Summer Fellowship Report

On

Scialb Case Studies

Submitted by

Dr. Deepan Nagarajan
Government Polytechnic College, Srirangam, Tiruchirappalli, Tamilnadu.
Directorate of Technical Education, Chennai.

Under the guidance of

Prof. Kannan M. Moudgalya
Chemical Engineering Department
IIT Bombay

Mentor
Mrs. Rashmi Patankar

August 12, 2025

Acknowledgment

I would like to express my deepest gratitude to the FOSSEE Team, IIT Bombay, for offering me the invaluable opportunity to participate in the FOSSEE Summer Fellowship 2025. I am immensely grateful to Prof. Kannan Moudgalya for spearheading this initiative, which plays a pivotal role in promoting open-source software.

A special note of thanks goes to Mrs. Rashmi Patankar for her unwavering guidance and encouragement throughout the internship. Her expertise significantly enriched my learning journey and was instrumental in the successful completion of my project.

I would like to express my sincere gratitude to The Commissioner, Directorate of Technical Education, Chennai, for providing me with the opportunity and support to carry out this work. I also extend my heartfelt appreciation to my friends, colleagues, and family for their unwavering support and understanding throughout this work.

Contents

Chapter 1

Introduction

The Free and Open Source Software in Education (FOSSEE) initiative works to promote the adoption of open-source tools as a means to enhance the quality of technical education in India. Its vision is to reduce reliance on proprietary software in STEM fields by encouraging the integration of free and open-source solutions into academia. As a part of this initiative, the summer fellowship programme offers students an opportunity to explore, contribute to, and apply FOSS tools to solve practical engineering problems.

Scilab is a prime example of a cross-platform numerical computation environment, featuring a powerful high-level programming language. It supports a wide range of applications, including signal processing, statistical analysis, image processing, numerical optimisation, and the modelling and simulation of complex dynamic systems. Its built-in Xcos environment provides a visual interface for simulating dynamic models, while the GUI development capabilities allow the creation of interactive applications tailored to specific engineering needs.

During my internship, I successfully completed three case studies, each focusing on different aspects of communication systems and image processing:

- **Case Study 1:** Comparative Study of Analog and Digital Modulations in Communication Systems using Scilab Xcos. This study models various communication blocks and simulates them using the Xcos platform.
- **Case Study 2:** Performance Study of Single-antenna and Multi-antenna Wireless Communication Systems using Scilab GUI. This work evaluated the capacity, reliability, and signal quality differences between SISO and MIMO systems through an interactive Scilab GUI.
- **Case Study 3:** Comparative Performance Study of Image Segmentation using Scilab GUI. This investigation compared different image segmentation techniques, such as grayscale, thresholding, and K-means, and analyzed their accuracy and suitability for various applications in image processing.

These studies demonstrate the versatility of Scilab and its toolboxes in modelling, simulation, and performance evaluation across different engineering domains, and highlight the importance of FOSS tools in academic research and engineering education.

Chapter 2

Case Study 1 (Scilab Xcos): The Comparative Study of Analog and Digital Modulations in Communication Systems

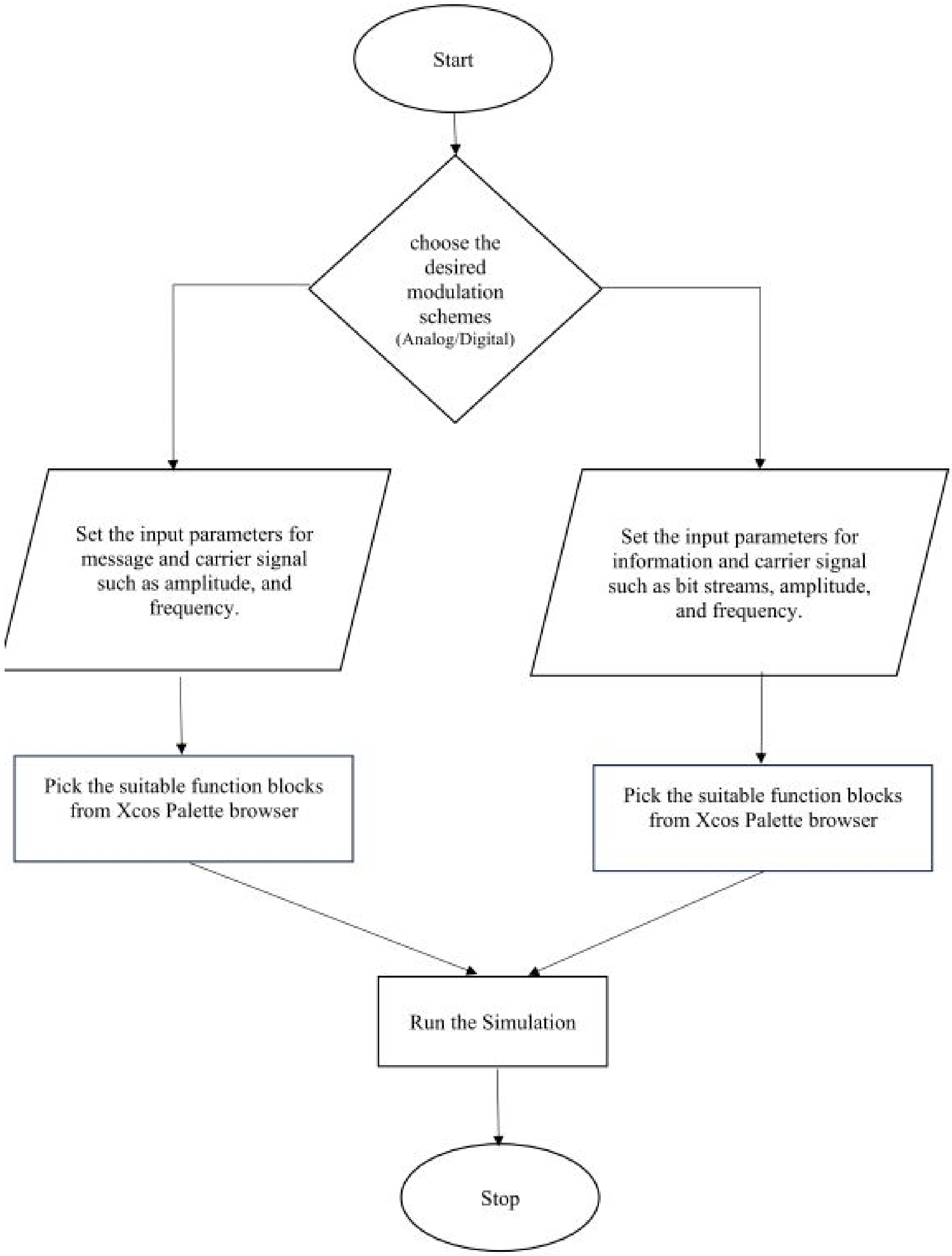
2.1 Abstract

Modulation is a fundamental technique in communication systems that enables the transmission of information over various media by varying the properties of a carrier signal. Analog modulation techniques, such as Amplitude Modulation (AM), Frequency Modulation (FM), and Phase Modulation (PM), modify continuous signals, while digital modulation schemes, including Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK), encode discrete data. This study aims to simulate and analyze both analog and digital modulation techniques using Scilab Xcos, an open-source graphical modeling and simulation tool. The insights and techniques presented herein serve as a valuable resource for researchers, engineers, and practitioners engaged in the design and optimization of communication systems operating in challenging fading environments.
Index terms: Modulation, AM, FM, PM, ASK, FSK, Xcos.

