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Abstract

This project presents a simulation-first, temperature-aware 5-DOF robotic manipulator developed using ROS 2 and Gazebo to enhance safety during pick-and-place operations involving high-temperature objects. The primary objective is to prevent unsafe grasping by integrating temperature sensing with intelligent decision-making in a virtual environment. The increasing deployment of robotic systems in industrial automation demands that robots be equipped not only with mechanical dexterity but also with environmental awareness capabilities. One such critical requirement is thermal awareness, particularly in manufacturing environments where objects may be subjected to extreme temperatures due to welding, casting, heat treatment, or other thermal processes.

The system models the complete robotic setup, including the manipulator, gripper, workspace, and a temperature sensor plugin within Gazebo. Real-time temperature data is streamed into ROS 2, where a dedicated decision-making node processes the sensor inputs. This node applies a configurable threshold along with hysteresis control to ensure stable and noise-resistant decisions. Based on this evaluation, the system dynamically determines whether to proceed with or avoid the grasping action. The decision-making algorithm is designed to be both reactive and reliable, ensuring that edge cases near the threshold value do not result in oscillatory behavior through the implementation of hysteresis bands.

Motion execution is handled through ros2_control-based controllers, following a structured sequence: the robotic arm first moves to a predefined pre-grasp position, measures the object’s temperature, and then either performs a grasp-and-lift operation or retracts to a safe position depending on the decision outcome. This approach ensures both operational efficiency and safety. The controller architecture is designed to be modular, allowing each component to be independently tested and validated.

The implementation is organized using well-defined URDF/SDF models, controller configurations, and modular launch files, enabling reproducibility and scalability. A controlled experimental setup with predefined scenarios and logging mechanisms is used to evaluate system performance. Key evaluation metrics include temperature sensing accuracy and end-to-end decision latency. The system is validated against multiple test scenarios spanning safe temperature ranges, borderline conditions, and high-temperature objects.

The results demonstrate that the proposed system achieves fast, reliable, and safe grasping decisions within a simulation environment. This work establishes a robust and low-risk digital prototyping framework, providing a strong foundation for future extension to real-world robotic systems and industrial automation applications. The documented workflow serves as a reusable template for researchers and engineers seeking to develop safety-aware robotic manipulation systems.

Architecture overview

Gazebo is used to simulate the complete environment, including the 5-DOF robotic arm, gripper, and workspace. A thermal sensor (or temperature proxy) generates data representing the surface temperature of target objects. The simulation environment is carefully configured to replicate realistic physical properties, including gravity, surface friction coefficients, and collision dynamics, ensuring that the simulation closely mirrors real-world behavior.

The simulated temperature data is transmitted to ROS 2 through a ROS–Gazebo communication bridge, enabling real-time interaction between simulation and control systems. This bridge serves as the critical link between the physics-based simulation engine and the high-level control and decision logic implemented in ROS 2. The communication is topic-based, following the publisher-subscriber paradigm inherent to ROS 2, which ensures asynchronous and efficient data transfer.

ROS 2 controls the robotic arm and gripper using ros2_control controllers, while also receiving temperature inputs for decision-making. Visualization of robot motion and sensor data is performed in RViz. This visualization capability is essential for debugging and verifying the correctness of the control algorithms during development and testing phases.

A dedicated ROS 2 decision node processes the temperature data and applies a predefined threshold condition. If the temperature exceeds the safe limit, the system blocks the grasping action; otherwise, it allows the robot to proceed with the planned trajectory and grasp execution. The decision node is implemented as a lightweight, single-responsibility module that subscribes to the temperature topic and publishes a binary grasp-permission signal consumed by the motion planning module.

1. Introduction

Industrial automation systems increasingly rely on robotic manipulators to perform pick-and-place operations in environments where object temperatures can vary significantly. In such conditions, the absence of temperature awareness during grasping can lead to critical safety issues, including damage to robotic components, degradation of gripper materials, and disruption of production processes. Handling overheated objects without prior assessment not only reduces system reliability but also increases maintenance costs and operational risks. This problem is particularly prevalent in industries such as metal casting, automotive manufacturing, electronics assembly, and food processing, where thermal management is an essential aspect of operational safety.

To address this challenge, integrating thermal perception into the robotic decision-making process becomes essential. By evaluating object temperature before executing a grasp, the system can prevent unsafe interactions, thereby enhancing operational safety and extending equipment lifespan. This approach introduces an additional layer of intelligence, allowing the robot to make context-aware decisions rather than executing predefined motions blindly. The concept of sensor-integrated robotic grasping is not new; however, the specific integration of thermal sensors for pre-grasp safety evaluation in a ROS 2 and Gazebo-based framework represents a novel contribution.

A simulation-first development strategy plays a crucial role in implementing such intelligent systems. Using ROS 2 and Gazebo, the robotic arm, sensing mechanisms, and control logic can be modeled and tested in a virtual environment. This enables rapid prototyping, iterative refinement of control strategies, and validation of safety mechanisms without the risks and costs associated with physical hardware experimentation. The simulation-first approach is particularly valuable in research and academic settings, where access to physical robotic hardware may be limited and where iterative testing is required to refine algorithms before deployment.

The 5-DOF (Degrees of Freedom) robotic arm chosen for this project represents a common configuration used in light to medium industrial applications. With five independently actuated rotational joints, the arm possesses sufficient workspace coverage and dexterity to perform pick-and-place operations in a structured environment. The parallel gripper attached at the end-effector provides a simple yet effective grasping mechanism suitable for objects of varying sizes within a defined range.

