# Scilab case study project on
# Inverse Heat Conduction Parameter Estimation

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## Abstract

This case study focuses on the analysis of a one-dimensional inverse heat conduction problem using numerical methods implemented in Scilab software. The objective is to estimate the unknown heat flux at one boundary of a rod based on temperature measurements. Initially, a forward problem was solved to generate temperature distribution, and controlled noise was added to simulate real-world measurement conditions. An inverse approach was then applied by minimizing the error between measured and computed temperatures to estimate the heat flux. The results were analyzed using graphical representations, and the estimated heat flux was compared with the actual value. The close agreement between the estimated and true heat flux demonstrates the accuracy and effectiveness of the implemented numerical method.

## 1. Introduction

Heat conduction is a fundamental mode of heat transfer in which thermal energy is transferred through a material due to a temperature gradient. In many engineering applications, determining temperature distribution within a system is essential for design and analysis.

In practical situations, it is often difficult to directly measure certain boundary conditions such as heat flux. This leads to the formulation of inverse heat conduction problems (IHCP), where unknown parameters are estimated using available temperature data. These problems are widely used in fields such as thermal engineering, material processing, and aerospace applications.

In this case study, a one-dimensional inverse heat conduction problem is analyzed using numerical methods implemented in Scilab. The forward problem is first solved to generate temperature data, and controlled noise is introduced to simulate real-world measurements. An inverse approach is then used to estimate the unknown heat flux by minimizing the error between measured and computed temperatures. Relevant literature was reviewed to understand inverse heat conduction and numerical solution techniques.

## 2. Problem Statement

In this case study, a one-dimensional rod of length L is considered for steady-state heat conduction analysis, as shown in Figure 1. The right end of the rod is maintained at a fixed temperature, while the heat flux at the left boundary is unknown. The objective is to estimate this unknown heat flux using temperature measurements taken along the rod.

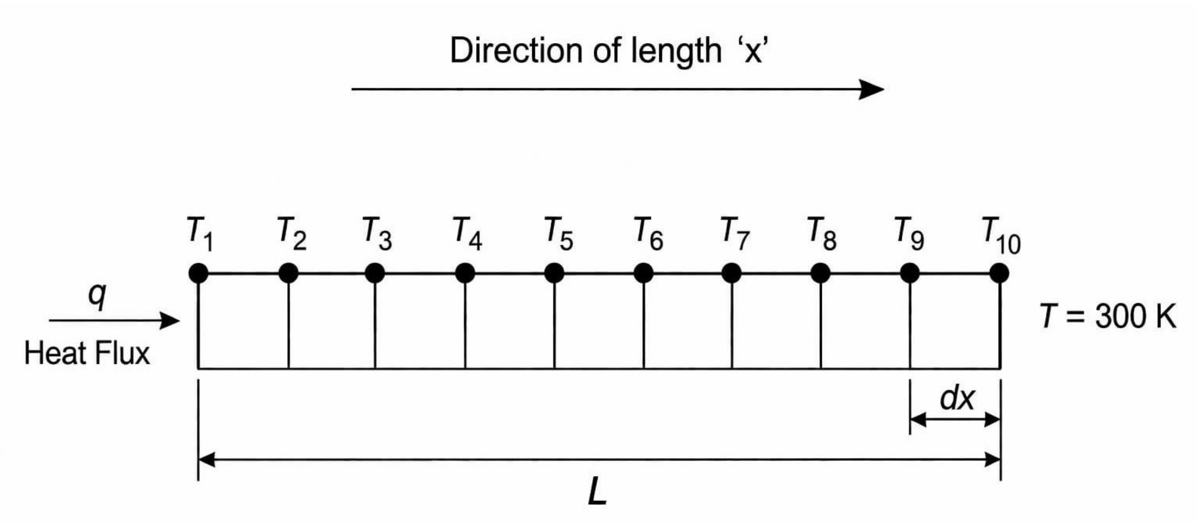


Figure 1: 1D rod discretization with boundary conditions

Initially, a forward heat conduction problem is solved to obtain the temperature distribution along the rod for a known heat flux. To simulate real-world conditions, a small amount of noise is added to the computed temperature data, representing measurement errors.

