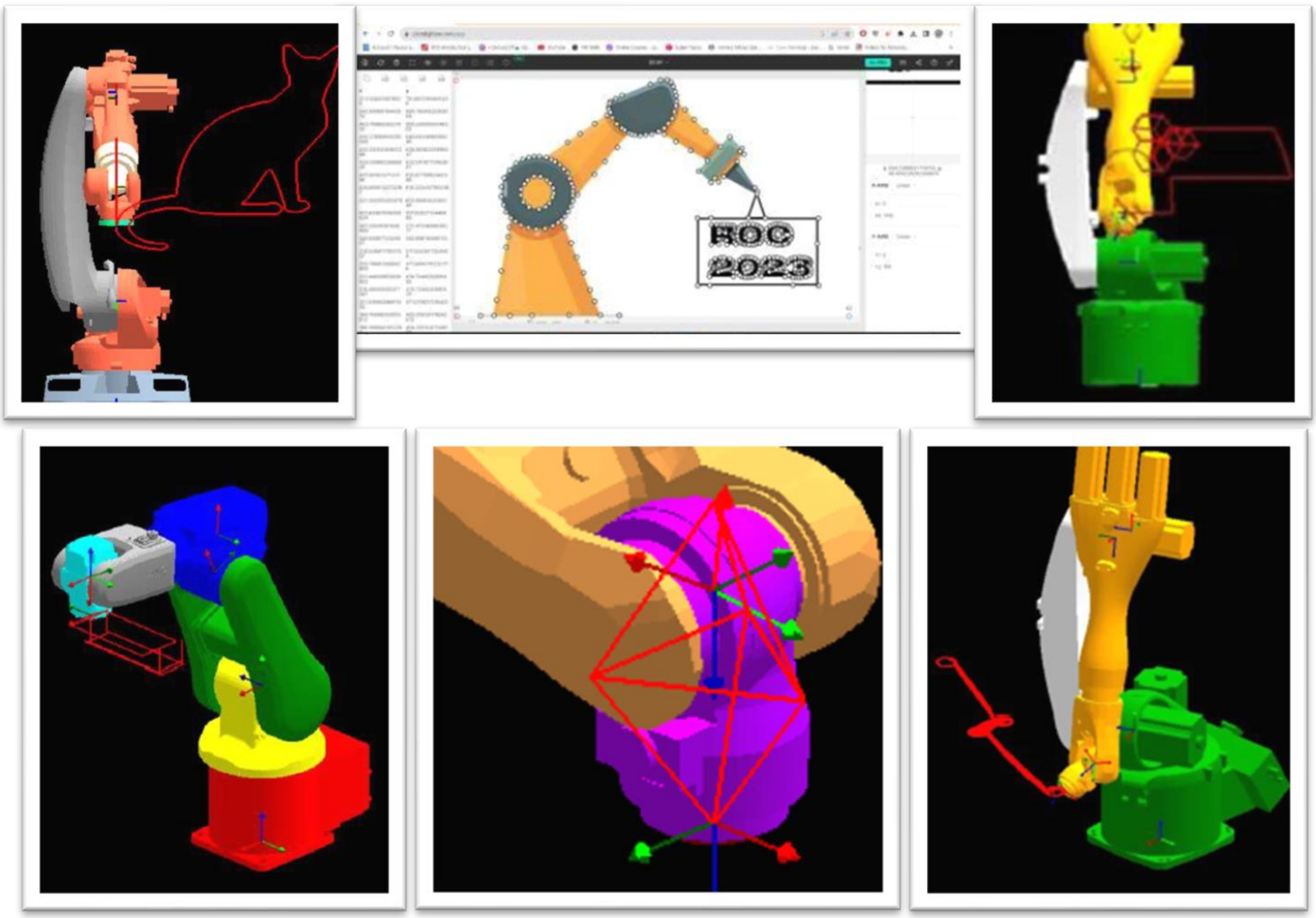
RoboAnalyzer

Self-driven
Self-learning
$S^3$ approach
Self-evaluating

# ROBOANALYZER-BASED ONLINE/OFFLINE COMPETITION ROC 2023 (VERSION 4.0)




## Proceedings of ROC Enclave on Sept 30, 2023
## IIT Delhi, New Delhi

# Timeline

| Date | Description | Remarks |
|---|---|---|
| May 8, 2023 | First Online Meeting of ROC Organizing Committee | Initial round of discussions on when and how to conduct ROC 2023. |
| May 31, 2023 | Second Online Meeting of ROC Organizing Committee | Dates and modalities were finalized. |
| June 1, 2023 | Call for Participation Announced | |
| June 13, 2023 | Deadline for Registration | 103 registrations were received |
| June 28, 2023 | Announcement of Teams | 25 teams were announced |
| July 10, 2023 | Interaction Session 1 | |
| July 20, 2023 | Interaction Session 2 | Teams were rearranged to have 11 teams |
| July 31, 2023 | Interaction Session 3 | Teams were rearranged to have 7 teams |
| August 31, 2023 | Interaction Session 4 | |
| Sept 10, 2023 | Submission of Final Task | |
| Sept 15, 2023 | Peer Evaluation | Done by 7 Teams |
| Sept 30, 2023 | ROC Conclave at IIT Delhi | It was planned for Sept 9 (Sat). However, due to G20 Summit, it was postponed to Sept 30 (Sat). |

# Schedule of ROC Conclave at IIT Delhi on Sept 30, 2023

| Time | Description |
|---|---|
| 08:00 to 08:45 | Registration/Kit Distribution in Hotel |
| 08:45 to 09:15 | Reach ME Seminar Hall (Block 2, 422), IIT Delhi |
| 09:15 to 09:30 | Welcome by Ms. Shilpa Pawar |
| 09:30 to 10:00 | Brief Overview of ROC by Prof. Nayan M. Kakoty |
| 10:00 to 11:00 | Inaugural Talk by Prof. S. K. Saha |
| 11:00 to 11:30 | Tea Break and Networking |
| 11:30 to 13:00 | Presentations by Participating Teams |
| 13:00 to 14:00 | Lunch |
| 14:00 to 15:00 | "Ways to Extend ROC Outcomes" by Dr. Rajeevlochana G. Chittawadigi |
| 15:00 to 15:30 | "Surprise Element" |
| 15:30 to 16:00 | Technology Developed and Marketed by SVR Infotech by Ms. Shilpa Pawar |
| 16:00 to 16:30 | Results Announcement and Valedictory Function |
| 16:30 to 17:00 | Photo Session and High Tea |

# Introduction to ROC

A survey by the National Association of Software and Service Companies reported that India produces 15 Lakhs of engineering graduates every year of which 2.5 Lakhs only succeed in getting engineering job. In another report by India Today dated November 2019, it was stated that 80 percent of Indian engineers were unemployed in 2019. This indicates that a large percentage of our graduates lack the skills that employers need.

RoboAnalyzer-based Online/ Offline Competition (ROC) was rooted to address these issues. ROC was started by the Embedded Systems and Robotics Laboratory, Tezpur University in collaboration with the two main developers of it, Professor Subir K. Saha from IIT Delhi and Dr. Rajeevlochana G. Chittawadigi, Amrita Vishwa Vidyapeetham, Bengaluru Campus. It aims to develop creative thinking ability for instilling technology-management skills among the budding engineers to create innovative solutions for indigenous problems.

In ROC spanning from 2020 to 2023, the young minds have been trained with the knowledge of robotics, which acted as the platform to develop skills of collaborative learning, creative thinking, time management, respect to multiculturalism through the motto of "Self-Driven, Self- Learning and Self-Evaluating" (an S3-approach of learning). All the activities of the participants are systematically recorded online (www.tezu.ernet.in/erl and www.roboanalyzer.com) for ready reference by the prospective learners and employers. Enthusiastic participation of young minds from India, Hong Kong, Romania have been encouraging to take the ROC to next higher levels every year.

