Introduction

The *da Vinci*® Surgical System integrates 3D endoscopy and state-of-the-art robotic technology to virtually extend the surgeon's eyes and hands into the surgical field, thus enhancing minimally-invasive access for complex surgical procedures.

The *da Vinci* Surgical System consists of an ergonomically designed surgeon's console, a patient-side cart with four interactive robotic arms, a high-performance stereo vision system and proprietary EndoWrist Instruments. The surgeon's hand movements are scaled, filtered and seamlessly translated into precise movements of the EndoWrist Instruments. The net result: an intuitive interface with breakthrough surgical capabilities.

In order to support research and further development of the *da Vinci* platform, we offer a research interface---also known as the da Vinci Application Programming Interface (API)---that allows third party developers and research collaborators to retrieve a real-time stream of kinematic and user event data from the *da Vinci* during clinical use. This data includes the motion of all master and slave manipulators, as well as a number of user events such as button and pedal activations. This data is streamed from a TCP/IP Ethernet server embedded within the robotic system, to an external research workstation. Figure 1 illustrates the main system components, including the Patient-Side Manipulators used to position the EndoWrist instruments and stereo endoscope, and the Surgeon Console that includes a stereo display and master controls used by the surgeon to maneuver the Patient-Side Manipulators.

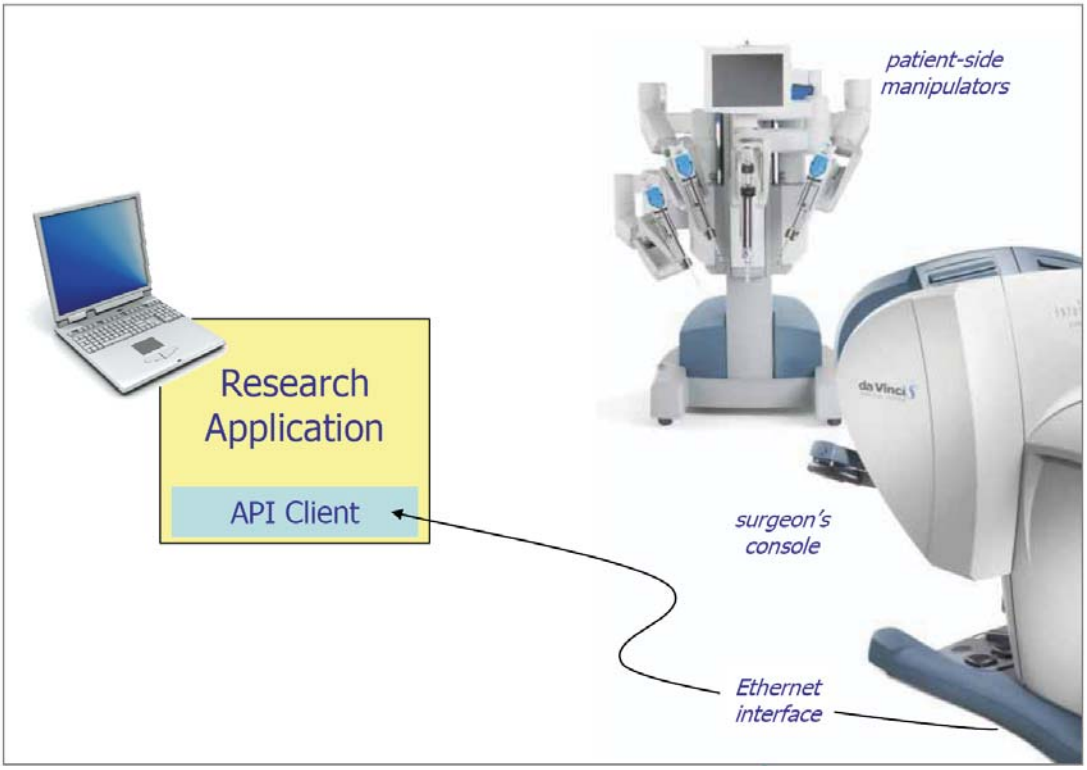

Figure 1 The da Vinci API allows researchers to obtain streaming kinematic and event data from the da Vinci Surgical System during human use.

Technical Overview

The *da Vinci* research interface is based on a TCP/IP client-server architecture, with the server residing on the *da Vinci* System and the client residing on the developer's research workstation. Communication between the server and client is facilitated by a standard Ethernet link. For obvious safety reasons, the API interface is strictly a read-only interface, meaning that kinematic information may only be read from the *da Vinci*, while the ability to effect master or slave manipulator motion---or other system state changes---is not provided by the API interface. Control commands are sent from the client to the server in order to configure, start, and stop the the data streams. This section describes the contents of the API data stream. Note that this description is intended to provide an outline of the data content, rather than a detailed technical reference.