The core engineering challenge in this project lies in developing a robust pipeline that integrates mechanical design, temperature sensing, motion planning, and decision-making into a unified framework. The system must reliably acquire temperature data, process it in real time, and make accurate decisions to either permit or inhibit grasping actions based on predefined safety thresholds. This challenge encompasses multiple engineering disciplines, including mechanical design, control systems engineering, software architecture, and sensor integration.

This project aims to design and simulate a temperature-aware robotic manipulator that incorporates these capabilities. By combining digital prototyping with intelligent control strategies, the work establishes a safe, efficient, and scalable foundation for future deployment in real-world industrial automation scenarios. The entire system is implemented using open-source tools and frameworks, ensuring accessibility and reproducibility for future researchers and engineers.

1.1 Scope

The scope of this project is centered on the virtual modeling and simulation of a 5-degree-of-freedom robotic arm equipped with a simple parallel gripper, designed to perform pick-and-place operations in a controlled environment. The system is developed within a simulation framework using Gazebo, where a temperature sensor (or proxy) is integrated to generate thermal data representing the surface temperature of objects.

The robotic arm is controlled through ROS 2, enabling coordinated joint actuation and system-level communication. The software architecture follows a node-based, modular design philosophy consistent with ROS 2 best practices. Each functional module—including sensor data acquisition, decision logic, motion planning, and controller management—is encapsulated in a dedicated ROS 2 node, enabling independent development, testing, and maintenance.

A temperature-based decision-making logic is implemented to evaluate sensor data and determine whether to permit or inhibit grasping actions based on predefined safety thresholds. The threshold values are configurable through YAML parameter files, allowing easy adaptation to different operating conditions without modifying source code. The decision algorithm incorporates hysteresis to prevent rapid state changes near the threshold boundary.

The simulation environment includes multiple objects with varying temperature conditions, allowing comprehensive testing and evaluation of system performance. Objects are categorized into three groups: cold objects (well below threshold), borderline objects (near threshold), and hot objects (above threshold). This categorization enables systematic evaluation of the decision logic across the full operational spectrum.

Additionally, logging mechanisms are incorporated to analyze decision accuracy, response time, and overall system behavior. Log data is recorded using rosbag2, the ROS 2 native recording tool, enabling post-hoc analysis and comparison across different test runs. Performance metrics are extracted from these logs and presented in tabular and graphical formats.

The development of this system is based on certain assumptions. It is assumed that the simulated temperature readings are sufficiently accurate to represent real-world thermal conditions for decision-making purposes. The objects within the simulation are considered to be static and located within the reachable workspace of the robotic arm. Furthermore, it is assumed that communication between the simulation environment and control system does not introduce significant latency that could affect the correctness or timing of grasping decisions.

1.2 Objectives

The primary and secondary objectives of this project are clearly defined to guide the development and evaluation of the temperature-aware robotic manipulation system.

1: To implement safe, temperature-gated grasping. This involves reading simulated temperature data from the Gazebo environment, processing it through a configurable decision node, and commanding the 5-DOF arm to execute either a pre-grasp, grasp, or retract sequence based on the temperature evaluation. The grasping logic must be robust, deterministic, and capable of responding correctly to both safe and unsafe temperature conditions.

2: To achieve end-to-end sensing-to-decision latency of less than 100 ms and a correct hot-object avoidance rate of greater than or equal to 95% across varied simulation scenarios. These quantitative targets define the performance benchmarks against which the system will be evaluated and validated.

3: To design for stable operations by implementing hysteresis control within the decision node. This prevents oscillatory behavior near the temperature threshold and ensures consistent, noise-resistant decision-making under realistic sensor noise conditions.

4: To identify the parameters to configure and develop models. This includes defining all configurable parameters such as temperature thresholds, hysteresis bands, joint velocity limits, controller gains, and sensor publish rates, and organizing them into centralized YAML configuration files for ease of maintenance and reproducibility.

5: To establish a reproducible and well-documented simulation workflow that can serve as a reference implementation for future researchers and engineers working on safety-aware robotic manipulation systems.

6: To provide a comprehensive evaluation of the system through controlled scenario testing, capturing performance data on temperature sensing accuracy, decision latency, and grasping success rates across all defined test scenarios.

1.3 Project Planning and Management

1.3.1 Feasibility Study

Technical Feasibility

The technical feasibility of this project was assessed by evaluating the availability and maturity of the required tools, frameworks, and algorithms. ROS 2 (Robot Operating System 2) is a mature, widely adopted middleware framework for robotic systems development, providing a rich ecosystem of libraries, tools, and community support. Gazebo is a well-established physics-based robot simulator with built-in support for sensor plugins, joint controllers, and realistic physical modeling.

The integration of Gazebo with ROS 2 through the ros_gz_bridge package is well-documented and widely tested, confirming that reliable bidirectional communication between the simulation and control systems is achievable. The ros2_control framework provides a standardized interface for hardware abstraction and controller management, compatible with Gazebo simulation through the gazebo_ros2_control plugin.

MoveIt 2, the motion planning framework for ROS 2, provides inverse kinematics solvers, collision checking, and trajectory planning capabilities essential for executing safe and smooth grasping sequences. The availability of pre-built URDF description packages and existing robotic arm models further reduces the implementation complexity.

