ROW NAVIGATION

import matplotlib.pyplot as plt

import numpy as np

from scipy.interpolate import CubicSpline

import math

import time

from matplotlib.patches import Polygon

import matplotlib.transforms as transforms

from farm\_safety import SafetyModule

import csv

import os

from datetime import datetime

import random

safety = SafetyModule()

STEP = 1.6 # Reduced back to original value for smoother movement (was 0.8)

TOLERANCE = 0.5 # Slightly reduced for better precision

MAX\_ATTEMPTS = 200 # Kept the same

DEBUG = False

ANIMATION\_SPEED = 0.001 # Increased for slowerment

# Moved from farm\_entry.py

class Rover:

def \_\_init\_\_(self):

self.x = 0.0

self.y = 0.0

self.heading = 0.0

self.last\_heading = 0.0 # Added memory for last heading

self.history = []

self.geofence = None

self.entry\_point = None

self.inside\_fence = False

self.command\_count = 0 # Add command count tracking

self.blocked\_directions = set() # Set of blocked directions

self.navigator = None

# Add to Rover class

def log\_movement(self, movement\_type, distance=None, angle=None):

"""Log movement commands to the terminal"""

if movement\_type == "forward":

print(f"⬆️ COMMAND: Move forward {distance:.2f}m")

elif movement\_type == "backward":

print(f"⬇️ COMMAND: Move backward {distance:.2f}m")

elif movement\_type == "turn\_left":

print(f"↩️ COMMAND: Turn left {angle:.1f}°")

elif movement\_type == "turn\_right":

print(f"↪️ COMMAND: Turn right {angle:.1f}°")

elif movement\_type == "stop":

print("🛑 COMMAND: Stop")

self.command\_count += 1

def calculate\_heading\_to(self, tx, ty):

dx, dy = tx - self.x, ty - self.y

if abs(dx)<1e-6 and abs(dy)<1e-6:

return self.heading

ang = math.degrees(math.atan2(dy, dx))

return ang if ang>=0 else ang+360

def set\_position(self, x, y, heading=None, force=False, add\_to\_history=True):

if self.geofence and not force:

in\_fence = self.is\_inside\_farm(x, y)

if not in\_fence:

return False

# Proceed with setting position

if self.geofence and not force:

if self.entry\_point and self.distance\_to(\*self.entry\_point) <= 0.8:

self.inside\_fence = True

in\_fence = self.is\_inside\_farm(x, y)

if (in\_fence and not self.inside\_fence) or (not in\_fence and self.inside\_fence):

print("⚠️ Movement blocked: would cross fence boundary")

return False

# Store previous position and heading before updating

prev\_x, prev\_y = self.x, self.y

prev\_heading = self.heading

# Update position with limited decimal places

self.x = round(x, 2)

self.y = round(y, 2)

if heading is not None:

self.heading = round(heading % 360, 1)

# Update last\_heading when heading changes

self.last\_heading = self.heading

print(f"DEBUG: Raw heading={heading:.1f}°, Compass={self.get\_compass\_direction(heading)}")

if add\_to\_history:

self.history.append((self.x, self.y))

self.command\_count += 1 # Increment command count

# Add GPS-like position reporting

print(f"📍 GPS: Position [{self.x:.2f}, {self.y:.2f}], Heading: {self.heading:.1f}°")

# Convert numerical heading to compass direction using the current heading

compass\_heading = self.get\_compass\_direction(self.heading)

# Get or create a run ID

if not hasattr(self, 'run\_id'):

# First time initialization

self.run\_id = self.get\_next\_run\_id()

# Calculate bearing angle (standard compass bearing)

bearing = self.heading # We're using heading directly as the bearing

log\_data = {

'timestamp': datetime.now().isoformat(),

'run\_id': self.run\_id,

'x': self.x,

'y': self.y,

'heading': self.heading,

'bearing': bearing, # Add standard bearing

'compass\_heading': compass\_heading,

'fix\_quality': '3D Fix', # Simulated fix quality

'satellite\_count': random.randint(8, 12), # Simulated satellite count

'deviation': (self.navigator.calculate\_deviation(self.x, self.y)

if hasattr(self, 'navigator') and self.navigator else 0)

}

log\_file\_path = r'F:\GPS\task\_2\_waypoints\rover\_log.csv'

with open(log\_file\_path, 'a', newline='') as csvfile:

# Add 'bearing' to fieldnames

fieldnames = ['timestamp', 'run\_id', 'x', 'y', 'heading', 'bearing', 'compass\_heading',

'fix\_quality', 'satellite\_count', 'deviation']

writer = csv.DictWriter(csvfile, fieldnames=fieldnames)

if not os.path.exists(log\_file\_path) or os.path.getsize(log\_file\_path) == 0:

writer.writeheader()

writer.writerow(log\_data)

return True

def get\_compass\_direction(self, heading):

"""

Convert rover's heading (0° = East, 90° = North) to standard compass direction.

Standard compass: North = 0°, East = 90°, South = 180°, West = 270°

"""

# Convert from rover heading to standard compass bearing

compass\_heading = (90 - heading) % 360

# Define standard compass bearings based on converted heading

if 348.75 <= compass\_heading or compass\_heading < 11.25:

return "North"

elif 11.25 <= compass\_heading < 33.75:

return "North-Northeast"

elif 33.75 <= compass\_heading < 56.25:

return "Northeast"

elif 56.25 <= compass\_heading < 78.75:

return "East-Northeast"

elif 78.75 <= compass\_heading < 101.25:

return "East"

elif 101.25 <= compass\_heading < 123.75:

return "East-Southeast"

elif 123.75 <= compass\_heading < 146.25:

return "Southeast"

elif 146.25 <= compass\_heading < 168.75:

return "South-Southeast"

elif 168.75 <= compass\_heading < 191.25:

return "South"

elif 191.25 <= compass\_heading < 213.75:

return "South-Southwest"

elif 213.75 <= compass\_heading < 236.25:

return "Southwest"

elif 236.25 <= compass\_heading < 258.75:

return "West-Southwest"

elif 258.75 <= compass\_heading < 281.25:

return "West"

elif 281.25 <= compass\_heading < 303.75:

return "West-Northwest"

elif 303.75 <= compass\_heading < 326.25:

return "Northwest"

elif 326.25 <= compass\_heading < 348.75:

return "North-Northwest"

else:

return "Unknown" # Should never reach here

def get\_next\_run\_id(self):

"""Determine the next run ID based on existing data in the log file."""

log\_file\_path = r'F:\GPS\task\_2\_waypoints\rover\_log.csv'

# If file doesn't exist, start with run 1

if not os.path.exists(log\_file\_path):

return 1

try:

