

Short thesis for the degree of doctor of philosophy (PhD)

**ADVANCED MOTION CONTROL IN ROBOTIC PATIENT
POSITIONING SYSTEM FOR BRAIN CANCER
RADIOSURGERY**

by

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ABSTRACT

Radiosurgery is essential in treating brain cancer, demanding high precision to target tumors effectively while minimizing damage to surrounding healthy tissues. This research enhances the precision and safety of radiosurgery using an advanced Robotic Patient Positioning System (PPS). The study addresses several key challenges, including precise radiation targeting, patient fixation, and the integration of a patient positioning bed with six degrees of freedom.

Our primary research questions focus on achieving 0.1 mm accuracy in patient positioning, developing solutions to overcome mechanical backlash, implementing multi-layered safety protocols in both hardware and software, and reducing radiation exposure to healthy tissues. Through detailed kinematics studies, advanced motion control strategies, and robust safety protocols, our innovative system aims to significantly improve the accuracy and reliability of radiosurgery.

The research employs a comprehensive approach, starting with kinematic model development and validation to ensure precise calculations of bed movements. Advanced algorithms address potential mechanical issues such as backlash. The dual-loop control systems enhance motor movement precision, ensuring sub-millimeter accuracy required for effective radiosurgery.

Safety is paramount in this research. Multi-layered safety protocols monitor and control the system in real-time, integrating hardware and software safety measures. The system incorporates real-time monitoring using high-resolution tracking to continuously verify patient position and orientation.

The findings demonstrate that integrating the patient positioning bed as a subsystem achieves the desired precision and stability for effective treatment. Additionally, multi-layered safety protocols ensure accuracy enhancements do not compromise timing and efficiency. The advanced safety measures significantly reduce the risk of radiation exposure to healthy tissues, minimizing side effects.

In conclusion, this state-of-the-art robotic positioning system represents a significant advancement in radiosurgery, offering improved outcomes and reduced side effects for patients undergoing brain cancer treatment. This research provides a novel approach to enhancing the precision and safety of radiosurgery, setting a new standard for future developments in this field.

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Introduction

2.1 Background

Brain cancer is a serious health issue that needs better treatment options. This research focuses on the Patient Positioning System (PPS), which helps position patients very accurately during treatment. The PPS can achieve precision up to 0.1 mm, ensuring that the tumor is targeted effectively while minimizing damage to healthy tissues. This accuracy is crucial for improving treatment success.

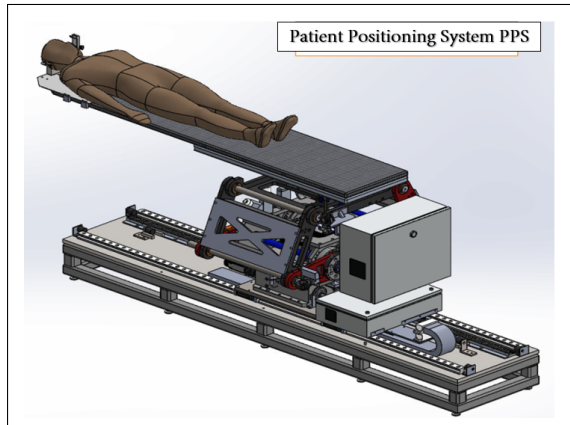


Figure 2.1: The Spinotron System

2.2 Significance of the Research

The PPS, pending patent approval, aims for 0.1mm precision in Stereotactic Radiosurgery (SRS). This study evaluates its kinematics and control mechanisms to ensure high precision and safety.

2.3 Problem Statement

Achieving 0.1mm accuracy in the PPS is challenging due to its complex mechanisms, precision requirements, advanced motion control, and safety standards. This dissertation addresses these challenges to optimize the PPS for SRS treatments.

2.4 Objectives

The main objectives are:

1. Conduct a kinematic study of the PPS.

2. Examine control algorithms for single-loop and dual-loop systems to achieve 0.1mm accuracy.
3. Validate findings through testing and measurements.

2.5 Scope

This dissertation focuses on the kinematic properties and control mechanisms of the PPS, using MATLAB simulations, CAD models, and real-world testing with the OptiTrack system to validate performance.

2.6 Research Gap

Despite advancements in SRS, detailed studies on PPS kinematics and control mechanisms are lacking. This dissertation aims to fill this gap, focusing on safety, effectiveness, and regulatory standards.

2.7 Methodology Overview

- **Kinematic Analysis:** Develop a MATLAB model to understand the motion characteristics of the PPS.
- **Control Systems Analysis:** Evaluate control algorithms in single-loop and dual-loop systems.
- **Measurement and Validation:** Use MATLAB simulations, CAD models, and the OptiTrack system for validation.
- **Comparative Analysis:** Compare simulation and real-world test results to validate performance.

2.8 Organization of the Dissertation

The dissertation is structured into the following chapters:

- **Chapter 2: Thesis I:** Optimizing Range of Motion in SRS.
- **Chapter 3: Thesis II:** Accurate Robotic Patient Positioning.
- **Chapter 4: Thesis III:** Geometric Approach to Inverse Kinematics.
- **Chapter 5: Thesis IV:** Advanced Motion Control in PPS.
- **Chapter 6: Thesis VI:** Developing Robust Safety Protocols for Radiosurgery within Patient Positioning System Framework.

This dissertation aims to fill gaps in existing research and provide insights for future interdisciplinary collaborations in SRS.