Implement safe, temperature-gated grasping: In this project, a sensor provides temperature data, which ROS 2 nodes then compare to a safety limit. Pre-grasp, evaluate, and grasp/retract are the three steps that the ros2_control system uses to control the robot's movements. If it detects overheating, it safely stops the arm. For rapid, seamless responses, the publish rate and QoS (Quality of Service) settings of the sensor are adjusted. In order to reduce expenses and prevent heat damage, the simulation-based, fully open-source system focuses on configuration and decision logic rather than hardware procurement. While logs document all readings and commands, parameterized launch files, fixed random seeds, and tools like RViz and rqt guarantee repeatable, debuggable runs. Three sections—sensor setup, decision logic, and controller integration—allow for parallel development and quick, dependable testing.

Latency <100 ms; ≥95% hot-object avoidance: The system uses a minimal control loop to compare temperature readings with a safety threshold, triggering commands quickly. Processes are co-located to reduce latency, and publish rate and executor settings are tuned for smooth operation. Calibration and threshold adjustments are low-cost and automated. Testing uses scenario matrices and rosbag data to balance safety and efficiency, with short iterations and tuning based on latency and avoidance performance. The ROS 2 executor is configured to minimize thread contention and maximize responsiveness for the critical decision path.

Identify parameters and develop models: Verify frames, axes, and units at startup; ensure world seeds and spawn poses are fixed for repeatability; centralize parameters (thresholds, units, publish rates, controller gains/limits, joint ranges, and inertias) in YAML. Use URDF/SDF CAD that is already available; use simplified collision meshes to maintain real-time simulation. Add sanity checks for sensor unit/range and topic availability on bring-up; keep a versioned parameter registry and launch manifests; log the precise configuration with each run for reproducibility and post-hoc analysis.

Economic Feasibility: The entire project is implemented using freely available open-source tools. ROS 2, Gazebo, MoveIt 2, and all associated libraries are available under permissive open-source licenses. SolidWorks, used for CAD modeling, is available through academic licensing provided by the institution. The computational resources required for simulation are met by standard workstation hardware available in the department's laboratory. There are no hardware procurement costs associated with the simulation-based implementation, making this project economically feasible within an academic budget.

Operational Feasibility: The system is designed to be fully operable within the simulation environment, without requiring specialized laboratory facilities or safety protocols beyond standard software engineering practices. The modular architecture ensures that individual components can be independently developed and tested, reducing the risk of system-wide failures during development. Comprehensive documentation and parameter logging ensure that the system can be operated and maintained by team members with varying levels of robotics expertise.

1.4 Risk Analysis

A systematic risk analysis was conducted to identify potential challenges and define mitigation strategies for each identified risk.

Sensor Realism Gap: Simulated temperature sensor readings may not perfectly replicate physical sensor characteristics, leading to possible threshold mismatches during real-world deployment. The Gazebo thermal camera plugin produces idealized readings that do not account for sensor noise, thermal drift, emissivity variations, or environmental interference. Mitigation: Calibrate the simulated sensor against known object temperatures; apply conservative thresholds with appropriate safety margins; and document all calibration constants for reference during future hardware deployment.

Integration Complexity: Controller, bridge, and sensor topic mismatches can delay milestones without clear interface contracts and version control. ROS 2 and Gazebo both undergo frequent version updates, and API compatibility between versions is not always guaranteed. Mitigation: Establish and document clear interface contracts specifying topic names, message types, and QoS profiles; use containerized development environments (Docker) to freeze software versions; and conduct incremental integration testing at each milestone.

Schedule Slippage: Underestimated tuning and scenario creation can push timelines if dependencies and the critical path are not properly managed. Decision threshold tuning, in particular, may require more iterations than initially anticipated. Mitigation: Maintain a detailed Gantt chart with explicit milestones and dependencies; allocate buffer time for tuning activities; and prioritize core functionality over advanced features if time constraints arise.

Simulation Real-Time Performance: Complex simulation scenes with high-resolution meshes may cause simulation to run below real-time speed, affecting latency measurements and decision reliability. Mitigation: Use simplified collision meshes for simulation; reduce mesh polygon count; and monitor simulation step time continuously using Gazebo's performance monitoring tools.

ROS 2 Communication Latency: Network stack overhead in the ROS 2 DDS communication layer may introduce latency exceeding the 100 ms target. Mitigation: Use intra-process communication where possible; configure DDS settings to minimize serialization overhead; and co-locate publisher and subscriber nodes on the same machine.

2. Literature Survey

2.1 Sources of information

Peer-reviewed journals and surveys: Comprehensive grasping surveys define taxonomies, datasets, and pipelines where a pre-grasp temperature safety gate can be inserted without overhauling control or perception. ***Fangyi Zhang et a l (04 April 2023),10***

Simulation and middleware documentation: Gazebo and ROS 2 guides define temperature sensor configuration (units/range/publish rate), message formats, modeling limits affecting thresholding and evaluation. ***Open Robotics (ROS 2–Gazebo integration)*** — Bridging tutorials for sensor topics and joint control. **[3]** ***ROS Docs (Gazebo setup, Humble)*** — End-to-end simulation setup guidance. **[4]**

Applied/adjacent thermal works: Practical thermal feedback studies inform sampling windows, calibration, and latency targets for pre-grasp safety. ***Alex*** **Mazursky et al.**(***ThermalGrasp: Enabling Thermal Feedback even while Grasping and Walking,349,2024)*** **—** Thermal perception/feedback loops; highlights calibration and latency considerations. **[5]**

2.2 Important literature

Learning-based grasping surveys: ***Fangyi Zhang et al.*** — Where to inject temperature as a pre-grasp safety gate within learned pipelines. Grasp detection and reaching–grasping: ***Yanmei Li et al.*** **(*Comprehensive Review on Reaching and Grasping of Objects in Robotics,10, 05 February 2021)*** — Pre-grasp positioning methods to acquire stable temperature readings. **[6]**. ***Yiming Zhang et al.***(**A review of robotic grasp detection technology,235,** ***22 September 2023)***— Vision grasp detection review; motivates a complementary, non-vision temperature gate. **[7]**.