# Read the existing file to find the highest run\_id

max\_run\_id = 0

with open(log\_file\_path, 'r', newline='') as csvfile:

reader = csv.DictReader(csvfile)

for row in reader:

if 'run\_id' in row:

try:

run\_id = int(row['run\_id'])

max\_run\_id = max(max\_run\_id, run\_id)

except (ValueError, TypeError):

pass

# Return the next run ID

return max\_run\_id + 1

except Exception as e:

print(f"Error determining run ID: {e}")

return 1 # Default to 1 if there's an error

def set\_geofence(self, vertices, entry\_point):

self.geofence = vertices

self.entry\_point = entry\_point

self.inside\_fence = self.is\_inside\_farm(self.x, self.y)

def distance\_to(self, tx, ty):

return math.hypot(tx - self.x, ty - self.y)

def is\_inside\_farm(self, x, y):

if not self.geofence:

return True

# Simple boundary check

min\_x = min(v[0] for v in self.geofence)

max\_x = max(v[0] for v in self.geofence)

min\_y = min(v[1] for v in self.geofence)

max\_y = max(v[1] for v in self.geofence)

return min\_x <= x <= max\_x and min\_y <= y <= max\_y

def move\_forward(self, distance, ax=None, fig=None, rover\_patch=None):

# Log the movement command to terminal

self.log\_movement("forward", distance=distance)

rad = math.radians(self.heading)

target\_x = self.x + distance \* math.cos(rad)

target\_y = self.y + distance \* math.sin(rad)

success = self.set\_position(target\_x, target\_y)

if success and ax and fig and rover\_patch:

update\_rover\_visualization(self, ax, fig, rover\_patch)

plt.pause(0.001) # Add pause for smoother animation

return success

# Added method to detect if rover is stuck

def detect\_and\_resolve\_stuck(self):

# If this method is called, we assume potential stuck situation

# Return recommendation for new heading if needed

if len(self.blocked\_directions) > 3:

# Clear blocked directions and suggest a completely new heading

self.blocked\_directions.clear()

# Try perpendicular to current heading

new\_heading = (self.heading + 90) % 360

return new\_heading

return None

# Moved from farm\_entry.py

def update\_rover\_visualization(rover, ax, fig, rover\_patch=None):

rover\_scale = 3.5 # Scale factor to make rover appear larger

if rover\_patch is None:

base\_verts = np.array([[0.7, 0], [-0.3, 0.4], [-0.3, -0.4]])

scaled\_verts = base\_verts \* rover\_scale # Apply scaling

rover\_patch = Polygon(scaled\_verts, closed=True, fc='blue', ec='black') # Correct: uses scaled vertices

ax.add\_patch(rover\_patch)

tr = transforms.Affine2D().rotate\_deg(rover.heading).translate(rover.x, rover.y)

rover\_patch.set\_transform(tr + ax.transData)

if hasattr(ax, 'path\_line') and len(rover.history) > 1:

ax.path\_line.set\_data(\*zip(\*rover.history))

fig.canvas.draw\_idle()

plt.pause(0.001)

return rover\_patch

# Moved from farm\_entry.py

def visualize\_turn(rover, target\_heading, ax, fig, rover\_patch=None, rotation\_speed\_factor=4):

"""

Turn the rover to face a new heading using the shortest possible rotation.

Includes logging for turn diagnostics.

"""

# Normalize headings to [0, 360)

current = rover.heading % 360

target\_heading = target\_heading % 360

# Calculate the absolute angle difference (shortest path)

clockwise\_diff = (target\_heading - current) % 360

counterclockwise\_diff = (current - target\_heading) % 360

# Choose the smallest rotation direction

if clockwise\_diff <= counterclockwise\_diff:

angle\_diff = clockwise\_diff

direction = "turn\_right"

else:

angle\_diff = -counterclockwise\_diff

direction = "turn\_left"

# Log turn details for debugging

print(f"🔄 TURN: From {current:.1f}° to {target\_heading:.1f}°, Direction: {direction}, Angle: {abs(angle\_diff):.1f}°")

# Skip small turns (threshold 5 degrees)

if abs(angle\_diff) < 5:

rover.heading = target\_heading

rover.last\_heading = target\_heading

print(f"✓ Skipped small turn (<5°), set heading to {target\_heading:.1f}°")

return update\_rover\_visualization(rover, ax, fig, rover\_patch)

# Log the turning command

rover.log\_movement(direction, angle=abs(angle\_diff))

# Calculate steps for smooth animation

steps = max(3, min(int(abs(angle\_diff) / 10), 18))

step\_ang = angle\_diff / steps

# Calculate pause duration

pause\_duration = min(0.01, 0.005 \* (180 / max(1, abs(angle\_diff)))) / rotation\_speed\_factor

# Animate the turn

for i in range(1, steps + 1):

rover.heading = (current + step\_ang \* i) % 360

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

plt.pause(pause\_duration)

# Ensure exact final heading

rover.heading = target\_heading % 360

rover.last\_heading = rover.heading

return update\_rover\_visualization(rover, ax, fig, rover\_patch)

class RowNavigator:

def \_\_init\_\_(self, rover):

self.rover = rover

self.interpolated\_path = []

self.current\_waypoint\_index = 0

self.waypoint\_threshold = 0.3

self.column\_spacing = 1.5

self.column\_height = 15

self.movement\_speed = 2.0

self.current\_row = 0 # Track which row we're on

self.zigzag\_pattern = True # Enable zigzag pattern by default

self.rows\_data = [] # Store information about each row

def load\_waypoints\_from\_csv(filename):

"""

Load waypoints from a CSV file

Returns a list of (x,y) tuples representing the waypoints path

"""

if not os.path.exists(filename):

print(f"⚠️ Waypoints file not found: {filename}")

return []

waypoints = []

try:

with open(filename, 'r') as csvfile:

reader = csv.DictReader(csvfile)

for row in reader:

x = float(row['x'])

y = float(row['y'])

waypoints.append((x, y))

print(f"✅ Loaded {len(waypoints)} waypoints from {filename}")

return waypoints

except Exception as e:

print(f"❌ Error loading waypoints: {e}")

return []

def load\_rows\_from\_csv(self, csv\_filename):

"""

Load waypoints from CSV file and process them into rows

"""

waypoints = RowNavigator.load\_waypoints\_from\_csv(csv\_filename)

if not waypoints:

return False

waypoints = normalize\_coordinates(waypoints)

# Extract row info from waypoints

self.interpolated\_path = waypoints

self.rows\_data = []

# Process waypoints to identify rows

current\_row\_index = -1

row\_start\_point = None

# Try to parse row info from the waypoints

for i, (x, y) in enumerate(waypoints):

# Look for significant changes in x or y to detect new rows

if i > 0:

prev\_x, prev\_y = waypoints[i-1]

# If there's a significant change in direction, it might be a new row

if abs(x - prev\_x) > 1 or abs(y - prev\_y) > 1:

# Finish previous row

if row\_start\_point is not None:

self.rows\_data.append({

'index': current\_row\_index,

'x\_pos': row\_start\_point[0],

'direction': "↑ UP" if i % 2 == 0 else "↓ DOWN",

'start': row\_start\_point,

'end': waypoints[i-1]

})

# Start new row

current\_row\_index += 1

row\_start\_point = (x, y)

elif i == 0:

# First waypoint is the start of the first row

current\_row\_index = 0

row\_start\_point = (x, y)

# Add the last row if needed

if row\_start\_point is not None and waypoints:

self.rows\_data.append({

'index': current\_row\_index,

'x\_pos': row\_start\_point[0],

'direction': "↑ UP" if len(self.rows\_data) % 2 == 0 else "↓ DOWN",

'start': row\_start\_point,

'end': waypoints[-1]

})

