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CONSISTENCY STUDY OF POSITION TRACKER FOR ULTRASOUND IMAGING

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ABSTRACT

This paper presents a hybrid-manipulator position tracking system for ultrasound imaging and a consistency study of the tracker system. The aim of the study is to see the consistency and accuracy of the proposed position tracker in order to apply it in ultrasound imaging. The experiment is performed by using ABB Robot as the reference path where the position tracker is attached as end effector to an ABB Robot. The ABB Robot is programmed to move in linear direction and the experiment is repeated for five times. The result showed that, each joint gives consistent reading for all experiments. However, there is a small vibration on the Z-axis data and inaccuracy of the reading for X-Y axis, due to the structural damping effect and inconsistency of the inertial measurement unit (IMU) sensor. The consistency proved the capability of the position tracker to give consistent positional data without any mechanical or interference problems, hence possible to be used in ultrasound imaging.

***Keywords**: position tracking system; ultrasound imaging; consistency study; ABB Robot arm*

1.0 INTRODUCTION

Position tracking system has been greatly developed for decades [1-3]. It has been used in many fields and gives enormous advantage, either stand alone for its own tracking purposes or for supporting other devices in data localization. By definition, the objective of a position tracking system is generally intended for object observation in term of location and movement recorded in an extent of time by measuring position and orientation in both virtual and real worlds, characterized by data acquisition, precision, working range, and degree-of-freedom (DOF), depending on the nature of the system and applications. With the capability in localizing the object's specific position and identifying the motion, position tracking system has played a big role in many important applications, such as aeronautics and transport system [4, 5], military [6, 7], telecommunication [8, 9], remote sensing [10], robotics and mechanical engineering [11, 12], biology and medicine [13, 14], sport and entertainment [15, 16], and so on.

Focusing on biology and medicine fields, position tracking system have been applied, from tracking human motion and posture, up to tracking important medical tools such as surgical instruments. In biology, position tracking system mostly used for supporting cellular imaging technology for miniscule object observation [17, 18]. On the other hand, for medical field, the application is much wider, ranging from diagnostics [19-21], image-guided navigation system for therapeutic, intervention, and surgical assistance [22-24], and rehabilitation medicine [25-27].

In medical imaging fields, ultrasound imaging is one of the image modalities which in need of the position tracking system for its clinical applications, either non-invasive or invasive clinical treatments. Ultrasound imaging has several advantages over the other image modalities in terms of non-radiation exposure, real-time, low-cost, high mobility, and ease to apply in scores of clinical environments. But, despite all the advantages, ultrasound probe has limitations during diagnosis and treatments. The freehand uniqueness of the ultrasound probe which enables the operator to sweep the ultrasound probe and grab the image based on the surface contour of the body directly to the specific region of the interest, largely requires operator's skills itself. Unskilled operators need to really understand the anatomy structure of the scanned location thus inquire longer time to get correct image. Meanwhile, skilled operators can easily find the exact location faster and obtained better images. Such work is often time consuming and has higher error risks that may affect the diagnosis or treatment results. Besides that, ultrasound imaging also has narrow field of view which hamper the accuracy of the diagnosis and treatment. Hence, an extended view technique is used to enlarge the field of view.

1.1 Position Tracking for Ultrasound Imaging

In general, there are varieties of position tracking technologies developed until now, but not all of the tracking devices can simply be used in ultrasound imaging. This is due to the limitation, advantages and disadvantages of each tracking device which limits the compatibility with the ultrasound imaging devices. There are two types of commercially available tracking systems used to track the probe position for ultrasound imaging which are optical tracking system and electromagnetic system [28, 29]. However, both tracking systems suffers from some disadvantages. Electromagnetic tracking system suffers from magnetic interference from surrounding metals which will affect the system accuracy. On the other hand, the optical tracking system suffers from occlusion problems [30].