2.2 Problem Formulation

To transmit the information over a longer distance, we need to perform modulation, which is necessary for any communication system. This ensures increased power, long range, and reduced antenna size. For a given application scenario, we must determine which modulation strategy, so called analog variants such as AM, FM, PM, that deal with analog information sources or digital counterparts like ASK, FSK, PSK which balances spectral occupancy, power efficiency, noise robustness, and implementation complexity. The formulation, therefore, involves modeling the baseband message, the carrier, and defining quantitative performance to identify the system constraints such as allowable power, regulatory bandwidth limits, and hardware cost. By establishing these criteria up front, we can systematically compare each scheme's theoretical capabilities and practical trade-offs. The ultimate goal is to select or hybridize the modulation techniques that satisfy the specified communication requirements while minimizing resource expenditure.

2.3 Flowchart



2.4 Results and Discussion

Figure 2.1 illustrates the amplitude modulation (AM) plot, which reveals a direct correlation between the modulating signal, carrier signal, and the resulting modulated signal. As shown in the figure, the frequency of the carrier wave remains constant, but its amplitude changes, creating an envelope that follows the shape of the modulating signal. The depth of modulation depends on the modulation index, μ. For instance, if $\mu = 0.5$, the carrier amplitude varies by 50% above (and below) its unmodulated level, as is shown in the waveform. Further if $\mu = 1$, the modulated amplitude reaches 100%. With 100% modulation, the wave amplitude sometimes reaches zero, and this represents full modulation using standard AM.

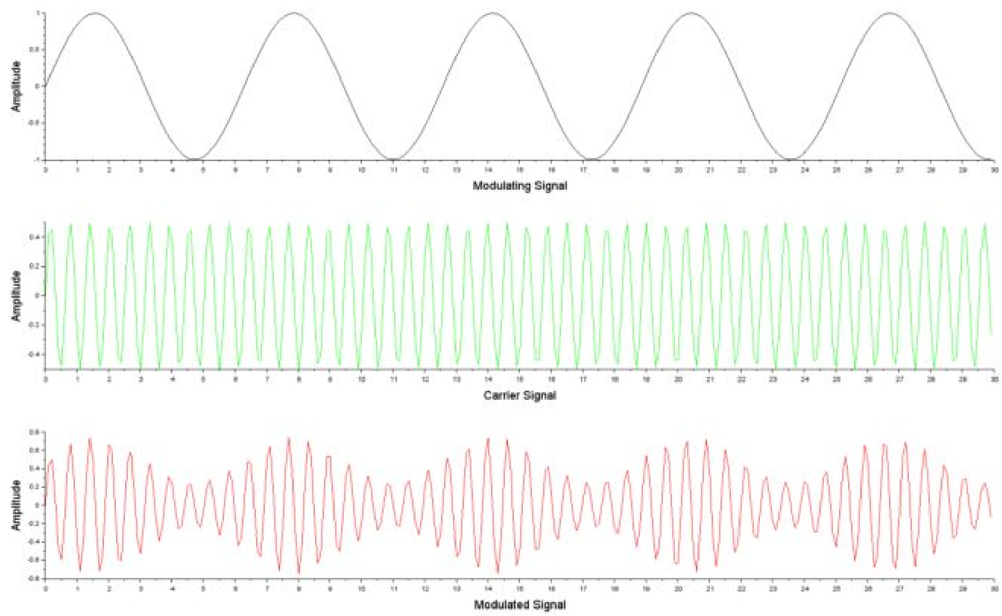


Figure 2.1: Amplitude Modulated Waveform

Figure 2.2 depicts a frequency-modulated (FM) waveform. FM is characterized by a constant amplitude but a varying frequency that changes proportionately to the modulating signal. The graph illustrates that the FM modulated signal appears to compress and expand, with higher instantaneous frequency where the modulating signal's amplitude is positive and lower instantaneous frequency where it is negative. Unlike AM, the envelope of an FM wave remains flat, but the spacing between peaks (zero crossings) changes dynamically.

Figure 2.3 illustrates the phase modulated waveform. PM is a type of angle modulation; hence, unlike FM, where frequency deviations occur, PM directly alters the phase shift of the carrier. Similar to FM, the envelope of a PM signal remains unchanged, making it resilient to amplitude noise.

Figure 2.4 illustrates ASK modulated waveform. A binary ASK (BASK), in its simplest form, where a "1" is transmitted as a burst of the carrier wave at a fixed amplitude, while a "0" is represented by the absence of the carrier (or a lower amplitude). The resulting waveform consists of abrupt transitions between "on" and

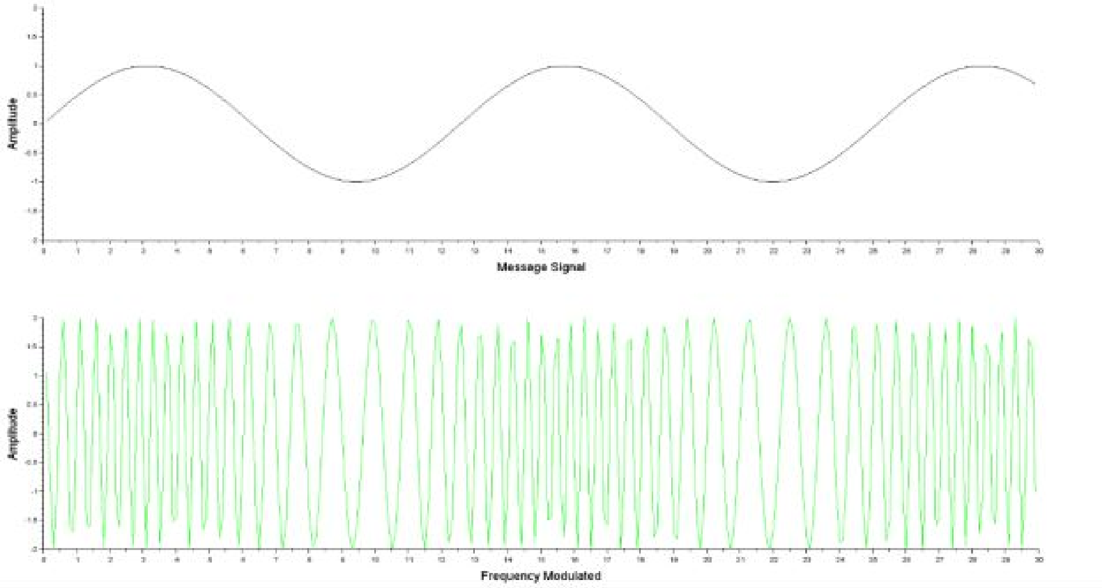


Figure 2.2: Frequency Modulated Waveform

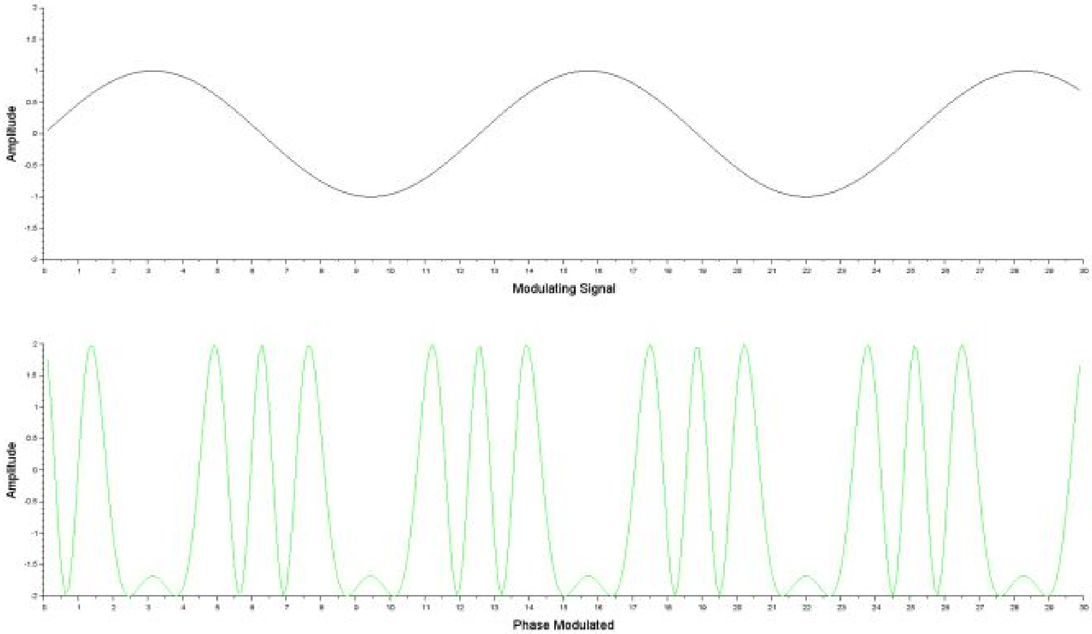


Figure 2.3: Phase Modulated Waveform

"off" states, creating a discontinuous envelope that mirrors the digital bitstream. Unlike analog AM, ASK is used for digital data transmission, where simplicity and power efficiency are prioritized over robustness in noisy environments.