Using this noisy temperature data, an inverse heat conduction approach is applied to estimate the unknown heat flux. The estimation is performed by minimizing the difference between the measured temperature and the temperature computed using guessed values of heat flux. The solution is obtained using numerical methods implemented in Scilab.

This approach helps in understanding how unknown thermal parameters can be accurately determined from limited experimental data.

## 3. Basic concepts related to the topic

Heat conduction is the mode of heat transfer in which thermal energy flows from a region of higher temperature to a region of lower temperature within a solid material. In this case study, steady-state heat conduction is considered, which means that the temperature at any point in the rod does not change with time.

For one-dimensional steady-state heat conduction without internal heat generation, the governing equation is:

$$\frac{d^2 T}{dx^2} = 0 \tag{1}$$

This equation indicates that the temperature distribution along the rod is linear in nature.

The general analytical solution of this equation is:

$$T(x) = T_1 + \left[\frac{(T_2 - T_1)}{L}\right] \times x \tag{2}$$

where $T_1$ and $T_2$ are the temperatures at the two ends of the rod, $L$ is the length of the rod, and $x$ is the position along the rod.

In this problem, the boundary conditions play a crucial role in determining the temperature distribution. At the right end of the rod, the temperature is fixed (Dirichlet boundary condition), while at the left end, the heat flux is specified (Neumann boundary condition). The heat flux represents the rate of heat transfer per unit area and is related to the temperature gradient along the rod.

To solve this problem numerically, the rod is divided into a number of discrete nodes. The temperature at each node is calculated using numerical methods based on finite difference approximation. This converts the continuous differential equation into a system of algebraic equations, which can be solved using Scilab.

In this case study, an inverse heat conduction approach is used. Instead of directly solving for temperature, the unknown heat flux at the boundary is estimated using measured temperature data. This is achieved by minimizing the difference between the measured and computed temperature values.

## 4. Flowchart

The flowchart represents the step-by-step procedure followed to solve the inverse heat conduction problem. It includes the steps involved in defining input parameters, solving the forward problem, generating temperature data with noise, and estimating the unknown heat flux using an inverse approach. The flowchart provides a clear visual understanding of the overall methodology used in this case study.

