Case Study: Spoofing Attack on Autonomous Vehicles.

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Course: Project Work

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Understanding Spoofing in Autonomous Vehicles

Background: Autonomous vehicles (AVs) rely on GPS, time synchronization, and sensors for safe navigation. However, these dependencies make them vulnerable to spoofing attacks.

Problem Statement: Spoofing attacks can misguide navigation, disrupt system synchronization, and falsify environmental data, posing significant risks to safety.

Objectives:

- Simulate spoofing attacks (GPS, time, and LiDAR)
- Assess their impacts.
- Propose mitigation strategies.

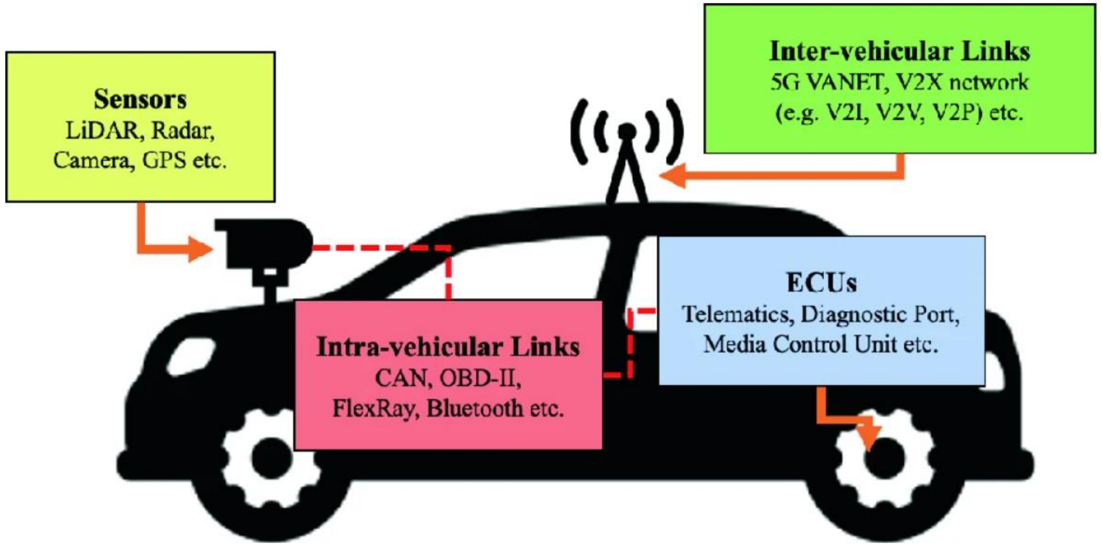


Fig: Vulnerable Attack surfaces of autonomous vehicles

Man Chun Chow, Maode Ma, and Zhijin Pan. Attack models andcountermeasures for autonomous vehicles. In Intelligent Technologies forInternet of Vehicles, pages 375–401. Springer, 2021.

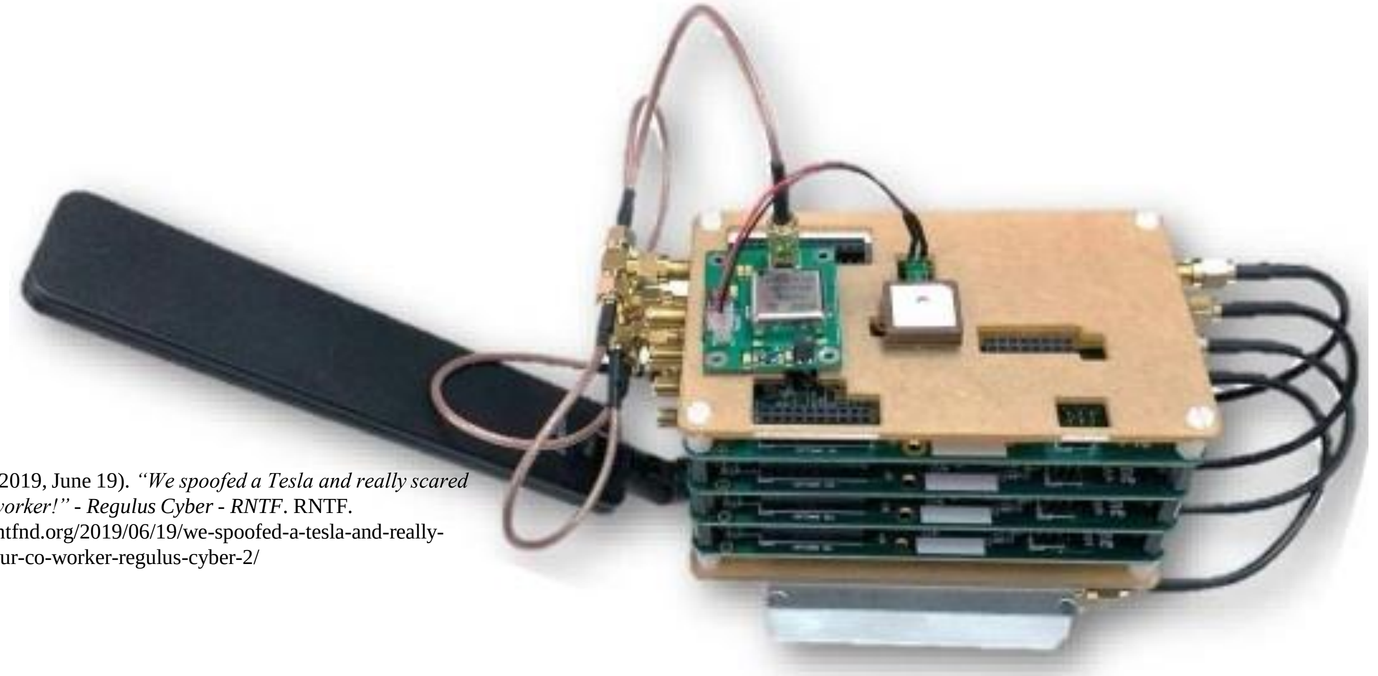
Research on Spoofing Attacks

- **GPS Spoofing (Regulus Cyber, 2019):** Misguided navigation with fake GPS signals.

- **Time Spoofing (Keen Security Lab, 2019):** System desynchronization causing critical errors.