# Print row information

print("\n📋 CSV-based Navigation Plan:")

print(f" Total waypoints: {len(self.interpolated\_path)}")

print(f" Estimated rows: {len(self.rows\_data)}")

for row in self.rows\_data:

print(f" Row {row['index']+1}: X-position {row['x\_pos']:.2f}m, Direction {row['direction']}")

return True

def generate\_rows(self, start\_x, start\_y, num\_strips=5, strip\_length=None, spacing=None):

if spacing is None:

spacing = self.column\_spacing

if strip\_length is None:

strip\_length = self.column\_height

bottom\_y = start\_y

top\_y = start\_y + strip\_length

self.interpolated\_path = []

self.rows\_data = [] # Reset rows data

print(f"\n🌾 Generating {num\_strips} rows with spacing {spacing:.2f}m")

print(f"🌾 Row length: {strip\_length:.2f}m")

for i in range(num\_strips):

x = start\_x + i \* spacing

# Determine row direction based on zigzag pattern

going\_up = (i % 2 == 0)

direction\_str = "↑ UP" if going\_up else "↓ DOWN"

# Create row points with more intermediate points for smoother movement

if going\_up:

# More points for smoother movement (was 5, now more)

y\_points = np.linspace(bottom\_y, top\_y, 8)

row\_start = (x, bottom\_y)

row\_end = (x, top\_y)

else:

y\_points = np.linspace(top\_y, bottom\_y, 8)

row\_start = (x, top\_y)

row\_end = (x, bottom\_y)

# Store row data for reporting

self.rows\_data.append({

'index': i,

'x\_pos': x,

'direction': direction\_str,

'start': row\_start,

'end': row\_end

})

# Add waypoints for this row

for y in y\_points:

self.interpolated\_path.append((x, y))

# Add improved transition to next row if not the last row

if i < num\_strips - 1:

next\_x = start\_x + (i + 1) \* spacing

transition\_y = top\_y if going\_up else bottom\_y

# Add curved transition points between rows instead of just one point

# This creates a smoother path for the rover to follow

num\_transition\_points = 5 # More points for smoother curve

for j in range(1, num\_transition\_points+1):

t = j / num\_transition\_points

# Create a slight curve for the transition

trans\_x = x + t \* (next\_x - x)

trans\_y = transition\_y

self.interpolated\_path.append((trans\_x, trans\_y))

# Print row information

print("\n📋 Row Navigation Plan:")

for row in self.rows\_data:

print(f" Row {row['index']+1}: X-position {row['x\_pos']:.2f}m, Direction {row['direction']}")

return self.interpolated\_path

def distance(self, p1, p2):

return math.hypot(p2[0] - p1[0], p2[1] - p1[1])

def calculate\_heading(self, p1, p2):

"""

Calculate heading between two points with tolerance for small differences.

Modified to handle position rounding precision.

"""

dx = p2[0] - p1[0]

dy = p2[1] - p1[1]

tolerance = 0.01 # Matches position rounding to 2 decimal places

if abs(dx) < tolerance:

print(f"📍 Vertical movement detected: dy={dy:.4f}, setting heading to {'90°' if dy > 0 else '270°'}")

return 90.0 if dy > 0 else 270.0

elif abs(dy) < tolerance:

print(f"📍 Horizontal movement detected: dx={dx:.4f}, setting heading to {'0°' if dx > 0 else '180°'}")

return 0.0 if dx > 0 else 180.0

else:

heading = math.degrees(math.atan2(dy, dx)) % 360

print(f"📍 Diagonal movement: dx={dx:.4f}, dy={dy:.4f}, heading={heading:.1f}°")

return heading

def heading\_difference(self, current, target):

diff = (target - current + 540) % 360 - 180

return diff

def smooth\_turn(self, target\_heading, ax=None, fig=None, rover\_patch=None):

"""

Perform a smooth turn to the target heading.

"""

heading\_diff = self.heading\_difference(self.rover.heading, target\_heading)

if abs(heading\_diff) < 10:

self.rover.heading = target\_heading

self.rover.last\_heading = target\_heading

if ax and fig and rover\_patch:

rover\_patch = update\_rover\_visualization(self.rover, ax, fig, rover\_patch)

print(f"✓ Skipped small turn (<10°), set heading to {target\_heading:.1f}°")

return rover\_patch

direction = "turn\_right" if heading\_diff > 0 else "turn\_left"

self.rover.log\_movement(direction, angle=abs(heading\_diff))

steps = max(5, int(abs(heading\_diff) / 30))

angle\_step = heading\_diff / steps

for i in range(steps):

self.rover.heading = (self.rover.heading + angle\_step) % 360

if ax and fig and rover\_patch:

rover\_patch = update\_rover\_visualization(self.rover, ax, fig, rover\_patch)

plt.pause(0.001)

self.rover.heading = round(target\_heading, 1)

self.rover.last\_heading = self.rover.heading

if ax and fig and rover\_patch:

rover\_patch = update\_rover\_visualization(self.rover, ax, fig, rover\_patch)

return rover\_patch

def move\_precisely\_to\_point(self, target\_point, ax=None, fig=None, rover\_patch=None):

"""

Move rover to target point with precision at constant speed.

Includes logging for turn diagnostics.

"""

max\_attempts = 40

attempts = 0

last\_time = time.time() # Initialize time tracking

print(f"🎯 Moving to point: ({target\_point[0]:.2f}, {target\_point[1]:.2f})")

while attempts < max\_attempts:

current\_time = time.time()

time\_elapsed = current\_time - last\_time

last\_time = current\_time

current\_pos = (self.rover.x, self.rover.y)

dist\_to\_target = self.distance(current\_pos, target\_point)

if attempts % 5 == 0:

print(f" Distance to target: {dist\_to\_target:.2f}m")

if dist\_to\_target <= self.waypoint\_threshold:

print(f"✅ Reached target within {self.waypoint\_threshold}m threshold")

self.rover.set\_position(target\_point[0], target\_point[1], force=True)

if ax and fig and rover\_patch:

rover\_patch = update\_rover\_visualization(self.rover, ax, fig, rover\_patch)

return True

desired\_heading = self.calculate\_heading(current\_pos, target\_point)

# Only turn if heading difference is significant

heading\_diff = self.heading\_difference(self.rover.heading, desired\_heading)

if abs(heading\_diff) > 10:

print(f"🧭 Initiating turn: Current {self.rover.heading:.1f}°, Desired {desired\_heading:.1f}°, Diff {heading\_diff:.1f}°")

self.smooth\_turn(desired\_heading, ax, fig, rover\_patch)

else:

print(f"✓ Heading diff {abs(heading\_diff):.1f}° < 10°, no turn needed")

# Calculate move\_dist based on constant speed and elapsed time

move\_dist = self.movement\_speed \* time\_elapsed

if move\_dist > dist\_to\_target:

move\_dist = dist\_to\_target # Prevent overshooting

self.rover.log\_movement("forward", distance=move\_dist)

path = [(self.rover.x, self.rover.y),

(self.rover.x + move\_dist \* math.cos(math.radians(self.rover.heading)),

self.rover.y + move\_dist \* math.sin(math.radians(self.rover.heading)))]

status, \_ = safety.check\_safety([self.rover.x, self.rover.y], self.rover.heading, path)

if status == 'safe':

success = self.rover.move\_forward(move\_dist, ax, fig, rover\_patch)

if not success:

print("⚠️ Movement failed - obstacle detected")

return False

else:

print(f"⚠️ Safety check failed: {status}")

return False

attempts += 1

plt.pause(0.001)

print("⚠️ Max attempts reached")

return False

def navigate\_to\_starting\_point(self, ax=None, fig=None, rover\_patch=None):

if not self.interpolated\_path:

return False

starting\_point = self.interpolated\_path[0]