Streaming Kinematic Data

The API data stream contains kinematic information for each of the *Patient-Side Manipulators* (PSMs), the *Endoscope Control Manipulator* (ECM), and the two *Master Manipulators* (MTMs). This information is sampled at a rate specified by the API client application (1-200Hz) and is transmitted as an asynchronous data stream.

The data stream includes the following data fields for each PSM and ECM:

- **Set-up Joint Values**: each patient-side manipulator and endoscope control manipulator is supported and positioned by a passive serial mechanism called a “set-up arm”. The angles and displacements of rotary and prismatic joints that constitute this arm are contained in this data field.
- **Manipulator Joint Values**: the angles and displacements of the manipulator's active joints.
- **Manipulator Joint Velocities**: the translational or angular velocity of each active joint.
- **Manipulator Remote Center**: the Cartesian position and orientation of the manipulator's remote center, which is determined by the pose of the manipulator's set-up arm. The remote center is reported relative to the ECM tip coordinate system.
- **Instrument Tip Pose**: the Cartesian position and orientation of the tip of the instrument attached to the manipulator. The instrument tip is reported relative to the ECM tip coordinate system. The tip of the ECM manipulator is reported relative to world coordinates, which is the base of the patient-side cart.
- **Instrument Tip Velocity**: the translational and rotational velocity of the instrument tip reported relative to the ECM tip coordinate system.

The data stream includes the following data fields for each MTM:

- **Manipulator Joint Angles**: the angles of the MTM joints.
- **Manipulator Joint Velocities**: the angular velocity of each active joint.
- **End-effector Pose**: the Cartesian position and orientation of the MTM end-effector reported relative to the eye coordinate system of the console.
- **End-effector Velocity**: the translational and rotational velocity of the MTM end-effector reported relative to the eye coordinate system of the console.

User Interface Events

In addition to the stream of kinematic information, the API interface also transmits a variety of events, triggered by user actions at the Surgeon's Console. Some of the most common events include the following:

- Head sensor trigger: the console detects the presence of the surgeon's head when he/she is looking through the display eyepiece. *Head In* and *Head Out* events are triggered and transmitted by the API server.
- Master clutch pedal pressed/released: the user has pressed/released the *Master Clutch*. pedal on the console, thus decoupling the master inputs from the slave manipulators in order to re-position the master inputs within the console workspace.
- Camera control pedal pressed/released: the user has pressed/released the *Camera Control* pedal on the console, in order to begin maneuvering the endoscope.
- Manipulator arm swap: on *da Vinci* systems with three PSMs, the user may trigger an "arm swap"—this facilitates control of three PSMs using just two master inputs.

Note: There are different types of events available from each generation of daVinci system. Please refer to the event table in the ISI API Overview for more information.

rotation matrix. All transform concatenation occurs right-to-left with column-vector matrices. Transform data obtained from the system is arranged in this manner as well.

$T = [\ t_x\ t_y\ t_z\ \ R_{11}\ R_{12}\ R_{13}\ \ R_{21}\ R_{22}\ R_{23}\ \ R_{31}\ R_{32}\ R_{33}\ ]$

da Vinci S/Si Nomenclature

Please see the figures at the end of this section.

The patient side cart (PSC) holds the passive setup joints, which in turn hold the motorized patient side manipulators (PSMs). The cart base supports the main column of the PSC. The setup joints mount to this column and slide on vertically aligned linear bearings. These are the first axis of each setup joint.

The SJA setup joints hold instrument patient-side manipulators (PSM), while the SJC setup joint holds the endoscopic camera manipulator (ECM). The base of each manipulator is the mounting surface where it attaches to the distal end of the setup joint. All patient-side manipulators are mechanically constrained remote-center devices, with a yaw-pitch-insertion design.

da Vinci S/Si Joint Definitions

For SJA setup joints, the first joint is prismatic (linear bearing), and the remaining four joints proceed distally in the obvious serial configuration.

For SJC setup joints, the first joint is prismatic (linear bearing), and the remaining three joints proceed distally in the obvious serial configuration.

For the PSM, the joints are ordered and labeled as follows. Note that motors five, six and seven are coupled nontrivially with joints 5, 6, and 7.