In 2008, Goldsmith *et. al.* [31] proposed a combination of optical mouse and MEMs inertial sensor as a tracking system for ultrasound imaging. The system track the translation of the probe using the optical registration from the optical mouse sensor by evaluating the skin surface and the inertial sensor will track the orientation of the probe [32]. The system has the advantage of compact size and mobility but lack of vertical translation tracking capability since the optical mouse sensor only provide horizontal translational tracking data. Then, Phillip *et. al.* proposed a tracking device using the combination of accelerometer sensor from Nintendo WiiMote and dual-optical mouse [33]. The system is quite similar to the one proposed by [31] but it differs by its dual-optical mouse tracking system thus having the same drawback issues. Meanwhile, Huang *et. al.* came out with a linear sweeping tracking mechanism [34]. Instead of using full six degree-of-freedom (DOF) tracking system, this system uses only one DOF which is robust to translational and rotational error. Since the system is produced using one DOF movement, it is not suitable for curvy surface such as spine or pregnancy scanning.

Hence, this paper proposed a new approach for position tracking in ultrasound imaging using hybrid inertial-manipulator based tracking system for multi degrees of freedom. This system will overcome the occlusion and magnetic interference problem suffered by optical and electromagnetic tracking system since the system will not use any camera or electromagnetic tracking technology. This will result in an easier scanning procedure, more accurate and comprehensive results. This progression has brought the ultrasound imaging system become more accurate, interactive, multidimensional, and ubiquitous with other systems. This paper will focus on the consistency study of the output data of the tracker by moving in one direction using robot arm as the reference path. The remainder of the paper is organized as follows. In Section 2, the proposed system design is being introduced. Section 3 discussed the methodology and experimental setup for the consistency study. The result and discussion of the study is shown in Section 4. Finally, the paper concludes with a brief appraisal and future recommendation in section 5.

2.0 SYSTEM DESIGN

The proposed tracking system consists of a 4-links manipulator with 2 rotary joints, 1 spherical joint and 1 prismatic joint as shown in Figure 2. The length of each links until the end effector is shown in Figure 3. This design enables the operator to attach the ultrasound probe to the end effector and operate the probe using freehand movement since the system is a passive or haptic without any motor as shown in Figure 4. In order to calculate the position of the position tracking system, forward kinematics theory is used. In this case, Denavit-Hartenberg parameter is used for calculation of the end effector of the manipulator. Equation 1,2 and 3 show the equation for X-position, Y-position and Z-position of the system respectively. The detail of the equation is written in [35]. Consequently, Inertial Measurement Unit (IMU) sensor is used to determine the orientation of the manipulator. This sensor consists of 3-axis accelerometer and 3-axis gyroscope and embedded processor called Digital Motion Processing (DMP) for built-in signal filtering and orientation calculation.