- **LiDAR Spoofing (Cao et al., 2024):** False obstacle detection via manipulated sensor inputs.

Editor. (2019, June 19). *"We spoofed a Tesla and really scared our co-worker!" - Regulus Cyber - RNTF*. RNTF. https://rntfnd.org/2019/06/19/we-spoofed-a-tesla-and-really-scared-our-co-worker-regulus-cyber-2/



Spoofing Signals from 4 Constellations at Once – Regulus Cyber

User, S. (2024, March 8). *Researchers uncover vulnerabilities in LiDAR technology for autonomous vehicles*. https://route.ee/en/news/2487-researchers-uncover-vulnerabilities-in-lidar-technology-for-autonomous-vehicles

Lab, B. T. K. S. (2024, April 11). *Tencent Keen Security Lab: Experimental Security Research of Tesla Autopilot*. Keen Security Lab Blog. https://keenlab.tencent.com/en/2019/03/29/Tencent-Keen-Security-Lab-Experimental-Security-Research-of-Tesla-Autopilot/

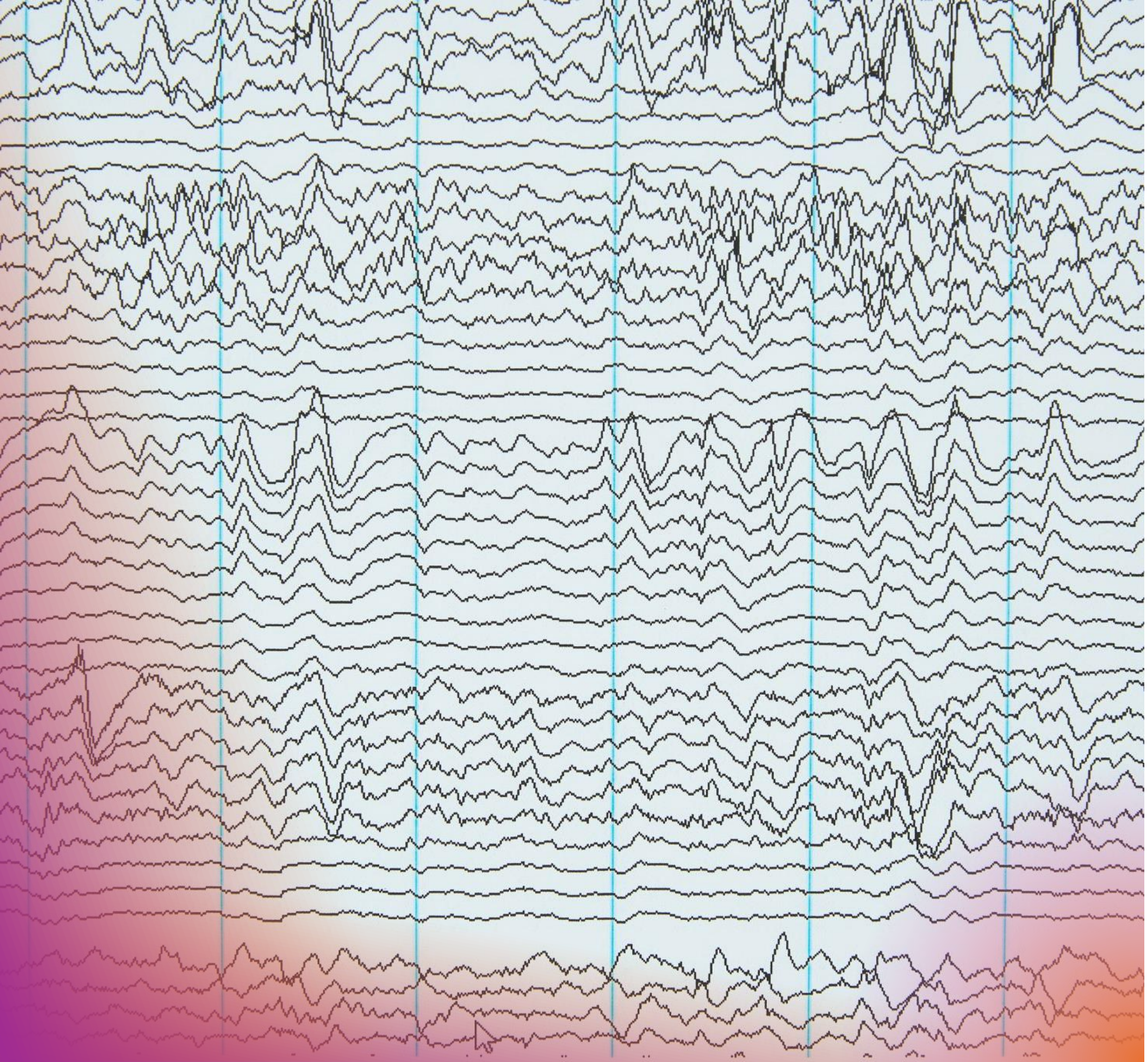
Simulation Design and Tools

Tools:

- MATLAB Live Script: Interactive computation and visualization.
- System: Windows 11, Intel i5, 16GB RAM.

Setup:

- **Simulation duration**: 10 seconds with 1000 time points.
- **Spoofing start points**: 20–30% of the timeline, depending on the simulation.



Key Parameters:

GPS Spoofing:

- Straight-line path with amplitude, frequency, and noise variations.

Time Spoofing:

- Linear time signal with deviations

LiDAR Spoofing:

- Constant distance of 20m with added linear drift and sinusoidal noise.