In this year, 2023, ROC is geared up with the collaboration of SVR Infotech, Pune and added ROC Conclave on September 30, 2023 in IIT Delhi.

Prof. Nayan M. Kakoty
Tezpur University, Assam

# Journey of ROC

It is a great pleasure to see that we could continue ROC, i.e., RoboAnalyzer (RA) based Online Competition, for the fourth consecutive year since COVID period in 2020. In this edition, we are meeting physically at IIT Delhi for the final presentations. I thank SVR to sponsor the event.

I am eagerly looking forward to the young students who are making the efforts to come from far way distances. At the same time, this booklet which resembles a conference proceedings will provide as much value as a proceeding does, mainly, in the area of various usages of the RA software.

Thanks to Nayan, Rajeev and Abhijit for being with the ROC since its inception.

Special acknowledgments are due to the team members of SVR including Viinod, Krunali, Shilpa, and others for making the efforts to conduct this event, those who are taking part. As the abbreviation sounds let us "rock" the show!

Prof. Subir K. Saha

IIT Delhi

# Importance of Indigenous Products

Robotics has been a technologically advanced topic ever since the first set of industrial robots were developed in 1960's. Thereafter many developing countries have successfully developed robots and deployed them in industries, space, healthcare and on field.

Though one can start using products developed by foreign countries, the following are the main problems associated with it:

1. Technical knowhow is Missing: The users get the product as a black box and any suitable changes to suit Indian demand may not be possible or it could be slow to implement by the parent company.
2. Over Dependent on Others: In situations like Covid-19, the technologies imported from abroad have a lot of dependencies and may stop or slow down the productivity in the country.
3. Import Costs: Any product imported has to be paid in Customs Duty and hence the cost of the product almost gets doubled, thereby making the product expensive.

To overcome all of these, we should strive hard to develop products inhouse and ensure that there is an ecosystem for it to prosper ahead and serve its purpose.

Good attempt has also been made by Indian organizations and companies to leave a mark in the field of robotics. Some of them are DRDO, CSIR Labs, ISRO, MTAB, Systemantics, TAL, IdeaForge, GreyOrange, Addverb, Botlab Dynamics and Orangewood to name a few.

On similar lines, the development of RoboAnalyzer software was actively started in 2009 in the Mechatronics Lab at IIT Delhi, New Delhi, under the able supervision of Prof. Subir K. Saha. It has been almost 14 years since then and we have been able to touch the lives of thousands of teachers and students who begin learning robotics in their courses.

The feedback from the users has motivated us to keep up the development of RoboAnalyzer. We look forward to younger members to join our team and one way to get involved and get our attention is by participating in RoboAnalyzer based Online Competition (ROC) held every year.

Finally, we wish all the participants of ROC 2023 to succeed in their lives and help the country in making it independent, along the lines of "Atma Nirbhar Bharat".

Dr. Rajeevlochana G. Chittawadigi

Amrita Vishwa Vidyapeetham, Bengaluru Campus

# Story of RoboAnalyzer as a Product

RoboAnalyzer has been in active development since 2009 at IIT Delhi. It was distributed for free through its website www.roboanalyzer.com since then.

Due to its simple-to-use interface and great utility, it has been used by teachers and students to teach and learn the concepts of Denavit-Hartenberg (DH) parameters, forward and inverse kinematics, forward and inverse dynamics, motion planning, etc.

However, as time progressed, the following things were observed:

1. As RoboAnalyzer was freely available, many labs and institutes in India were not able to spend their allocated budget to buy RoboAnalyzer. Many of them bought robot simulation software developed from other countries. This not only allowed money from India going abroad, but also gave an impression that the foreign products were better.

2. Any item obtained for free may not be valued by end-user. This is similar to having an open-gym in a park. As it is available for free, users may not use it optimally thinking they can use it anytime. However, if one signs up for a membership in a gym by paying upfront, the individual shall likely start using the gym to recover the amount paid.

Based on the above two arguments, SVR Infotech could convince Prof. S. K. Saha and Dr. Rajeevlochana G. Chittawadigi to let us own up the Commercialization Rights for RoboAnalyzer and an MoU was signed between FITT-IIT Delhi and SVR Infotech on Feb 2, 2022.

RoboAnalyzer Version 8 onwards has been sold by SVR Infotech and so far 210 licenses have been sold to 9 institutes/organizations. With the new modules and potential addition of hardware integration with RoboAnalyzer, we are confident of making the software grow further and help the teachers, students and researchers.

ROC 2023 is another avenue where we would like to reach out to the users of RoboAnalyzer and we are very proud to be associated with it.

Looking forward to capture some great talents during ROC 2023.

Mr. Viinod Atpadkar

SVR Infotech (Pune)

# Motion Planning of Robotic Manipulator

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## 1. Introduction

In this RoboAnalyzer based online Competition (ROC) 2023 we perform some experiments regarding the motion planning of various robotic manipulators. In this report we discussed about how we have done the motion planning of 6 D.O.F robotic manipulator in virtual robot module of RoboAnalyzer software. During the period of ROC 2023 competition, we learned the RoboAnalyzer software which is helpful for learning new robotic concepts, simulation of robots, motion planning of robotic manipulator using forward kinematics and inverse kinematics.

Using another software like MATLAB we write the code for the simulation of robotic manipulator and for getting the trajectory of the end-effector of robotic manipulator using forward kinematics for determining for angles for each and every joints for particular points in cartesian plain as well as inverse kinematics for getting the points in cartesian plain using the known angles for each joints [1]. This simulation of robot can be helpful in industry for visualizing the motion of the robot and to avoid any fatal damage in virtual environment to save the time and money.

## 2. Methodology

In our experiment we used the MATLAB software for test and visualizing the motion of 6 D.O.F. robotic manipulator. Here in our MATLAB code, we import the STL file of any 3D object and using the MATLAB code we trace the edge points and store it in CSV file format. Then open it in RoboAnalyzer software which contain the points of drawing in X, Y, Z coordinates in cartesian plain. Then select the particular robot in virtual robot module of RoboAnalyzer software. Then after clicking on start the robot will trace the edge points and draw the object as it is in STL file.

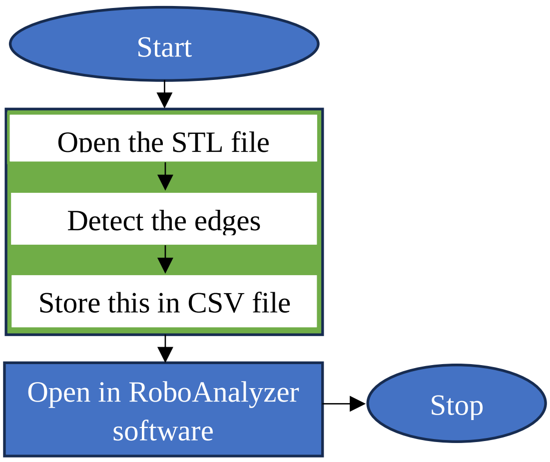


Figure 1: Block diagram of the process

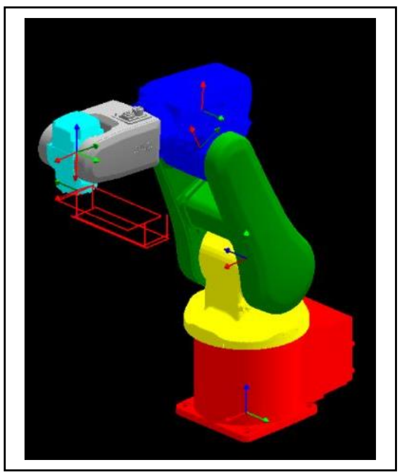

Figure 2: Drawing the cuboid as it was

## 3. Results and Discussions

In this program we learn basic concepts of robotics such as forward and inverse kinematics, Degree of Freedom and DH parameter, etc. for an animation of manipulator using MATLAB and RoboAnalyzer. We done some work with the software such as drawing names, 2D objects using STL files etc.