Setup Arms:
For PSM 1,2: known as SJA: 1 prismatic + 3 rotary setup joints (see SJA table below)
For PSM 3: known as SJX: 1 prismatic + 4 rotary setup joints (see SJX table below)
For ECM: known as SJC: 1 prismatic +3 rotary setup joints (see SJC table below)

PSM Joint	Joint type	Description
1	1	Outer Yaw or OY. This is the only joint that moves the entire PSM with respect to its mounting base. It pivots the tower about the remote center. Home position (zero joint-angle) is center range of motion, which makes the insertion axis perpendicular to the PSM mounting plate.
2	1	Outer Pitch or OP. This is the other DOF that pivots the tower about the remote center. Home position (zero joint-angle) is chose to make the insertion axis perpendicular to the PSM mounting plate, which it turns out is not quite center range of motion,
3	2	Insertion or IO. This axis moves the instrument along the axis of its shaft into or out of the patient. Home position (zero joint angle) is fully retracted.
4	1	Roll. This axis rolls the instrument shaft. Home position (zero joint-angle) is center range of motion.
5	1	Wrist Pitch or WP. This axis is the first (less distal) axis on the wrist mechanism (for standard 8mm instruments). Anthropomorphic to a human wrist knocking on a door. DaVinci does not home with instruments installed, so home is not defined in motor space. However, the zero joint-angle corresponds to a straight wrist.
6	1	Wrist Yaw or WY. This axis is the second (more distal) axis on the wrist mechanism (for standard 8mm instruments). Anthropomorphic to a human wrist wiping a surface. It is a coordinated motion of two mechanical joints representing the two grippers. DaVinci does not home with instruments installed, so home is not defined for instruments. However, the zero joint-angle corresponds to a straight wrist.
7	1	Grip. This joint axis is simply a different linear combination of the same two mechanical joints as WY.

For the ECM, the joints are qualitatively the same as the first 4 joints of the PSM.

da Vinci S/Si Parametric Data

All translation values are in meters and angles are in radians.

PSM1

Setup transform from world origin (frame F_0) to origin of SJA1:
T = [-0.2019, -0.0757, 0, –1, 0, 0, 0, –1, 0, 0, 0, 1]

DH parameters from origin of SJA1 to tip of SJA1:

Frame	Joint type	a	α	d	θ
1	2	0	0	0.1471	0
2	1	0	0	0.6654	0
3	1	0.4572	0	0.1397	0
4	1	0.4572	0	-0.1301	0
5	1	0.0490	$\pi/2$	0	$-\pi/4$
6	0	0	$-\pi/2$	0	0

Setup transform from tip of SJA1 to origin of PSM1:

da Vinci S/Si Diagrams

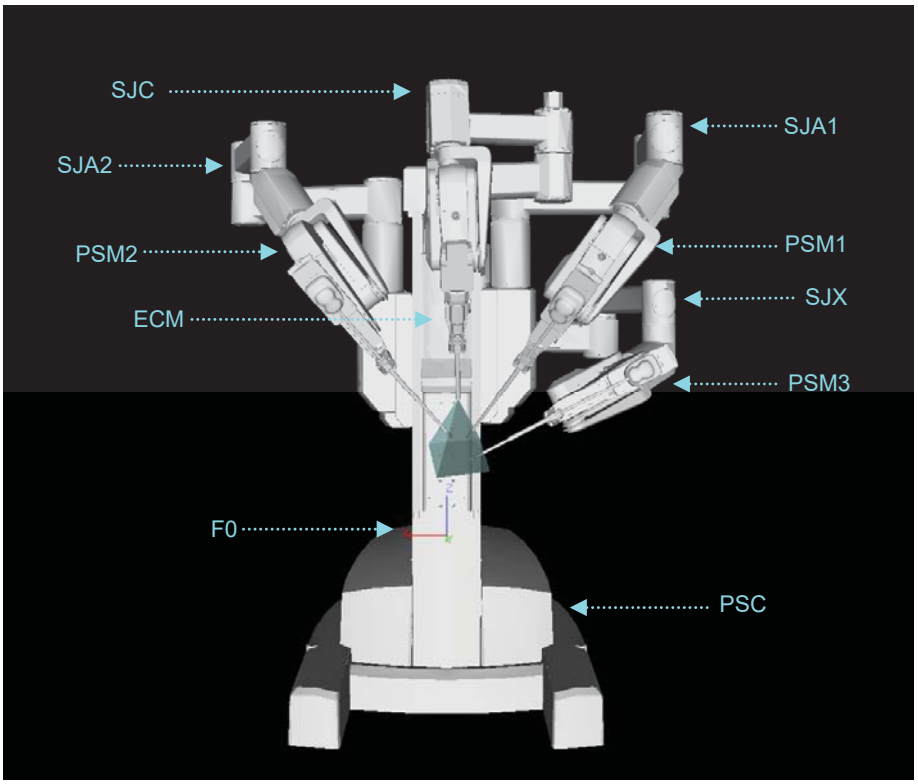

Figure 3 Front view of da Vinci-S PSC in typical surgical pose

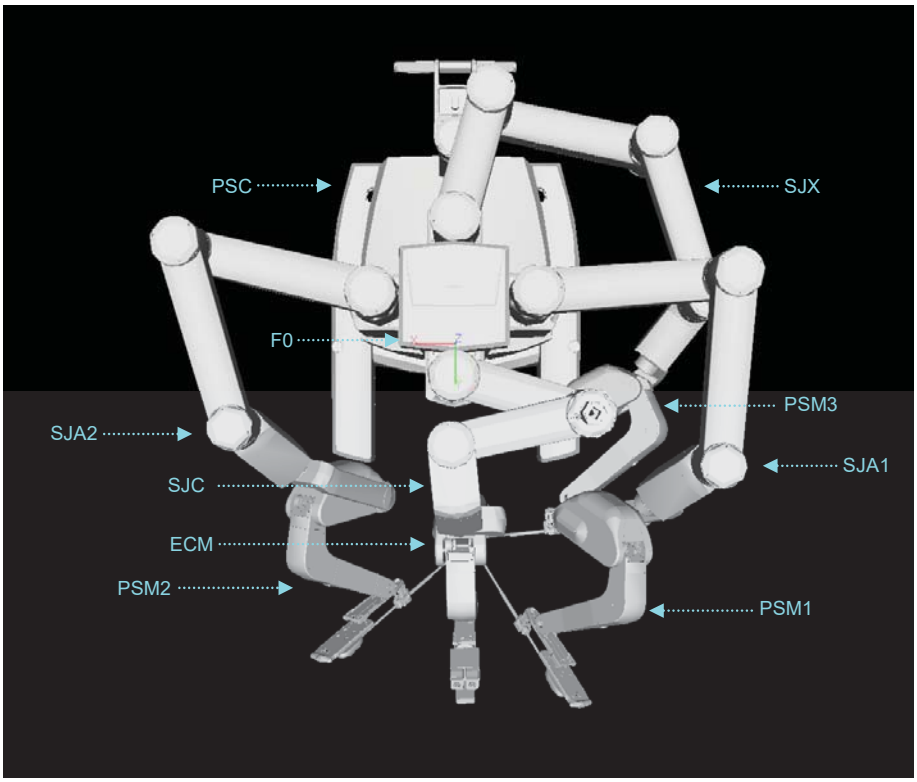

Figure 4 Top view of da Vinci-S PSC in typical surgical pose