Thesis I

Optimizing Range of Motion in Stereotactic Radiosurgery: A Comprehensive Analysis of the Patient Positioning System Design

Related Publications [P1, P3, P4, P6]

This thesis demonstrates that the Patient Positioning System (PPS) is a highly sophisticated system designed for precise patient positioning in stereotactic radiosurgery. The PPS exhibits a robust and expansive range of motion (ROM), which, combined with advanced kinematic analysis and visualization, validates its effectiveness in clinical applications. Optimizations have significantly expanded the workspace for all three axes, particularly enhancing the workspace on the X-axis and Roll. These improvements not only increase precision for brain cancer treatment but also enable the possibility of treating other types of cancer with greater accuracy and flexibility. These advancements clearly demonstrate the PPS's capability to provide precise and reliable patient positioning, ensuring accurate delivery of radiation for effective treatment outcomes.

3.1 Patient Positioning System Characteristics

The PPS is a 6-degree-of-freedom (DOF) robotic patient bed, engineered for precise patient positioning. It aligns clinical targets with the Mechanical Isocenter (MIC), ensuring accurate radiation delivery. The PPS comprises three key elements: a Linear Rail System, a Linkage System, and a Tabletop.

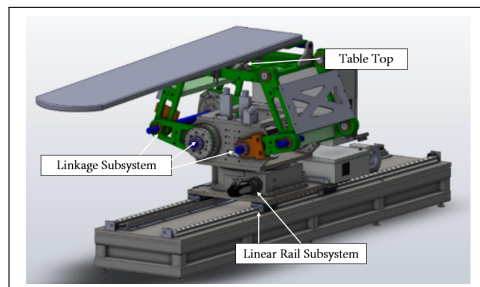


Figure 3.1: Patient Positioning Table (PPT) Subsystems

3.1.1 Design Overview

An overview of the key components and design choices of the PPS.

The Linear Rail System

Controls movement across two axes, maneuvering the main plate in relation to the bottom base plate along a rail system. This linear motion capability allows for flexible patient positioning.

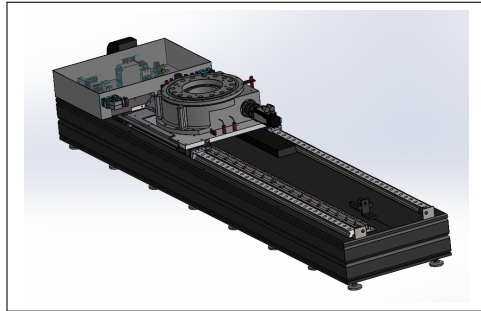


Figure 3.2: Linear Rail System

The Linkage System

Includes four linkage arms (three active, one passive), connected to a stationary weldment. The active arms, driven by three motors, facilitate 2D motion and offer a large envelope size. The system can adjust to varying heights for different patient needs.

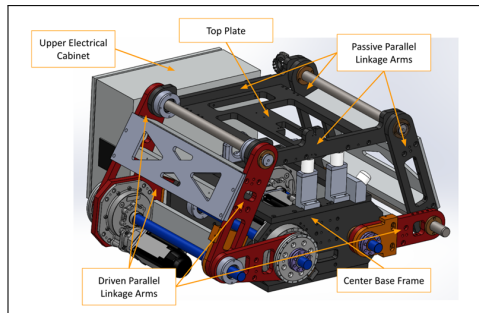


Figure 3.3: Linkage Major Components

Tabletop

Enables pitching movements via a helical cam following system, driven by a servo motor.

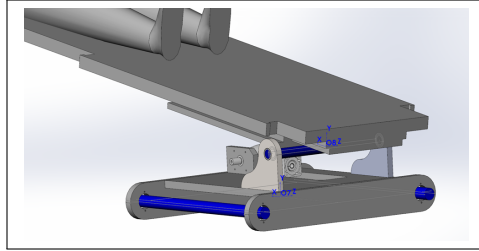


Figure 3.4: Table Top Pitching Axis

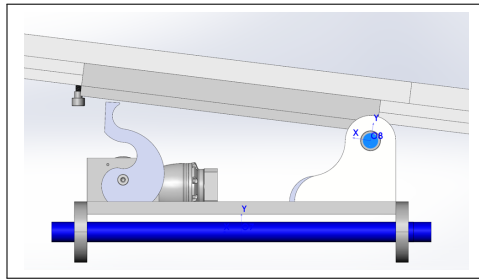


Figure 3.5: Side view of Pitching Helical Cam

3.2 Patient Positioning System Coordinate System

The origin of the coordinate system coincides with the Mechanical Isocenter (MIC). A description of each axis is shown in Table 3.1.

Note: In our frame visualizations, the axes are color-coded:

- **X-axis** is Red (R).
- **Y-axis** is Green (G).
- **Z-axis** is Blue (B).

3.3 Range of Motion

The ROM is essential for understanding the system's versatility, ensuring patient comfort and precision during procedures, especially for minute adjustments like tumor misalignment.

Table 3.1: PPS Coordinate System

Axis	Description
X	Left and Right
Y	Up and Down
Z	Along the patient axis
Roll	Rotation about Z axis
Pitch	Rotation about X axis
Yaw	Rotation about Y axis

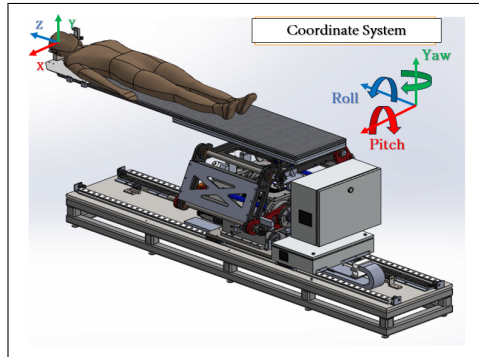


Figure 3.6: Patient Positioning Coordinate System

3.4 Range of Motion in the Linkage System of the Patient Positioning System

The Linkage System, a central mechanism in the PPS, is responsible for patient positioning in the 2D plane. It has a robust and expansive ROM, essential for precise and safe medical interventions.