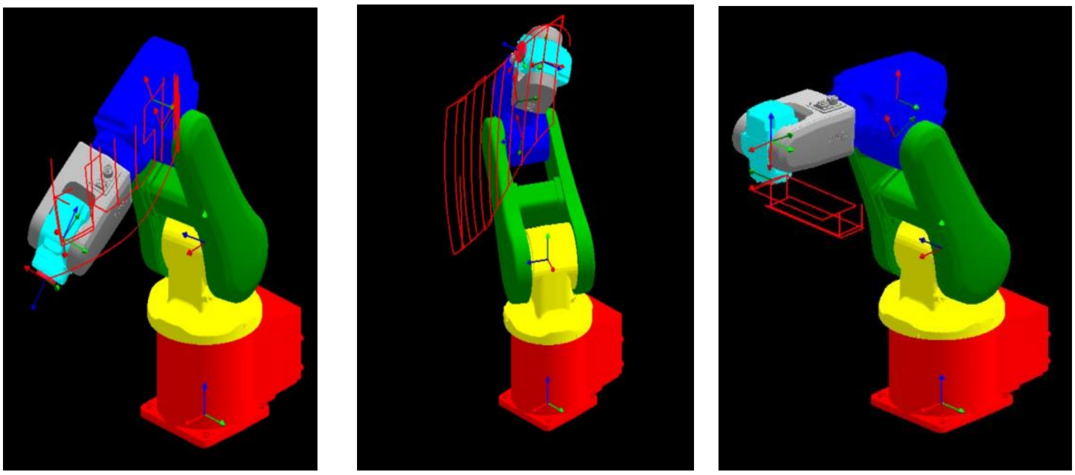

Figure 3: Drawing name KRUSHNA, Drawing panel, Drawing 2D object

During the whole period of the competition, we attended every session of ROC competition and it was very helpful for learning new things and was helpful for improvement in our work.


### Acknowledgements

We want to give thanks to RoboAnalyzer team who uploaded the helpful videos of tutorial from which we get lot of help for successful completion of our work.


### References


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# Integrating G-Code Reading and Solution Integration in MATLAB, RoboAnalyzer, andPlot Digitizer for Enhanced Robotic System Analysis and Visualization

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## 1. Introduction

Robotic systems have become integral to various industries, necessitating advanced tools for modeling, analysis, and visualization. The integration of G-Code reading and solution integration techniques within MATLAB, coupled with RoboAnalyzer and Plot Digitizer, holds promise in providing a comprehensive solution for researchers and engineers to enhance their understanding of robotic systems. This paper presents a novel approach that leverages these tools to improve accuracy and efficiency in theanalysis of robotic systems.

## 2. Methodology

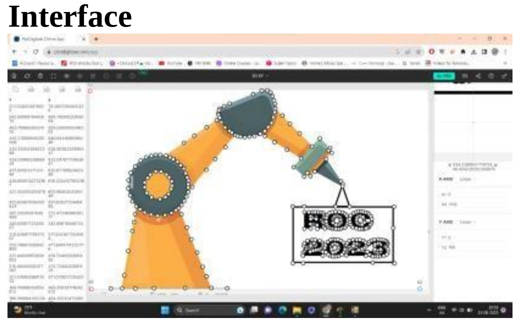
We have used 3 Methodologies for Drawing the Sketches: 1] G-Code Reader in MATLAB, 2] Plot Digitizer, 3] Snap Maker Luban

**2.1 G-Code Reading:** Proposed approach is first part: MATLAB G-Code reader development. G-Code, used for CNC and 3D printers, adapted for robotics. Paper explains reader's implementation, parsing G- Code for robot motion.

**2.2 Solution Integration in MATLAB:** Second part: MATLAB integrates solution with inverse and forward kinematics, trajectory planning. Paper explains integration benefits for precise robot movement simulation.

**2.3 Utilization of RoboAnalyzer:** RoboAnalyzer integrated in proposed framework. Paper details how it enhances understanding of robot motion capabilities through kinematic analysis and visualization.

**2.4 Integration with Plot Digitizer:** Final part: Plot Digitizer integrated, converts images to numerical data. Researchers extract info from robot images, validating simulations practically.

| **G-CODE** | **Plot Digitizer:** |
|---|---|
| **Solution Integration in RoboAnalyzer:**<br>RoboAnalyzer simulates robotic mechanisms. Integrating MATLAB's G-code reader enables analyzing robotic movements from G-code. This expands RoboAnalyzer to simulate real-world machining in a nutshell.<br>**Steps Involved:**<br>**Data Exchange:** Connect MATLAB's G-code reader to RoboAnalyzer for communication.<br>**File Input:** Provide the G-code file to the G-code reader module in MATLAB.<br>**Interpretation:** G-code reader interprets commands, generates trajectory points.<br>**Trajectory Generation:**<br>G-code reader's trajectory points simulate movements in RoboAnalyzer.<br>**Visualization:** RoboAnalyzer displays simulated robot movements, encompassing tool paths and interactions. | Plot Digitizer extracts XY coordinates from plots. Users upload an image, mark data points, and eliminate manual entry for accurate digitization swiftly.<br>**Steps Involved**<br>Step 1: Access the Plot Digitizer Website Step 2: Upload the Image<br>Step 3: Calibrate the Axes<br>Step 4: Add Data Points<br>Step 5: Adjust Axes Labels<br>Step 6: Review and Export Step 7: Export the Data **Software User Interface**<br><br> |

### 3. Benefits and Applications

Integrating G-code reader, MATLAB, RoboAnalyzer, and Plot Digitizer benefits robotics R&D by enabling efficient data extraction from plots, enhancing analysis.

**1] Realistic Simulation:** Simulation aids machining optimization/validation. Plot Digitizer extracts plot data, enabling result comparison with real-world data, refining simulation for higher accuracy.

**2] Tool path Visualization:** Clear visualization of tool paths helps users understand the machining process and identify potential issues.

**3] Process Optimization / Performance Evaluation:** Users optimize G-code inputs for machining. Graphs of robotic metrics are digitized for analysis using Plot Digitizer.

**4] Educational Tool:** Integrated solution educates CNC programming, machining, data analysis, and graph interpretation, enhancing learning in a concise manner.

**5] Research Reproducibility:** In robotics, Plot Digitizer aids result replication by digitizing published plots. This helps researchers compare their findings with past studies succinctly.

## 4. Results and Discussions

1] The results section showcases the accuracy and efficiency achieved through the integrated approach. 2] The paper concludes by summarizing the key contributions of the integrated approach, emphasizing its potential to revolutionize robotic system analysis and visualization.
3] The presented framework bridges the gap between theory and practical application, providing researchers and engineers with a powerful toolset to enhance their understanding of complex robotic systems.


**Acknowledgements**

We acknowledge the V B Kumbhar from DKTE, for helping us in the successful completion of the MATLAB & G Code integration in RoboAnalyzer.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[5] PlotDigitizer. https://plotdigitizer.com/app (Accessed: 2023)

# Motion Planning of Virtual Robots in RoboAnalyzer to Draw 2D & 3D Shapes

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## 1. Introduction

I am thrilled to share that I recently participated in an exhilarating online competition, the RoboAnalyzer event, hosted by the prestigious institution IIT Delhi. Engaging in this event was an incredible opportunity to explore the intricate world of robotics and analysis. Throughout the competition, I immersed myself in challenging tasks that required a deep understanding of robotic mechanisms and their analytical intricacies. The experience was not only intellectually stimulating but also immensely rewarding, as I gained a plethora of valuable knowledge about advanced robotic systems, their design, and their functional analysis. This competition has undoubtedly enriched my understanding of robotics and has left an indelible mark on my journey of learning and exploration.