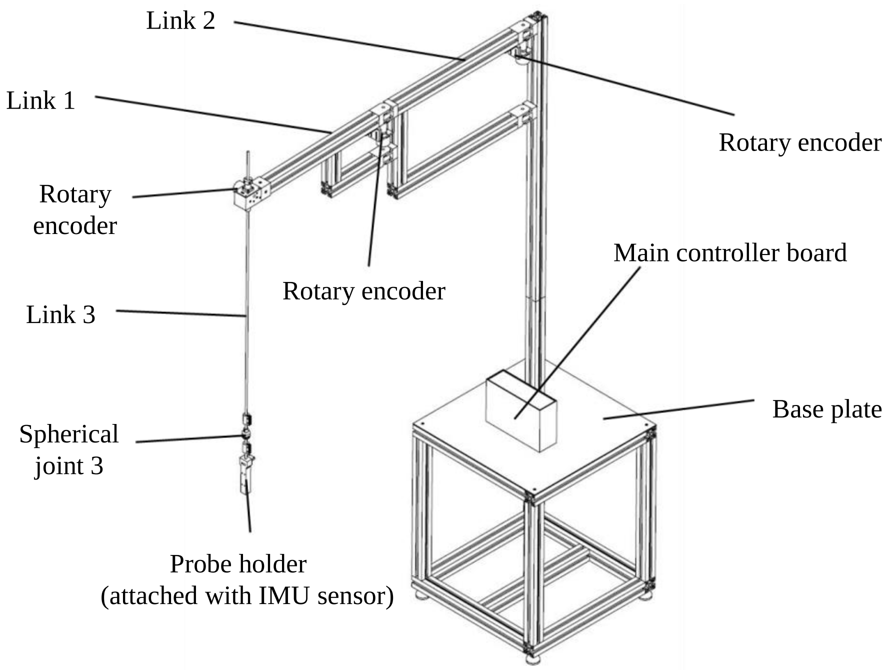

Figure 2: The proposed position tracking system

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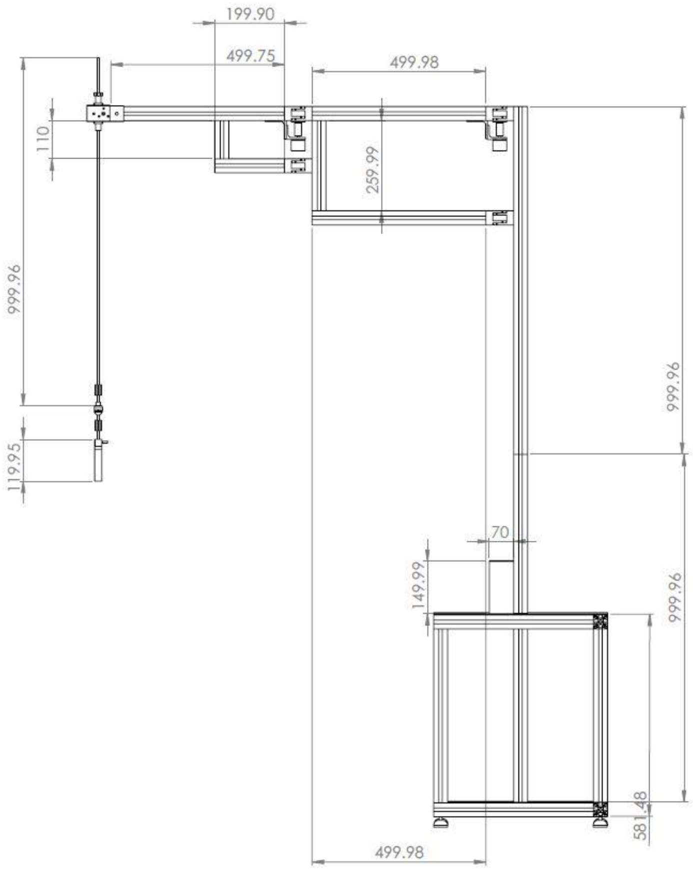