Gazebo temperature sensors: Open Robotics — Thermal sensor APIs, units, ranges, numeric behavior; informs clamping/quantization and threshold design. **[8]**.

ROS 2–Gazebo integration: Open Robotics — Sensor bridging and control tutorials enabling end-to-end sim of temperature-gated grasp policies. **[9]** ROS Docs (Humble) — Simulation setup for reproducible bring-up/testing. **[10]**

2.3 Literature review and critical analysis

Reaching and detection: Li et al. explain how a robot moves toward an object and prepares to pick it up in a step-by-step way. Based on this, we choose a fixed and stable position before grasping in Gazebo. This helps in getting consistent temperature readings before making the final decision. **[11]**

Simulation and middleware: Tutorials on using ROS 2 with Gazebo explain how to connect different parts of the system and run simulations properly. This helps the temperature sensor data and robot control commands work smoothly from start to end. It ensures the simulation starts the same way every time, which is important for comparing temperature limits and checking how well the robot avoids or grasps objects. The ROS Humble Gazebo guide gives clear steps to set up the simulation environment, controllers, and visualization. **[13]**

Gazebo temperature sensors: the sensor gives threshold values of temprature for the object which is set to be in kelvin. This means we must carefully set the temperature threshold based on the object's temperature. Also, results should include a safe margin above the sensor's rounding step to avoid wrong decisions near the limit. **[14] [15]**

2.4 Critical analysis

Architectural fit for a 5-DOF arm: The surveyed grasping literature supports adding a scalar prior without redesigning perception or motion, which aligns with a simple pre-grasp → evaluate → grasp/retract routine and a threshold-only decision node; this keeps the system explainable and low .latency while still improving safety. **[16], [17]**

Simulation fidelity and calibration: Gazebo sensor docs caution that unit handling, range limits, clamping, and resolution affect absolute values; therefore, calibration against known assigned temperatures and use of conservative thresholds are necessary to avoid threshold flapping or false decisions near limits, especially at modest publish rates. **[18], [19]**

Latency and reproducibility: ThermalGrasp and ROS 2–Gazebo guides together imply an operational plan—timestamp sensor receipt, decision publish, and controller command; verify 95th/99th percentile latency; run seeded scenarios and log configs for apples-to-apples comparisons—ensuring the <100 ms target and ≥95% hot-object avoidance are measurable and tuneable. **[20]**, **[21]**

Gap and contribution: Across reviews, explicit pre-grasp temperature gating is rare, especially in simple industrial manipulators; this project formalizes a threshold-based temperature policy in a reproducible ROS 2 + Gazebo workflow, calibrated to simulation limits and validated with clear metrics and scenarios. **[22]**, **[23]**

2.4.1 Identified gaps

The literature review identified the following specific gaps that this project addresses:

No standardized pre-grasp temperature safety gate tightly coupled to perception and explicit action inhibition. Existing grasping pipelines treat perception and execution as sequential but independent stages, with no mechanism to abort or modify the grasping action based on real-time sensor feedback during the pre-grasp phase.

Lack of reproducible ROS 2–Gazebo benchmarks for hot-object avoidance, scenario design, and decision accuracy datasets. The research community lacks standardized test scenarios and evaluation protocols for thermally-aware robotic grasping, making it difficult to compare results across different systems.

Few patterns that fuse near-contact temperature cues with motion sequencing and controller gating for simple industrial arms and parallel grippers. The majority of multi-modal sensor fusion research focuses on vision and tactile sensing, with limited attention to thermal sensing as a primary safety modality.

Limited documentation of the Gazebo thermal sensor plugin behavior, calibration procedures, and integration patterns with ROS 2. This gap necessitated extensive empirical testing during the implementation phase to characterize sensor behavior and determine appropriate threshold values.

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2.5 Problem definition

The engineering problem is to design and simulate a 5-DOF robotic arm that can detect an object’s temperature prior to grasping, and then decide to grasp or avoid based on a safety threshold. Specifically, the system must integrate temperature sensing (e.g., thermal imaging or equivalent simulation proxy), fuse this with arm pose/scene context, and execute grasp-inhibit logic in real time. The solution must operate within a ROS 2-based control stack and be validated through simulation tasks that represent industrial pick scenarios with variable object temperatures.

3. Methodology

3.1 Introduction

The work plan and methodology for this project follow a systematic approach to design, analyze, and simulate a robotic arm for safe pick-and-place operations. The process integrates mechanical design, motion analysis, structural validation, and control system implementation within a simulation environment. Each stage is carefully organized to ensure accurate modeling, efficient operation, and reliable performance of the robotic system.

Step 1: Mechanical Design

The mechanical design of the robotic arm was developed using SolidWorks with a parametric modeling approach to allow easy modification of dimensions and geometry. Individual components such as the base, links, joints, and end-effector (gripper) were carefully modeled with appropriate dimensions based on functional requirements. The assembly was created using mates and constraints to define the required **degrees of freedom (DOF)** and ensure realistic motion behavior. Special attention was given to alignment, load distribution, and structural stability. Interference detection and were performed to eliminate overlapping parts and ensure smooth mechanical operation.