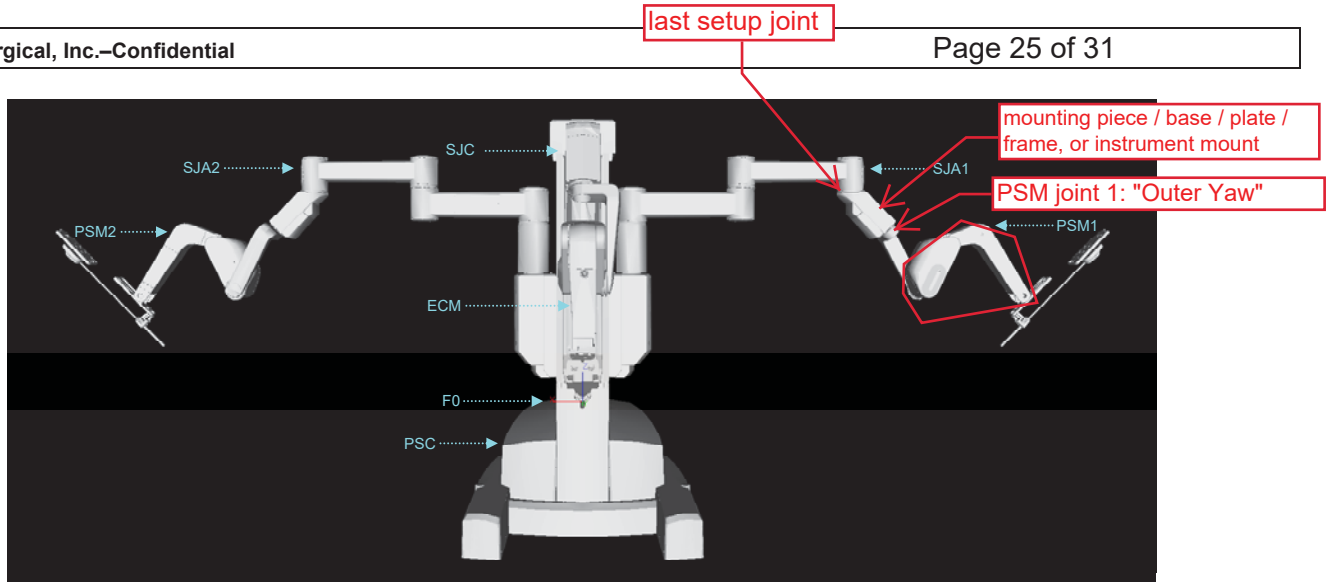

Figure 5 Front view of da Vinci-S PSC in zero joint value pose

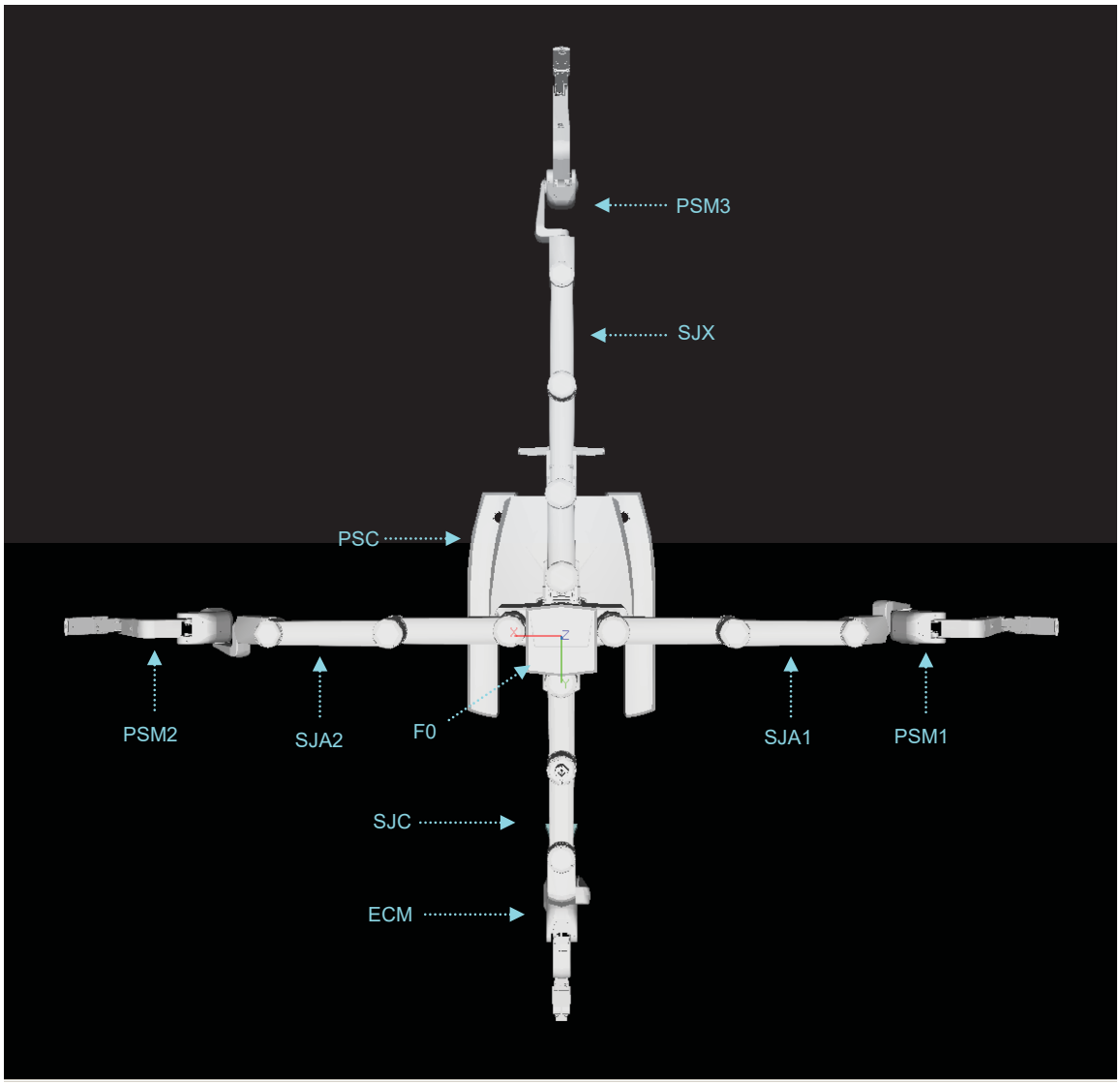

Figure 6 Top view of da Vinci-S PSC in zero joint value pose

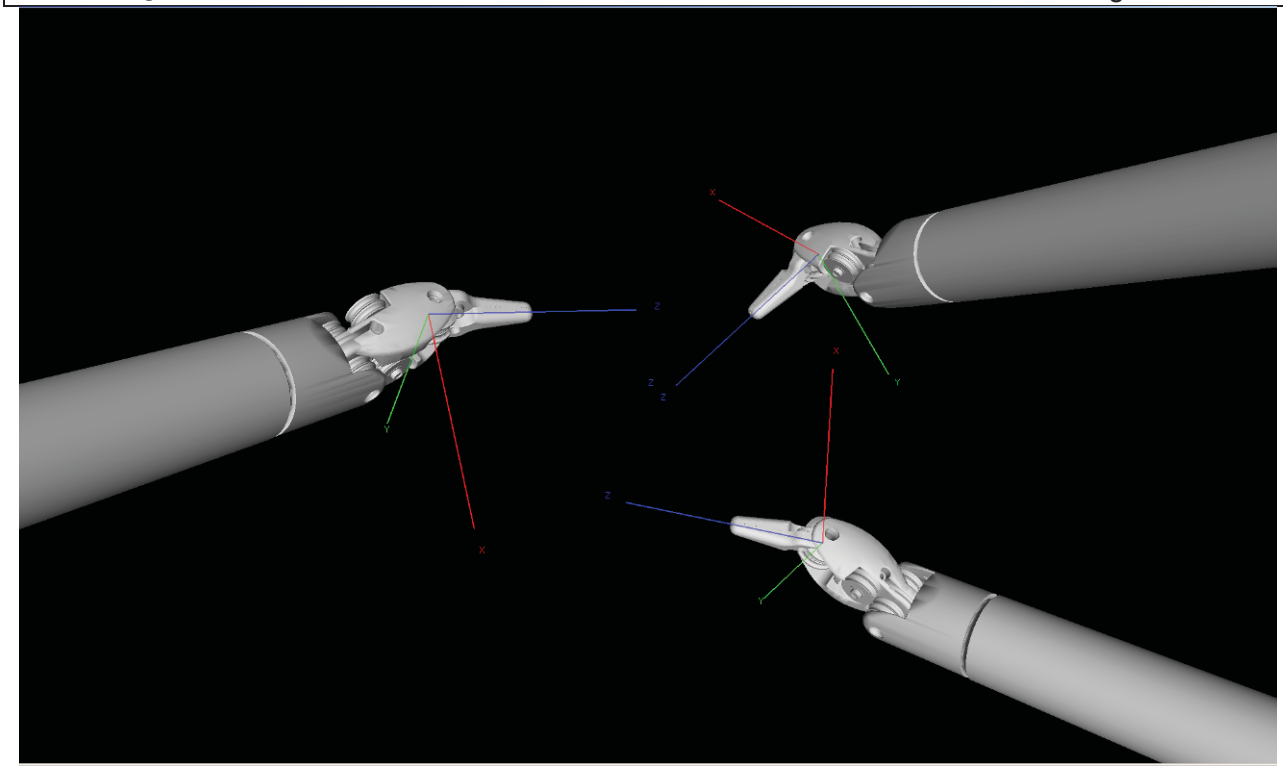

Figure 7 da Vinci Instruments as viewed by ECM with control point coordinate frames displayed. Note that the Z axis (blue) of the tip frame is aligned with the instrument pointing direction and the Y axis (green) is aligned with the jaw open/close axis.