Figure 3: The length of each links from the position tracker

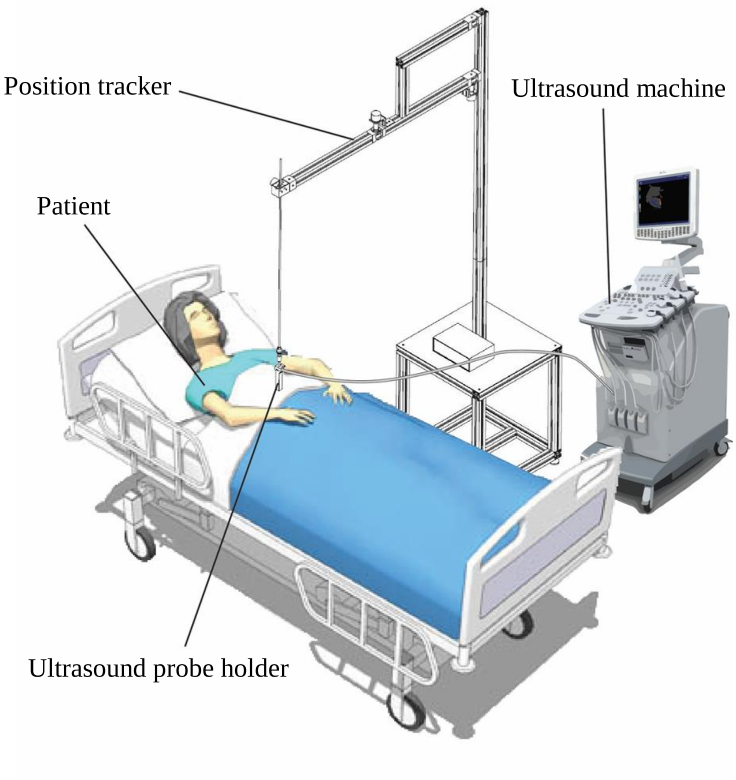

Figure 4: Position tracker attached to the ultrasound probe during scanning procedure

$$X_{pose} = d_6 cos(\theta_1 + \theta_2 + \theta_4) \sin\theta_5 + a_1 \cos\theta_1 + a_2 cos(\theta_1 + \theta_2) \quad (1)$$

$$Y_{pose} = d_6 \sin(\theta_1 + \theta_2 + \theta_4) \sin\theta_5 + a_1 \sin\theta_1 + a_2 \sin(\theta_1 + \theta_2) \quad (2)$$

$$Z_{pose} = -d_6 \cos\theta_5 + d_3 \quad (3)$$

where a_i is the link length, d_i is the link offset and θ_1 is the joint angle.

3.0 METHODOLOGY

In order to evaluate the consistency of the position tracker, a well-established robot arm (ABB Robot variant IRB120) is used rather than a human hand in order to produce precise motions and trajectories. The ABB Robot is used as the reference motion path to the position tracker where the robot arm's base frame coordinates were used as the standard reference point. Table 1 shows the specification and accuracy of the ABB Robot. The end effector of the position tracker is mounted onto the ABB Robot using a pneumatic gripper and the robot arm is moved in the predefined direction. The motion path including starting point and ending point of the experiment is predefined and programmed in the ABB Robot. Figure 5 and 6 show the experimental setup, starting and ending point of the experiment's motion path, the ABB Robot and controller used in the experiment.

Table 1: Specification of ABB Robot arm used in the experiment

Variants	**IRB120-3/0.6**	
Controllers	**IRC5 Compact**	**IRC5 Single Cabinet**
Axis movements	Axis 1 Rotation	+165 to -165
	Axis 2 Arm	+110 to -110
	Axis 3 Arm	+70 to -110
	Axis 4 Wrist	+160 to -160
	Axis 5 Bend	+120 to -120
	Axis 6 Turn	+400 to -400
Weight	25kg	
Acceleration time 0-1m/s	0.07s	
Height	700 mm	
Reach	580 mm	

