

As the error distribution is Maxwellian and there is independence in localization, the fiducial localization error (FLE) can be described as the expected value of the localization error.

The localized positions were then compared with gold standard data acquired with an Optotrak 3020. The individual daVinci trials were registered to the mean Optotrak data using a rigid point based registration method. Exhaustive combinometric combinations of fiducial and target pairs were tested. The fiducial registration error (FRE) and target registration error (TRE) were computed for each localized target [6]. The fiducial localization error was then computed from the individual FRE and TRE values [1,7].

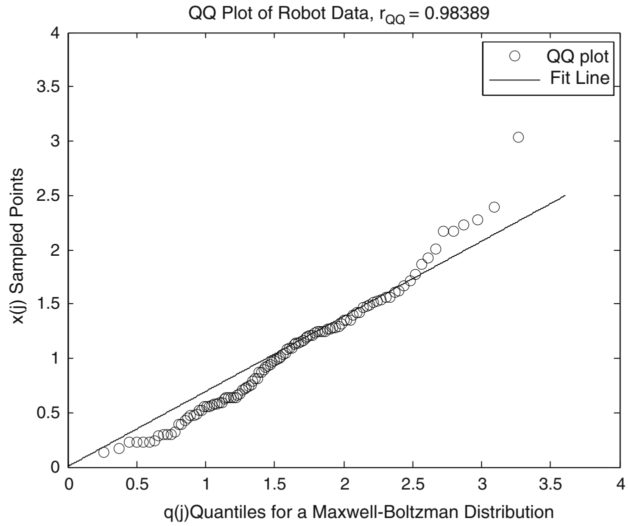

Fig. 2 Quantile-Quantile (QQ) plot demonstrating that the sampled errors come from a Maxwell-Boltzmann distribution

Results

Analysis of the acquired localizations allowed for the computation of the fiducial localization error through both inter-device and intra-device comparisons. Computation of the accuracy and precision of the daVinci-S allows for comparison of the daVinci-S system to the daVinci "classic" and to other commonly used localizer devices.

Using the intra-device computation, the localization error was shown to come from a Maxwell–Boltzmann distribution with a 99% confidence (Fig. 2). With the knowledge that the errors were normal in each direction and the assumption of sample independence the mean FLE was computed as 1.05 ± 0.24 mm.

In the inter-device error computations, the FLE was computed using both the FRE which includes only those points used in registration and TRE which includes only the points not used in registration. The computed FLE using the TRE basis was 1.25 mm. The computed FLE from the FRE was 1.31 mm.

Discussion

The ability to use the daVinci-S surgery system as a localizer in a RIGS system is largely driven by the accuracy and precision of that system. Measurement of the accuracy and precision can be established by both comparing the system to itself and to a gold standard system. In the companion work, the daVinci "classic" system is compared with other commonly used localizers for image guided surgery [1]. Comparison of the measured accuracy to other devices commonly used as localizers will allow for the characterization efficacy of the daVinci-S system as a localizer in a RIGS system.

Table 1 Comparison of mean localization error in the daVinci "classic" and daVinci-S surgical systems. The errors are reported as computed from intra-device comparison and inter-device comparison (all errors reported in millimeters)

	Internal comparison	External comparison (FRE)	External comparison (TRE)
daVinci "classic"	1.02	1.31	1.35
daVinci-S	1.05	1.31	1.25

In testing the daVinci-S system a number of functional differences from the daVinci "classic" were experienced. There is an increased tool shaft length leading to additional tool flexion, not experienced in the "classic" system. This flexion is detected and is displayed as change in the position of the last two joints. This offset has the same sign regardless of the direction the tool is flexed. Additionally the daVinci-S system has an increased inertia when the tools are clutched. This inertia makes precise positioning difficult without use of the master tool manipulators (MTM). These differences could in part contribute to the nominal increase in measured localization error over the daVinci "classic". In comparison with the daVinci "classic" system the localization errors were measured as being the same (Table 1). There is no improvement provided in localization error for the daVinci-S system. In context with other comparable localization devices; however, it was demonstrated that the accuracy of the daVinci "classic" system was acceptable for use in a RIGS system. As the measured error of the daVinci-S system is essentially the same, the daVinci-S system is also acceptable for use as a localizer in a RIGS system.

Conclusion

Implementation of a robotic image guided surgery (RIGS) system requires a robot with a high level of accuracy and precision. The accuracy and precision of the daVinci-S system was computed and compared with that of the daVinci "classic" system. The daVinci-S system was found to have an expected localization error of 1.05 mm as compared to the daVinci "classic's" expected error of 1.02 mm. The difference in localization errors is minor and thus the daVinci-S system would be appropriate to use in an RIGS system. Integration of the daVinci-S system into the ORION image guided surgery system will allow for further development of a RIGS system.

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