# Enhanced terminal output (point 4.i)

print(f"\n🚩 Starting point: ({starting\_point[0]:.2f}, {starting\_point[1]:.2f})")

if self.rows\_data:

print(f"🌾 This is the beginning of Row 1, moving {self.rows\_data[0]['direction']}")

# Navigate to starting point

result = self.move\_precisely\_to\_point(starting\_point, ax, fig, rover\_patch)

if result:

self.current\_waypoint\_index = 0

self.current\_row = 0

print(f"✅ Successfully reached Row 1 starting point")

return result

def determine\_next\_task(self):

if not self.interpolated\_path or self.current\_waypoint\_index >= len(self.interpolated\_path) - 1:

return None

next\_idx = self.current\_waypoint\_index + 1

return self.interpolated\_path[next\_idx]

def align\_to\_next\_task(self, ax=None, fig=None, rover\_patch=None):

"""

Align rover to the next waypoint.

"""

next\_point = self.determine\_next\_task()

if not next\_point:

return False

current\_pos = (self.rover.x, self.rover.y)

desired\_heading = self.calculate\_heading(current\_pos, next\_point)

current\_heading = self.rover.heading

heading\_diff = self.heading\_difference(current\_heading, desired\_heading)

if abs(heading\_diff) < 10:

print(f"✓ Already aligned to correct heading: {current\_heading:.1f}°")

return True

print(f"🧭 Aligning from {current\_heading:.1f}° to {desired\_heading:.1f}°")

if ax and fig:

rover\_patch = visualize\_turn(self.rover, desired\_heading, ax, fig, rover\_patch, rotation\_speed\_factor=6)

else:

self.rover.heading = desired\_heading

self.rover.last\_heading = desired\_heading

print(f"✓ Aligned to heading: {self.rover.heading:.1f}°")

return True

def navigate\_all\_rows(self, ax=None, fig=None, rover\_patch=None):

if not self.interpolated\_path:

print("⚠️ No path generated - call generate\_rows first")

return False

if not self.navigate\_to\_starting\_point(ax, fig, rover\_patch):

return False

while self.current\_waypoint\_index < len(self.interpolated\_path) - 1:

next\_point = self.determine\_next\_task()

if not next\_point:

break

if not self.align\_to\_next\_task(ax, fig, rover\_patch):

continue

if self.move\_precisely\_to\_point(next\_point, ax, fig, rover\_patch):

self.current\_waypoint\_index += 1

return True

def navigate\_path(self, ax=None, fig=None, rover\_patch=None):

"""

Navigate through all waypoints with improved turning and reporting.

"""

print(f"🚜 COMMAND: Navigate zigzag path with {len(self.interpolated\_path)} points")

# Add command logging for each path segment

for i in range(self.current\_waypoint\_index, len(self.interpolated\_path)-1):

current\_point = self.interpolated\_path[i]

next\_point = self.interpolated\_path[i+1]

print(f"➡️ COMMAND: Move from ({current\_point[0]:.2f}, {current\_point[1]:.2f}) to ({next\_point[0]:.2f}, {next\_point[1]:.2f})")

if not self.interpolated\_path:

print("⚠️ No path generated - call generate\_rows first")

return False

# Check if we're already at a waypoint

if self.current\_waypoint\_index >= len(self.interpolated\_path):

print("⚠️ Navigation complete - already at end of path")

return True

# Track current row during navigation

current\_row\_index = 0

for i, row\_data in enumerate(self.rows\_data):

if self.current\_waypoint\_index >= i\*5: # Rough estimation

current\_row\_index = i

print(f"\n🌾 Currently at Row {current\_row\_index+1}, Waypoint {self.current\_waypoint\_index}")

print(f"🧭 Row direction: {self.rows\_data[current\_row\_index]['direction']}")

success = True

previous\_heading = self.rover.heading # Store previous heading for context

while self.current\_waypoint\_index < len(self.interpolated\_path) - 1:

next\_waypoint\_index = self.current\_waypoint\_index + 1

next\_point = self.interpolated\_path[next\_waypoint\_index]

current\_point = self.interpolated\_path[self.current\_waypoint\_index]

# Determine if we're changing rows

new\_row\_index = current\_row\_index

for i, row\_data in enumerate(self.rows\_data):

if abs(next\_point[0] - row\_data['x\_pos']) < 0.1: # Close to this row's x-position

new\_row\_index = i

# Detect row transitions for smarter turning

is\_row\_transition = new\_row\_index != current\_row\_index

# Report row transition if applicable

if is\_row\_transition:

print(f"\n🔄 Transitioning from Row {current\_row\_index+1} to Row {new\_row\_index+1}")

print(f"🧭 New row direction: {self.rows\_data[new\_row\_index]['direction']}")

# IMPROVED TURNING LOGIC FOR ROW TRANSITIONS:

# Calculate the optimal heading for the upcoming row

if new\_row\_index < len(self.rows\_data):

# Get start and end points of new row

row\_start = self.rows\_data[new\_row\_index]['start']

row\_end = self.rows\_data[new\_row\_index]['end']

# Calculate heading based on row direction

if self.rows\_data[new\_row\_index]['direction'].startswith("↑"):

optimal\_heading = self.calculate\_heading(row\_start, row\_end)

else:

optimal\_heading = self.calculate\_heading(row\_end, row\_start)

# Plan the turn considering the current position and target row alignment

print(f"🧭 Planning efficient turn from {self.rover.heading:.1f}° to {optimal\_heading:.1f}°")

# This is a direct turn to the optimal orientation for the next row

# Rather than first turning to face the next waypoint which might not be aligned with the row

if not self.align\_to\_next\_task(ax, fig, rover\_patch):

print("⚠️ Failed to align to next waypoint")

success = False

break

current\_row\_index = new\_row\_index

else:

# For movements within the same row, use the standard alignment

# But only turn if needed (avoid micro-adjustments)

current\_heading = self.rover.heading

desired\_heading = self.calculate\_heading((self.rover.x, self.rover.y), next\_point)

# Only turn if the heading difference is significant (save unnecessary turns)

if abs(self.heading\_difference(current\_heading, desired\_heading)) > 3:

if not self.align\_to\_next\_task(ax, fig, rover\_patch):

print("⚠️ Failed to align to next waypoint")

success = False

break

# Navigate to next point with detailed reporting

print(f"\n🚗 Navigating to waypoint {next\_waypoint\_index} at ({next\_point[0]:.2f}, {next\_point[1]:.2f})...")