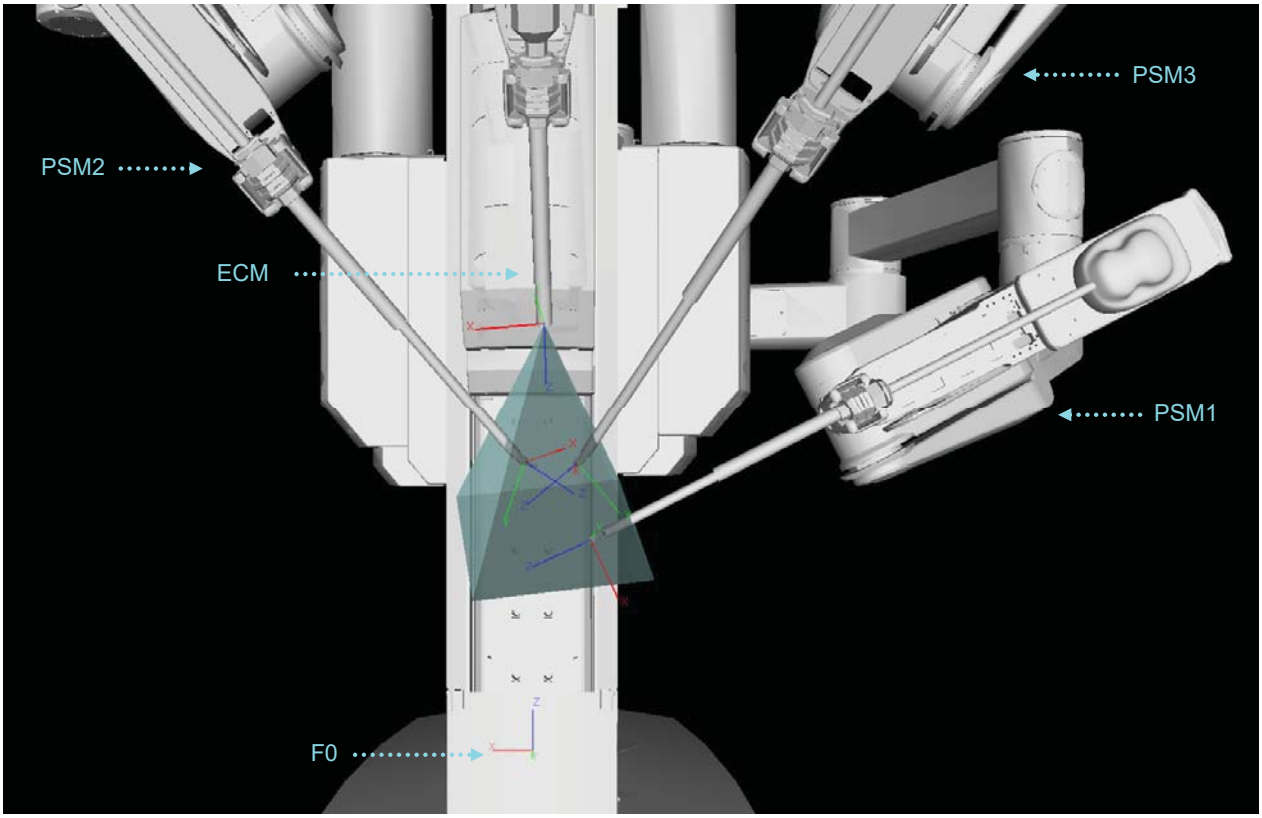

Figure 8 da Vinci Instruments positioned within rendered endoscope view volume. Note the Y axis (green) of the endoscope tip frame points upwards in the view and the Z axis (blue) points into the view.