3.4.1 Analysis of Robotic Linkage Subsystem Behavior

The robotic linkage subsystem facilitates movements along the X and Y axes, and pivotal rotations about the Z-axis (Roll). Analyzing its behavior is crucial for understanding its performance at extremities.

3.4.2 Visualization of Parameters against Position and Orientation

The 3D scatter plots visualize the relationship between the positional data (X, Y), the orientation (ROLL), and the parameters q_1 , q_2 , and q_3 .

Table 3.2: PPS Dimensions and Mass

Length (z) [mm]	Width (x) [mm]	Height (y) [mm]	Mass (kg)
3098.8	1179.3	3022.6	2000

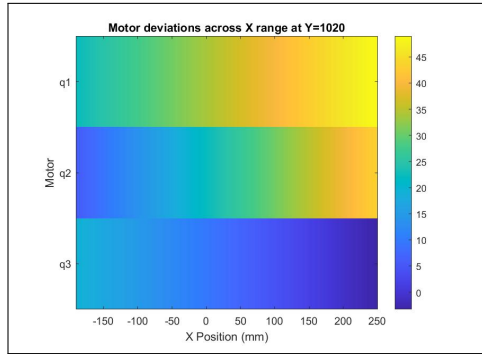


Figure 3.7: Motor deviations across X range at $Y = 1020$

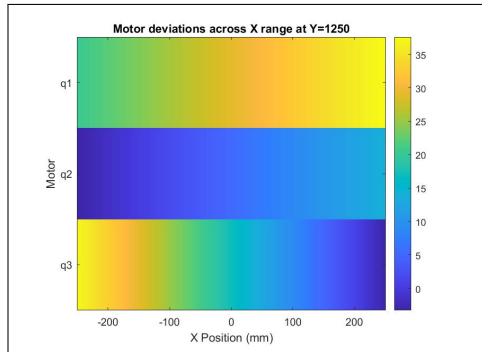


Figure 3.8: Motor deviations across X range at $Y = 1250$

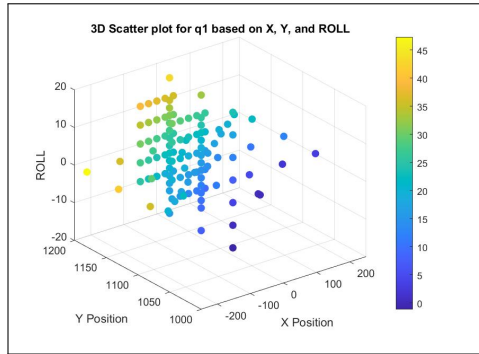


Figure 3.9: 3D scatter plot illustrating the variation of q_1 against X, Y positions and ROLL orientation. The color intensity indicates the magnitude of q_1 at a particular position and orientation.

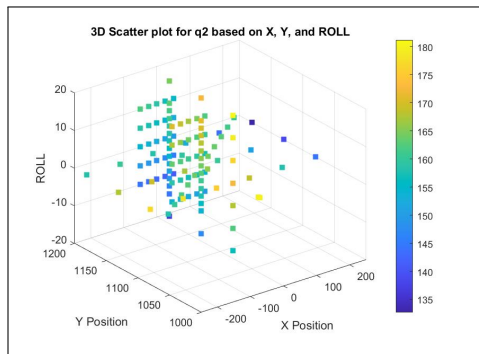


Figure 3.10: 3D scatter plot showing the variation of q_2 against X, Y positions and ROLL orientation. The color intensity indicates the magnitude of q_2 at a particular position and orientation.

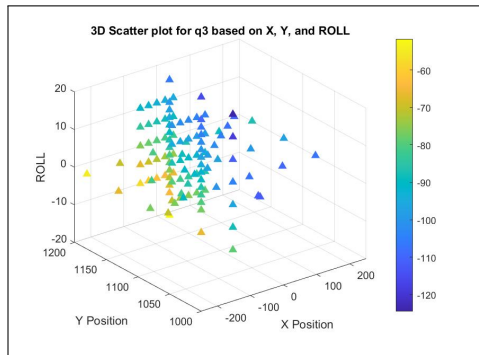


Figure 3.11: 3D scatter plot for q_3 variation against X, Y positions and ROLL orientation. The color intensity indicates the magnitude of q_3 at a particular position and orientation.

Thesis II

Accurate Robotic Patient Positioning: Integrating Forward Kinematics in Advanced System Design

Related Publications [P2, P3, P4]

This forward kinematic study serves as solid evidence that our equations and calculations are accurate, ensuring the patient's precise alignment within the PPS, and thereby guaranteeing the reliability and accuracy of the entire system. These outcomes validate the precision of our kinematic models and computational methods, underscoring the capability of the PPS to align patients accurately for medical procedures.

In this comprehensive thesis, an in-depth analysis of forward kinematics within the Patient Positioning System (PPS) has been conducted, yielding significant outcomes that enhance the system's operational efficacy. For more details, you can read the full dissertation in the Forward Kinematics chapter.

4.1 Forward Kinematics

Forward kinematics, a foundational concept in robotics and mechanical systems, revolves around the determination of the end effector's position and orientation based on given joint parameters and link lengths.