# Then move to the next point

if self.move\_precisely\_to\_point(next\_point, ax, fig, rover\_patch):

print(f"✅ Reached waypoint {next\_waypoint\_index} in Row {current\_row\_index+1}")

self.current\_waypoint\_index = next\_waypoint\_index

previous\_heading = self.rover.heading # Update previous heading

else:

print(f"⚠️ Failed to reach waypoint {next\_waypoint\_index}")

success = False

break

# Pause briefly for visualization

if ax and fig:

plt.pause(0.05)

# Special case for the last waypoint

if success and self.current\_waypoint\_index == len(self.interpolated\_path) - 1:

print("\n✅ Successfully navigated entire path")

# Report completion of final row

final\_row = len(self.rows\_data) - 1

print(f"🎉 Completed Row {final\_row+1} - All rows navigated!")

# Make sure we're exactly at the final point

final\_point = self.interpolated\_path[-1]

if self.rover.distance\_to(\*final\_point) > 0.1: # Small tolerance

print(f"📍 Final adjustment to end point ({final\_point[0]:.2f}, {final\_point[1]:.2f})...")

self.rover.set\_position(final\_point[0], final\_point[1], force=True)

if ax and fig and rover\_patch:

rover\_patch = update\_rover\_visualization(self.rover, ax, fig, rover\_patch)

plt.pause(0.5) # Extended pause at the end

return success

def find\_best\_path\_angle(rover, tx, ty, blocked\_angles=None):

direct = math.degrees(math.atan2(ty - rover.y, tx - rover.x)) % 360

if not blocked\_angles or int(direct/10)\*10 not in blocked\_angles:

return direct

for off in range(10,360,10):

for sign in (1,-1):

ta = (direct+sign\*off)%360

if int(ta/10)\*10 not in blocked\_angles:

return ta

import random; return random.randint(0,359)

def normalize\_coordinates(waypoints):

"""

Transform coordinates from large values (like UTM) to simulation coordinate space

"""

if not waypoints:

return []

# Find min values to use as origin

min\_x = min(point[0] for point in waypoints)

min\_y = min(point[1] for point in waypoints)

# Normalize all points relative to this origin

normalized = []

for x, y in waypoints:

normalized.append((x - min\_x, y - min\_y))

print(f"✓ Normalized coordinates from ({min\_x:.1f}, {min\_y:.1f}) origin")

return normalized

def get\_float(prompt):

while True:

try:

return float(input(prompt))

except ValueError:

print("⚠️ Please enter a valid number.")

def navigate\_to\_point(rover, tx, ty, ax, fig, rover\_patch=None, step\_size=STEP, tolerance=TOLERANCE):

print(f"\n🚗 Navigating to point ({tx:.3f}, {ty:.3f})...\n")

dist = rover.distance\_to(tx,ty)

attempts=0; last\_dist=float('inf'); alt=False; blocked=0

while dist>tolerance and attempts<MAX\_ATTEMPTS:

attempts+=1

rec = rover.detect\_and\_resolve\_stuck()

if rec is not None:

rover\_patch = visualize\_turn(rover, rec, ax, fig, rover\_patch)

alt=True; continue

if attempts%5==0:

if dist>last\_dist\*0.95 and not alt:

print("⚠️ Limited progress detected, trying alternative approach...")

rover.blocked\_directions.clear()

angle=(rover.heading+90+attempts%90)%360

rover\_patch=visualize\_turn(rover,angle,ax,fig,rover\_patch)

step\_size=min(step\_size\*2,dist/2); alt=True

else:

alt=False; step\_size=min(STEP,dist/2)

last\_dist=dist

if blocked>2:

tgt=find\_best\_path\_angle(rover,tx,ty,rover.blocked\_directions)

blocked=0

else:

tgt=rover.calculate\_heading\_to(tx,ty)

diff=(tgt-rover.heading+180)%360-180

if abs(diff)>5:

rover\_patch=visualize\_turn(rover,tgt,ax,fig,rover\_patch)

step=min(step\_size,dist)

# Set up movement parameters

target\_x = rover.x + step \* math.cos(math.radians(rover.heading))

target\_y = rover.y + step \* math.sin(math.radians(rover.heading))

path = [(rover.x, rover.y), (target\_x, target\_y)]

# Safety check before movement

status, recovery\_data = safety.check\_safety([rover.x, rover.y], rover.heading, path)

ok = False # Default to unsuccessful movement

if status == 'safe':

# Safe to proceed with normal movement

ok = rover.move\_forward(step, ax, fig, rover\_patch)

elif status == 'drift':

# Handle drift scenario

pos, heading, drift\_status, updated\_data = safety.handle\_drift(

[rover.x, rover.y], rover.heading, recovery\_data)

# Update rover position and visualize

rover.set\_position(pos[0], pos[1], heading, add\_to\_history=True)

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

# Update drift data or clear it if recovered

if drift\_status == 'recovered':

ok = True

else:

recovery\_data = updated\_data

ok = False

blocked += 1

elif status in ['no-go', 'outside']:

# Handle no-go zone or boundary violation

pos, heading, violation\_status = safety.handle\_no\_go\_violation(

[rover.x, rover.y], rover.heading, recovery\_data)

# Update rover position and visualize

rover.set\_position(pos[0], pos[1], heading, add\_to\_history=True)

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

if violation\_status == 'recovered':

ok = True

else:

ok = False

blocked += 1

# Update visualization

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

dist = rover.distance\_to(tx, ty)

if not ok:

blocked += 1

if blocked >= 2:

ch = 45 + blocked \* 15

ch = min(ch, 180)

rover\_patch = visualize\_turn(rover, (rover.heading + ch) % 360, ax, fig, rover\_patch)

else:

blocked = 0

if dist <= tolerance:

print(f"✅ Reached target point ({rover.x:.3f}, {rover.y:.3f})")

return True, rover\_patch

print("🔄 Making final approach attempt with larger step size...")

direct = rover.calculate\_heading\_to(tx, ty)

rover\_patch = visualize\_turn(rover, direct, ax, fig, rover\_patch)

rover.move\_forward(dist \* 0.9, ax, fig, rover\_patch)

fd = rover.distance\_to(tx, ty)

if fd <= tolerance \* 1.5:

print(f"✅ Reached target point on final attempt ({rover.x:.3f}, {rover.y:.3f})")

return True, rover\_patch

print(f"⚠️ Could not reach target point. Current position: ({rover.x:.3f}, {rover.y:.3f})")

print(f" Distance to target: {fd:.3f}")

return False, rover\_patch

def follow\_path\_precisely(rover, waypoints, ax, fig, rover\_patch):

"""

Follows the planned path with ultra-high precision by enforcing strict path adherence

Args:

rover: Rover instance

waypoints: List of (x,y) points to follow

ax: Matplotlib axis

fig: Matplotlib figure

rover\_patch: Visual representation of rover

Returns:

bool: True if path followed successfully, False otherwise

rover\_patch: Updated rover patch

"""

print(f"🛣️ COMMAND: Follow path with {len(waypoints)} waypoints")

if not waypoints or len(waypoints) < 2:

print("⚠️ Path too short or empty")

return False, rover\_patch

print(f"\n🛣️ Following planned path with {len(waypoints)} waypoints...")