Code Setup for All simulation

```
%Setup for All the Simulations

% Time Vector (Shared Setup)
t = linspace(0, 10, 1000);  % Time vector for 10 seconds

% GPS Spoofing Setup
original_position = t;      % Original GPS signal path
spoofing_start_index = round(length(t) * 0.2); % Start of spoofing

% Time Spoofing Setup
original_time = t;          % Original time signal (linear progression)

% LiDAR Spoofing Setup
true_obstacle_distance = 20; % Fixed obstacle distance (meters)
spoofing_start_index = round(length(t) * 0.3); % Start of spoofing

```

A GPS live script where parameter are defined

```
% GPS Spoofing Simulation with Real-Time Animation

% Parameters and Setup
t = linspace(0, 10, 1000);  % Time vector for 10 seconds
original_position = t;  % Original GPS signal path (straight line)
spoofed_position = original_position;  % Initialize spoofed position

% Spoofing starts at 20% of the timeline with increased noise and deviation
spoofing_start_index = round(length(t) * 0.2);
amplitude_variation = 1.0 + 0.3 * sin(0.1 * t(spoofing_start_index:end));  % Increased amplitude
frequency_variation = 1.0 + 0.1 * cos(0.05 * t(spoofing_start_index:end)); % Increased frequency
random_walk = cumsum(0.05 * randn(1, length(t) - spoofing_start_index + 1)); % Random walk
gaussian_noise = 0.2 * randn(1, length(t) - spoofing_start_index + 1); % Noise

% Spoofed position calculation
spoofed_position(spoofing_start_index:end) = original_position(spoofing_start_index:end) + ...
    amplitude_variation .* sin(frequency_variation .* t(spoofing_start_index:end)) + ...
    random_walk + gaussian_noise;
```

Key Components

- Original Path: Straight-line trajectory (original_position = t).

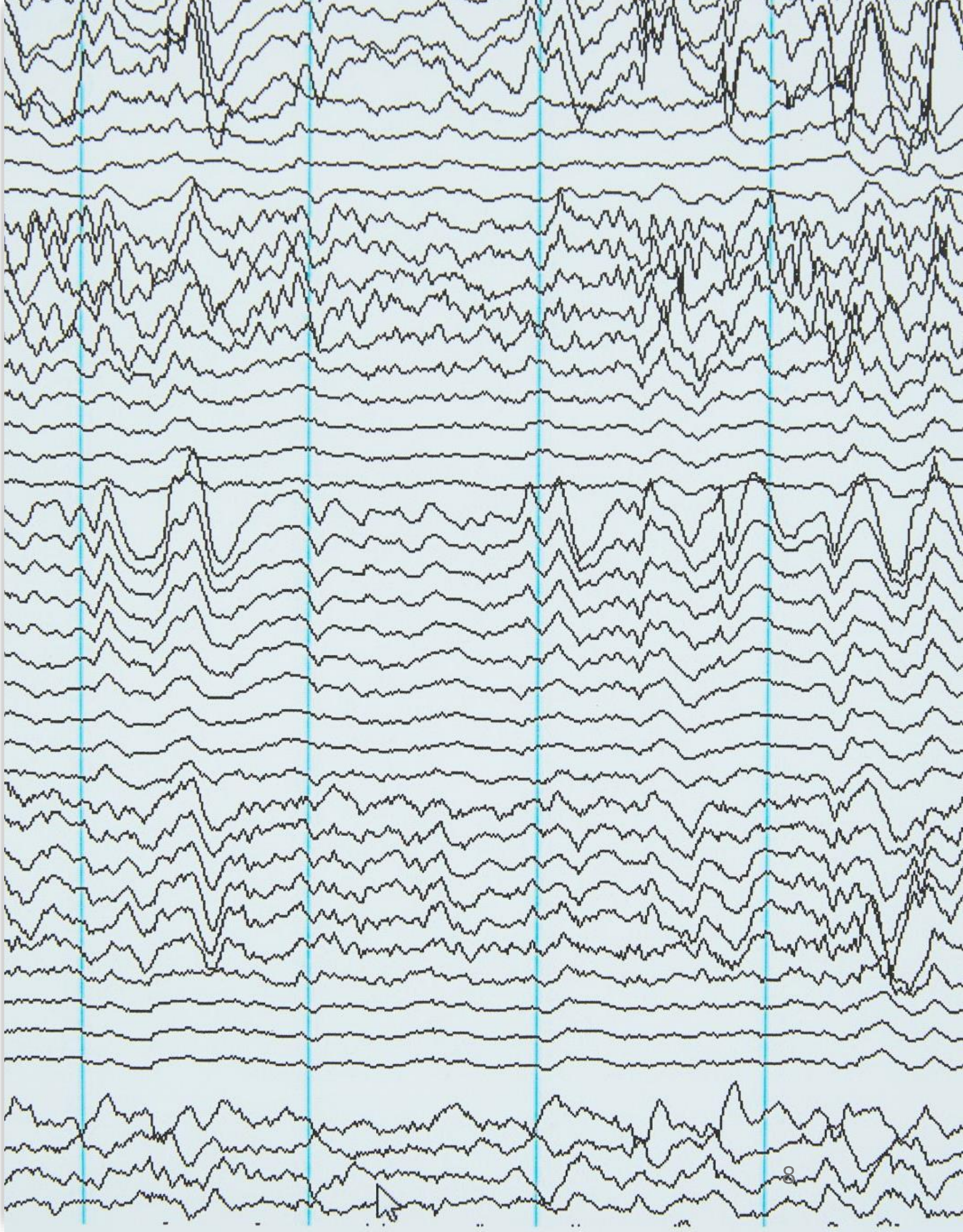
Spoofing Elements:

- **Amplitude variation** $A(t) = 1.0 + 0.3 \cdot \sin(0.1t)$ which Adds smooth oscillations.
- **Frequency variation** $f(t) = 1.0 + 0.1 \cdot \cos(0.05t)$ which Adds periodic deviations.
- **Random walk** $W(t) = \sum_{i=1}^{n} 0.05 \cdot \mathrm{randn}()$ which Introduces gradual drift.
- **Gaussian noise** $N(t) = 0.2 \cdot \mathrm{randn}()$ Simulates real-world randomness.

Analysed Metrics:

Position: Deviation of spoofed path from original.

Velocity and Acceleration: Effects on motion dynamics.