4.1.1 Homogeneous Transformation Matrix

In the kinematics study for our PPS, we utilize the homogeneous transformation matrix, a 4×4 construct, to seamlessly represent both rotation and translation between coordinate frames. This matrix is pivotal in capturing the spatial relationships required for precise patient positioning.

$$T = \begin{bmatrix} R & d \\ 0 & 1 \end{bmatrix} \quad (4.1)$$

4.1.2 Denavit-Hartenberg (DH)

The Denavit-Hartenberg (DH) method is a prominent approach in kinematic modeling for robot manipulation, playing a vital role in achieving effective control over robotic systems. This method enables the traversal from the base frame to the end effector frame by sequentially transitioning through intermediate frames. It delineates the transformations required, encompassing both rotational and translational motions of the manipulator.

$$T_i = \begin{bmatrix} \cos \theta_i & -\cos \alpha_i \sin \theta_i & \sin \alpha_i \sin \theta_i & a_i \cos \theta_i \\ \sin \theta_i & \cos \alpha_i \cos \theta_i & -\sin \alpha_i \cos \theta_i & a_i \sin \theta_i \\ 0 & \sin \alpha_i & \cos \alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4.2)$$

where:

- a_i : The distance between the z_i and z_{i+1} axes along the x_i axis.
- α_i : The angle between the z_i and z_{i+1} axes along the x_i axis.
- d_i : The distance between the x_i and x_{i+1} axes along the z_i axis.
- θ_i : The angle between the x_i and x_{i+1} axes along the z_i axis.

4.2 PPS Subsystems Functionality Description and Coordinate Frame Assignment

This system plays a crucial role in facilitating precise patient alignment in a variety of medical scenarios. Its construction and functionality embody several distinctive features that contribute to its effective performance. These characteristics span across the system's three main components: the Linear Rail System, the Linkage System, and the Table Assembly. Each component introduces unique attributes that, when combined, result in a highly efficient, versatile, and patient-friendly positioning system.

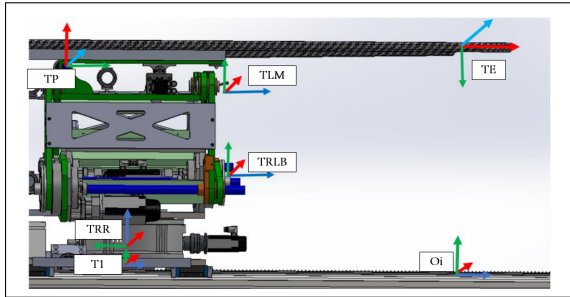


Figure 4.1: PPS Frame Assignment

4.2.1 Frame Assignments for the PPS

The Patient Positioning System (PPS) utilizes specific frame assignments to capture its distinct components and their movements as shown in the figure:

- **Base Frame (O_i):** Located at the junction of the main rails.

- **Linear Rail Frame** (T_{RR}): Positioned at the end of the linear rail.
- **Lower Linkage System Frame** (T_{RLB}): At the midpoint of the lower linkage arm.
- **Upper Linkage System Frame** (T_{LM}): At the midpoint of the upper linkage arm.
- **Table Rod Frame** (T_P): Centered on the table rod.
- **Tabletop Frame** (T_E): Centered on the tabletop.

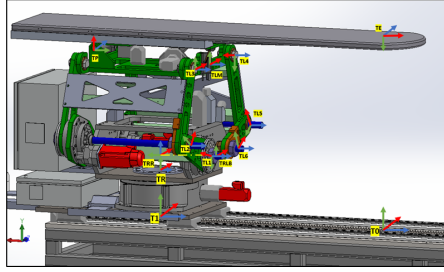


Figure 4.2: PPS Frame Assignment with Linkage Frames

4.2.2 Utilize the Denavit-Hartenberg (DH) Parameters

With the essential parameters and points now determined, we can utilize the Denavit-Hartenberg (DH) parameters. This allows us to transition from one frame to the subsequent frame, ultimately leading us to the final transformation matrix representing our PPS.

The final transformation matrix T_o^E is given by:

$$T_o^E = T_o \cdot T_1 \cdot T_R \cdot T_{RR} \cdot T_{RLB} \cdot T_{L1} \cdot T_{L2} \cdot T_{L3} \cdot T_{LM} \cdot T_P \cdot T_E \cdot T_{E1} \cdot T_{E2} \cdot T_{E3} \quad (4.3)$$

The 4×4 matrix T_o^E is a homogeneous transformation matrix used to represent both the position and orientation of a body in space.

The matrix T_o^E is given by:

$$T_o^E = \begin{bmatrix} \mu_x & O_x & \alpha_x & p_x \\ \mu_y & O_y & \alpha_y & p_y \\ \mu_z & O_z & \alpha_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

- **Position (Translation Vector):** The elements p_x , p_y , and p_z in the fourth column represent the position of the target point with respect to the origin.
- **Orientation (Rotation Matrix):** The 3×3 matrix on the top-left corner of T_o^E represents the orientation of the body in space.

From this, we can extract Euler angles using the following equations:

$$\begin{aligned}\alpha &= \tan^{-1} \left(\frac{\sin \alpha}{\cos \alpha} \right) \\ &= \tan^{-1} \left(\frac{-\mathbf{R}_{2,3}}{\mathbf{R}_{2,2}} \right)\end{aligned}\tag{4.4}$$

$$\begin{aligned}\beta &= \tan^{-1} \left(\frac{\sin \beta}{\cos \beta} \right) \\ &= \tan^{-1} \left(\frac{\mathbf{R}_{3,1}}{\mathbf{R}_{1,1}} \right)\end{aligned}\tag{4.5}$$

$$\begin{aligned}\gamma &= \tan^{-1} \left(\frac{\sin \gamma}{\cos \gamma} \right) \\ &= \tan^{-1} \left(\frac{\mathbf{R}_{2,1}}{\sqrt{\mathbf{R}_{2,2}^2 + \mathbf{R}_{2,3}^2}} \right)\end{aligned}\tag{4.6}$$

You can find more equations and detailed forward kinematics study in the dissertation's Forward Kinematics chapter.