## 2. Methodology

1. Robot Model Input (Step 1): Begin by providing the geometric and kinematic parameters of the robotic system. This includes defining the robot's links, joints, joint types, lengths, and relative orientations.
2. Forward Kinematics (Step 2): Perform forward kinematics calculations to determine the end effector's pose (position and orientation) based on joint angles. This involves propagating transformation matrices through each joint to compute the end effector's transformation relative to the base frame.
3. Inverse Kinematics (Step 3): Implement the inverse kinematics algorithm to determine the joint angles required to achieve a desired end effector pose. This step involves solving equations to find the joint angles that satisfy the given end effector position and orientation.
4. Trajectory Generation (Step 4): Define a desired trajectory for the end effector's motion. This could involve specifying waypoints or target poses. The software employs interpolation techniques to generate a smooth trajectory between these points.
5. Path Planning (Step 5): Utilize path planning algorithms to generate a collision-free path for the robot's end effector. This step ensures that the robot can reach the desired waypoints without encountering obstacles along the way.
6. Motion Simulation (Step 6): Perform a simulated motion of the robot along the generated path. This step enables visualizing the robot's movement and verifying the correctness of the kinematic calculations and planning strategies.

7. Dynamic Analysis (Step 7): If required, proceed with dynamic analysis to study the forces and torques experienced by the robot's joints during motion. This provides insights into the robot's stability and performance.

Flowchart of RoboAnalyzer Methodology:
1. Robot Model Input
2. Forward Kinematics
3. Inverse Kinematics
4. Trajectory Generation
5. Path Planning
6. Motion Simulation
7. Dynamic Analysis

## 3. Results and Discussions

**3.1 Key Results and Outcomes Achieved:** The RoboAnalyzer program yielded significant results and outcomes, demonstrating successful implementation of kinematic analysis and motion planning. Through rigorous simulations and analysis,the following achievements were obtained:

1. **Accurate Motion Execution:** The program successfully executed complex robotic motions, validated through traces of robot motion captured during simulations. These traces highlightedthe precise trajectory following, showcasing the accurate implementation of forward and inversekinematics, as well as effective motion planning.
2. **Collision-Free Path Planning:** The path planning algorithm efficiently generated collision-free paths for the robotic system. This ensured that the robot reached its target positions while avoiding obstacles, further enhancing its applicability in real-world scenarios.
3. **Dynamic Analysis Insights:** Dynamic analysis provided valuable insights into the forces and torques experienced by the robot's joints during motion. This information is crucial for optimizing robot designs, improving stability, and enhancing overall performance.

**3.2 Key Learnings:** Participating in the RoboAnalyzer program yielded invaluable insights into robotics and motionplanning:

1. **Algorithm Understanding:** I gained a deep understanding of the algorithms underpinning kinematic analysis, inverse kinematics, and motion planning. This knowledge equipped me to tackle intricate challenges in robotic systems.
2. **Simulation Skills:** Through the motion simulations, I developed proficiency in simulating and visualizing complex robotic movements. This experience is essential for validating theoretical concepts and refining practical implementations.
3. **Real-World Application:** The program's emphasis on collision-free path planning highlighted the importance of considering real-world constraints for safe and efficient robot operation in various environments.

**3.3 Suggestions for Program Improvement:**

1. **Integration of Dynamics:** While dynamic analysis was an optional step, incorporating more comprehensive dynamic analysis tools could provide a deeper understanding of the robot's behavior under varying conditions.
2. **Enhanced Visualization:** Incorporating 3D visualization tools or augmented reality

interfaces could offer more immersive insights into robotic movements and aid in better understanding complex motion scenarios.

3. **Expanded Scenario Library:** Introducing a diverse range of predefined scenarios for analysis and planning could provide participants with a broader understanding of different robotic applications and challenges.

**Acknowledgements**

I am grateful for the unwavering support and guidance from various individuals and units throughout the journey of successfully completing the RoboAnalyzer program. I extend my heartfelt appreciation to the faculty members and researchers at IIT Delhi, who meticulously developed this comprehensive program and provided the necessary resources for learning and experimentation. Their expertise and dedication were instrumental in fostering an environment of growth and exploration.

I would also like to acknowledge the technical support team, whose prompt assistance and troubleshooting guidance were invaluable whenever challenges arose during the program. Their responsiveness ensured that roadblocks were swiftly overcome, enabling a seamless learning experience.

Furthermore, I am thankful to my fellow participants for their camaraderie and exchange of ideas. Our discussions and collaborations added depth to my understanding and enriched the learning process.

Lastly, I express my gratitude to my mentors, both within and outside the program, for their invaluable insights, encouragement, and mentorship. Their expertise and willingness to share their knowledge played a pivotal role in shaping my understanding and driving successful outcomes.

This journey of kinematic analysis, motion planning, and robotics was truly a collaborative effort, and Iam fortunate to have been supported by such a remarkable community.

**References**

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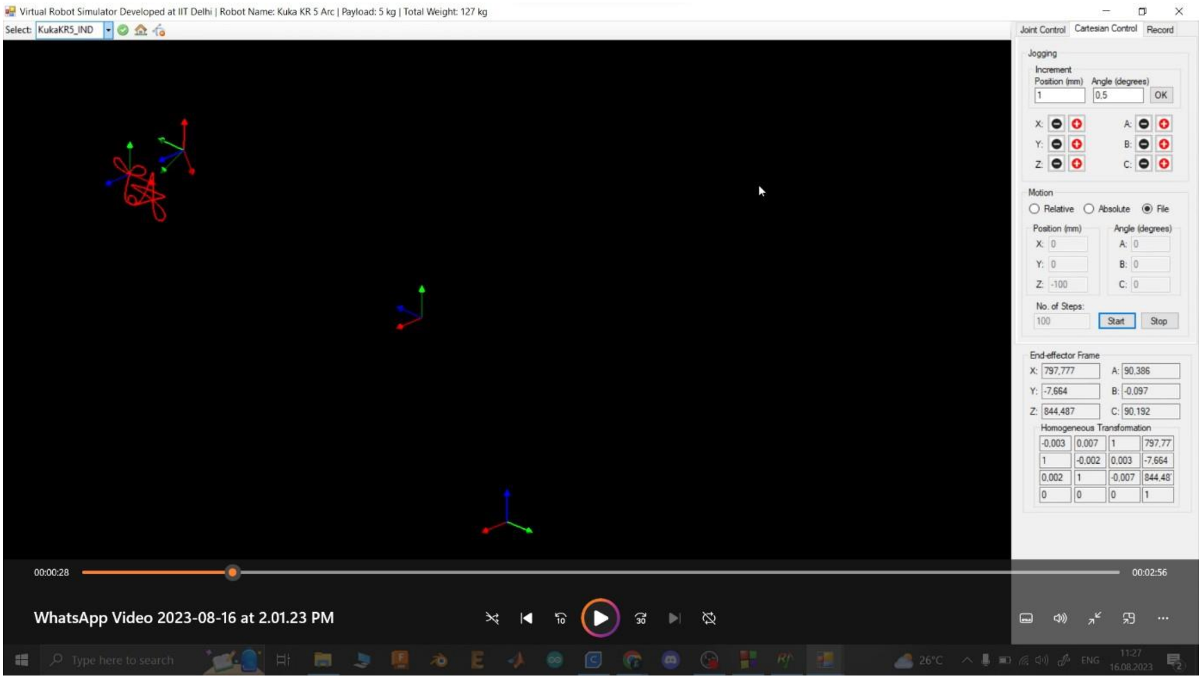
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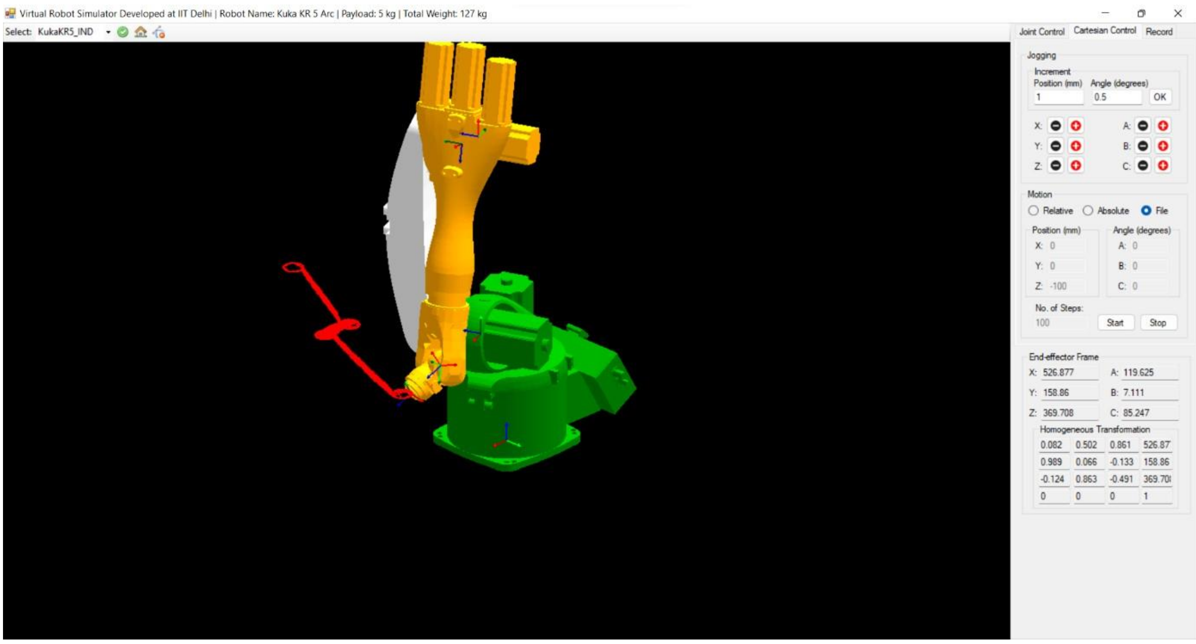
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Motion
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Absolute
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Start
Stop
End-effector Frame
Homogeneous Transformation