# Constants for strict path following - adjusted for speed

PATH\_STEP = 2.4 # Increased step size for faster movement (was 0.2)

PATH\_TOLERANCE = 0.05 # Small tolerance to enforce strict adherence

ANIMATION\_SPEED = 0.001 # Faster animation (was 0.01)

ROTATION\_STEP\_FACTOR = 8 # Rotate faster

# Start with current position

start\_idx = 0

# Find closest waypoint if we're not already at the first one

if rover.distance\_to(\*waypoints[0]) > PATH\_TOLERANCE:

closest\_idx = 0

min\_dist = float('inf')

for i, wp in enumerate(waypoints):

dist = rover.distance\_to(\*wp)

if dist < min\_dist:

min\_dist = dist

closest\_idx = i

# If we're closer to a waypoint further along the path, start from there

if closest\_idx > 0 and min\_dist < PATH\_TOLERANCE:

start\_idx = closest\_idx

print(f"Starting from waypoint {start\_idx} which is closest to current position")

else:

# We need to first move to the first waypoint

print(f"Moving to the first waypoint at ({waypoints[0][0]:.2f}, {waypoints[0][1]:.2f})")

initial\_heading = rover.calculate\_heading\_to(\*waypoints[0])

rover\_patch = visualize\_turn(rover, initial\_heading, ax, fig, rover\_patch, rotation\_speed\_factor=ROTATION\_STEP\_FACTOR)

# Don't teleport - move properly to first waypoint

init\_distance = rover.distance\_to(\*waypoints[0])

if init\_distance > PATH\_TOLERANCE:

segments = max(2, int(init\_distance / PATH\_STEP))

step\_dist = init\_distance / segments

for \_ in range(segments):

success = rover.move\_forward(step\_dist, ax, fig, rover\_patch)

if not success:

# If blocked, try with smaller steps

half\_step = step\_dist / 2

if half\_step > 0.1: # Don't try with too small steps

success = rover.move\_forward(half\_step, ax, fig, rover\_patch)

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

plt.pause(ANIMATION\_SPEED)

# For path visualization

actual\_path = []

path\_line = None

# Traverse waypoints

for i in range(start\_idx, len(waypoints)-1):

current\_wp = waypoints[i]

next\_wp = waypoints[i+1]

print(f"\n📍 Moving from waypoint {i} to {i+1}: ({current\_wp[0]:.2f}, {current\_wp[1]:.2f}) → ({next\_wp[0]:.2f}, {next\_wp[1]:.2f})")

# Calculate segment vector and length

segment\_vec = (next\_wp[0] - current\_wp[0], next\_wp[1] - current\_wp[1])

segment\_len = math.hypot(\*segment\_vec)

if segment\_len < 0.01: # Skip tiny segments

continue

# Unit vector along segment

unit\_vec = (segment\_vec[0]/segment\_len, segment\_vec[1]/segment\_len)

# Align precisely to segment direction with faster rotation

segment\_heading = math.degrees(math.atan2(segment\_vec[1], segment\_vec[0])) % 360

rover\_patch = visualize\_turn(rover, segment\_heading, ax, fig, rover\_patch, rotation\_speed\_factor=ROTATION\_STEP\_FACTOR)

# Before starting segment, ensure we're exactly at the start point (if not already there)

if rover.distance\_to(\*current\_wp) > PATH\_TOLERANCE:

# Move to start point without teleporting

remaining\_dist = rover.distance\_to(\*current\_wp)

segments = max(2, int(remaining\_dist / PATH\_STEP))

step\_dist = remaining\_dist / segments

for \_ in range(segments):

if rover.distance\_to(\*current\_wp) <= PATH\_TOLERANCE:

break

success = rover.move\_forward(step\_dist, ax, fig, rover\_patch)

if not success:

# Try with smaller step if blocked

rover.move\_forward(step\_dist/2, ax, fig, rover\_patch)

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

plt.pause(ANIMATION\_SPEED)

# Calculate appropriate number of interpolated points for this segment

num\_interp = max(3, int(segment\_len / PATH\_STEP))

# Move along the segment with precise steps

for j in range(1, num\_interp + 1):

t = j / num\_interp

interp\_point = (

current\_wp[0] + t \* segment\_vec[0],

current\_wp[1] + t \* segment\_vec[1]

)

# Always ensure heading is aligned with path

point\_heading = rover.calculate\_heading\_to(\*interp\_point)

if abs((point\_heading - rover.heading + 180) % 360 - 180) > 1:

rover\_patch = visualize\_turn(rover, point\_heading, ax, fig, rover\_patch,

rotation\_speed\_factor=ROTATION\_STEP\_FACTOR)

# Calculate exact distance to move

move\_dist = rover.distance\_to(\*interp\_point)

# Move to interpolated point without teleporting

if move\_dist > PATH\_TOLERANCE:

success = rover.move\_forward(move\_dist, ax, fig, rover\_patch)

# If direct movement fails, try with smaller steps

if not success and move\_dist > PATH\_STEP:

smaller\_step = min(PATH\_STEP, move\_dist/2)

success = rover.move\_forward(smaller\_step, ax, fig, rover\_patch)

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

# Visualize the actual path

actual\_path.append((rover.x, rover.y))

if len(actual\_path) > 1 and path\_line:

safe\_remove(path\_line)

if len(actual\_path) > 1:

path\_x, path\_y = zip(\*actual\_path)

path\_line = ax.plot(path\_x, path\_y, 'g-', linewidth=1, alpha=0.7)[0]

fig.canvas.draw\_idle()

plt.pause(ANIMATION\_SPEED)

# Safety check if available

if hasattr(safety, 'check\_safety'):

status, \_ = safety.check\_safety([rover.x, rover.y], rover.heading, [(rover.x, rover.y), interp\_point])

if status != 'safe':

print("⚠️ Safety violation detected during path following!")

return False, rover\_patch

# For the final waypoint, use exact positioning with proper movement

last\_wp = waypoints[-1]

final\_heading = rover.calculate\_heading\_to(\*last\_wp)

rover\_patch = visualize\_turn(rover, final\_heading, ax, fig, rover\_patch, rotation\_speed\_factor=ROTATION\_STEP\_FACTOR)

# Move directly to last waypoint without teleporting

final\_dist = rover.distance\_to(\*last\_wp)

if final\_dist > PATH\_TOLERANCE:

# Break into smaller steps

segments = max(2, int(final\_dist / PATH\_STEP))

step\_dist = final\_dist / segments

for \_ in range(segments):

if rover.distance\_to(\*last\_wp) <= PATH\_TOLERANCE:

break

success = rover.move\_forward(step\_dist, ax, fig, rover\_patch)

if not success:

# Try smaller step if blocked

rover.move\_forward(step\_dist/2, ax, fig, rover\_patch)