Thesis III

Geometric Approach to Inverse Kinematics in Multi-Subsystem Robotic Patient Positioning System

Related Publications [P2, P4, P5, P6]

The inverse kinematic study demonstrates the robustness of our equations and calculations, ensuring the accurate determination of joint angles within the PPS. This precision guarantees the correct alignment of the patient's position, validating the reliability and accuracy of the entire system. These outcomes highlight the effectiveness of our kinematic models and computational methods, reinforcing the PPS's capability to position patients precisely for medical procedures.

This thesis delves into the intricate geometric approach to inverse kinematics within the multi-subsystem of the Robotic Patient Positioning System (PPS).

5.1 Inverse Kinematics Study of Subsystems

In the context of our project, dealing with multiple subsystems and a high degree of freedom (DOF) presents a complex kinematic scenario. To effectively handle this complexity and ensure precise control and positioning, we employ the geometric method for our kinematic analysis. This approach allows us to decompose the multilayered system into simpler geometric entities, making the analysis more manageable and straightforward while ensuring the accuracy and reliability of our computations.

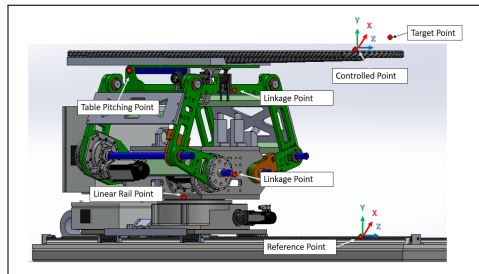


Figure 5.1: Inverse Kinematics main Points

5.1.1 Description of Points and Rotations in the PPS

In the context of the Patient Positioning System (PPS), specific points and rotations are crucial in accurately establishing and calculating positional data within the system.

5.1.1.1 Controlled Point (CP)

The Controlled Point (CP) in the PPS, specifically located at the center of the bed, plays a pivotal role due to its known coordinates relative to the origin frame. This point is expressed as:

$$\mathbf{CP} = (x, y, z) = (0, L_{home}, 0) \quad (5.1)$$

in Cartesian coordinates, and its orientation is described using the Pitch, Yaw, and Roll angles as

$$(\alpha, \beta, \gamma) = (0, 0, 0). \quad (5.2)$$

Rotations in the PPS

- **Pitch (Rotation around X-axis):** The Pitch rotation, denoted as α or simply as "Pitch", is the rotation about the x -axis.
- **Yaw (Rotation around Y-axis):** The Yaw rotation, represented as β or "Yaw", involves rotation about the y -axis.
- **Roll (Rotation around Z-axis):** Denoted as γ or "Roll", this rotation around the z -axis involves positive angles for counterclockwise rotations and negative angles for clockwise rotations.

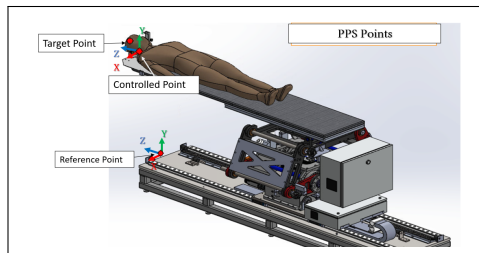


Figure 5.2: PPS's Control, Target and Reference Points

5.1.1.2 Reference Point

The *Reference Point* serves as the origin frame in the PPS, from which all other points, coordinates, and orientations are defined. Rotations (Pitch, Yaw, and Roll) and translations (in x, y, z) within the PPS are specified with respect to this fundamental point.

5.1.1.3 Target Point (TP)

The Target Point (TP) signifies the focal point for treatment in the PPS, representing the precise location of a tumor within the brain. Gamma radiation beams are directed towards this point to ensure targeted and effective treatment. It's crucial to note that the TP varies across patients, dependent on individual cases and the specifics of their treatment plan. The position and orientation of this point act as the primary input for our system, providing necessary details for subsequent kinematic calculations.

5.1.2 Mapping Target Point to Controlled Point

The foundational layer of the inverse kinematics process in the PPS aims to establish a correlation between the TP and the CP. By doing so, we can ensure that the desired treatment point, TP, is accurately aligned with the controlled point, CP, thus guaranteeing that the radiation beams are directed correctly for optimal treatment efficacy.

Ensuring the precise alignment of the Target Point (TP) with the Controlled Point (CP) in the Patient Positioning System (PPS) involves both positional and rotational transformations.

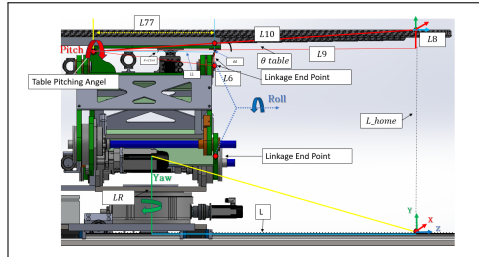


Figure 5.3: PPS Inverse Kinematics Geometry

5.1.3 Mapping Controlled Point to Linear Horizontal Rail

The effective length of the linear horizontal rail in the PPS can be determined to enable controlled linear movement and rotational alignment of the linkage system, ensuring precise patient positioning.