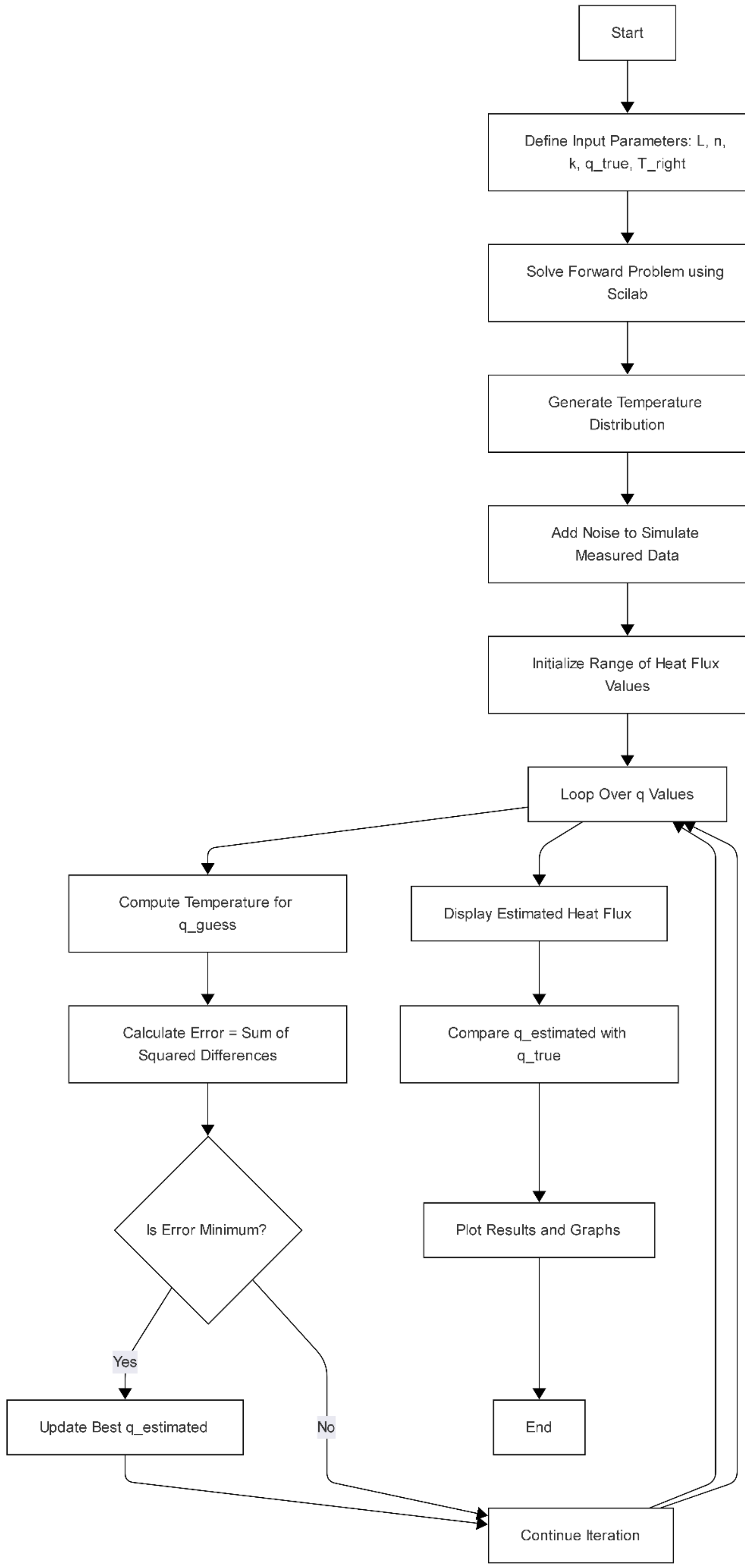


Figure 2: Flowchart of inverse heat conduction problem

## 5. Software/Hardware used

The simulations were performed on a system running Windows 11 operating system. Scilab 2026.0.1 was used for numerical computation and graphical visualization. No additional toolboxes were used in this case study.

## 6. Procedure of execution

The execution of the code can be carried out as follows:

1. Open the Scilab 2026.0.1 software on the desktop.
2. Set the working directory to the project folder, i.e., **Inverse_Heat_Conduction**, using the cd command.
3. Open the functions folder and execute the function file **solve_temperature.sci** to load the function into the workspace.
4. Next, open and execute the file **01-forward problem.sce**, ensuring that the working directory is correctly set. This generates the temperature distribution along the rod.
5. Then, execute the file **02_generate data.sce** to generate temperature data with added noise, simulating real-world measurements.
6. After that, run the file **03_inverse problem.sce** to estimate the unknown heat flux.
7. The program computes the error for different heat flux values and determines the heat flux corresponding to the minimum error.
8. The results, including true heat flux, estimated heat flux, and percentage error, are displayed in the Scilab console.
9. Graphs for temperature distribution, measured data, inverse solution, and error variation are generated for analysis.

## 7. Results

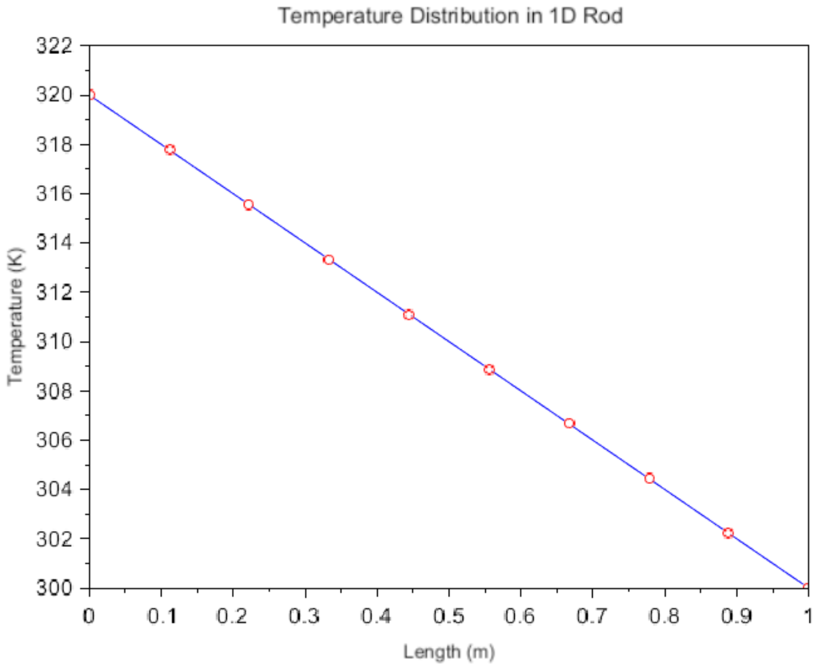


Figure 3: Temperature Distribution (Forward Problem)