GPS Spoofing Simulation and Results

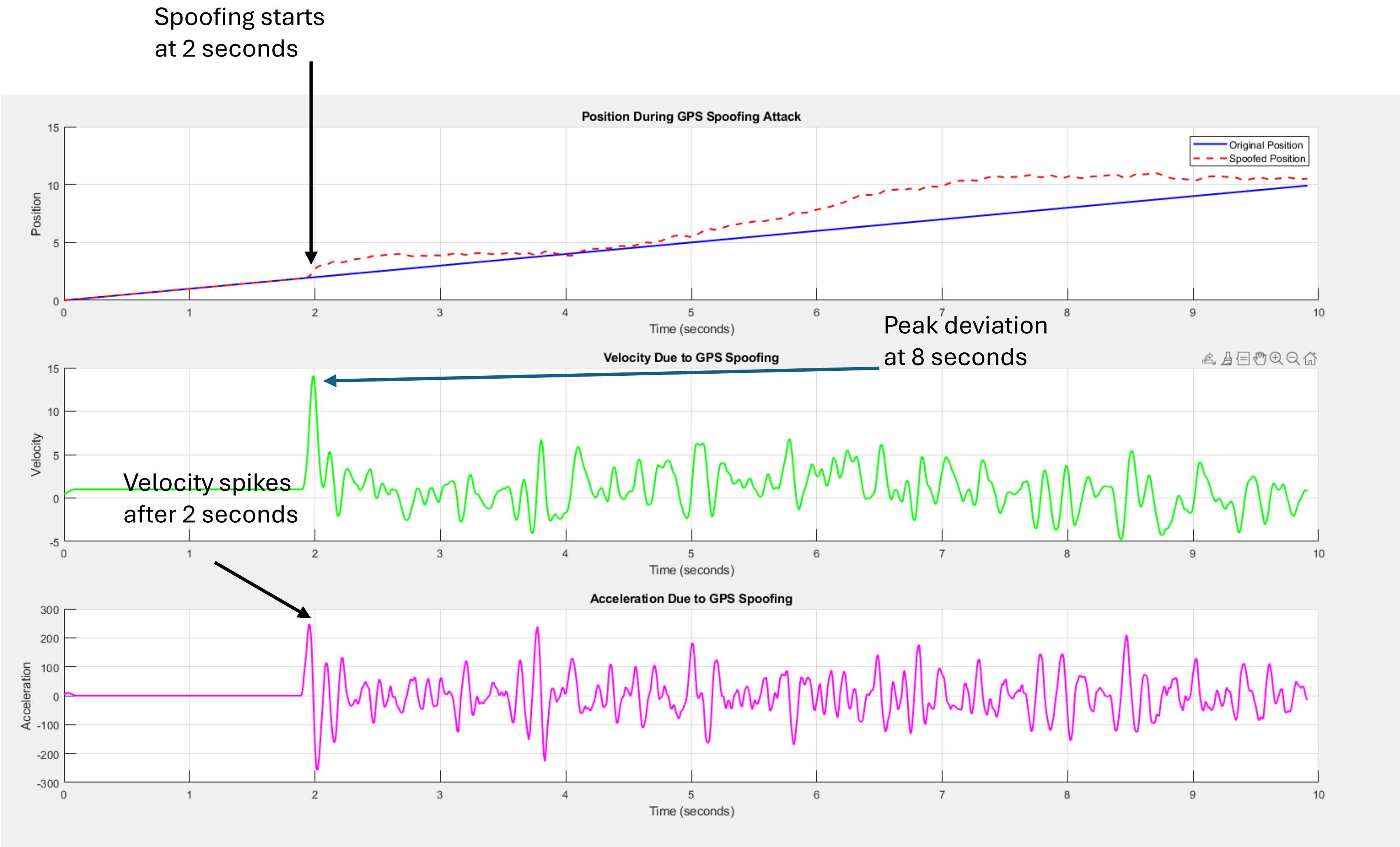
- **Overview:**
- Simulated GPS spoofing to observe its impact on position, velocity, and acceleration.
- Spoofing starts at 2 seconds, introducing deviations through amplitude variations, frequency changes, random walk, and Gaussian noise.
- Results highlight how spoofing disrupts the vehicle's navigation system by creating noticeable deviations in the trajectory.

Main script for calculation

```
% Spoofed position calculation with enhanced dynamic components
spoofed_position(spoofing_start_index:end) = original_position(spoofing_start_index:end) + ...
    amplitude_variation .* sin(frequency_variation .* t(spoofing_start_index:end)) + ...
    random_walk + gaussian_noise;
```

Key Logic for Spoofed Path Generation

Results for GPS spoofing



Time Spoofing Simulation and Results

Overview:

- Simulated **time spoofing attack** to observe its impact on GPS signals.
- Spoofing starts at **20% of the timeline**, introducing:
  - **Linear drift**: Mimics gradual timing errors.
  - **Sinusoidal oscillations**: Adds periodic disturbances.
  - **Random noise**: Simulates real-world signal disruptions.
- Results highlight deviations in time signal, measurable offsets, and disturbances in signal stability.

Spoofing elements:

- **Linear Drift**: Gradual time shifts using : $0.5 * (t - t_start)$

- **Sinusoidal Disturbance**: Periodic variations modeled as:

$$0.2 * sin(2 * pi * 0.5 * t)$$

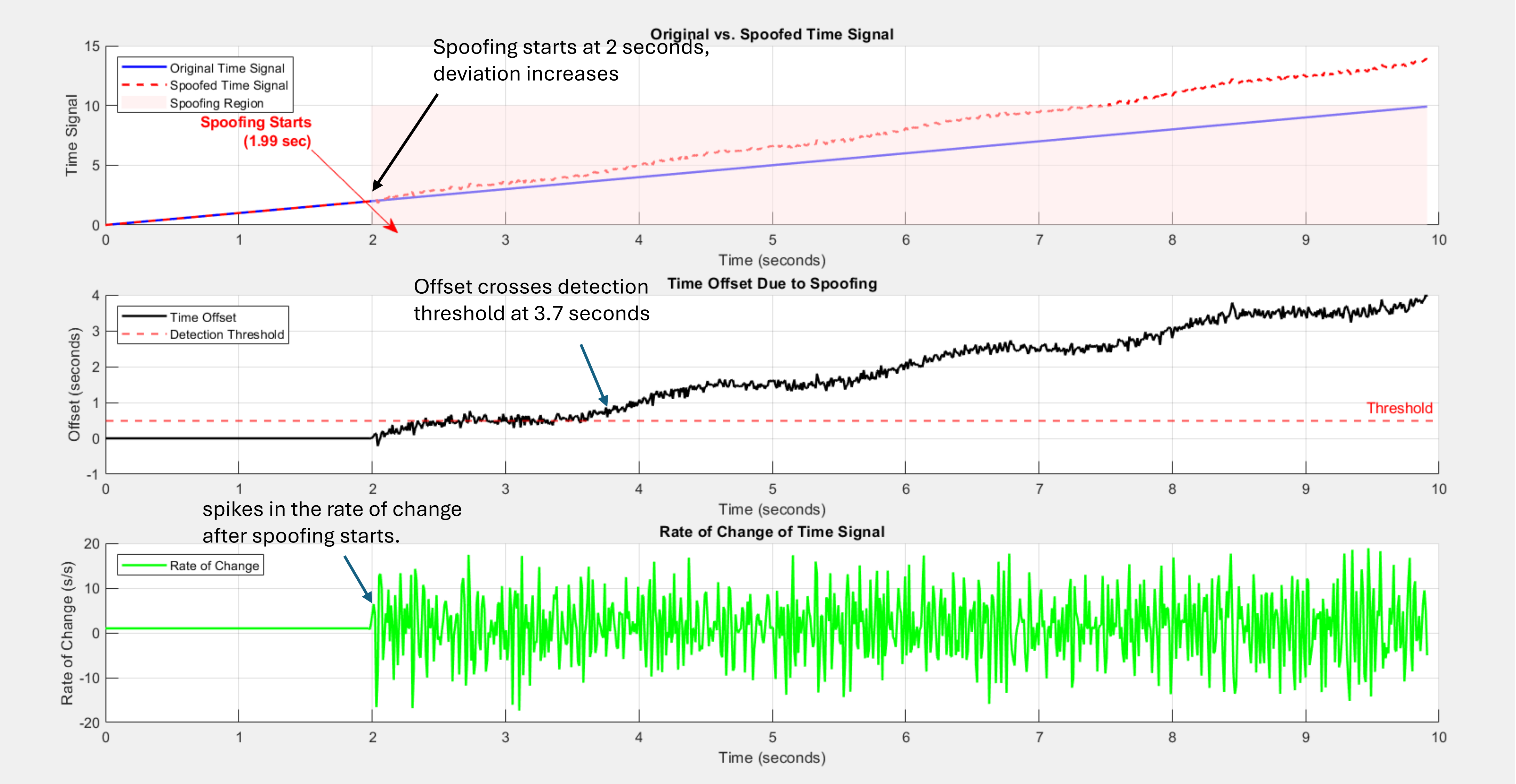
- **Gaussian Noise**: Adds random fluctuations using : $0.1 * randn(...)$

Main script for calculation

```
% Spoofed Time Signal
spoofed_time = original_time; % Initialize spoofed time
spoofed_time(spoofing_start_index:end) = original_time(spoofing_start_index:end) + ...
    time_deviation + sinusoidal_disturbance + gaussian_noise;
```

Demonstrates how drift, oscillations, and noise are combined to simulate the spoofed time signal.

Results for time spoofing



Sensor Spoofing Simulation and Results

- **Overview**:
- Simulated sensor spoofing attack on LiDAR distance measurements to analyze its impact.
- Spoofing begins at 30% of the timeline and ends at 60%, introducing:
    - **Linear drift**: Gradual increase in distance readings.
    - **Sinusoidal disturbances**: Mimics periodic fluctuations in distance.
    - **Gaussian noise**: Adds random variations to the data.
- Results highlight deviations in measured distances and significant impacts on sensor accuracy.

Sensor Spoofing Elemets:

- Linear Drift: Gradual shift using:

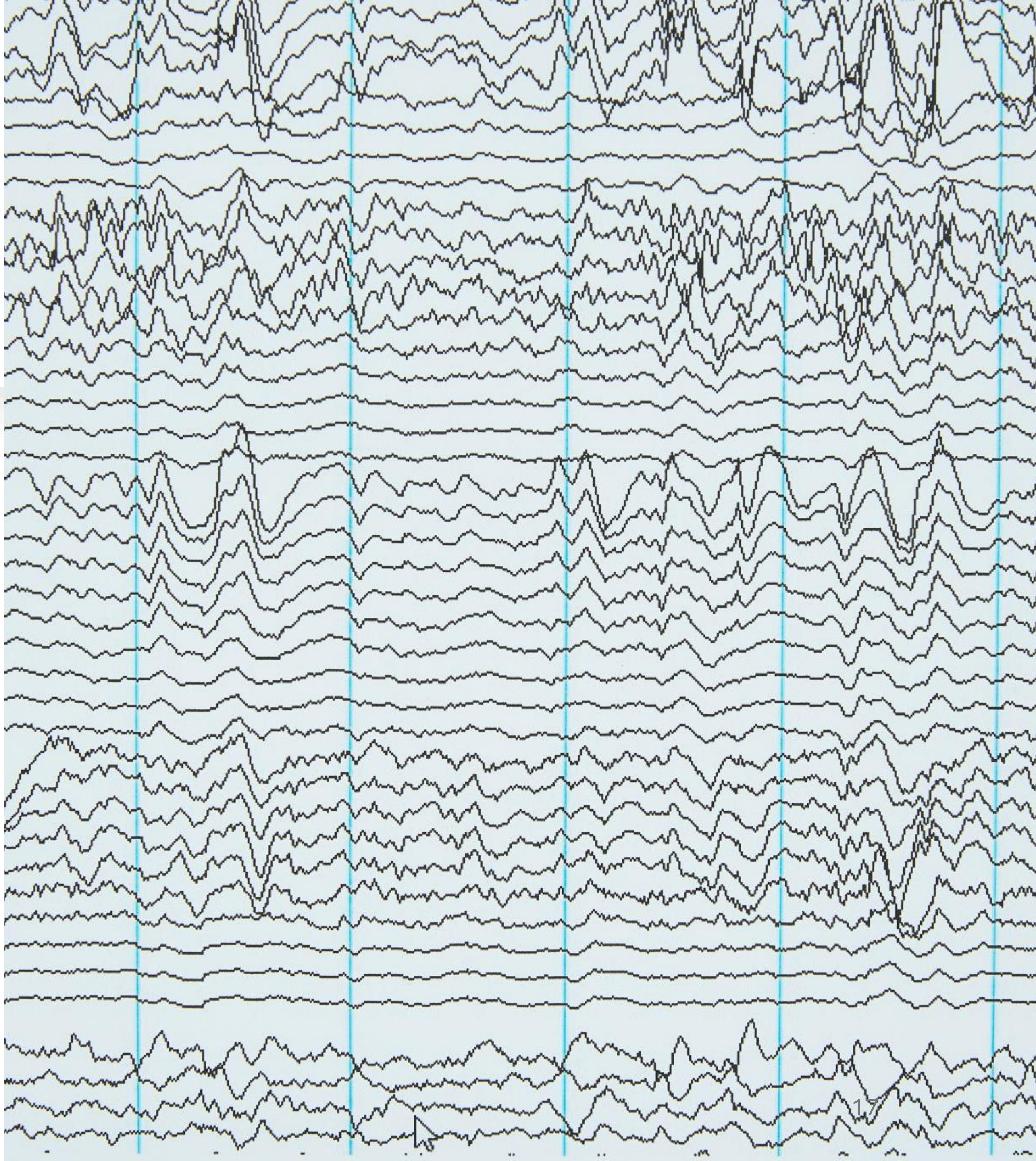
$$0.5 * (t - t_start)$$

- Sinusoidal Disturbance: Periodic fluctuations modeled as:

$$2 * sin(2 * pi * 0.2 * t)$$

- Gaussian Noise: Simulates randomness with:

$$0.5 * randn(...)$$

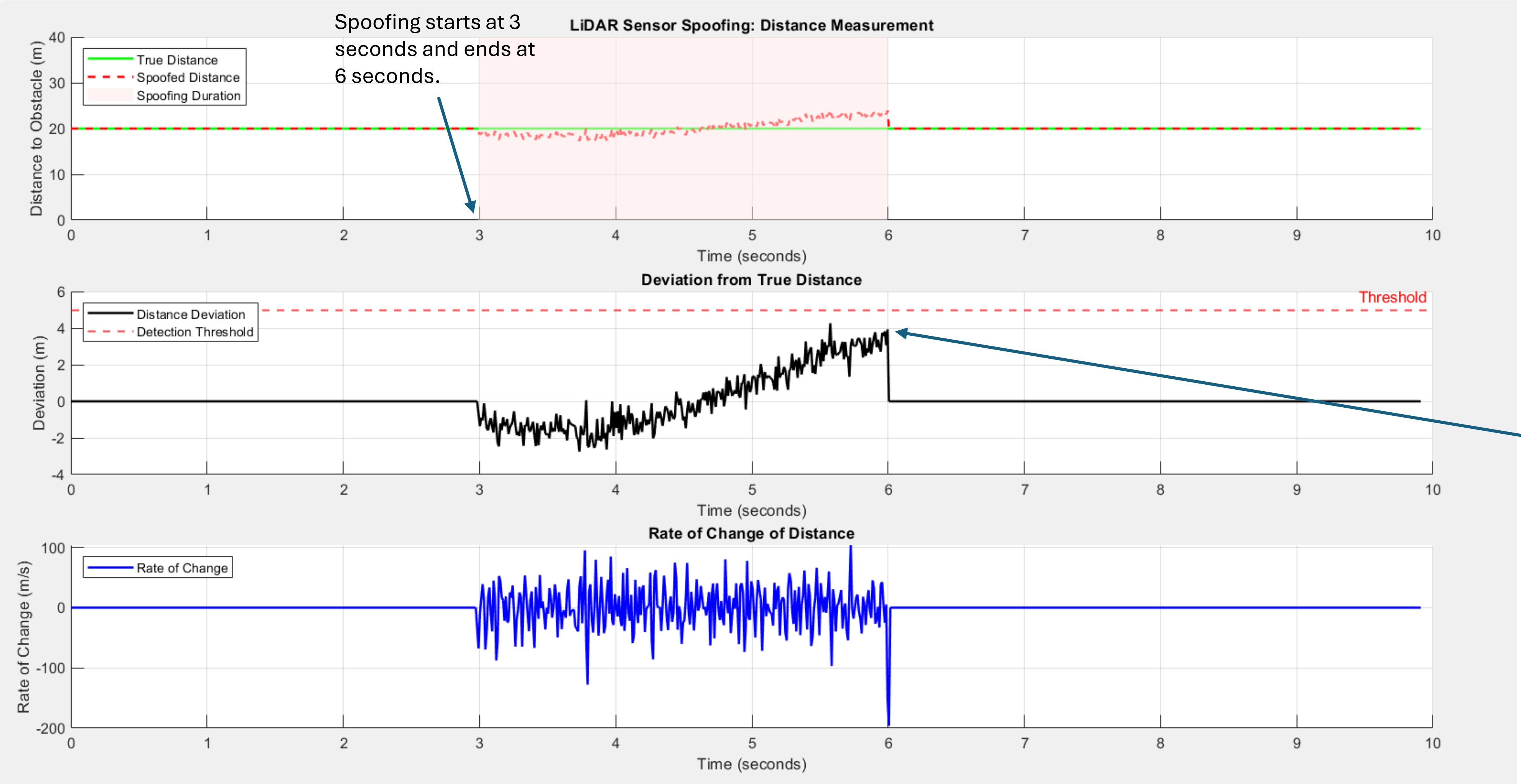


Main script for calculation

```
% Apply Spoofing
spoofed_distance(spoofing_start_index:spoofing_end_index) = true_obstacle_distance + ...
    linear_drift + sinusoidal_disturbance + gaussian_noise;
```

This code shows how the spoofing elements (drift, oscillations, noise) are combined to create a spoofed sensor reading.

Results for sensor spoofing



Although this does not change major effect above the threshold.