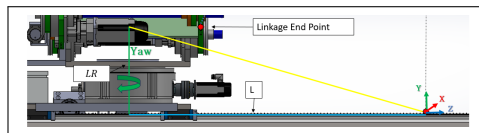


Figure 5.4: Linear Rail Inverse Geometry

5.1.4 Mapping Controlled Point to Table Pitching Axis

Based on the table angle geometry, we can calculate the table angle to understand the pitch axis and its effects on the positioning system.

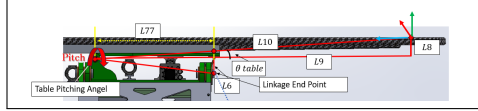


Figure 5.5: Table Angle Geometry

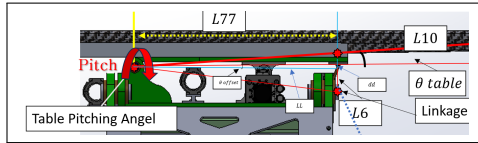


Figure 5.6: Zoomed-in view showcasing the blue triangle with sides dd and ll .

5.1.5 Linkage Inverse Kinematics

In our inverse kinematics framework, we focus on accurately determining the joint angles— q_1 , q_2 , and q_3 —to ensure the top bar is aligned with the target locations both rapidly and precisely. This model accepts the mid-point position as its input, translating it into the necessary joint angles for output. Consequently, the robotic linkage can optimally position its midpoint via appropriate motor commands.

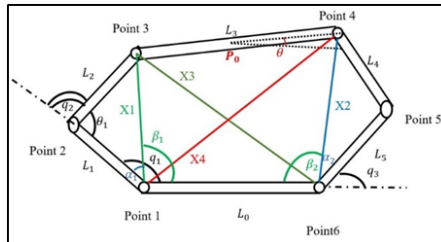


Figure 5.7: Linkage Inverse Kinematic Study Strategy

You can find more equations and detailed inverse kinematics study in the dissertation's Inverse Kinematics chapter.

Thesis IV

Advanced Motion Control in Robotic Patient Positioning System: Optimizing Performance Through Comparative Analysis of Single and Dual Control Loops

Related Publications [P1, P3, P4]

This thesis provides a comprehensive examination of control algorithms for the PPS, highlighting that dual-loop control significantly enhances system performance. By effectively reducing errors and improving precision, dual-loop control proves crucial in achieving optimal patient alignment for radiosurgical procedures. The findings underscore the importance of advanced control mechanisms, particularly dual-loop control, in ensuring the reliability and accuracy of the PPS.

6.1 Control Architecture

The control architecture of the PPS includes both single-loop and dual-loop control systems. Single-loop control, while simpler and faster, lacks the flexibility to handle complex system dynamics. Dual-loop control, on the other hand, provides enhanced accuracy by incorporating feedback from multiple sources, making it more robust against issues like mechanical backlash.

6.1.1 Single-loop Control

Single-loop control utilizes feedback from the motor for both position and velocity control, offering simplicity and faster response times.

6.1.2 Dual-loop Control

Dual-loop control uses separate feedback for position and velocity, significantly improving performance by overcoming mechanical slack and enhancing accuracy. This approach is particularly effective in systems with belt-driven mechanisms where mechanical variances can impact performance.

6.2 Tuning of the Patient Positioning System

The tuning process involves several steps to ensure precise alignment and optimal performance:

- **Current Loop Tuning:** Establishes the foundational gains for subsequent tuning stages.

- **Open Loop Verification:** Assesses system behavior without feedback control.
- **Velocity Loop Tuning:** Fine-tunes the system to match the desired velocity profile.
- **Position Loop Tuning:** Achieves precise positional accuracy.
- **Dual Loop Implementation:** Enhances accuracy by using both velocity and position feedback.

6.3 Performance Enhancement with Dual-Loop Control

The dual-loop control system was implemented and tested to evaluate its impact on the PPS performance.

6.3.1 Error Reduction

The implementation of dual-loop control demonstrated a significant reduction in system errors, improving the overall accuracy of patient positioning.

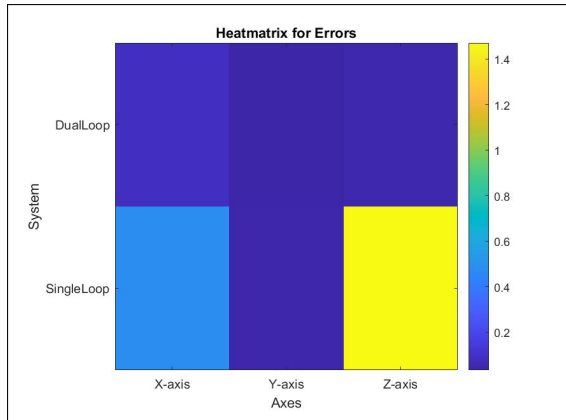


Figure 6.1: Error Reduction with Dual-Loop Control

6.3.2 Comparative Analysis of Single-Loop and Dual-Loop Systems

A thorough analysis was conducted comparing the performance of single-loop and dual-loop systems. Statistical and visual analysis revealed that dual-loop control significantly reduces errors in the X, Y, and Z axes compared to single-loop control.