The forward temperature distribution shows a steady decrease in temperature along the length of the rod from 320 K to 300 K. The profile is linear, indicating one-dimensional steady-state heat conduction without internal heat generation.

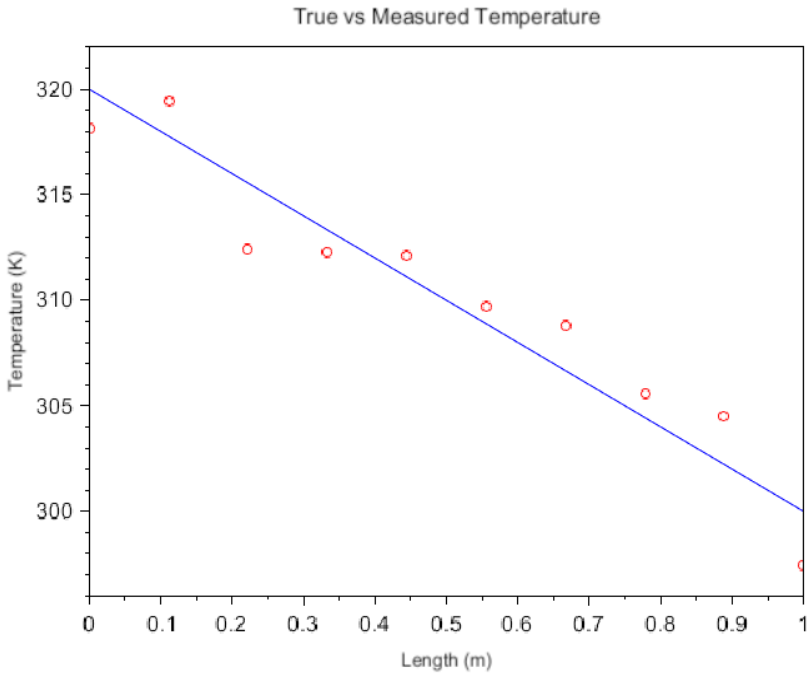


Figure 4: Comparison of True and Measured Temperature

The true temperature distribution is represented by a smooth linear curve, showing the theoretical steady-state variation along the rod. The measured temperature values are plotted using red markers and include small random noise. It can be observed that the measured data closely follows the true temperature profile, with slight deviations due to simulated measurement errors.