# ROBOSKETCH: Automating Shape Drawing Through Virtual Robot Motion Planning in RoboAnalyzer

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## 1. Introduction

In the ever-evolving landscape of robotics and automation, the convergence of technology and artistry has opened a realm of possibilities that extend far beyond conventional industrial applications. This research endeavors to explore a captivating fusion of these domains by harnessing the power of motion planning in robotics to create intricate and aesthetically pleasing drawings. At the core of this endeavor lies the robust software tool, RoboAnalyzer, which serves as both a canvas and a brush, enabling virtual robots to gracefully trace an array of diverse shapes.

## 2. Methodology

The methodology employed in this research encompasses a systematic approach that synergizes the capabilities of RoboAnalyzer, kinematic analysis, and motion planning algorithms to enable virtual robots to intricately draw various shapes. The following sections outline the key steps undertaken in the process:

i. **Robot Model Creation and Configuration:** The foundation of our methodology lies in the creation and configuration of a virtual robot model within the RoboAnalyzer environment. This involves defining the robot's kinematic structure, specifying joint types, link lengths, and joint limits. The choice of robot configuration is crucial to facilitate the desired range of motion and dexterity required for drawing intricate shapes.
ii. **Importing Shapes and Defining Paths:** To realize the artistic potential of motion planning, geometric shapes are imported into the RoboAnalyzer software. These shapes serve as the blueprint for the robot's drawing trajectories. Shapes can be represented as a series of points, curves, or paths. The software's graphical interface allows for intuitive positioning and orientation of the imported shapes.
iii. **Inverse Kinematics Calculations for Path following:** The core of motion planning involves determining the joint angles necessary for the robot's end-effector to accurately trace the desired shape path. Utilizing the principles of inverse kinematics, the software calculates the joint angles that result in the desired end-effector pose. This step ensures that the robot's movements faithfully replicate the intended shape.
iv. **Path Interpolation and Trajectory Generation:** To achieve smooth and continuous motion, path interpolation techniques are applied to the series of points obtained from

the inverse kinematics calculations. By interpolating between these points, a continuous trajectory is generated, guiding the robot's motion along the desired path. The resulting trajectory represents a seamless sequence of joint angles that the robot follows to recreate the shape.

v. **Simulation and Visualization:** The generated trajectory is then simulated within the RoboAnalyzer environment. The software's visualization capabilities allow for real-time monitoring of the robot's movements as it traces the shape. Visualization aids in validating the accuracy of the motion planning and provides insights into potential collisions, singularities, or other issues that may arise during execution.

vi. **Iterative Refinement and Optimization:** Motion planning for shape drawing often requires an iterative process of refinement. Adjustments may be made to the robot's configuration, path definition, or trajectory generation to achieve the desired level of precision and aesthetic appeal.Optimization techniques, such as smoothing algorithms or parameter tuning, can be employed to enhance the quality of the drawn shapes.

vii. **Data Export and Integration:** Upon successful simulation and validation, the generated trajectory data is exported from RoboAnalyzer. This data, comprising a sequence of joint angles over time, serves as the blueprint for controlling physical or virtual robots outside the RoboAnalyzer environment. Integration with external control mechanisms, such as programming languages or robotic frameworks, enables the execution of the planned trajectories on the chosen robot platform.

The methodology outlined above forms the foundation for motion planning of virtual robots in RoboAnalyzer to draw different shapes. By seamlessly integrating kinematics, path planning, and artistic expression, this approach showcases the harmonious synergy between technology and creativity, fostering an innovative intersection of robotics and art.

## 3. Results and Discussions

The motion planning approach within RoboAnalyzer successfully enabled virtual robots to draw a diverse range of shapes, from basic geometries to intricate patterns. Precision and accuracy assessments demonstrated consistent replication of intended shapes, highlighting the effectiveness of the methodology. Real-time visualization empowered users to interactively refine motion parameters, enhancing user engagement and creative exploration. The research illuminates the potential for collaborative artistry between humans and robots, while acknowledging computational complexities and optimization challenges. This study not only showcases the convergence of technology and art but also opens doors to innovative applications in education, interactive installations, and the emergence of novel artistic expressions.

## Acknowledgements

We wish to express our sincere appreciation to those who contributed to the success of this research. Our gratitude goes to our advisors, colleagues, and the creators of RoboAnalyzer for their support and insights. We are also thankful to our families for their unwavering encouragement.

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# Depiction of Sustainability Through Robots and the Efficiency of Traced Paths though RoboAnalyzer and MATLAB

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## 1. Introduction

This paper explores the intersection of robotics and sustainability, focusing on the depiction of sustainable practices through the actions of robots. It investigates the concept that the efficient paths traced by robots can have a positive impact on sustainability efforts. As robots continue to play an integral role across various industries, ensuring their reliability and availability becomes paramount for sustaining efficient operations. Reliability and availability co-exist in the sense of reporting for equipment maintainability issue. The availability of equipment or a robot is measured as a factor of its reliability. A robot which performs without failure for a specified period of time under specified operating conditions is considered having high reliability. The discipline of reliability engineering basically is a study of the causes, distribution and prediction of failures. From mechanical limitations to software vulnerabilities, external factors, and maintenance complexities, this analysis sheds light on the diverse issues that impact the dependability of robotic systems. But instead on focusing on mechanical inaccuracies, this paper focuses on how by minimizing energy consumption, avoiding unnecessary movements, and promoting environmentally conscious trajectories, organizations can not only enhance the reliability and availability of robots but also contribute to a greener and more sustainable future.