Table 6.1: Error Analysis for Single and Dual Loop Control Systems

Control System	Axis	Statistical Measures			
		Mean	Standard Deviation	Min	Max
Single Loop	X-axis	0.4752	0.5962	0.0	2.8304
	Y-axis	0.0444	0.0816	-0.0321	0.4307
	Z-axis	1.4713	2.4429	0.0	10.7805
Dual Loop	X-axis	0.0866	0.0582	0.0	0.3356
	Y-axis	0.0333	0.0430	-0.0213	0.2243
	Z-axis	0.0468	0.0339	0.0	0.2051

Thesis VI

Developing Robust Safety Protocols for Radiosurgery within Patient Positioning System Framework

Related Publications [P1, P3, P4]

This thesis highlights the vital importance of safety and fault handling in the PPS for radiotherapy. Emergency stops, continuous fault detection, and limit sensors are crucial for quickly responding to problems, ensuring the safety of both patients and operators. The fault classification system and responsive fault configurator improve reliability by allowing fast identification and fixing of faults. This strong safety framework shows a commitment to keeping high safety standards in medical equipment operation. Ongoing improvement of safety protocols is essential to providing high-quality patient care.

7.1 Safety Concerns in Radiosurgery

Accuracy in radiation delivery is paramount, as deviations can compromise patient health and treatment outcomes. Managing involuntary patient movements, such as breathing, necessitates real-time motion tracking. Equipment maintenance and calibration protocols are critical to circumvent dosimetric errors, and the multidisciplinary nature of radiosurgery amplifies the need for flawless communication and synchronized efforts to preempt safety oversights.

7.2 Technological Advances in PPS Safety

Advancements in PPS technology, such as real-time imaging (MRI or CT) and movement detection sensors, enhance patient safety by ensuring continuous target visualization and detecting even the slightest patient movements.

7.3 Implementation and Safety Assurance in Our PPS

The PPS implementation is underscored by an unwavering commitment to safety through an ecosystem of emergency stops, fault detection capabilities, limit sensors, and rigorous daily initialization procedures.

7.3.1 Fault Classification

Faults within the PPS are classified into two categories:

- **Axis Faults:** Pertaining to motor motion.
- **System Faults:** Associated with the controller program.

7.3.2 PPS Internal Safety Conditions

The PPS includes built-in checks to monitor operational states. If irregularities are detected, the system automatically takes preventive actions to ensure safe operation.

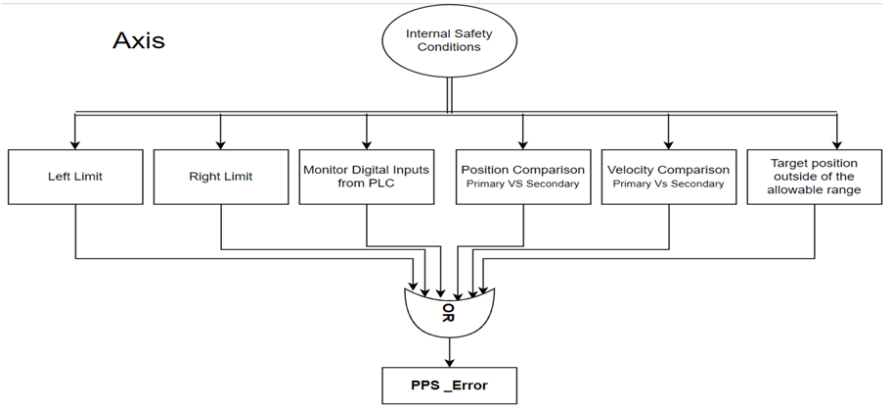


Figure 7.1: Internal Safety Conditions Diagram

We have detailed this intricate process through various safety conditions:

- **Left/Right Limit Check:** Ensures operation within defined boundaries.
- **Primary/Secondary Encoder Slipping Check:** Monitors for position and velocity discrepancies.
- **Target Position Monitoring:** Ensures the machine's target position stays within an allowable range.
- **Digital Inputs from PLC Monitoring:** Continuously monitors digital inputs from the PLC.

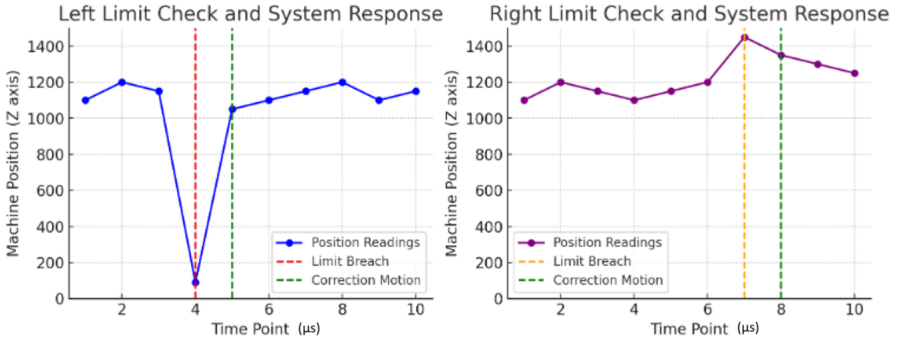


Figure 7.2: Left and Right Limit Check and System Response. The graphs show the system’s response to a limit breach, triggering correction motion to maintain the desired position.

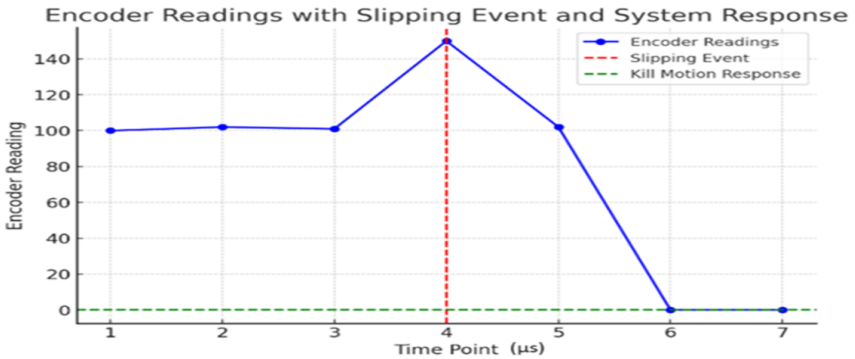


Figure 7.3: Encoder Readings with Slipping Event and System Response. This graph illustrates the system’s response to a slipping event, leading to a rapid kill motion response to halt operations.