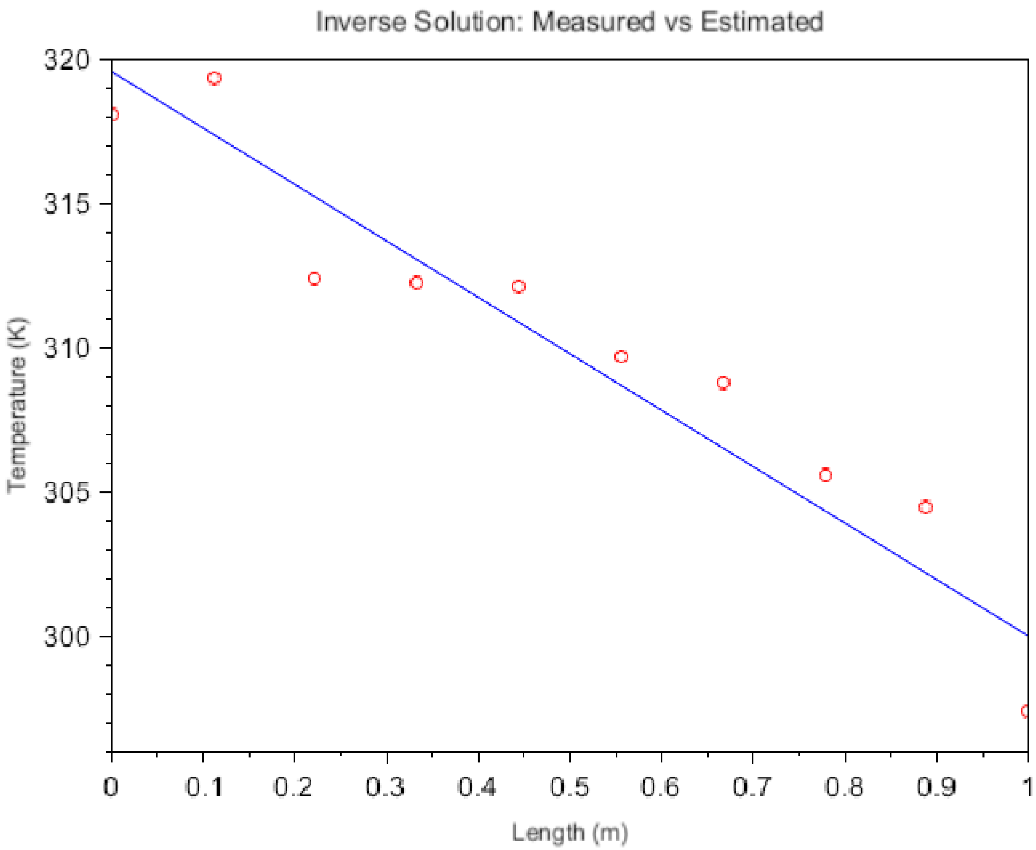


Figure 5: Measured vs Estimated Temperature (Inverse Solution)

This graph compares the measured temperature data (obtained after adding noise) with the estimated temperature distribution computed using the inverse heat conduction model. The inverse algorithm uses an optimization approach by minimizing the error between measured and computed temperature values for different heat flux guesses. The estimated temperature curve is obtained using the best-fit heat flux value that results in minimum error.

It can be observed that the estimated temperature closely follows the measured temperature trend, indicating that the inverse method is able to reconstruct the temperature field accurately. Small deviations between the curves are due to measurement noise introduced in the system to simulate real-world conditions.