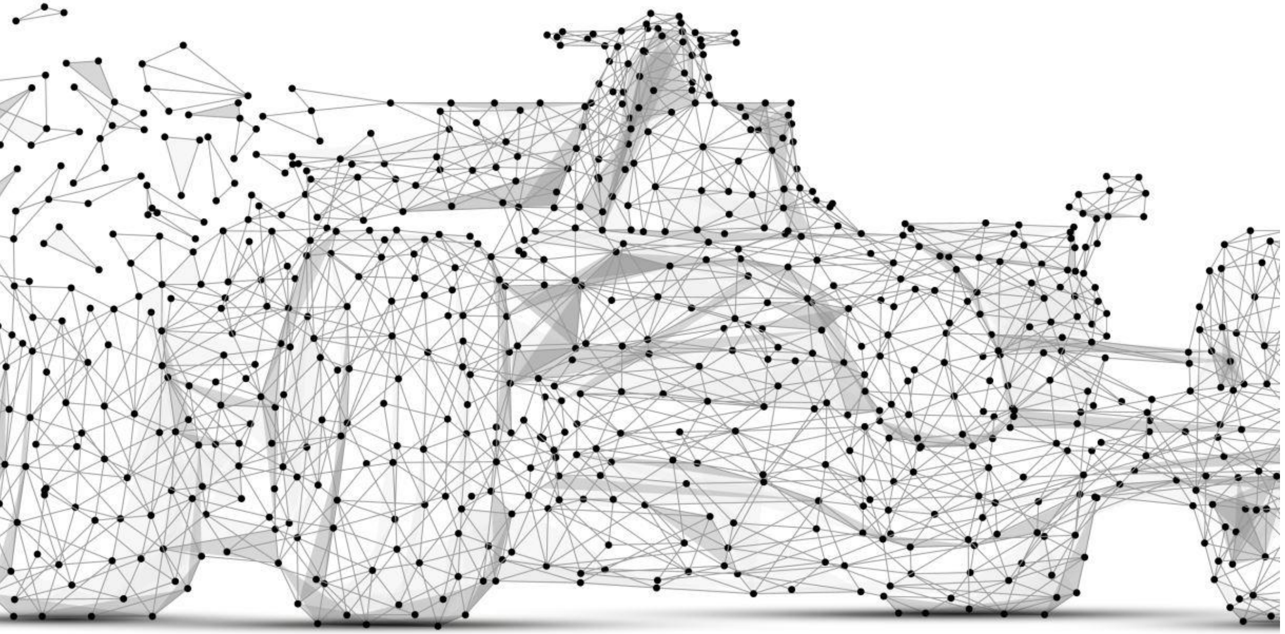
Comparison of Spoofing Types

- **Process:**
- Simulated each spoofing type using unique dynamics.
- Measured deviations, rate of change, and threshold crossing.

Metrics Evaluated:

- Maximum Deviation (quantifies error severity).
- Rate of Change (measures signal stability).
- Threshold Crossing (detectability).

Spoofing Type	Max Deviation	Error Percentage	Noise Duration
GPS	3.5 m	35%	t =2 to 9 seconds
Time	1.5 s	15%	t =2 to 6 seconds
Sensor	4 m	20%	t =3 to 6 seconds



An Implementation of GPS Spoofing in Real World using API

Goal:

- Simulate GPS spoofing effects on a vehicle’s movement.
- Show incremental spoofing dynamics and their combined impact.

Step-by-Step Process

1. Original Path (Blue Line):

- Real GPS route from dorm to university (via ORS API).

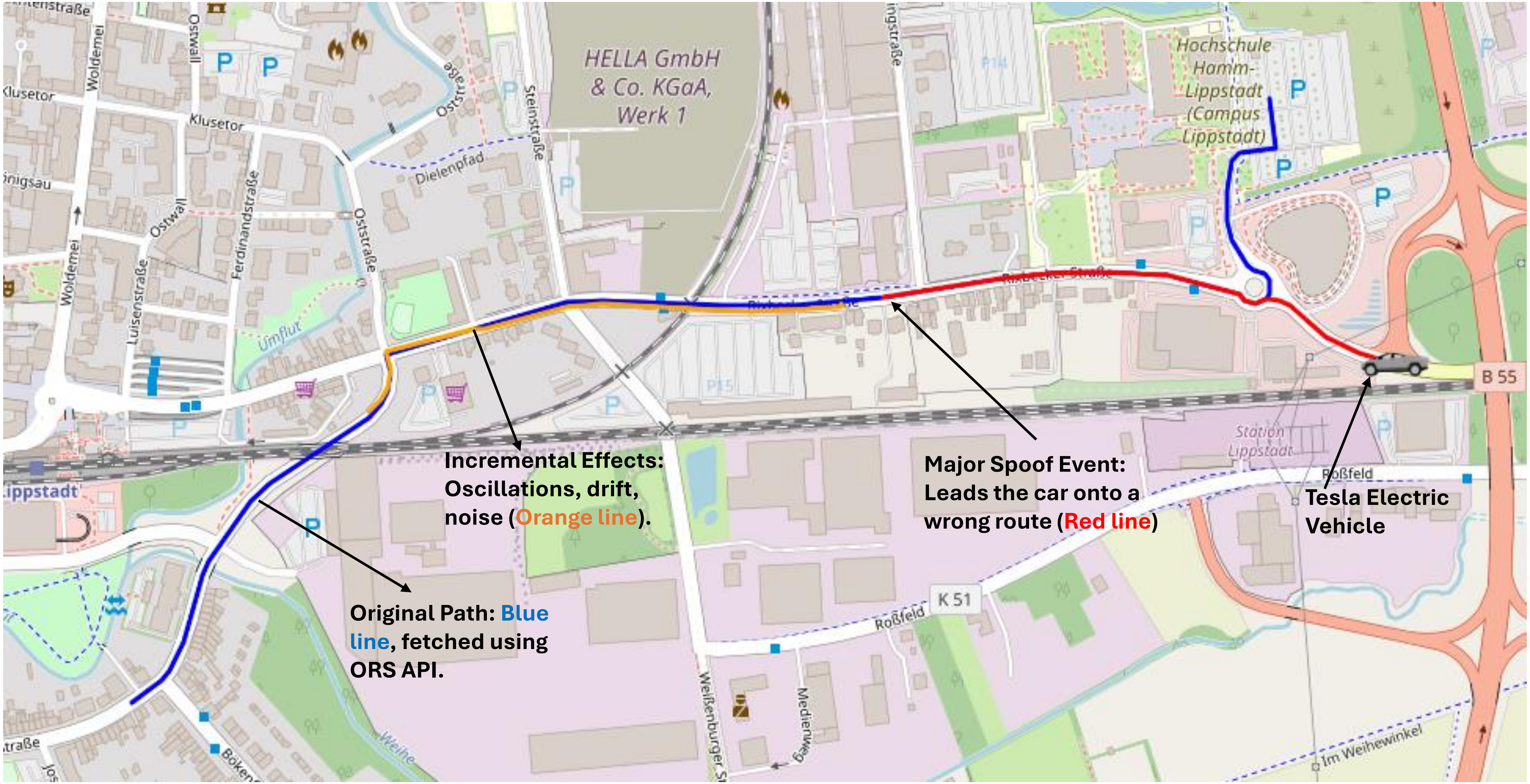
2. Incremental Spoofing Dynamics (Orange Line):

- Amplitude Variation: Small oscillations.
- Frequency Variation: Varying motion.
- Random Walk: Gradual drift.
- Gaussian Noise: Random jitter.