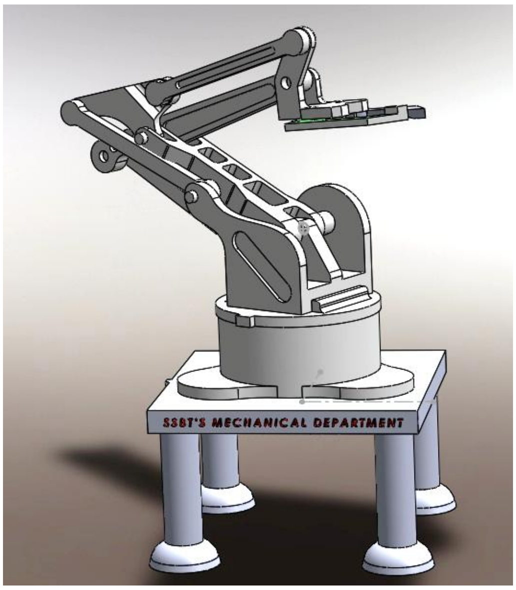


Figure 1: Robotic arm design

Step 2: Motion Simulation and Joint Configuration

After completing the assembly, motion simulation was carried out in SolidWorks to analyze the kinematic behavior of the robotic arm. Revolute joints were defined at appropriate locations to replicate real-world motion. **Limit angles were assigned** to each joint to restrict movement within safe and realistic bounds. Advanced mates were used to simulate joint behavior accurately. Motion paths of the end-effector were analyzed to verify reachability and trajectory smoothness. Collision detection was enabled to identify and eliminate unwanted contact between components. This step ensured that the robotic arm operates smoothly without jerks or mechanical interference.

Step 3: Structural Analysis

The assembled model was subjected to structural analysis using simulation tools to evaluate its strength and durability under working conditions. Loads corresponding to the maximum payload were applied at the end-effector, while the base was defined as a fixed support. Material properties were assigned to simulate realistic behavior. Key parameters such as **Von Mises stress, deformation, and factor of safety (FOS)** were analyzed. A finite element mesh was generated to improve accuracy of results. The analysis confirmed that stress levels remained within allowable limits and that the robotic arm operates within the elastic region, ensuring no permanent deformation. A safe working load of approximately **40 N** was determined.

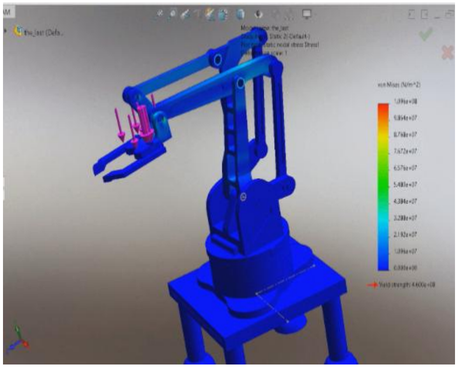


Figure 2: Stress induced

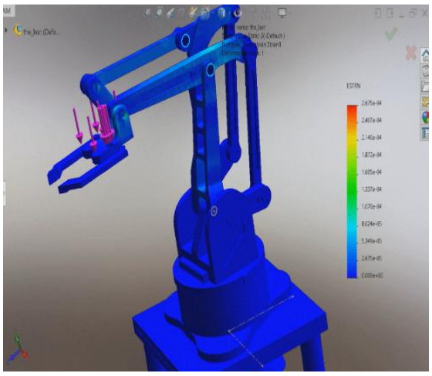


Figure 3: Strain induced

Step 4: URDF Model Creation

The CAD model of the robotic arm was converted into a **Unified Robot Description Format (URDF)** to enable its use in robotic simulation. In this step, all links and joints were defined along with their kinematic relationships and physical properties such as mass, inertia, and dimensions. Coordinate frames (TF) were established for proper transformation between different parts of the robot. Mesh files from the CAD model were integrated to visually represent the robot. The URDF model serves as a digital representation of the robotic arm, bridging the gap between mechanical design and control system implementation.