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

plt.pause(ANIMATION\_SPEED)

print("✅ Successfully followed the planned path with precision")

return True, rover\_patch

def safe\_remove(element):

if element:

try:

element.remove()

return True

except:

if DEBUG: print(f"Warning: failed to remove {element}")

return False

def run\_simulation():

plt.rcParams['figure.max\_open\_warning'] = 50

rover = Rover()

print("🚜 Farm Rover Navigation Simulation 🚜")

print("=====================================")

farm\_width = get\_float(" Farm width: ")

farm\_height = get\_float(" Farm height: ")

min\_x = -farm\_width / 2

max\_x = farm\_width / 2

min\_y = -farm\_height / 2

max\_y = farm\_height / 2

verts = [(min\_x, min\_y), (max\_x, min\_y), (max\_x, max\_y), (min\_x, max\_y)]

entry\_point = (0, min\_y)

rover.set\_geofence(verts, entry\_point)

safety.set\_geofence(verts)

plt.ion()

fig, ax = plt.subplots(figsize=(10, 8))

ax.set\_title("Rover Farm Navigation Simulation")

margin = max(farm\_width, farm\_height) \* 0.2

ax.set\_xlim(min\_x - margin, max\_x + margin)

ax.set\_ylim(min\_y - margin, max\_y + margin)

ax.grid(True)

fence = Polygon(np.array(verts), closed=True, facecolor='lightgreen', edgecolor='darkgreen', alpha=0.3)

ax.add\_patch(fence)

ax.scatter(entry\_point[0], entry\_point[1], c='purple', s=100, marker='o', label='Farm Entry', zorder=10)

path\_line, = ax.plot([], [], 'b-', alpha=0.5, label='Path')

ax.path\_line = path\_line

ax.legend(loc='upper left')

fig.canvas.draw\_idle()

plt.pause(0.5)

rover.set\_position(entry\_point[0], entry\_point[1], force=True, add\_to\_history=False)

rover.history.append((rover.x, rover.y))

rover\_patch = update\_rover\_visualization(rover, ax, fig)

print(f"\n✅ Starting simulation at farm entry point: ({entry\_point[0]:.2f}, {entry\_point[1]:.2f})")

spacing = 1.5

start\_x = min\_x

start\_y = min\_y

strip\_length = max\_y - min\_y

num\_strips = math.floor((max\_x - min\_x) / spacing) + 1

row\_navigator = RowNavigator(rover)

rover.navigator = row\_navigator

row\_navigator.generate\_rows(start\_x, start\_y, num\_strips, strip\_length, spacing)

row\_navigator.navigate\_all\_rows(ax, fig, rover\_patch)

plt.ioff()

plt.show(block=True)

if \_\_name\_\_ == "\_\_main\_\_":

try:

run\_simulation()

except KeyboardInterrupt:

print("\n\n🛑 Simulation terminated by user.")

except Exception as e:

print(f"\n❌ Simulation error: {e}")

FARM\_SIMULATION

import matplotlib.pyplot as plt

import numpy as np

import random

from astar\_algo import AStarPlanner

# Import our modules

from row\_navigation import Rover, navigate\_to\_point, TOLERANCE, follow\_path\_precisely, update\_rover\_visualization, visualize\_turn

from row\_navigation import RowNavigator

from farm\_safety import SafetyModule

debug = False

safety = SafetyModule()

def get\_float(prompt):

"""Get a float value from user with error handling"""

while True:

try:

value = float(input(prompt))

return value

except ValueError:

print("⚠️ Please enter a valid number.")

def random\_position\_in\_farm(min\_x, max\_x, min\_y, max\_y, safety\_margin=2.0):

"""Generate a random position inside the farm with a safety margin from boundaries"""

x = random.uniform(min\_x + safety\_margin, max\_x - safety\_margin)

y = random.uniform(min\_y + safety\_margin, max\_y - safety\_margin)

return x, y

def safe\_remove(element):

if element:

try:

element.remove()

return True

except:

if debug: print(f"Warning: failed to remove {element}")

return False

def run\_simulation():

print("🚜 Farm Rover Navigation Simulation 🚜")

print("=====================================")

plt.rcParams['figure.max\_open\_warning'] = 50

# Create the rover

rover = Rover()

# Setup the farm boundaries (only input required from user)

# Create row navigator first to load waypoints

navigator = RowNavigator(rover)

navigator.zigzag\_pattern = True

# Load waypoints from CSV file

csv\_loaded = navigator.load\_rows\_from\_csv(r"F:\GPS\task\_2\_waypoints\waypoints\_100mm.csv")

if not csv\_loaded:

print("❌ Failed to load waypoints from CSV. Simulation cannot proceed without waypoints.")

return

# Calculate farm boundaries based on waypoints with margin

margin = 3.0 # Add margin around waypoints

min\_x = min(point[0] for point in navigator.interpolated\_path) - margin

max\_x = max(point[0] for point in navigator.interpolated\_path) + margin

min\_y = min(point[1] for point in navigator.interpolated\_path) - margin

max\_y = max(point[1] for point in navigator.interpolated\_path) + margin

# Create vertices for the farm boundary

verts = [(min\_x, min\_y), (max\_x, min\_y), (max\_x, max\_y), (min\_x, max\_y)]

print(f"📏 Dynamic farm boundaries: X [{min\_x:.2f}, {max\_x:.2f}], Y [{min\_y:.2f}, {max\_y:.2f}]")

# Create vertices for the farm boundary

verts = [(min\_x, min\_y), (max\_x, min\_y), (max\_x, max\_y), (min\_x, max\_y)]

# Generate a random entry point (we'll still set this for compatibility even though not used)

# Choose a random side and position on that side

side = random.randint(0, 3)

if side == 0: # Bottom side

entry\_x = random.uniform(min\_x, max\_x)

entry\_y = min\_y

elif side == 1: # Right side

entry\_x = max\_x

entry\_y = random.uniform(min\_y, max\_y)

elif side == 2: # Top side

entry\_x = random.uniform(min\_x, max\_x)

entry\_y = max\_y

else: # Left side

entry\_x = min\_x

entry\_y = random.uniform(min\_y, max\_y)

entry\_point = (entry\_x, entry\_y)

# Set geofence in rover and safety module

rover.set\_geofence(verts, entry\_point)

safety.set\_geofence(verts)

# Remove no-go zone creation

# The following block is commented out to remove the reddish square

"""

# Add a rectangular no-go zone in the middle of the farm

center\_x = (min\_x + max\_x) / 2

center\_y = (min\_y + max\_y) / 2

size = 1.5 # Size of the no-go zone

safety.add\_no\_go\_zone(center\_x - size, center\_y - size, center\_x + size, center\_y + size)

"""

# Generate random starting position inside the farm

random\_x, random\_y = random\_position\_in\_farm(min\_x, max\_x, min\_y, max\_y)

print(f"🎲 Randomly placing rover inside farm at: ({random\_x:.3f}, {random\_y:.3f})")

# Initialize visualization

plt.ion()

fig, ax = plt.subplots(figsize=(10, 8))

ax.set\_title("Rover Farm Navigation Simulation")

# Draw farm boundary

farm\_polygon = plt.Polygon(np.array(verts), closed=True,

facecolor='lightgreen', edgecolor='darkgreen', alpha=0.3)

ax.add\_patch(farm\_polygon)

# Remove no-go zone visualization

# The following block is commented out to remove the reddish square

"""

# Draw no-go zone

no\_go\_verts = [

(center\_x - size, center\_y - size),

(center\_x + size, center\_y - size),

(center\_x + size, center\_y + size),

(center\_x - size, center\_y + size)

]

no\_go\_polygon = plt.Polygon(np.array(no\_go\_verts), closed=True,

facecolor='red', edgecolor='darkred', alpha=0.3)

ax.add\_patch(no\_go\_polygon)

"""

# Mark random start position

ax.scatter(random\_x, random\_y, c='green', s=80, label='Start (Inside)')