## 2. Methodology

This paper presents a methodology that leverages MATLAB and RoboAnalyzer software to achieve precise path planning, thereby reducing wear and tear and extending the operational life of robots. By integrating these tools, organizations can enhance both reliability and availability while contributing to a more sustainable future. Efficient path tracing is a pivotal aspect of sustainable robotic operations. MATLAB offers advanced algorithms for path optimization, taking into account factors such as energy consumption and smoothness of motion. This step ensures energy-efficient trajectories, minimizing wear and tear on components while RoboAnalyzer software facilitates detailed kinematic analysis, enabling accurate simulation of robotic movements. Precise analysis ensures that paths are mechanically sound, reducing stress on joints and enhancing reliability. Although RoboAnalyzer is a simulation tool, the depicted traced paths symbolize sustainable trajectories that minimize mechanical stress. Traced paths, despite being simulations, represent trajectories that put less strain on robotic components. By showcasing smoother, stress-minimized paths, the methodology visually emphasizes reduced wear and tear and enhanced robot longevity. To exhibit the various capabilities of the RoboAnalyzer Software in terms of efficient Path tracing with aid of MATLAB, the following are the experiments and case studies recorded:

### 2.1. Image Contour Modification in MATLAB

RoboAnalyzer allows users to import data from external sources, including CSV files. In this case, the CSV file containing the modified contour coordinates generated by MATLAB can be imported into RoboAnalyzer. In this MATLAB code performs efficient path tracing and contour modification on an input image. It converts the image to grayscale, creates a binary mask using a threshold value, and detects boundaries of regions. The extracted contour coordinates from these boundaries are collected and stored. Subsequently, the code modifies these coordinates by adding a specified range of values, creating a matrix of modified coordinates. A subset of these modified coordinates is chosen, and every fourth element is selected to reduce the data volume.

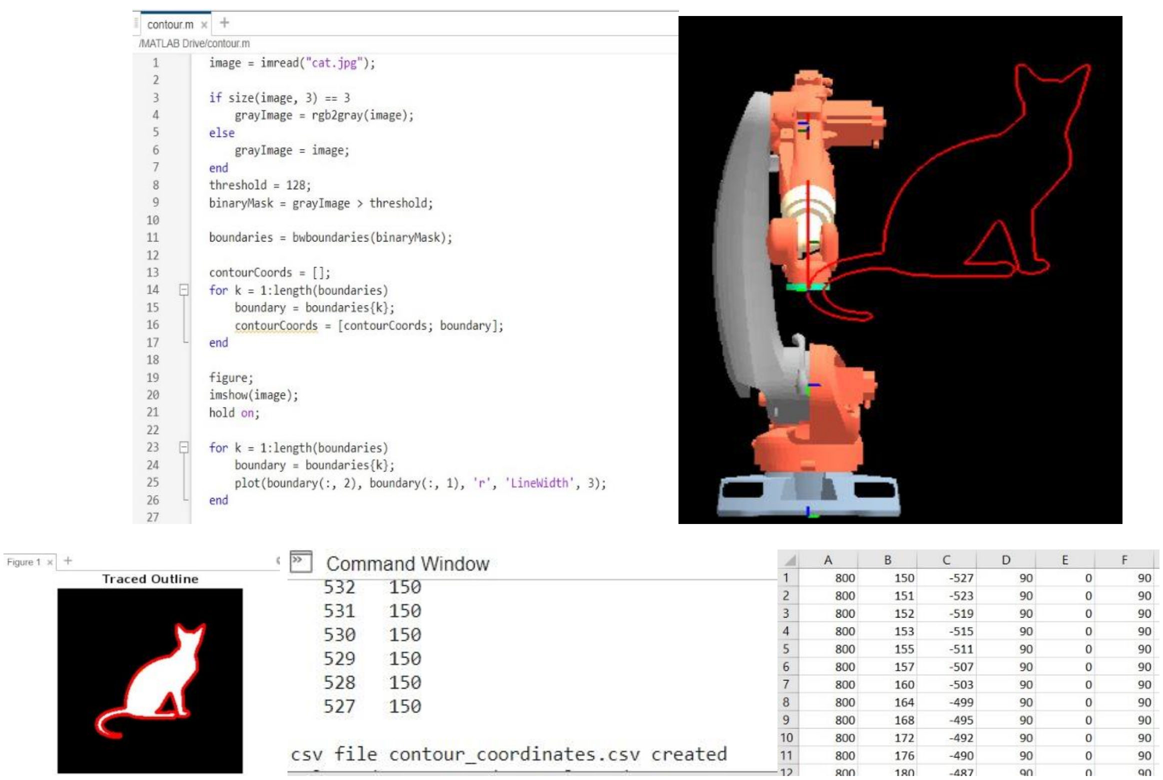


Figure 1: Code and Various Outputs of the Case Study

Finally, the selected subset of coordinates is saved to a CSV file. This comprehensive process showcases how MATLAB can efficiently process images, extract and manipulate contour coordinates, and prepare data for further analysis or simulation, with implications for enhancing sustainability through optimized robotic paths.

### 2.2. Navigating Sustainability through Maze Traversal

The given MATLAB code creates and navigates a maze represented as a matrix. The maze is defined with specified dimensions and walls, where 0s denote paths and 1s denote walls. The maze is visualized using the imshow function, with walls displayed in black and paths in white. Using a Depth-First Search (DFS) algorithm, the code explores the maze to find a path from a starting position to an exit point. A stack is utilized to keep track of positions visited during traversal. The code iterates through positions, checking for valid neighbors and adding them to the stack. The process continues until either the exit is found or all paths are explored. During traversal, the code updates the maze visualization to indicate the current position and explored path. If a path to the exit is found, the code colors the path in black, providing a clear visual representation of the navigated route. If no path is found, a message is displayed indicating the absence of a viable path to the exit. The CSV file containing the modified contour coordinates, generated through MATLAB, can be imported into RoboAnalyzer. These coordinates, which represent the optimized path, are then made available within the software environment. RoboAnalyzer generates visual outputs, such as animations or graphs, illustrating the robot's trajectory and interactions with its surroundings. This dynamic visualization helps users assess the feasibility of the optimized path. In essence, the code's maze traversal algorithm and visualization exemplify the principles of