3. Major Spoof Event (Red Line):

- All dynamics combined at 50% of the route.
- Redirects the car to a wrong route fetched using ORS.

Demo In
Next Slide


HELLA GmbH & Co. KGaA, Werk 1
Hochschule Hamm-Lippstadt (Campus Lippstadt)
Incremental Effects: Oscillations, drift, noise (Orange line).
Major Spoof Event: Leads the car onto a wrong route (Red line)
Tesla Electric Vehicle
Original Path: Blue line, fetched using ORS API.
B 55
K 51
Station Lippstadt

Dem

Original Demo

- file:///C:/Users/shiha/OneDrive/Desktop/11th%20semester/Final%20Project/Javascript%20Visualisation%20-%20Attempt%20with%20Matlab%20-.html

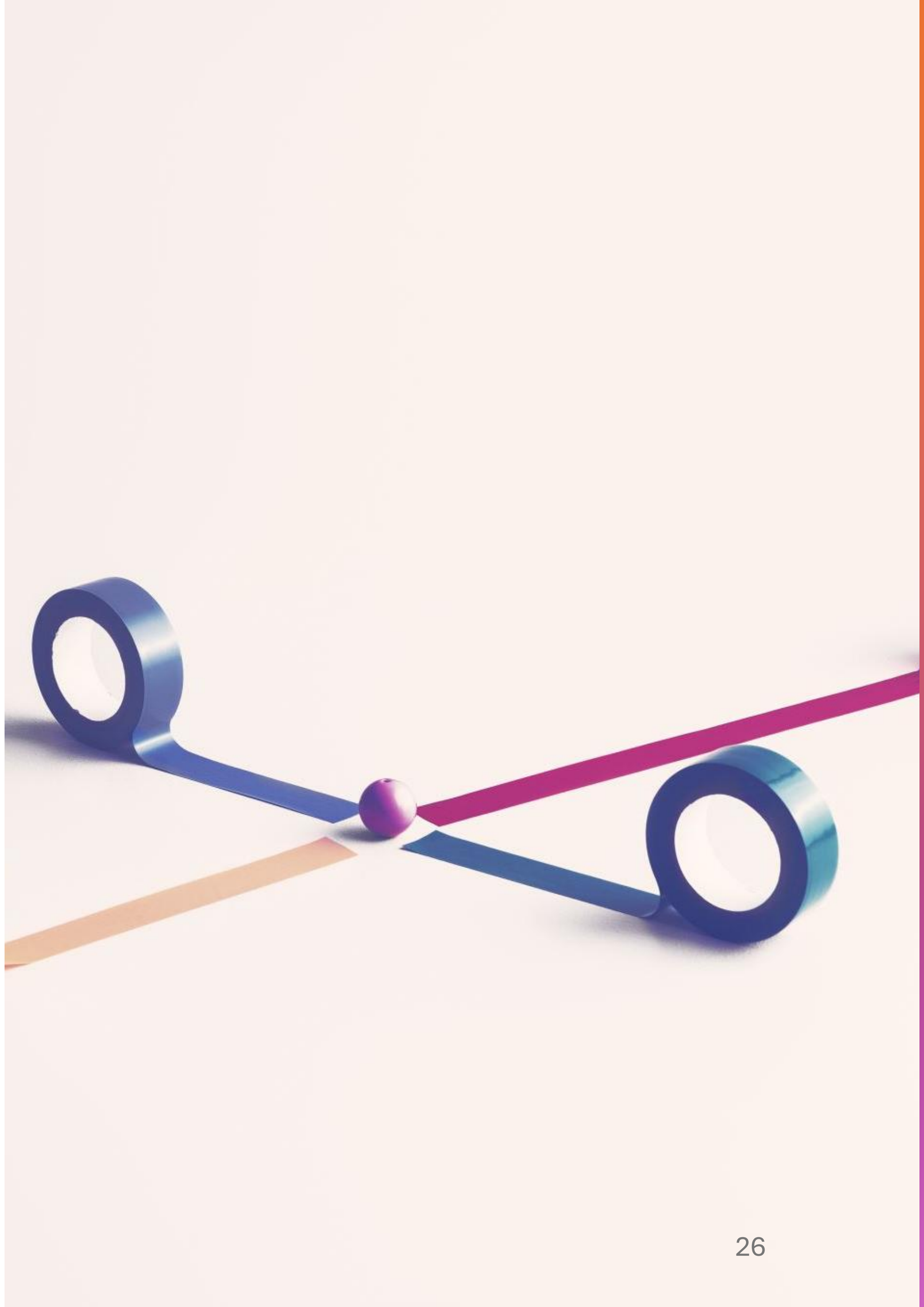
Discussion and Insights

Findings:

- GPS spoofing: Path deviations can misguide vehicles.
- Time spoofing: Sync delays impact system reliability.
- LiDAR spoofing: False readings compromise obstacle detection.

Challenges:

- Balancing simplicity and realism in simulations.
- Interpreting results in real-world contexts.



Conclusion and Future Work

Summary:

- Spoofing attacks significantly disrupt AV safety and navigation.
- Based on the parameter and the conducted experiments on chosen parameters , GPS spoofing has the most direct impact on navigation.

Future Directions:

- Real-world testing to validate findings.
- Developing countermeasures for spoofing detection.
- Exploring combined spoofing scenarios for deeper insights.

References

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- Questions?