Figure 2.5 shows the FSK modulated waveform. In Binary FSK (BFSK), a "1" is transmitted as a high-frequency burst of the carrier, while a "0" is represented by a lower frequency. The resulting waveform shows smooth transitions between frequencies, preserving a constant amplitude but shifting the instantaneous frequency

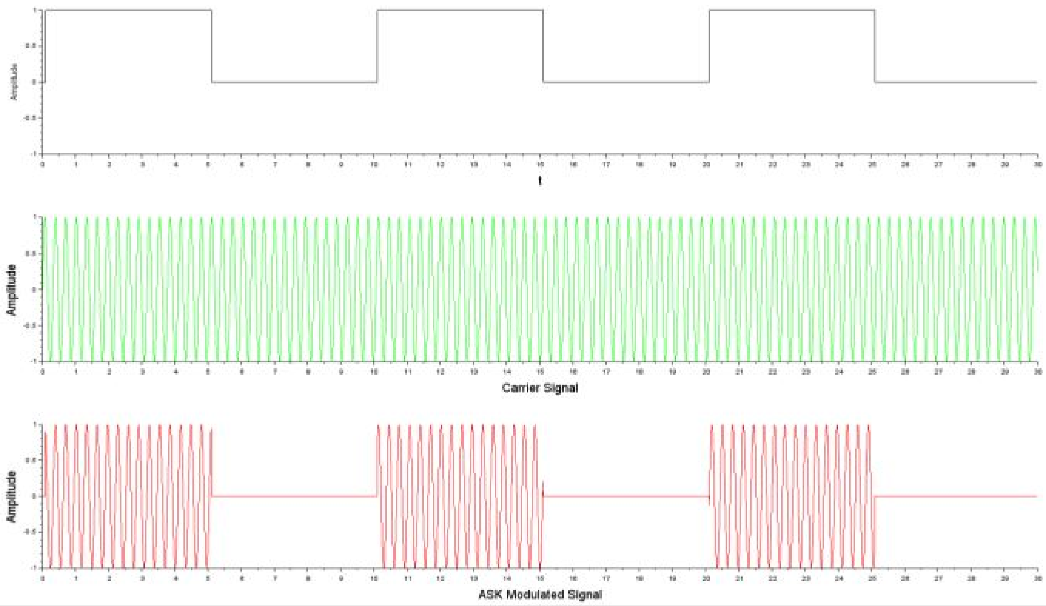


Figure 2.4: Amplitude Shift Keying Modulated Waveform

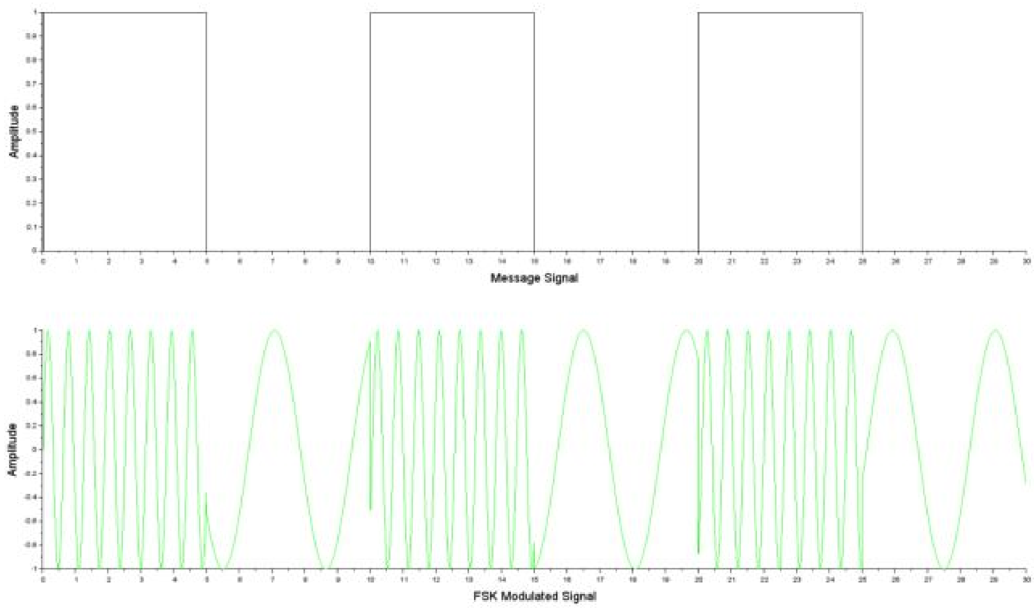


Figure 2.5: Frequency Shift Keying Modulated Waveform

abruptly at each symbol boundary. FSK is more resilient to noise than ASK.

Figure 2.6 shows the PSK modulated waveform. In Binary PSK (BPSK), a "0" and "1" are distinguished by a 180° phase shift (e.g., 0° for "0" and 180° for "1"), creating abrupt transitions in the waveform where the carrier inverts polarity. The PSK waveform maintains a constant amplitude, but its phase discontinuities appear as sudden "jumps" at symbol boundaries. Unlike ASK or FSK, PSK is highly resistant to noise and interference, as data is encoded in phase differences rather

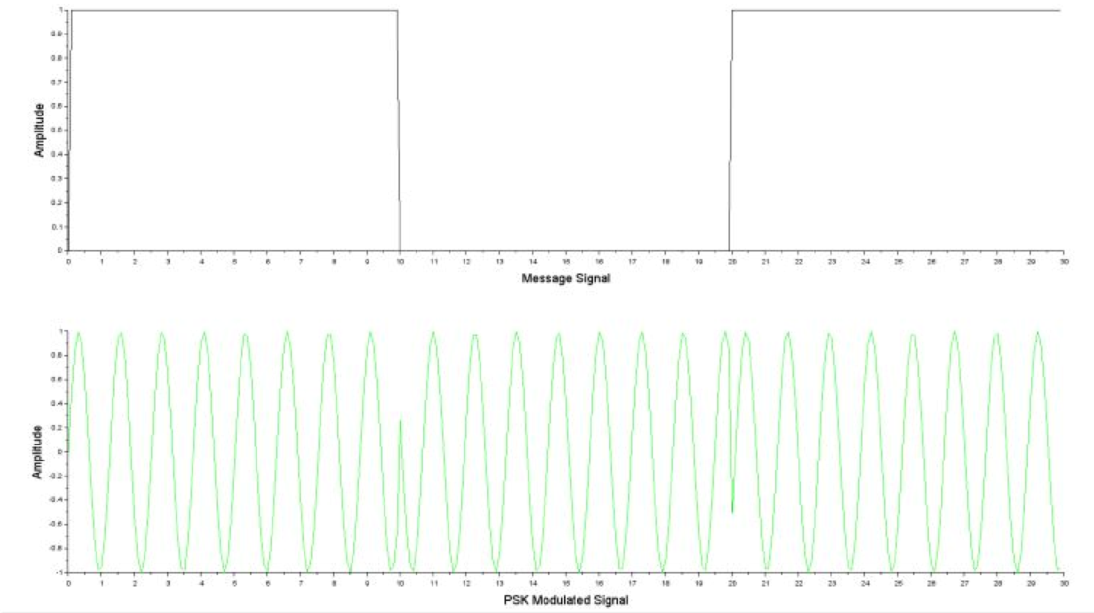


Figure 2.6: Phase Shift Keying Modulated Waveform

than amplitude or frequency.