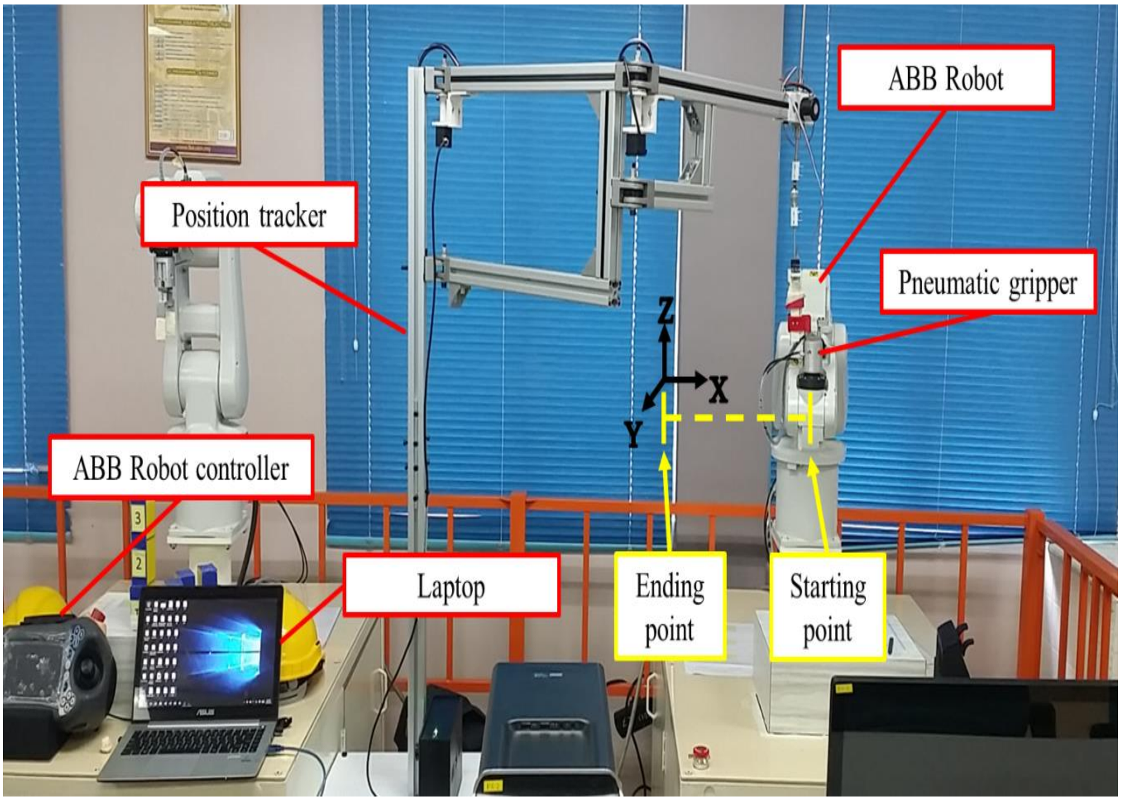

Figure 5: Experimental setup and starting/ending point of the ABB Robot

Figure 6: ABB Robot's controller (left) and ABB Robot main body (right)

For this experiment, a simple linear movement which mimic the simple sweeping movement used in one of the 3D-ultrasound scanning method is used for evaluation [36]. The ABB Robot is programmed to move in a linear line between starting and ending point in one degree-of-freedom movement. The length of the motion path is 20cm. The ABB Robot is programmed to move at 80mm/s and the experiment is repeated for 5 times. Thus, the consistency of the tracker can be evaluated by calculating the means and standard deviation. Section 4 shows the results of the experiment.

4.0 RESULT AND DISCUSSION

In this study, the important criteria to be evaluated is the accuracy and consistency of the position tracker. The experiment methodology and setup is based on experimental evaluation done by [37]. As mentioned in section 3.0, the position tracker which attached to the ABB Robot is programmed to move linearly from starting point (0,0,0) to the ending point (20,0,0) and the experiment is repeated 5 times in order to evaluate consistency of the position tracker.

The 3D plot of the trajectory measurement is shown in Figure 7. The red line represents the actual movement of the ABB Robot during the experiment. The Z-axis trajectory data for each reading fluctuated between the ranges of -0.033mm to 0.097mm. This is due to the small structural vibration from the third link of the tracker which affected the reading.