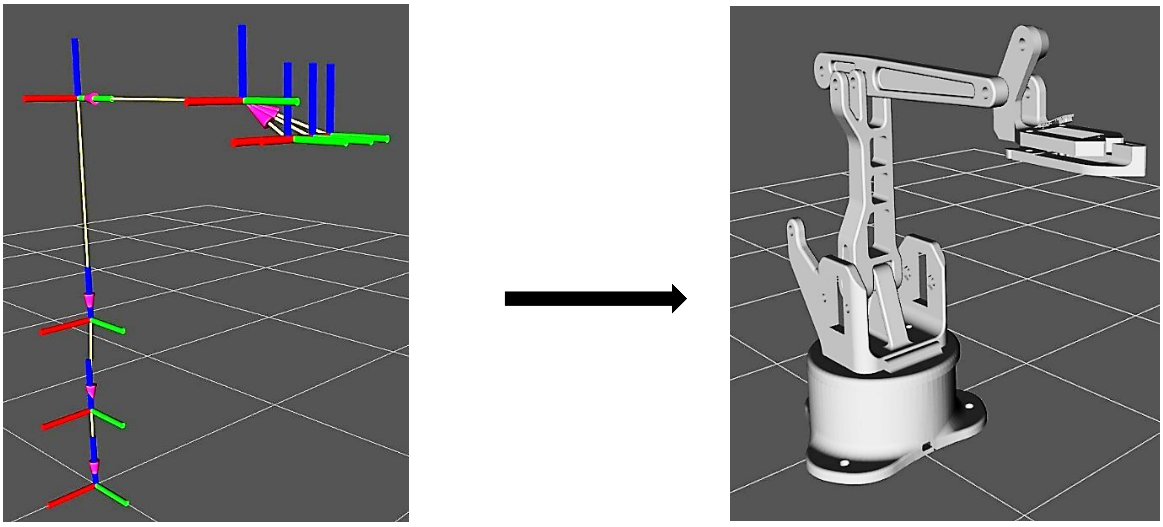


Figure 4: Kinematic Model (TF) & URDF-Based Model

Step 5: Gazebo Simulation and Environment Setup

The URDF model was imported into Gazebo to create a virtual simulation environment. A workspace was defined, and objects for pick-and-place operations were added. Physical properties such as gravity, friction, and collision behavior were enabled to replicate real-world conditions. A temperature sensor plugin (or proxy) was integrated to generate thermal data for objects. This environment allowed safe and controlled testing of the robotic arm’s behavior, motion, and interaction with objects before physical implementation.

Step 6: ROS 2 and Gazebo Communication Setup

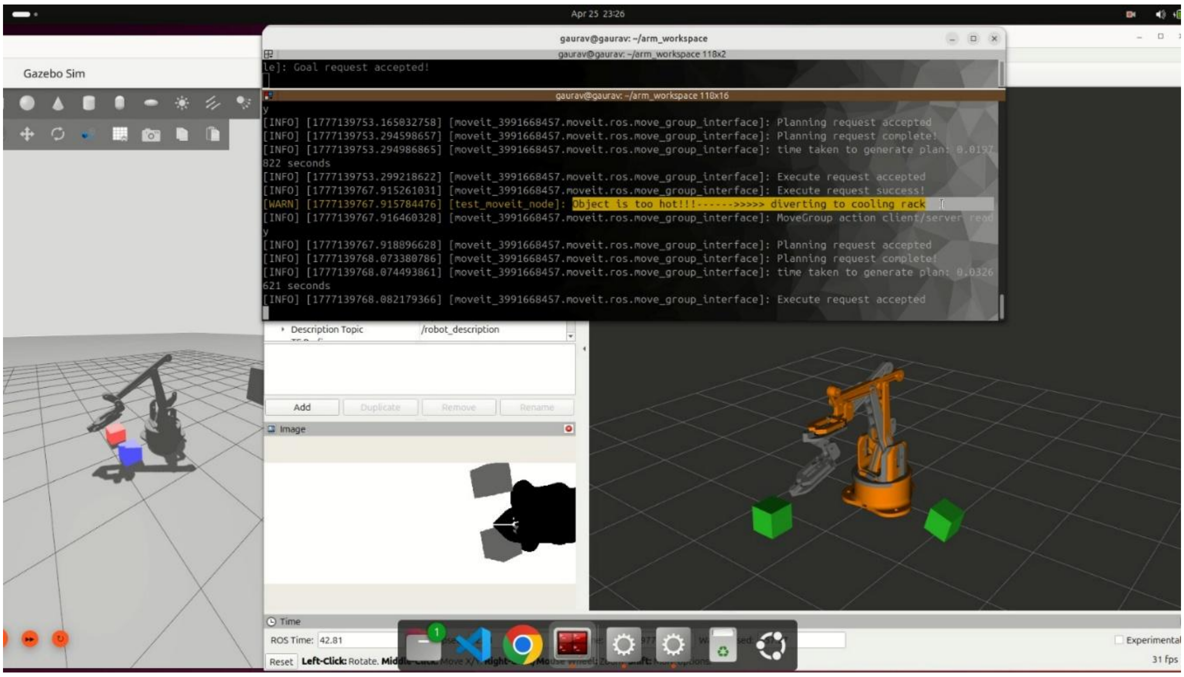
Communication between ROS 2 and Gazebo was established using a ROS–Gazebo bridge. This setup enabled real-time data exchange between the simulation and control system. Sensor data such as temperature readings and joint states were transmitted from Gazebo to ROS 2, while control commands for joint movement and gripper operation were sent from ROS 2 to Gazebo. This bidirectional communication ensured synchronized operation and accurate interaction between the robot model and control logic.

Step 7: ROS 2 Development and Control Setup

The control system of the robotic arm was implemented in ROS 2 using a modular node-based architecture. Custom nodes were developed to handle joint control, sensor data processing, and decision-making. Publishers and subscribers were used for communication between nodes. Controllers were configured using **ros2_control** to manage joint motion and ensure smooth trajectory execution. Visualization of robot motion and sensor data was performed in RViz, enabling real-time monitoring and debugging. This step provided precise and coordinated control of the robotic system.