Chapter 3

Case Study 2 (Scilab GUI): The performance study of single-antenna and multi-antenna wireless communication systems using GUI

3.1 Abstract

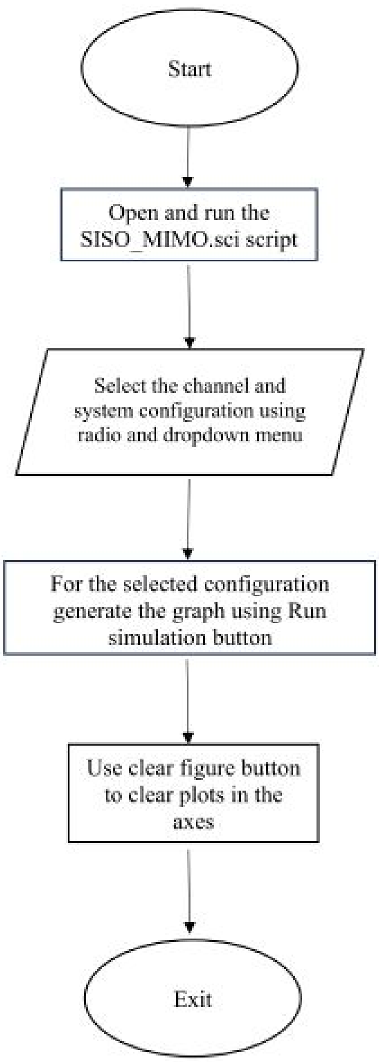
Modern wireless communication systems demand higher data rates and more reliable connectivity. To address these needs, system designers continuously strive to enhance spectrum efficiency, link reliability, and network coverage. Space-time wireless technology, leveraging multiple antennas with advanced signaling and receiver techniques, has emerged as a key solution for improving wireless performance. While some aspects of this technology are already integrated into 3G standards, more sophisticated space-time methods are being developed for future wireless networks, including 5G, WLANs, and WANs. This study focuses on evaluating the performance of different antenna configurations—namely, single-input single-output (SISO), single-input multiple-output (SIMO), multiple-input single-output (MISO), and multiple-input multiple-output (MIMO) systems. A SCILAB-based graphical user interface (GUI) is designed to facilitate comparative analysis, with a particular emphasis on SISO and MIMO systems, highlighting their respective advantages in wireless communication.

Index terms: Capacity Analysis, SISO, MISO, SIMO, MIMO, GUI.

3.2 Problem Formulation

The capacity of multi-antenna wireless communication systems is critically important as it directly determines the maximum achievable data rates in modern networks, enabling them to meet the exponentially growing demand for high-speed connectivity driven by applications like 4K/8K streaming, IoT, and AR/VR. By employing multiple antennas through techniques like MIMO, SIMO, and MISO, these systems overcome fundamental limitations of traditional SISO configurations by simultaneously enhancing spectral efficiency through spatial multiplexing, improving reliability via spatial diversity, and extending coverage via beamforming - all without requiring additional spectrum. As wireless systems face increasing pressure to deliver higher data rates within constrained spectrum and power budgets, understanding and maximizing multi-antenna capacity remains essential for developing next-generation wireless communication systems. The capacity improvements from multiantenna systems form the technological foundation for 5G/6G mobile networks. In this case study, A SCILAB-based graphical user interface (GUI) is designed to facilitate comparative analysis of SISO and MIMO systems over a flat fading AWGN channel and a fluctuating Rayleigh fading channel, highlighting their advantages in wireless communication.

3.3 Flowchart



3.4 Results and Discussion

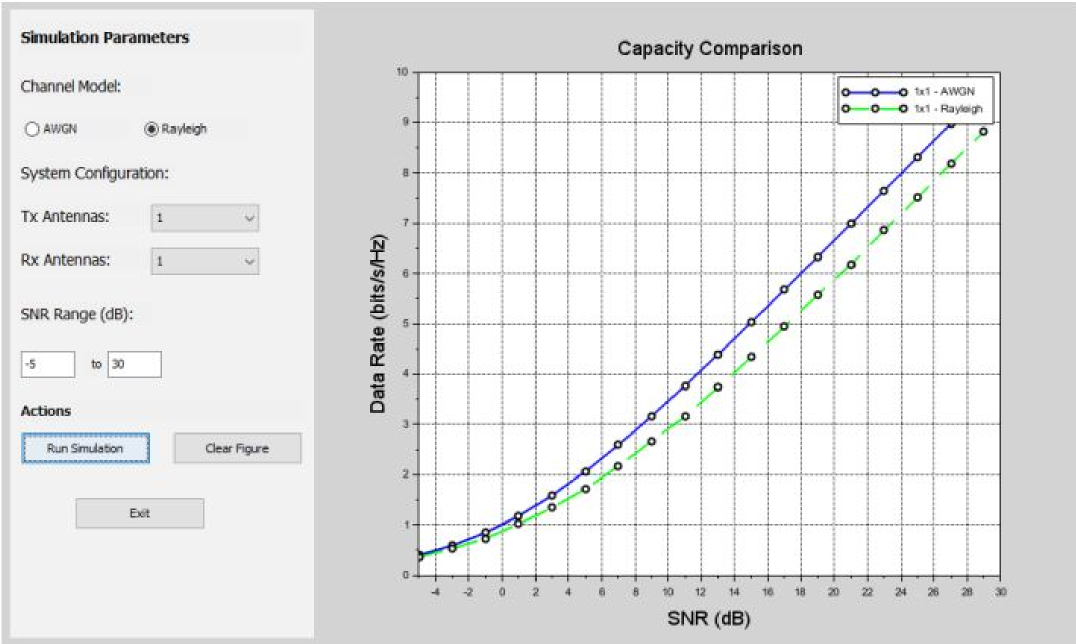


Figure 3.1: Capacity comparison of SISO System over AWGN and Rayleigh Fading Channel

Figure 3.1 illustrates the capacity comparison of a SISO system over AWGN and Rayleigh fading channels across a range of SNR values from -5 dB to 30 dB. From the graph, it is evident that the capacity of the system under the AWGN channel is consistently higher than that under the Rayleigh fading channel for the same SNR values. This difference is due to the unpredictable fluctuations and deep fades in signal amplitude caused by Rayleigh fading, which leads to a reduction in the overall data rate. In contrast, the AWGN channel maintains a relatively stable transmission environment, allowing for better utilization of the available SNR. As the SNR increases, both curves exhibit a logarithmic growth in capacity, but the gap between AWGN and Rayleigh remains noticeable, emphasizing the detrimental effect of fading on wireless communication performance.

Figure 3.2 presents a capacity comparison between SISO (1x1) and SIMO (1x2) systems over an AWGN channel across a range of SNR values from -5 dB to 30 dB. The graph clearly shows that the SIMO configuration achieves a higher data rate than the SISO system for the same SNR values. This improvement is due to the use of multiple receive antennas in the SIMO system, which provides receive diversity and enhances signal reliability by mitigating the effects of noise and channel impairments. As a result, the SIMO system is able to extract more useful information from the transmitted signal, thus improving the overall capacity. The increasing gap between the 1x1 and 1x2 curves with rising SNR further highlights the advantage of employing multiple antennas at the receiver in terms of performance gain in AWGN environments.