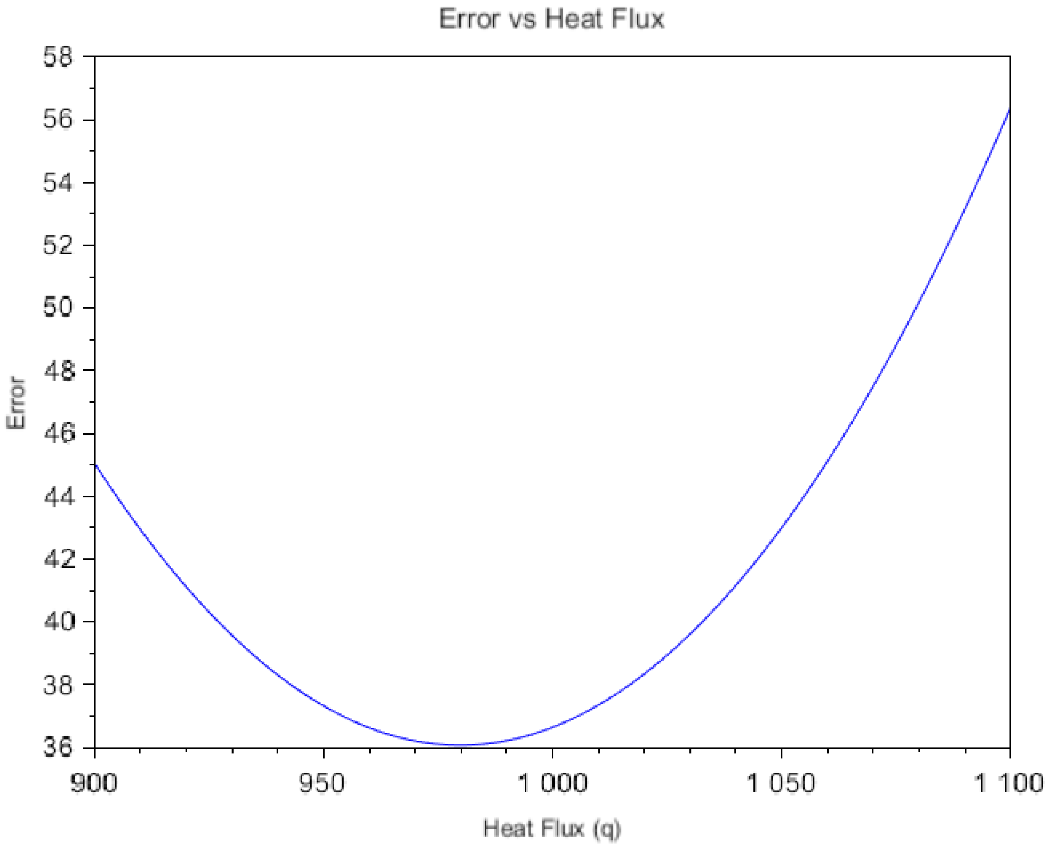


Figure 6: Error vs Heat Flux

The graph shows variation of error with respect to assumed heat flux values. The error decreases as the guessed heat flux approaches the true value and reaches a minimum at the estimated heat flux. Beyond this point, the error increases again, forming a convex curve.

# 8. Observations

### 8.1 True Temperature Values

| Node | Distance (m) | Temperature (K) |
|---|---|---|
| 1 | 0 | 320 |
| 2 | 0.111 | 317.778 |
| 3 | 0.222 | 315.556 |
| 4 | 0.333 | 313.333 |
| 5 | 0.444 | 311.111 |
| 6 | 0.556 | 308.889 |
| 7 | 0.667 | 306.667 |
| 8 | 0.778 | 304.444 |
| 9 | 0.889 | 302.222 |

| | | |
|---|---|---|
| 10 | 1 | 300 |

Table 1: True Temperature Distribution

**8.2 Measured Temperature Values**

| Node | Distance (m) | Temperature (K) |
|---|---|---|
| 1 | 0 | 318.152 |
| 2 | 0.111 | 319.405 |
| 3 | 0.222 | 312.401 |
| 4 | 0.333 | 312.27 |
| 5 | 0.444 | 312.14 |
| 6 | 0.556 | 309.682 |
| 7 | 0.667 | 308.812 |
| 8 | 0.778 | 305.575 |
| 9 | 0.889 | 304.508 |
| 10 | 1 | 297.41 |

Table 2: Measured Temperature Distribution (Noisy Data)

The measured temperature data shows small deviations from the true temperature values due to added noise, simulating real experimental conditions.

**8.3 Heat Flux Result**

| Parameter | Value |
|---|---|
| True Heat Flux (q_true) | $1000\ W/m^2$ |
| Estimated Heat Flux (q_estimated) | $980\ W/m^2$ |
| Percentage Error (%) | 2 |

Table 3: Heat Flux Estimation Results

The estimated heat flux shows a very small deviation of 2% from the true value, indicating that the inverse heat conduction method provides an accurate and reliable parameter estimation.

# 9. Conclusion

In this case study, a one-dimensional inverse heat conduction problem was successfully analyzed using numerical methods implemented in Scilab. The forward heat conduction problem was first solved to obtain the temperature distribution along the rod, and controlled noise was introduced to simulate real-world measurement conditions.

Using the inverse approach, the unknown heat flux at the boundary was estimated by minimizing the error between the measured and computed temperature values. The results showed that the estimated heat flux closely matched the true value, with a percentage error of approximately 2%, demonstrating the accuracy and effectiveness of the implemented method.

The study confirms that inverse heat conduction techniques can reliably estimate unknown boundary conditions even in the presence of noisy data. This case study was developed as an independent problem formulation by the author, and the methodology was inspired and validated using concepts and approaches studied from relevant research literature on inverse heat conduction problems. The references were used only for understanding the theoretical background and standard solution approaches.

## 10. References


[1] "Heat and Mass Transfer: Fundamentals & Applications (4th ed.)," Y. A. Çengel and A. J. Ghajar, McGraw-Hill Education.

[2] "Fundamentals of Heat and Mass Transfer (4th ed.)," C. P. Kothandaraman, New Age International Publishers.

[3] "Numerical Solution of Inverse Heat Conductivity Problem Based on Minimax Optimization," IEEE Xplore, Available: https://ieeexplore.ieee.org/document/10139195

[4] "Scilab Spoken Tutorials," Spoken Tutorials, Available: https://scilab.in/spoken-tutorial