List Of Publications

1. **A. Saadah**, D. Medlin, J. Saud, L. Menyhárt, X. Zheng, and G. Husi, "Developing Robust Safety Protocols for Radiosurgery within Patient Positioning System Framework," *Machines*, vol. 12, no. 2, pp. 106, 2024. (Q2)
2. **A. Saadah** and G. Husi, "Six DOF Robotic Arm Prototype Modelling By Matlab," in *Papers on Technical Science*, vol. 15, pp. 94–98, Erdélyi Múzeum-Egyesület, 2021.
3. **A. Saadah**, D. Medlin, J. Saud, X. R. Zheng, and G. Husi, "A State-of-the-Art Design: Applying Forward Kinematics to Improve Patient Positioning in Radiosurgery," in *2023 International Conference on Microelectronics (ICM)*, pp. 86-90, IEEE, December 2023.
4. **A. Saadah**, D. Medlin, J. Saud, X. R. Zheng, and G. Husi, "Kinematics Study for Linkage System (Parallel Robotics System): linkage system of patient positioning system PPS to accurately position a human body for radiosurgery treatment," in *2023 Advances in Science and Engineering Technology International Conferences (ASET)*, IEEE, 2023, pp. 1–6.
5. **A. Saadah**, M. Al Kadi, and G. Husi, "KUKA arc KR5 Industrial Manipulator's Trajectory Planning Modelling using MATLAB Based on Kinematics Study," in *2023 Advances in Science and Engineering Technology International Conferences (ASET)*, IEEE, 2023, pp. 01–06.
6. **A. Saadah** and G. Husi, "Kuka KR5 arc Welding Industrial Manipulator Workspace Modelling Based on Kinematics Study," in *IOP Conference Series: Materials Science and Engineering*, vol. 1169, no. 1, pp. 012037, IOP Publishing, 2021.
7. **A. Saadah** and G. Husi, "Hat szabadságfokos robotkarprototípus-modellezés Matlab által," in *Műszaki Tudományos Közlemények*, no. 15, pp. 94–98, Erdélyi Múzeum-Egyesület, 2021.
8. **A. Saadah**, H. Abdulkareem, and G. Husi, "Computing the kinematics study of a 6 DOF industrial manipulator prototype by matlab," in *Recent Innovations in Mechatronics*, vol. 7, no. 1, pp. 1–5, 2020.



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Doctoral School: Doctoral School of Informatics
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List of publications related to the dissertation

Foreign language scientific articles in international journals (2)

1. Saadah, A., Medlin, D., Saud, J., Menyhárt, L., Zheng, X. R., Husi, G.: Developing Robust Safety Protocols for Radiosurgery within Patient Positioning System Framework. *Machines*. 12, 1-21, 2024. EISSN: 2075-1702.
DOI: <https://doi.org/10.3390/machines12020108>
IF: 2.6 (2022)
2. Saadah, A., Husi, G.: Six DOF Robotic Arm Prototype Modelling By Matlab. *Műsz. tud. közl. = PTS.* 15 (1), 94-98, 2021. ISSN: 2601-5773.
DOI: <http://dx.doi.org/10.33894/mtk-2021.15.18>

Foreign language conference proceedings (3)

3. Saadah, A., Medlin, D., Saud, J., Zheng, X. R., Husi, G.: A State-of-the-Art Design: Applying Forward Kinematics to Improve Patient Positioning in Radiosurgery. In: 2023 International Conference on Microelectronics (ICM) ISBN: 9798350380828
4. Saadah, A., Medlin, D., Saud, J., Zheng, X. R., Husi, G.: Kinematics Study for Linkage System (Parallel Robotics System): linkage system of patient positioning system PPS to accurately position a human body for radiosurgery treatment. In: Advances in Science and Engineering Technology International Conferences (ASET)
5. Saadah, A., Al, K. M., Husi, G.: KUKA arc KR5 Industrial Manipulator's Trajectory Planning Modelling using MATLAB Based on Kinematics Study. In: Advances in Science and Engineering Technology International Conferences (ASET)

Foreign language abstracts (1)

6. Saadah, A., Husi, G.: Kuka KR5 arc Welding Industrial Manipulator Workspace Modelling Based on Kinematics Study. *IOP Conf. Ser. Mater. Sci. Eng.* 1169, 1-7, 2021. ISSN: 1757-8981.
DOI: <http://dx.doi.org/10.1088/1757-898X/1169/1/D12037>





List of other publications

Hungarian scientific articles in international journals (1)

7. Saadah, A., Husi, G.: Hat szabadságfokos robotkarprototípus-modellezés Matlab által.

Műsz. tud. közl. = PTS. 15, 94-98, 2021. ISSN: 2393-1280.

DOI: <http://dx.doi.org/10.33895/mtk-2021.15.18>

Foreign language scientific articles in Hungarian journals (1)

8. Saadah, A., Almusawi, H. A., Husi, G.: Computing The Kinematics Study of a 6 DOF Industrial Manipulator Prototype by Matlab.

Recent Innov. Mechatron. 7 (1), 1-5, 2020. EISSN: 2064-9622.

DOI: <http://dx.doi.org/10.17867/riim.2020.1/8>.

Total IF of journals (all publications): 2,6

Total IF of journals (publications related to the dissertation): 2,6

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

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