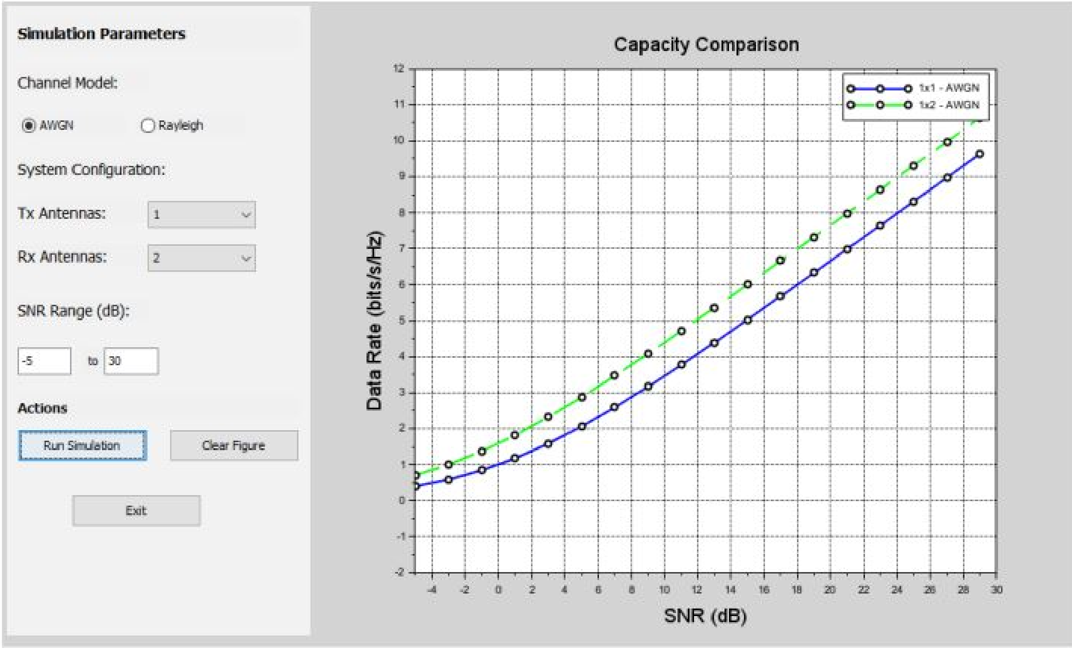


Figure 3.2: Capacity comparison of SISO and SIMO systems

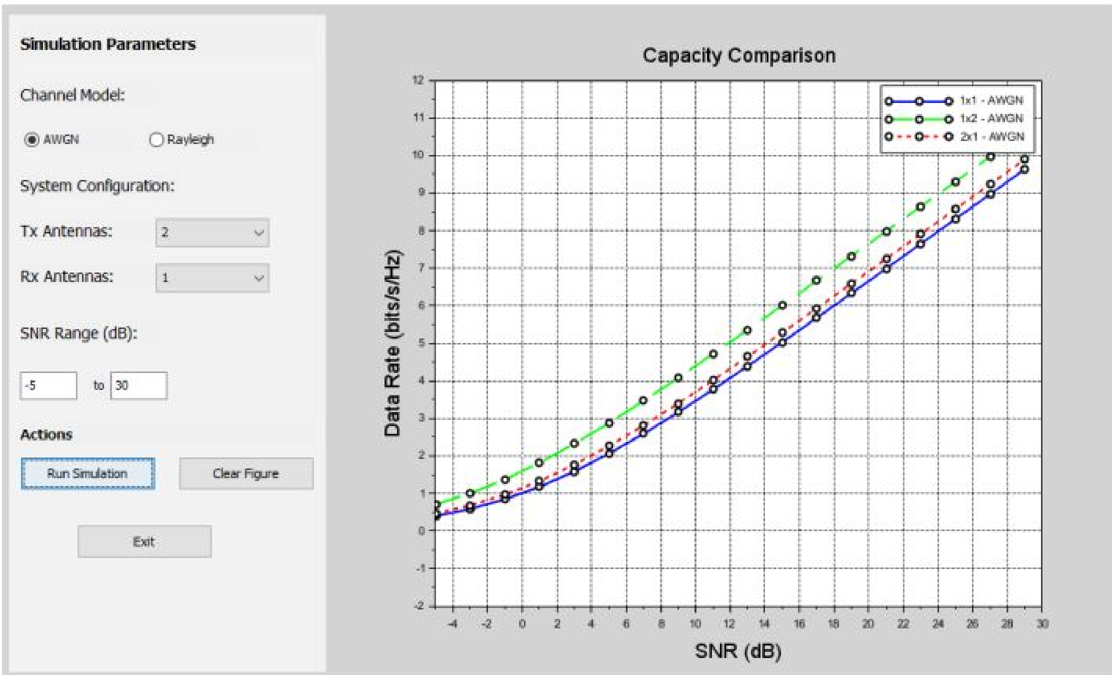


Figure 3.3: Capacity comparison of SISO, MISO, and SIMO systems

The given plot compares the channel capacity of SISO (1x1), SIMO (1x2), and MISO (2x1) systems over an AWGN channel across a wide SNR range. It is evident that both SIMO and MISO systems outperform the basic SISO configuration, offering higher data rates for the same SNR values. Among them, the SIMO (1x2) system demonstrates the best performance due to receive diversity, which provides a greater ability to combat noise and enhance signal detection. The MISO (2x1) system also shows improvement over SISO, leveraging transmit diversity to enhance reliability. However, SIMO slightly outperforms MISO, especially at higher SNR values, due to the better capability of multiple receive antennas to effectively process and combine the incoming signals. Overall, the use of multiple antennas—either at the transmitter or receiver—significantly improves capacity in AWGN channels, with receive diversity offering a marginally higher benefit.