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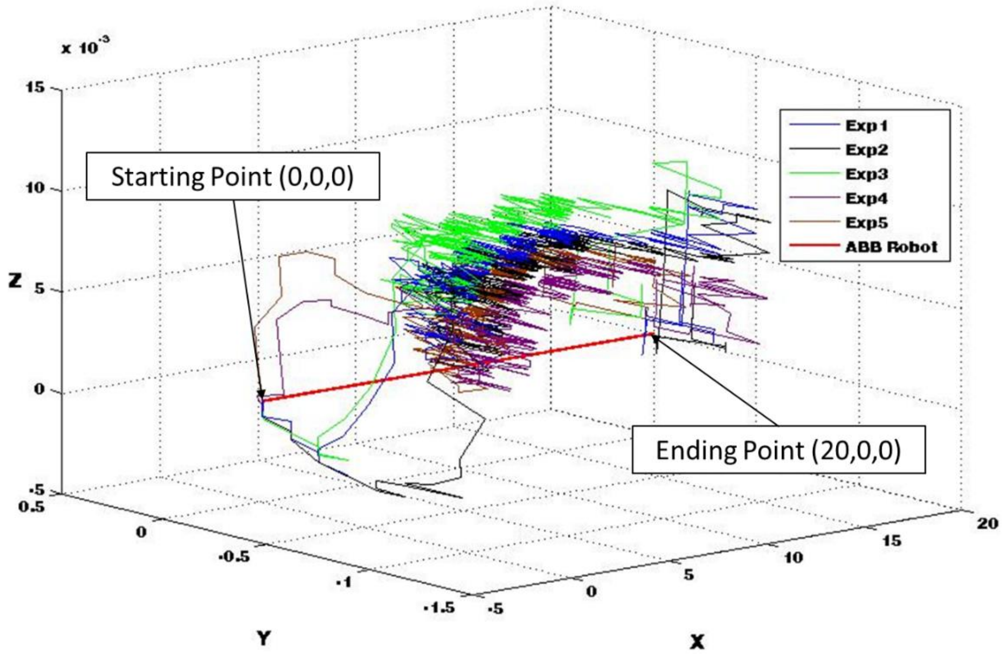

Figure 7: Trajectory of the position tracker

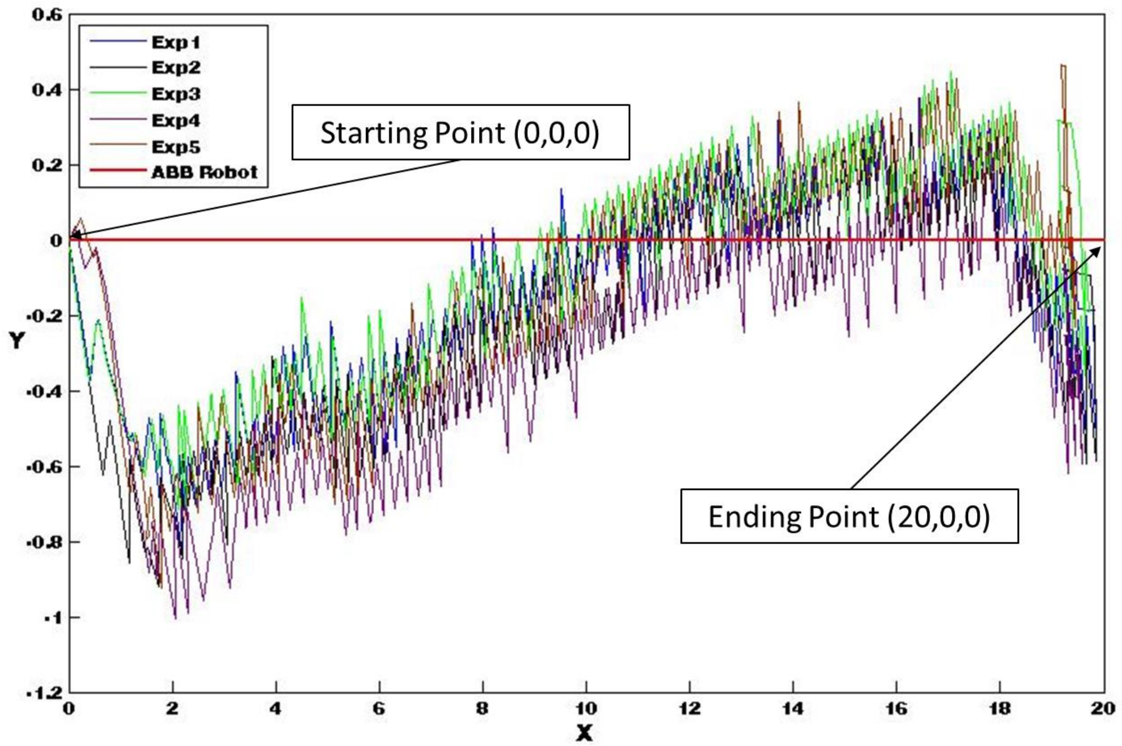

Figure 8: X-Y axis view of the trajectory

Figure 8 shows the X-Y axis view of the same trajectory measurement. The X-axis trajectory data ranged between -0.041mm to 19.85cm, on the other hand, Y-axis trajectory data ranged between -1.006cm to 4.676mm. For X-axis trajectory data, the reason for inaccuracy in the reading is because of the joint flexibility which affecting the encoder readings from link 1 and 2 [38, 39]. Likewise, the same reason happened to the inaccuracy of the reading for Y-axis. In addition to that, the inconsistent reading from IMU sensor also affecting the Y-axis output [40, 41].