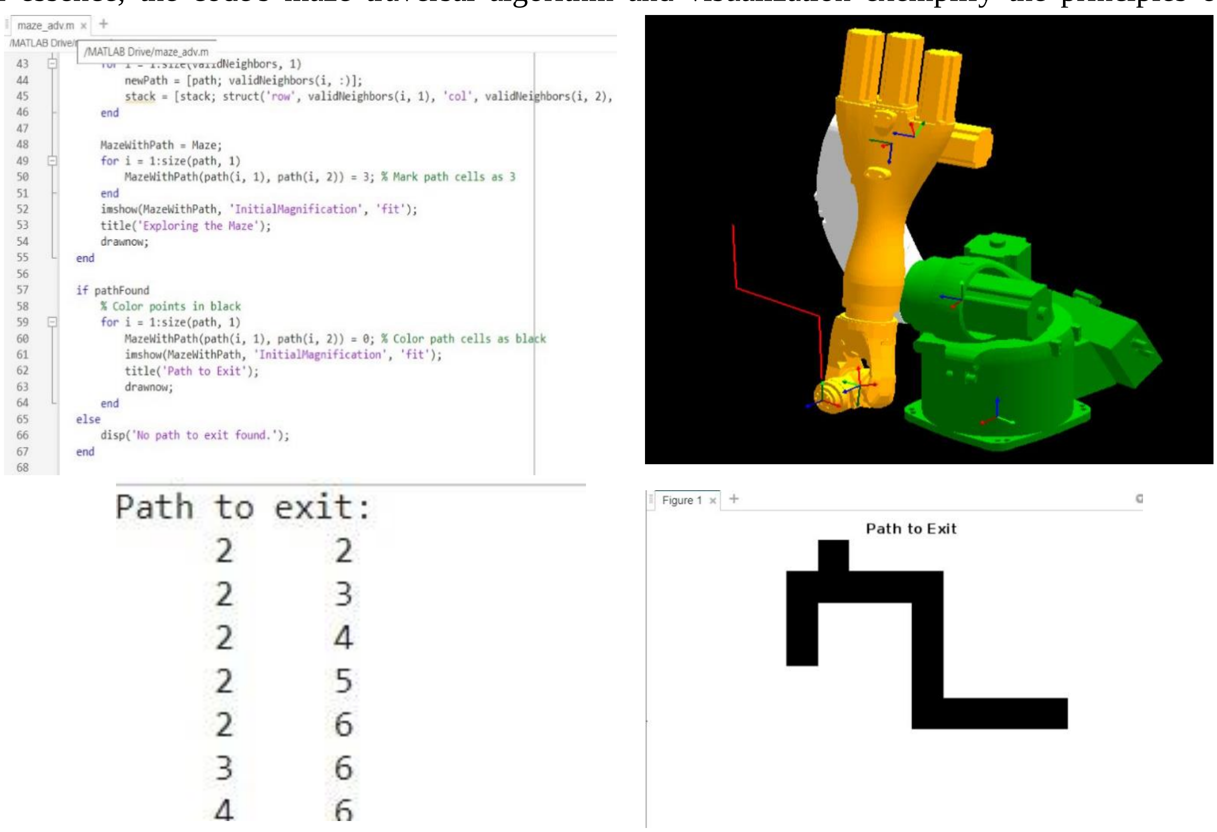


Figure 2: Code and Various Outputs of the Case Study

efficiency, decision-making, and optimization, which are core components of sustainable practices. Just as the code seeks to navigate the maze with minimal resource consumption, sustainability encourages responsible resource management and thoughtful actions to achieve long term environmental and operational goal.

## 3. Results and Discussions

These MATLAB code case studies exemplified how technology can be harnessed to optimize paths and conserve resources, aligning with sustainability objectives. The integration of RoboAnalyzer further showcased how simulation tools contribute to the visualization and analysis of optimized paths, contributing to the broader goal of sustainable and efficient robotic operations. This has illuminated the path forward for achieving reliable, available, and sustainable robotic solutions in various applications.

**Acknowledgements**

We extend our sincere appreciation to Prof. Nayan M. Kakoty (Tezpur University) and Prof. Subir K. Saha (IIT Delhi) for their guidance and for enriching our project. Dr. Rajeevlochana G. Chittawadigi (Amrita Bengaluru) contributed valuable insights. The industry partner of ROC23, SVR InfoTech, Pune, provided invaluable real-world perspectives. Our collaborative effort benefited from their expertise and commitment. This endeavor reflects the collective contributions that shaped its success. We acknowledge and thank each individual mentioned above for their role in this journey.

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# Motion Planning of Virtual Robots in RoboAnalyzer Software to Draw 3d and 2d Shapes and Names

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## 1. Introduction

RoboAnalyzer is a software developed to facilitate the analysis and visualization of robotic mechanisms. With a focus on education and research, RoboAnalyzer empowers users to explore the kinematics and behavior of robotic systems through intuitive graphical interfaces and through Virtual Robot module .Robot mechanisms play a pivotal role in industries ranging from manufacturing to healthcare. Understanding the motion and behavior of these mechanisms is essential for optimizing their performance and designing new systems. RoboAnalyzer addresses this need by offering a user-friendly platform that enables users to analyze and visualize the kinematics of robotic mechanisms.One of RoboAnalyzer's primary objectives is to enhance robotics education. Its interactive interface and visualizations facilitate the understanding of complex kinematic concepts, enabling students and learners to grasp theoretical principles through practical applications. RoboAnalyzer serves as an effective tool for teaching forward and inverse kinematics, joint constraints.

## 2. Methodology

We performed Forward kinematics of a 2R planar manipulator in Octave GNU by calculating the end-effector's position and orientation based on the joint angles using trigonometric transformations and the Denavit-Hartenberg parameters. We visualized the manipulator's pose using plot functions in

Octave GNU, showing the manipulator's configuration based on the joint angles.We performed Forward kinematics of a 2R planar manipulator in Octave GNU by determining the end-effector's position and orientation based on the joint angles using trigonometric calculations and transformation matrices. We iteratively applied rotations and translations through each joint, the final pose of the manipulator's end-effector which can be computed within the Octave environment.

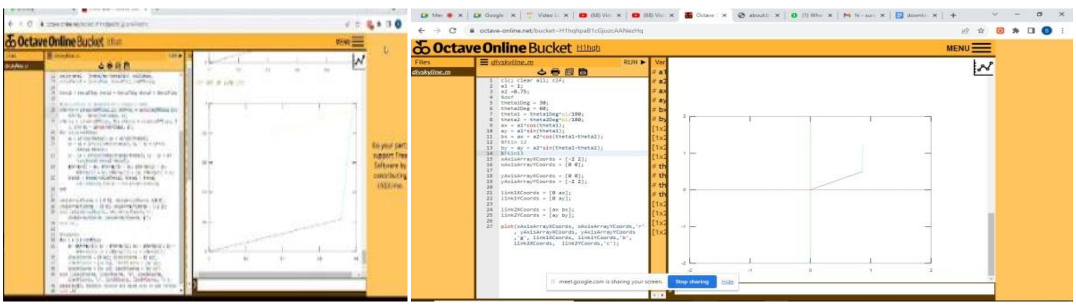


Figure 1: Forward kinematics of 2R & 3R planar manipulator in Octave GNU

## 3. Results and Discussions

We successfully applied kinematic principles to design and analyze robotic mechanisms.The software facilitated the creation of accurate kinematic models, enabling us to simulate and visualize robot motion effectively.Using RoboAnalyzer, we conducted simulations of complex robot motions, including trajectory planning and end-effector manipulation.we addressed a range of motion-related challenges, such as inverse kinematics for precise positioning, joint constraints.We used AutoCAD in robotics and kinematics analysis for creating detailed and precise 2D and 3D designs of a Flower ,Star shape and our Names along with Roc 2023 We plotted the drawing in the virtual robot module using a CSV File.We used AutoCAD to design and create detailed models of a 3 Cube Shape in the Virtual Robot Module . In the context of the United Nations Sustainable Development Goal (SDG) for Industry, Innovation, and Infrastructure,Some enhancements could further enhance the learning experience for example Comprehensive documentation detailing advanced features, troubleshooting tips, and best practices would greatly assist users in overcoming technical challenges.

Real-world Examples: Incorporating more real-world examples and case studies into the program would enhance our understanding of the software's application across diverse robotic scenarios.

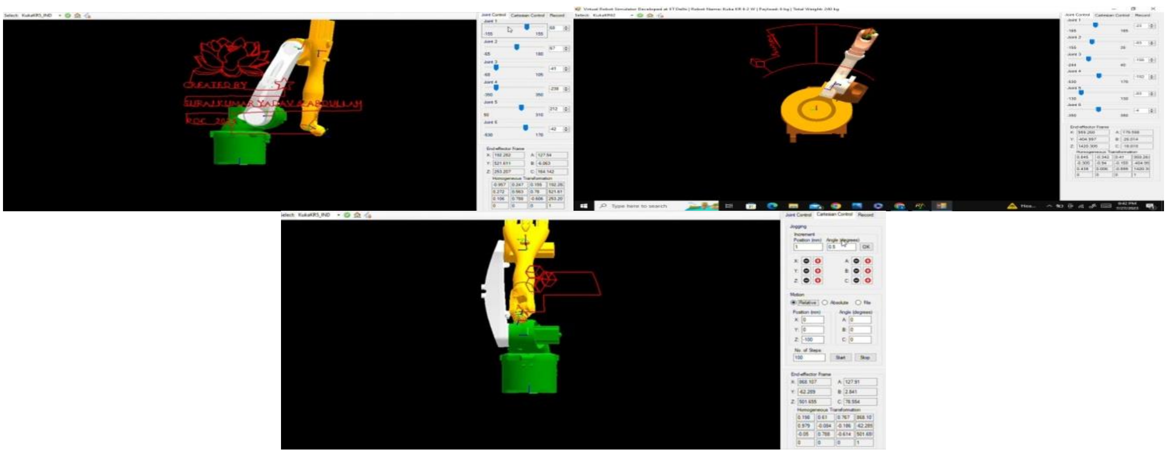

Figure 2: Drawings on Virtual Robot Modules

1. 2D Image of Flower,Star shape and Name of team Members Abdullah and Suraj Kumar
2. 3D Cube and Signature Of Team Member Suraj Kumar Yadav
3. A 3 cube model based on United Nation Sustainable goals Number 9 on Industry

**Acknowledgements**

We would like to express our sincere gratitude to the developers and contributors of RoboAnalyzer, an invaluable software.