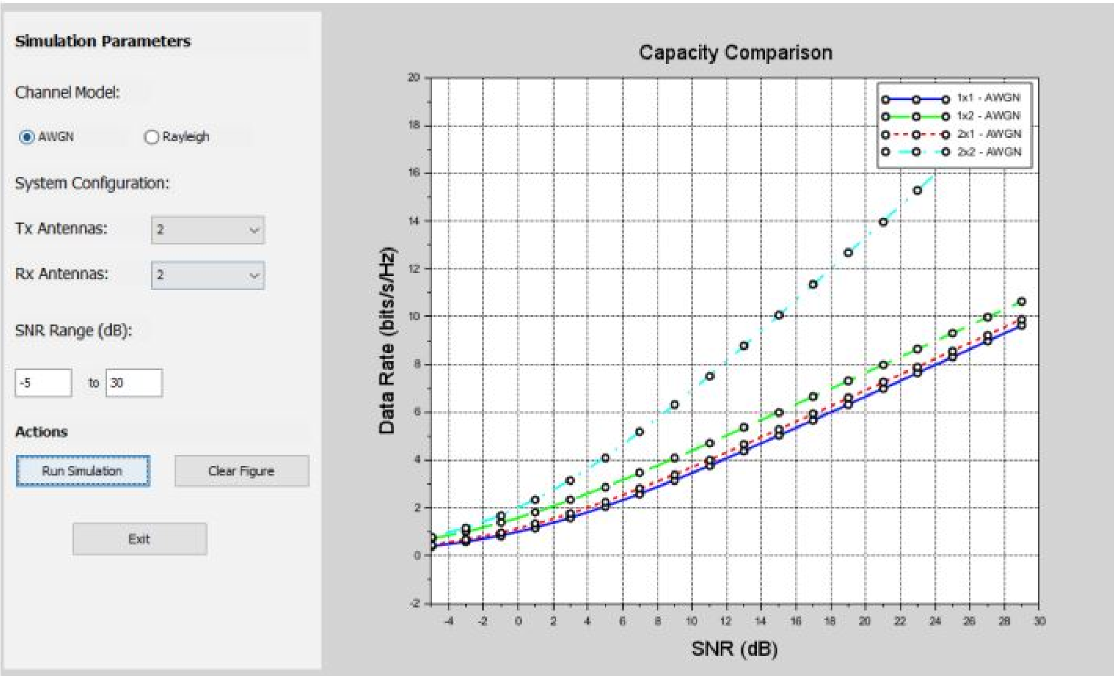


Figure 3.4: Capacity comparison of SISO, MISO, SIMO, and MIMO systems

Figure 3.4 provides a comprehensive capacity comparison of SISO (1x1), SIMO (1x2), MISO (2x1), and MIMO (2x2) systems over an AWGN channel for an SNR range of -5 dB to 30 dB. As expected, the MIMO system (2x2) significantly outperforms all other configurations, achieving the highest data rates due to spatial multiplexing gains from multiple transmit and receive antennas. SIMO (1x2) and MISO (2x1) systems also exhibit improved capacity compared to the baseline SISO system, owing to diversity gains. Notably, SIMO performs slightly better than MISO across the SNR range due to more effective signal combination at the receiver. The capacity increase becomes more pronounced with rising SNR, highlighting the advantage of employing multiple antennas. Overall, this comparison clearly demonstrates that using both transmit and receive diversity in a MIMO configuration offers the greatest capacity improvement in AWGN environments.

Figure 3.5 illustrates the capacity comparison of SISO (1x1) and various MIMO configurations (2x2, 3x3, and 4x4) over a Rayleigh fading channel across an SNR range of -5 dB to 30 dB. It is evident that as the number of antennas increases at both the transmitter and receiver, the channel capacity improves significantly. The 4x4 MIMO system achieves the highest data rate, demonstrating the power of

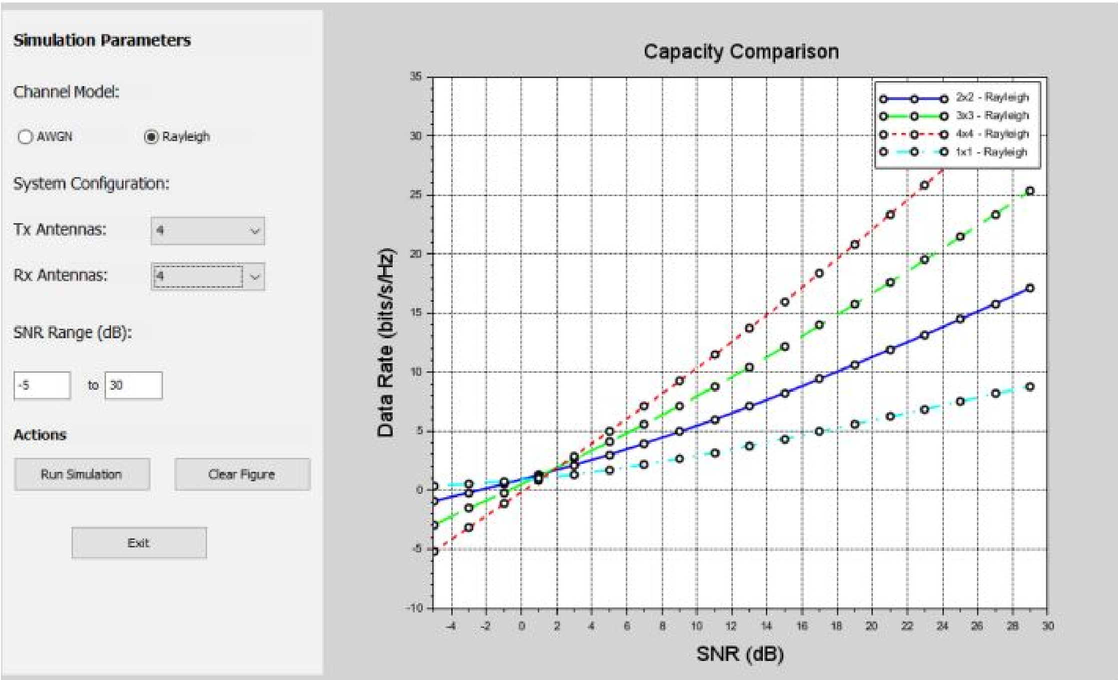


Figure 3.5: Capacity Comparison between SISO and Various Antenna Configurations of MIMO Systems

spatial multiplexing and diversity gain in overcoming the severe multipath effects of Rayleigh fading. The capacity curves show a near-linear increase with SNR for higher antenna configurations, in contrast to the relatively slow growth seen in the SISO system. This indicates that MIMO systems can exploit the rich scattering environment of Rayleigh channels to dramatically enhance throughput. Thus, the inference is clear: employing more antennas in a MIMO setup substantially boosts capacity and resilience in fading environments, making it a highly effective technique for modern wireless communication systems.

Chapter 4

Case Study 3 (Scilab GUI): The Comparative Performance Study of Image Segmentation Using GUI

4.1 Abstract

Image segmentation is a fundamental technique in computer vision, with applications ranging from medical imaging to object detection. It involves partitioning an image into regions where pixels within each region share similar attributes such as color, intensity, or texture. This study presents a comparative performance analysis of two widely used segmentation techniques: K-means clustering (an unsupervised partition-based method) and thresholding-based methods (including global and adaptive approaches), implemented through an interactive Scilab graphical user interface (GUI) and image processing and computer vision (IPCV) toolbox. The GUI interface enables real-time experimentation with critical parameters (e.g., cluster count K), facilitating a deeper understanding of trade-offs between method complexity and output quality. Results demonstrate that K-means excels in multi-region segmentation but is computationally intensive, while thresholding offers faster execution but struggles with intensity overlap. This work bridges theoretical principles with practical implementation, serving as an educational resource for students and researchers in image processing.
Keywords: Image segmentation, K-Means clustering, Thresholding, Image Processing and Computer Vision (IPCV), Graphical User Interface (GUI).

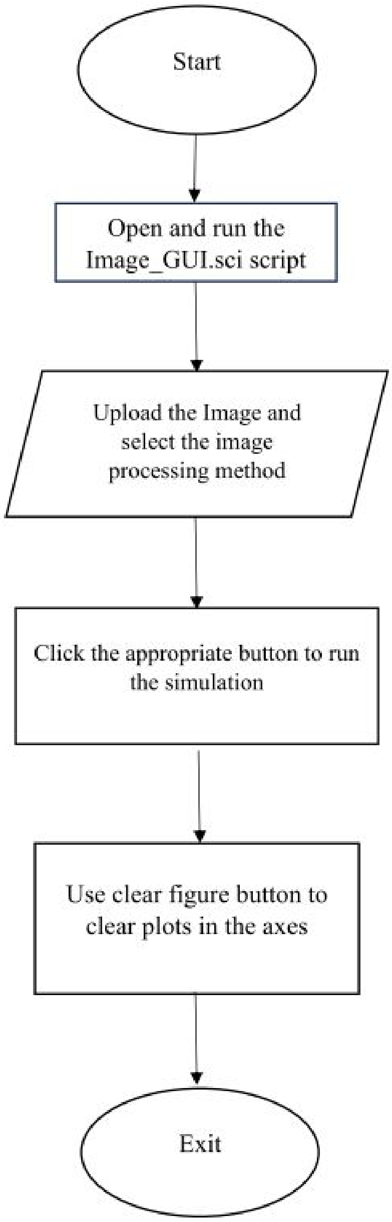
4.2 Problem Formulation

Despite advancements in deep learning-based segmentation (e.g., U-Net, Mask R-CNN), traditional methods like K-Means and thresholding remain relevant due to their low computational cost and interpretability. The primary objectives of this study are:

- To implement and analyse K-Means and thresholding for image segmentation.