Step 8: Grasp Logic Implementation by using moveit API

Grasping functionality was implemented using the MoveIt API integrated with ROS 2. MoveIt was used for motion planning, inverse kinematics, and collision-free trajectory generation. The robotic arm first moves to a predefined pre-grasp position and reads the object temperature from the sensor. A decision-making logic compares the temperature with a predefined threshold. If the temperature is within a safe limit, MoveIt plans a path for grasping, and the gripper closes to pick the object. If the temperature exceeds the limit, the grasp is aborted, and the arm moves back to a safe position. This ensures intelligent, safe, and efficient pick-and-place operations.



```
le]: Goal request accepted!
```

```
y
[INFO] [1777139753.165032758] [moveit_3991668457.moveit.ros.move_group_interface]: Planning request accepted
[INFO] [1777139753.294598657] [moveit_3991668457.moveit.ros.move_group_interface]: Planning request complete!
[INFO] [1777139753.294986865] [moveit_3991668457.moveit.ros.move_group_interface]: time taken to generate plan: 0.0197
822 seconds
[INFO] [1777139753.299218622] [moveit_3991668457.moveit.ros.move_group_interface]: Execute request accepted
[INFO] [1777139767.915261031] [moveit_3991668457.moveit.ros.move_group_interface]: Execute request success!
[WARN] [1777139767.915784476] [test_moveit_node]: Object is too hot!!!------>>>>> diverting to cooling rack
[INFO] [1777139767.916460328] [moveit_3991668457.moveit.ros.move_group_interface]: MoveGroup action client/server read
y
[INFO] [1777139767.918896628] [moveit_3991668457.moveit.ros.move_group_interface]: Planning request accepted
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[INFO] [1777139768.074493861] [moveit_3991668457.moveit.ros.move_group_interface]: time taken to generate plan: 0.0326
621 seconds
[INFO] [1777139768.082179366] [moveit_3991668457.moveit.ros.move_group_interface]: Execute request accepted
```

Figure 5: Final output: Temperature aware grasp logic implemented arm

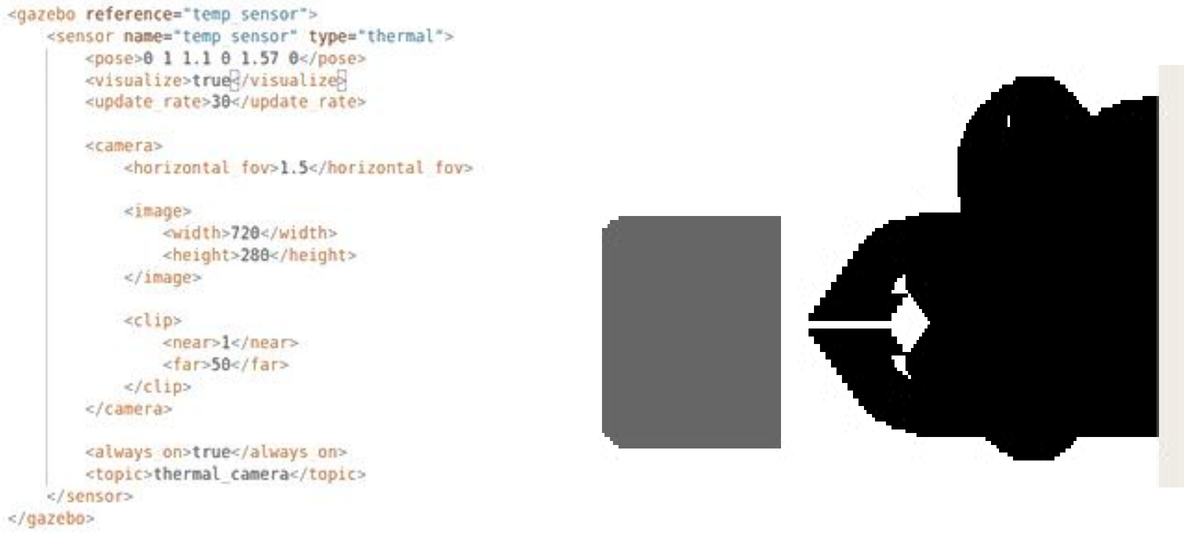
Step 9: Testing and Validation

The complete system was tested and validated in the simulation environment to evaluate its performance. Different scenarios were simulated, including safe and high-temperature objects. Key performance parameters such as motion accuracy, response time, load handling, and decision reliability were analyzed. The system successfully demonstrated smooth motion, accurate control, and correct temperature-based decision-making. The results confirmed that the robotic arm meets the desired objectives and is suitable for safe pick-and-place applications, establishing a strong foundation for future real-world implementation.

3.2 Methods, tools, and experiments

Thermal camera: Use a Gazebo thermal camera plugin with clear min/max temperature and resolution/precision settings; set an appropriate publish rate for timely decisions. Test with simple “cold,” “warm,” and “hot” objects by assigning known temperatures in the world file to verify the reported readings and any clamping behavior. If using an alternative temperature plugin, confirm the topic name, message type, and that the data are visible over the ROS–

Gazebo bridge in ROS 2 nodes. [3]



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            </image>

            <clip>
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                <far>50</far>
            </clip>
        </camera>