We extend our appreciation to the Organizers of ROC 2023 Dr Subir Kumar Saha(IITD), Dr Nayan Kakoty(Tezpur University), Dr Rajiv (Amrita Vishwa Vidyapeetham) and Industry Partner SVR Infotech Mr Vinod for actively supporting us and, fostering an environment of collaborative learning and knowledge sharing. The availability of comprehensive

documentation, tutorials, and interactive sessions enriched our understanding and proficiency in utilizing the software effectively.

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The RoboAnalyzer based Online/Offline Competition (ROC) as Virtual Summer Internship
1st June – 9th September, 2023
Conducted by Prof. Nayan M. Kakoty (Tezpur University), in collaboration with Prof. Subir K. Saha (IIT Delhi), Dr. Rajeevlochana G. Chittawadigi (Amrita Bengaluru) and Industry Partner SVR InfoTech, Pune

# Motion Planning of 6R Virtual Robots in RoboAnalyzer to Draw Perimeters of 3D Objects Using MATLAB

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## 1. Introduction

The realm of robotics intertwines with real-world applications, navigating three-dimensional spaces beyond planes or linear paths. This paper delves into inverse kinematics, focusing on tracing a 3D object's perimeter. Leveraging MATLAB’s computational prowess, this study processes objects, generating a coordinate list. This data interfaces with RoboAnalyzer's Virtual Robot Module, performing intricate inverse kinematics. This yields angles guiding robotic navigation along MATLAB's analyzed path. This research unites MATLAB's analytics and RoboAnalyzer's precision, advancing robotic motion in intricate 3D terrains.

## 2. Methodology

### 2.1. Creating the 3D model

This is pretty straight forward, we can use any 3D modelling software for this, the only requirement being that the file should be saved in a **.stl format**. A STL file is necessary as all the faces are split into triangles when the model is saved, this makes our next step much easier.

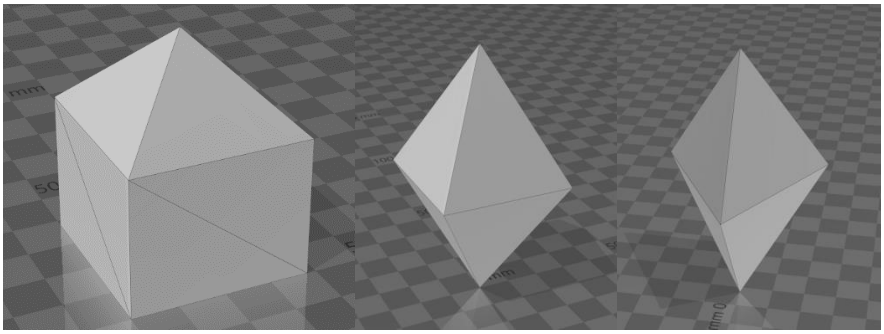

Figure 1: STL Models demonstrating how each face gets split into triangles
(Cuboid with Pyramidal Top, Square Bipyramid, Triangular Dipyramid)

### 2.2. Using MATLAB to get coordinates of all the edges of the model and exporting them to a CSV file:

This is where things get a little interesting. The **stlread()** function generates a triangulation of the .stl file, which contains two components, the Points which contains the vertices of each numbered point and the ConnectivityList which links the vertex numbers to the faces of each triangle.

The program then utilizes this triangulation and stores the start and end point of the edges, these are then sorted and arranged such that the path is continuous. Then we interpolate linearly between these points and generate a list of coordinates that the end effector has to follow.

These coordinates are then stored in a CSV file using the writematrix() function for the VRM to use.

### 2.3. Output from VRM

The VRM of RoboAnalyzer is very straightforward to use, one can simply input the .csv file generated and the software performs inverse kinematics for any kind of robot. Below are a few results from the VRM drawings:

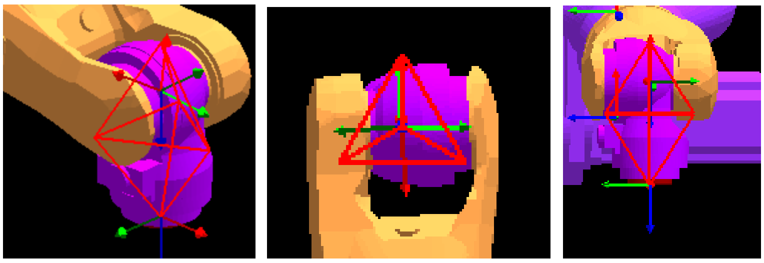

Figure 2: Isometric, Top and Front views of a Triangular Dipyramid drawn by a Kuka KR5

## 3. Results and Discussions

Some applications of this study may include things like programming surgical operations through the simple task of 3D modelling, i.e., a STL file may be generated such that the edges of the shape translate to a surgical action by the robotic arm. Another application may include a 6-R arm 3D printer, this can be achieved with the help of an extruder that can be attached to the arm and the arm can print out any complex 3D shape.
A point to note is that the calculations performed by the VRM are approximate and not so accurate. To accommodate these errors, the linear interpolation of points was important in the step 2.2. The larger the number of points we interpolate, the higher the resolution or accuracy of the movement of the end effector.

### Resources

- GitHub Repository of all the MATLAB Codes: https://github.com/Rudy8k/ROC_TEAM_E2/tree/main
- YouTube Playlist of Videos Demonstrating working of Robots in VRM: https://youtube.com/playlist?list=PL7k_2mOzFOSN_ROHvQvnbRyumfv5oaclT

**Acknowledgements**

We would like to thank Prof. Nayan M. Kakoty, Prof. Subir K. Saha and Dr. Rajeevlochana G. Chittawadigi for providing us with this amazing opportunity to work on this amazing project and also creating very detailed and informational lecture series on RoboAnalyzer which greatly helped us in this endeavour.

We would also like to extend our thanks to Ms. Krunali Kadam for aiding us in tasks throughout the competition.

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# Notes

# Notes

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# Modality

This online & offline event "RoboAnalyzer based Online Competition (ROC) as Virtual Summer Internship" was conducted by Embedded Systems and Robotics Lab, Tezpur University, in collaboration with the two main developers of the RoboAnalyzer software, Professor Subir K. Saha, Indian Institute of Technology Delhi and Dr. Rajeevlochana G. Chittawadigi, Amrita Vishwa Vidyapeetham, Bengaluru & Industry Partner SVR InfoTech.

# Past Versions of ROC

Details and the results of ROCs held in 2020, 2021 and 2022 are available at www.tezu.ernet.in/erl and www.roboanalyzer.com

# Organizing Team

- Dr. Nayan M Kakoty, Tezpur University, Assam
- Mr. Abhijit Boruah, Dibrugarh University, Assam
- Dr. Rajeevlochana G. Chittawadigi, Amrita Vishwa Vidyapeetham, Bengaluru
- Prof. Subir K. Saha, IIT Delhi, New Delhi.
- Ms. Shilpa Pawar, SVR InfoTech
- Ms. Krunali Kadam, SVR InfoTech

# Industry Partner and Sponsor