- To compare their performance using quantitative metrics and qualitative assessment.
- Guidelines for selecting segmentation methods based on image properties.
- To discuss practical insights for improving segmentation outcomes.

4.3 Flowchart



4.4 Results and Discussion

Figure 1 illustrates the comparative performance of the image segmentation algorithm using K-means clustering and thresholding algorithms on a sample butterfly image. The original and grayscale images serve as references, showing the intricate details and intensity variations present in the scene.

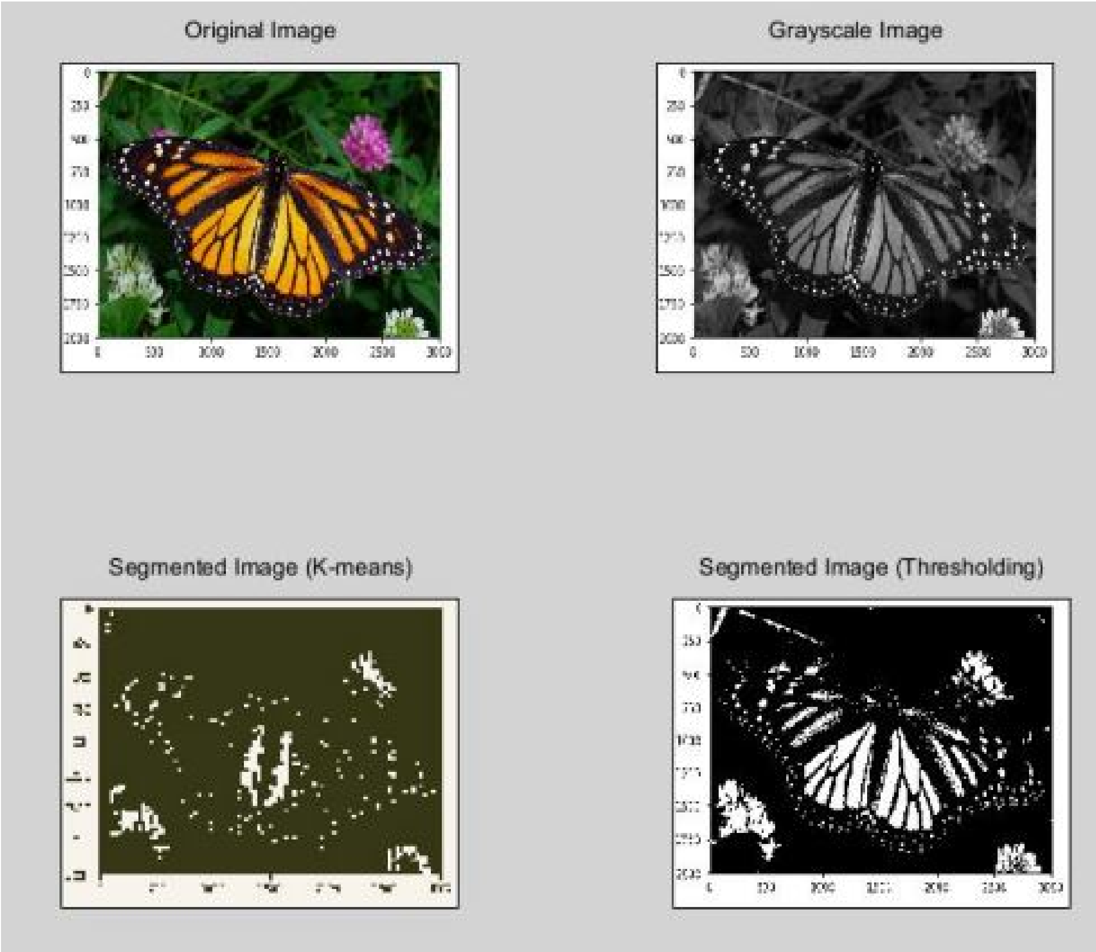


Figure 4.1: Comparative performance of the image segmentation algorithm using K-means (K=2) clustering and thresholding algorithms

The first observation from the figure is that the segmented image using K-means demonstrates the algorithm's ability to partition the image into multiple regions based on colour similarity, though with some noise and scattered regions around the initial cluster centres. On the other hand, the thresholding result effectively highlights the prominent foreground object (the butterfly) against the background, providing a sharper and more distinct segmentation but at the cost of losing finer details and ignoring subtle intensity variations.

The second observation is that, with k=2, the K-means algorithm effectively divided the image into two clusters, broadly corresponding to the butterfly and the background. This choice of k simplifies the segmentation into a binary classification, similar to thresholding, but it still considers pixel intensity and colour similarity across the entire image, making it more adaptive to subtle variations than simple thresholding.

Overall, K-means is better suited for multi-region segmentation where colour variation is significant, whereas thresholding is more effective for binary foreground-background separation in high-contrast images.

Figure 2 demonstrates that the image segmentation over the butterfly image using K-means clustering with k=5 and a thresholding algorithm for comparison. When k=5, the K-means algorithm partitions the image into five distinct clusters based on colour similarity. The segmented image shows a more nuanced representation of the scene compared to k=2. Multiple shades of green, brown, and purple in the background, as well as different orange and black regions of the butterfly, are differentiated. This higher number of clusters allows finer details to emerge, preserving subtle texture and colour variations both in the object of interest and in the background.

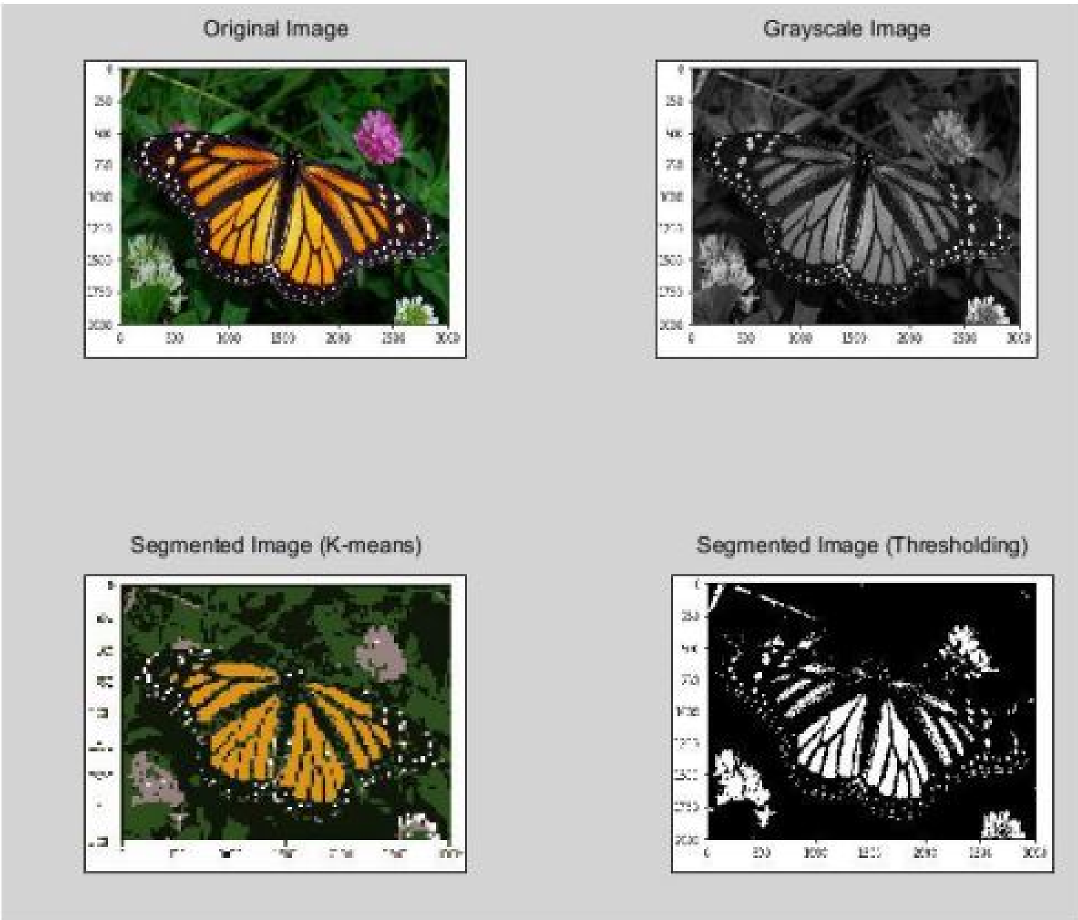


Figure 4.2: Comparative performance of the image segmentation algorithm using K-means (K=5) clustering and thresholding algorithms.