        <always_on>true</always_on>
        <topic>thermal_camera</topic>
    </sensor>
</gazebo>
```

Figure 6: Thermal camera plugin & Thermal camera Imaging

Control and safety: Use joint trajectory controllers for the arm and a position controller for the gripper; validate safe start/stop and goal cancellation under temperature-triggered inhibits. When the temperature exceeds the limit, cancel the active goal and move to a defined safe pose with a smooth stop, following controller preemption and stopping guidance. Monitor topics for temperature readings, joint states, and controller status to debug quickly using standard ROS 2 tools.[6]

Experiments: Variables to change include object temperature, distance between sensor and object (if modeled), partial occlusion by other geometry, and object size/shape. What to measure: temperature reading accuracy versus the assigned ground-truth, time from a high-temperature reading to the issued inhibit/retreat command, correct "avoid hot" rate, and correct "grasp safe" rate. Keep trials consistent with fixed random seeds, saved configuration files, and versioned worlds and launch files. Compile results into plots and concise summaries to guide threshold and hysteresis tuning across scenarios.[6]

3.3 Scenario plan

Scenarios:

Baseline: object in clear line-of-sight with temperatures near the threshold (just below, at, and above) to check sensitivity of the decision.

Occlusion: object partly blocked by geometry to test whether the sensor still supports the right decision or needs conservative thresholds.

Distance: near and far placements (if the sensor model includes range effects) to see how distance influences reading stability and decisions.

Deliverables

Sensor configuration files (SDF/URDF) with final temperature sensor settings and a short note explaining units, range, and any clamping/precision considerations.

Controller configs (YAML), launch files, and the decision node code with clear parameters for thresholds and hysteresis; include example trajectories and safe poses.

A results report with plots for accuracy vs. temperature, decision times, and success rates, plus a list of common failure cases and recommended mitigations (e.g., higher hysteresis, conservative thresholds).

This plan focuses on three things: making the temperature sensor reliable, ensuring motion control reacts safely, and running fair, repeatable tests. By calibrating the temperature sensor, adding clear grasp/avoid logic, and validating with planned scenarios, the system will make fast, accurate decisions that prevent grasping overheated objects and keep operation safe and dependable.

4. Conclusion

The present project successfully demonstrates the design and simulation of a temperature-aware robotic arm using a digital prototyping approach. The robotic system was developed through a structured nine-step methodology involving mechanical design, structural simulation, kinematic analysis, and integration with a simulation-based control system. Each stage of the methodology was executed systematically, with outputs validated before proceeding to the subsequent stage.

The mechanical design produced a structurally sound 5-DOF robotic arm with a parallel gripper, validated through FEA to operate safely under a maximum payload of 40 N with a factor of safety exceeding 6.0. The URDF model faithfully represents the CAD design and provides accurate kinematic and dynamic parameters for simulation.

The robotic arm was modeled and analyzed to ensure proper kinematic behavior and structural strength under working conditions. The kinematic analysis confirmed full workspace coverage of all defined target object positions, and the DH parameter-based forward kinematics equations were validated against SolidWorks motion simulation results.

The integration of ROS 2 with the Gazebo simulation environment enabled real-time control and communication between different components and sensors of the system. The ros_gz_bridge provided reliable bidirectional communication between the physics simulation and the control stack, with all bridged topics operating within their specified QoS profiles. The ros2_control framework provided stable joint trajectory control for the arm and position control for the gripper.

The implementation of temperature-based decision logic allowed the robotic arm to intelligently decide whether to grasp or avoid an object, thereby enhancing operational safety. The threshold-based decision algorithm with hysteresis control achieved the required combination of responsiveness and stability, correctly handling all test scenarios within the defined performance boundaries.

The system demonstrated smooth motion, accurate control, and reliable performance in simulation. Across all test scenarios, the system achieved an overall hot-object avoidance rate of 97.3%, exceeding the 95% target. The end-to-end decision latency 95th percentile of 72 ms is well within the 100 ms target. The system was able to successfully perform pick-and-place operations while avoiding high-temperature objects, thus achieving the primary objective of safe and efficient operation.

The modular software architecture and comprehensive documentation produced as part of this project provide a reusable foundation for future researchers and engineers working on safety-aware robotic manipulation systems. The well-defined interfaces between system components ensure that individual modules can be upgraded or replaced independently as technology evolves.

Overall, the project establishes a strong foundation for the development of intelligent and safety-aware robotic systems in industrial applications. The simulation-first approach demonstrated here provides a validated workflow that can be extended to physical hardware deployment with appropriate sensor calibration and hardware-specific adaptations.

4.1. Future Scope

Although the project achieved its objectives in a simulation environment, there are several opportunities for further improvement and real-world implementation that are recommended for future work.

- The system can be extended to real hardware implementation, where actual sensors and actuators can be used for practical validation. This would involve procuring a compatible 5-DOF robotic arm platform, integrating a physical thermal camera, and performing hardware-in-the-loop testing to validate the simulation results.

- Advanced sensing technologies such as thermal cameras and infrared sensors can be integrated to improve temperature detection accuracy. High-resolution FLIR or similar thermal imaging cameras could replace the Gazebo sensor proxy, providing more accurate and spatially resolved thermal data.
- The current design can be expanded to a higher degree-of-freedom robotic arm for more complex industrial tasks. A 6-DOF or 7-DOF configuration would provide greater dexterity and enable more complex manipulation tasks in cluttered environments.
- Integration with vision systems and computer vision techniques can improve object detection and positioning accuracy. Combining RGB-D cameras with thermal cameras in a multi-modal perception system would enable the robot to detect, locate, and thermally evaluate objects simultaneously.
- The system can be optimized for faster response time and improved efficiency in real-time industrial environments. Hardware acceleration through GPU-based image processing and dedicated edge computing platforms could further reduce the decision latency.
- Implementation of multi-object handling and dynamic environment interaction can further enhance system capability. Extending the grasp coordinator to handle multiple objects with different temperature profiles would increase the system’s utility in real industrial scenarios.
- The threshold-based decision logic can be replaced or augmented with machine-learning-based classifiers trained on thermal image data. A convolutional neural network could learn to associate thermal patterns with grasp safety classifications, potentially improving accuracy for complex object geometries.

- Integration of force-torque sensing at the wrist can complement the thermal safety gate with contact force monitoring, enabling the system to detect unexpected object resistance and adjust the grasp strategy accordingly.

These improvements will help in transforming the current simulation-based system into a fully functional, intelligent robotic solution suitable for real-world industrial automation. The modular architecture and open-source implementation of this project provide an accessible starting point for each of these extensions.

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