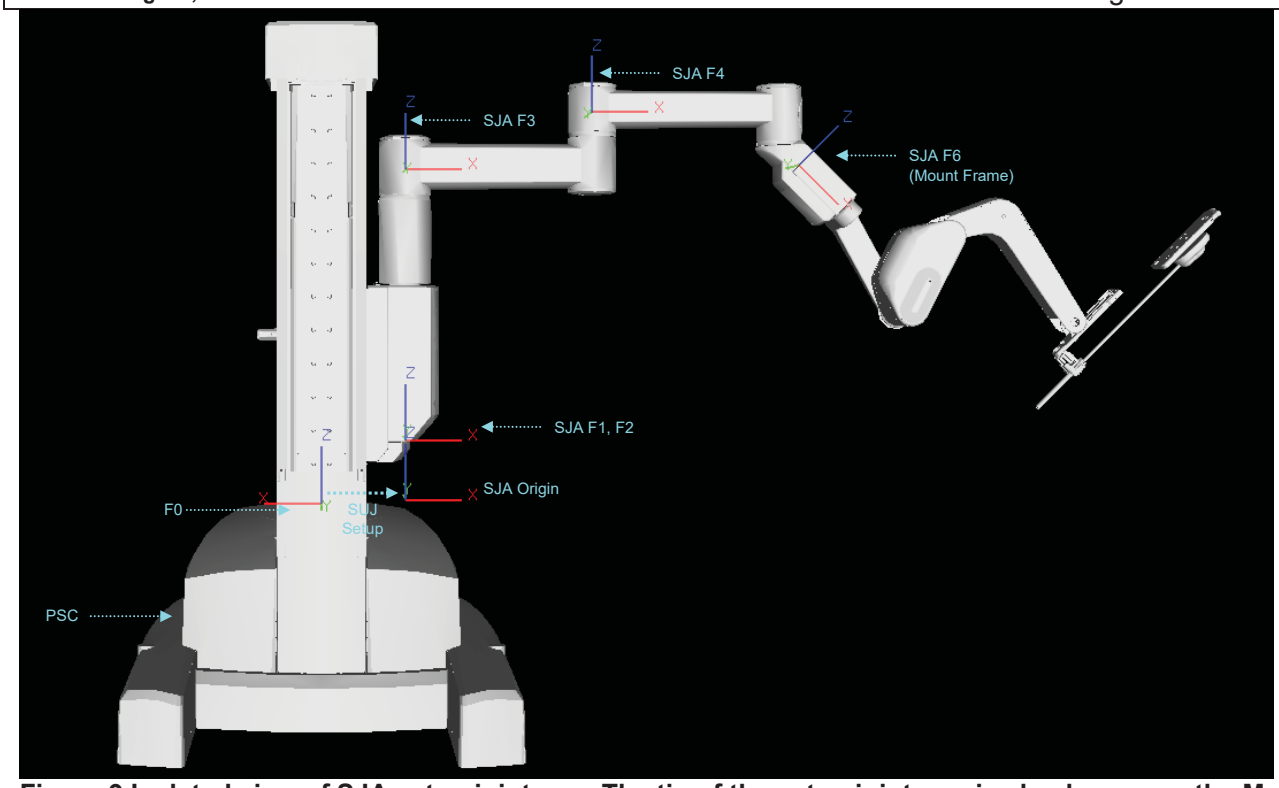

Figure 9 Isolated view of SJA setup joint arm. The tip of the setup joint arm is also known as the Mount Frame.

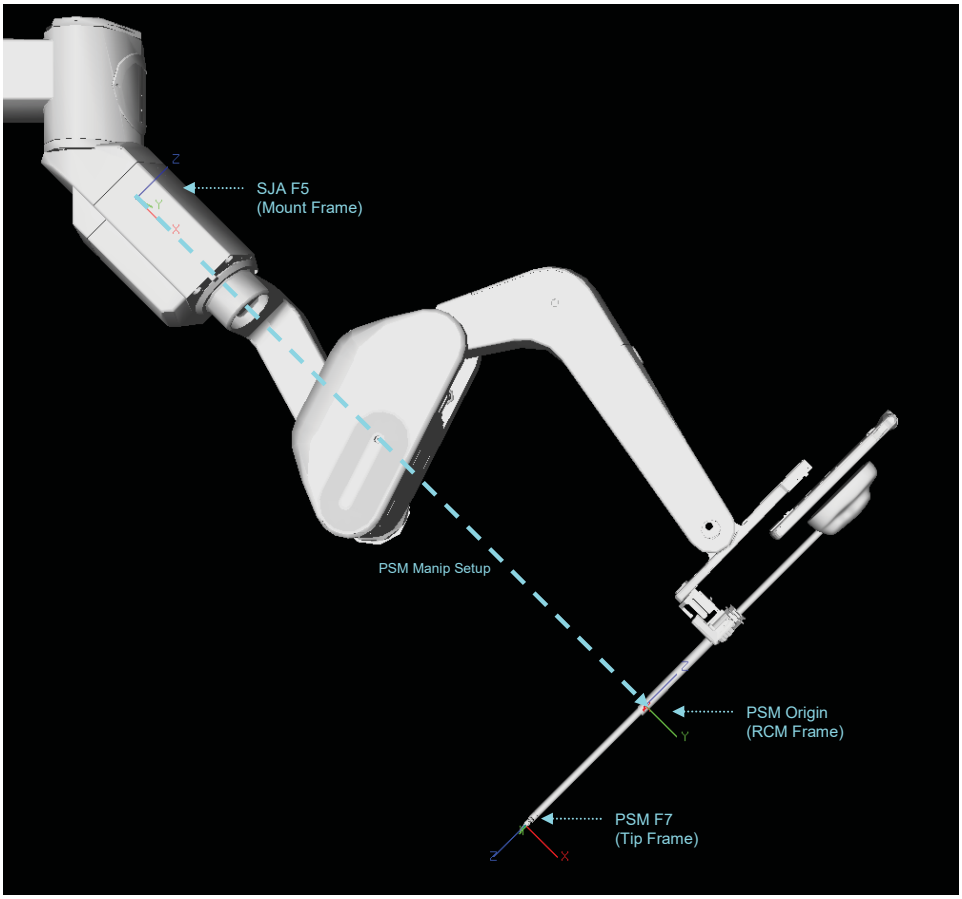

Figure 10 Isolated view of PSM showing setup transform between Mount Frame and PSM origin, also known as the RCM frame.