Table 2 shows the mean, standard deviation and mean-squared error for each experiment. Each experiment has different total number of sampling data due to the inconsistency of the data acquisition rate from the micro-controller to the computer. The total sampling ranged from 655 to 763. The mean for each experiment are between -0.19 to 0.01, meanwhile the standard deviation varies from 0.183 to 0.245. Experiment 4 has the highest mean-squared error (MSE) with the value of 0.09, meanwhile experiment 1 has the lowest mean-squared error with the value of 0.05.

Table 2: Mean, standard deviation and mean-squared error for each experiment

Experiment	Total number of sampling data	Mean	Standard deviation	Mean-squared error (MSE)
1	763	-0.12	0.18	0.05
2	707	-0.17	0.20	0.07
3	680	0.01	0.20	0.04
4	721	-0.19	0.23	0.09
5	655	0.00	0.25	0.06

Table 3: Means and standard deviation of each joints for each experiment

	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Joint 1 (Means ± Std)	-29.61 ± 6.96	-29.66 ± 6.88	-30.53 ± 6.94	-30.39 ± 6.94	-29.79 ± 6.95
Joint 2 (Means ± Std)	67.88 ± 14.78	67.56 ± 14.59	69.12 ± 14.52	68.72 ± 14.72	67.19 ± 14.46
Joint 3 (Means ± Std)	2.32 ± 0.002	2.32 ± 0.002	2.32 ± 0.002	2.32 ± 0.002	2.32 ± 0.002
Joint 4 (Means ± Std)	-30.75 ± 0.11	-31.28 ± 0.10	-31.32 ± 0.18	-31.74 ± 0.10	-33.09 ± 0.07
Joint 5 (Means ± Std)	-1.17 ± 0.36	-1.2 ± 0.36	-1.22 ± 0.41	-0.74 ± 0.40	-0.89 ± 0.35
Joint 6 (Means ± Std)	0.52 ± 0.27	0.6 ± 0.28	0.62 ± 0.27	0.99 ± 0.29	1.28 ± 0.26

Table 3 shows the means and standard deviation of each joints in each experiment. Joint 2 have highest standard deviation among all the joint, while joint 1 is the second highest. Nevertheless, this value could be neglected because joint 1 and 2 are both moving in this experiment whereas the other 4 joints are left static. Thus, the standard deviation supposed to be higher in both joints. Joint 3 until joint 6 are supposed to have 0 standard deviation since all of the joints are not moving, but due to the small vibration of ABB Robot's motor, the reading varies from starting point to the ending point. Overall, each joint showed consistency in the reading for each experiment. This shows the capability of the position tracker to give consistent positional data without any interference problems, hence possible to be used in ultrasound imaging.

5.0 CONCLUSION

This paper presented the proposed hybrid-manipulator based position tracking system for ultrasound imaging and the consistency study of the tracker by using ABB Robot as the reference path. The position tracker is attached to the ABB Robot which is programmed to move linearly in one direction and the experiment is repeated 5 times in order to evaluate consistency of the position tracker. The result shows that there is small vibration on the Z-axis data during the experiment. For X-Y axis, there are inaccuracy of the reading due to the structural damping effect from link 1 and 2, and also the inconsistency of the IMU sensor on joint 4. Overall, each joint and each reading showed consistency for each experiment which proved the capability of the position tracker to give consistent positional data without any mechanical or interference problems, hence possible to be used in ultrasound imaging. This experiment can be further investigated for different directions and orientations.

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