In contrast, the thresholding output remains binary, with a clear separation of the butterfly from the background, but at the cost of finer details. From this observation, it can be inferred that choosing a higher k, such as 5, enables the capture of finer details and colour variations, which is beneficial for applications where texture and subtle differences matter (e.g., pattern analysis, medical imaging). On the other hand, it can also lead to over-segmentation and may require additional post-processing (e.g., region merging or filtering) to consolidate meaningful regions.

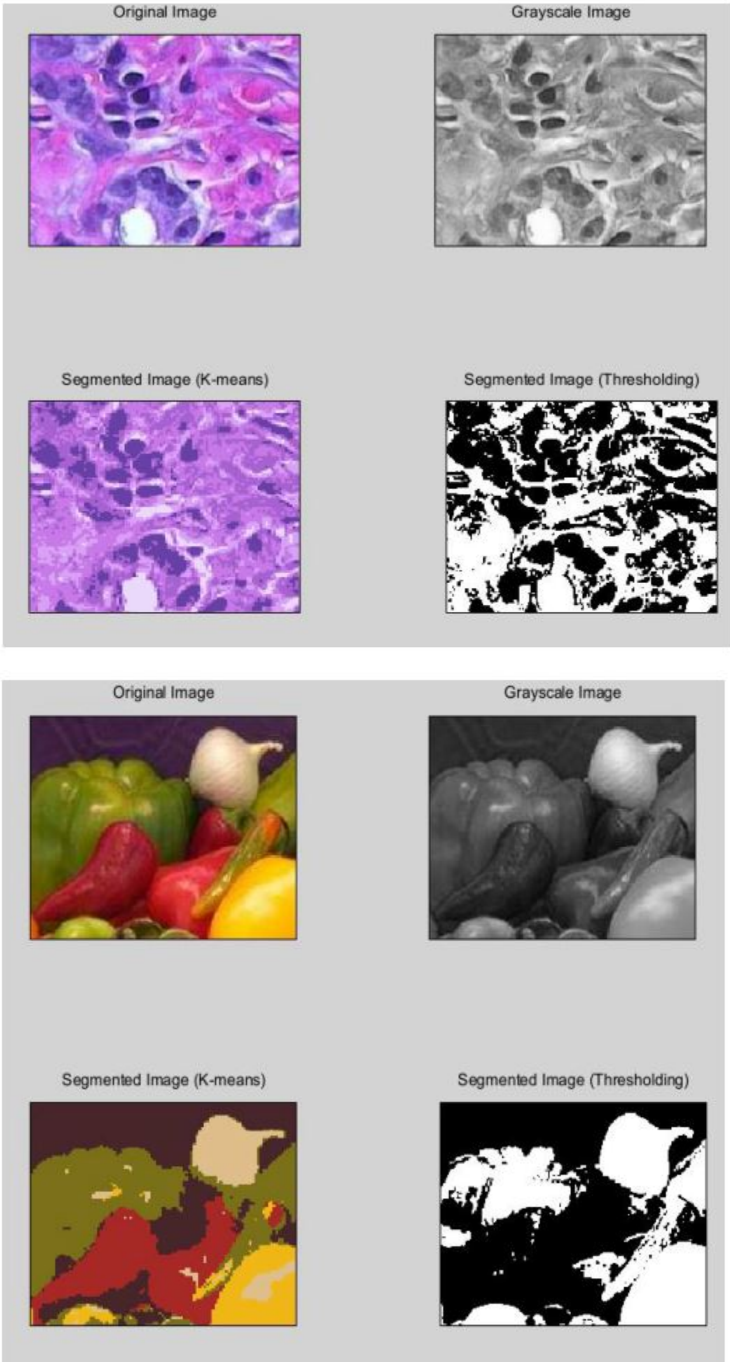


Figure 4.3: Comparative performance of the image segmentation algorithm using K-means clustering and thresholding algorithms with different images (Hestain and onion).

Chapter 5

Conclusion

This summer fellowship has provided an enriching opportunity to explore, implement, and evaluate advanced concepts in communication systems and image processing using Scilab and its associated toolboxes. Across the three case studies, the versatility of Scilab as a free and open-source platform for modelling, simulation, and GUI development has been clearly demonstrated.

In **Case Study 1**, the comparative study of analog and digital modulation techniques using Scilab Xcos offered valuable insights into the theoretical and practical aspects of modulation. By modelling AM, FM, PM, ASK, FSK, and PSK systems, the work illustrated the trade-offs between spectral efficiency, noise immunity, and implementation complexity, highlighting the strengths and limitations of each scheme in real-world applications.

Case Study 2 investigated the performance of single-antenna and multi-antenna wireless communication systems via a Scilab GUI. The comparative analysis of SISO, SIMO, MISO, and MIMO configurations under both AWGN and Rayleigh fading channels demonstrated the significant gains achievable through diversity and spatial multiplexing. The results reinforced MIMO's potential to meet the increasing capacity demands of modern wireless networks.

In **Case Study 3**, the comparative performance study of image segmentation techniques using Scilab's IPCV toolbox provided a practical evaluation of K-means clustering and thresholding methods. The analysis revealed K-means' suitability for multi-region segmentation and thresholding's efficiency for high-contrast binary separation, offering clear guidelines for method selection based on application requirements.

Collectively, these studies emphasize the impact of open-source tools in bridging theory and practice. They showcase how Scilab's simulation, computation, and GUI development capabilities can address diverse engineering problems—from communication signal design to image analysis—while providing a cost-effective platform for education and research.

Chapter 6

References

1. Mishra, Rashmi Rekha, and Sagupha Parween. “Design of AM, FM, PM, ASK, FSK, PSK Using OptiSystem Simulator.” *International Journal of Research in Engineering, Science and Management* 3, no. 1 (2020): 306–311.

2. Sharma, D.K., Mishra, A. and Saxena, R., 2010. Analog & digital modulation techniques: an overview. *International Journal of Computing Science and Communication Technologies*, 3(1), p.2007.

3. Bhagyaveni, M.A., Kalidoss, R. and Vishvaksenan, K.S., 2022. *Introduction to analog and digital communication*. River Publishers.

4. Bala, Diponkor, G. M. Waliullah, M. Hena, M. Abdullah, and M. Hossain. “Study the Performance of Capacity for SISO, SIMO, MISO and MIMO in Wireless Communication.” *Journal of Network and Information Security* 8, no. 1&2 (2020): 01–06.

5. Panwar, Preeti, Girdhar Gopal, and Rakesh Kumar. ”Image Segmentation using K-means clustering and Thresholding.” Image 3, no. 05 (2016): 1787-1793.

6. Scilab Enterprises. “Scilab: Free and Open Source software for numerical computation.” Available at: https://www.scilab.in/.

7. FOSSEE Project, IIT Bombay. “Free/Libre and Open Source Software for Education (FOSSEE).” Available at: https://fossee.in/.

8. Scilab case studies. Available at: https://scilab.in/case-study-portal/case-study-project.