# Setup plot limits and grid

# Setup rover path visualization

path\_line, = ax.plot([], [], 'b-', alpha=0.5, label='Path')

ax.path\_line = path\_line

ax.legend(loc='upper left')

# Set rover starting position (inside farm)

rover.set\_position(random\_x, random\_y, force=True, add\_to\_history=False)

rover.inside\_fence = True # Force the rover to be considered inside the farm

rover.fence\_locked = True # Lock the rover inside the farm

rover.history.append((rover.x, rover.y))

rover\_patch = update\_rover\_visualization(rover, ax, fig)

print("\n🚜 TASK 1: Determining farm navigation plan with zigzag pattern...\n")

# Create row navigator

navigator = RowNavigator(rover)

navigator.zigzag\_pattern = True # Ensure zigzag pattern is enabled

# Generate rows within the farm using zigzag pattern

# Load waypoints from CSV file

csv\_loaded = navigator.load\_rows\_from\_csv(r"F:\GPS\task\_2\_waypoints\waypoints\_100mm.csv")

if navigator.interpolated\_path:

wp\_min\_x = min(point[0] for point in navigator.interpolated\_path)

wp\_max\_x = max(point[0] for point in navigator.interpolated\_path)

wp\_min\_y = min(point[1] for point in navigator.interpolated\_path)

wp\_max\_y = max(point[1] for point in navigator.interpolated\_path)

# Use the wider range between farm boundaries and waypoints

plot\_min\_x = min(min\_x, wp\_min\_x)

plot\_max\_x = max(max\_x, wp\_max\_x)

plot\_min\_y = min(min\_y, wp\_min\_y)

plot\_max\_y = max(max\_y, wp\_max\_y)

# Add a larger margin

margin = max(plot\_max\_x - plot\_min\_x, plot\_max\_y - plot\_min\_y) \* 0.15

ax.set\_xlim(plot\_min\_x - margin, plot\_max\_x + margin)

ax.set\_ylim(plot\_min\_y - margin, plot\_max\_y + margin)

else:

# Fallback to original farm boundaries

margin = 3

ax.set\_xlim(min\_x - margin, max\_x + margin)

ax.set\_ylim(min\_y - margin, max\_y + margin)

ax.grid(True)

if not csv\_loaded:

print("❌ Failed to load waypoints from CSV. Simulation cannot proceed without waypoints.")

return

safety.set\_waypoints(navigator.interpolated\_path)

# Visualize zigzag row pattern

x\_coords, y\_coords = zip(\*navigator.interpolated\_path)

ax.plot(x\_coords, y\_coords, 'b-', alpha=0.5, label='Zig-Zag Path')

# Mark start and end points

path\_start = navigator.interpolated\_path[0]

path\_end = navigator.interpolated\_path[-1]

ax.scatter(path\_start[0], path\_start[1], c='orange', s=50, marker='s', label='Path Start')

ax.scatter(path\_end[0], path\_end[1], c='red', s=50, marker='o', label='Path End')

fig.canvas.draw\_idle()

plt.pause(0.5)

# --- TASK 1: Navigate directly to the path start point ---

print("\n🚜 TASK 1: Navigating directly to path start point...\n")

print(f"🎯 Path start point: ({path\_start[0]:.3f}, {path\_start[1]:.3f})")

print(f"📏 Distance to path start: {rover.distance\_to(\*path\_start):.3f}m")

# Navigate to path start

def navigate\_to\_path\_start(rover, safety, path\_start, ax, fig, rover\_patch):

"""

Navigate rover to the starting point of the path using direct point-to-point moves

with a larger step size and a slightly more generous tolerance to avoid getting stuck.

"""

print("\n🗺️ Navigating directly to starting point...")

reached\_start, rover\_patch = navigate\_to\_point(

rover,

path\_start[0],

path\_start[1],

ax,

fig,

rover\_patch,

step\_size=1.5, # larger increments per move

tolerance=0.8 # accept slightly further from the exact point

)

return reached\_start, rover\_patch

# Use our custom function to navigate to path start

reached\_start, rover\_patch = navigate\_to\_path\_start(rover, safety, path\_start, ax, fig, rover\_patch)

if not reached\_start:

print("\n⚠️ Could not reach path start point after multiple attempts.")

print(" Try adjusting simulation parameters or path positioning.")

return

# Force rover position to exactly match path start

rover.set\_position(path\_start[0], path\_start[1], force=True)

rover\_patch = update\_rover\_visualization(rover, ax, fig, rover\_patch)

# Mark path start reached

ax.scatter(path\_start[0], path\_start[1], c='lime', s=80, marker='\*', label='Start Reached')

ax.legend(loc='upper left')

fig.canvas.draw\_idle()

plt.pause(1)

print("\n✅ TASK 1 COMPLETE: Successfully reached path start point")

print(f" Current position: ({rover.x:.3f}, {rover.y:.3f})")

# --- TASK 2: Align to the path direction ---

print("\n🚜 TASK 2: Aligning rover to path direction...\n")

# Find next waypoint (should be index 1 since we're at index 0)

navigator.current\_waypoint\_index = 0 # Force to start at the beginning of the path

next\_point = navigator.interpolated\_path[1]

desired\_heading = navigator.calculate\_heading((rover.x, rover.y), next\_point)

# Align to the path direction

rover\_patch = visualize\_turn(rover, desired\_heading, ax, fig, rover\_patch)

print(f" Aligned rover to heading: {desired\_heading:.1f}°")

print("\n✅ TASK 2 COMPLETE: Successfully aligned to path direction")

# --- TASK 3: Navigate through the path ---

print("\n🚜 TASK 3: Starting path navigation pattern...\n")

# Start navigation from the beginning of the path

navigator.current\_waypoint\_index = 0

path\_success = navigator.navigate\_path(ax, fig, rover\_patch)

if not path\_success:

print("\n⚠️ Failed to navigate path. Simulation halted.")

return

# Mark completion of path

final\_point = navigator.interpolated\_path[-1]

ax.scatter(final\_point[0], final\_point[1], c='green', s=100, marker='\*', label='Mission Complete')

ax.legend(loc='upper left')

fig.canvas.draw\_idle()

plt.pause(1)

print("\n🎉 TASK 3 COMPLETE: Successfully navigated the path")

print("\n🏁 SIMULATION COMPLETE! 🏁")

print(f" Total commands executed: {rover.command\_count}")

print(f" Final position: ({rover.x:.3f}, {rover.y:.3f})")

# Keep plot open until closed manually

plt.ioff()

plt.show(block=True)

if \_\_name\_\_ == "\_\_main\_\_":

try:

run\_simulation()

except KeyboardInterrupt:

print("\n\n🛑 Simulation terminated by user.")

except Exception as e:

print(f"\n❌ Simulation error: {e}")

CSV FILES

id,left,top,right,bottom,row\_index,col\_index,id\_2,distance,angle,x,y,start\_point

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FARM SAFETY

import math

import random

class SafetyModule:

"""

A module to handle drift and enforce no-go rules in farm rover navigation.

No-go now covers:

1) Revisiting a waypoint (in the user-defined waypoint list).

2) Exiting the farm boundary.

Drift logic is unchanged.

"""

def \_\_init\_\_(self, revisit\_threshold=0.2):

# Drift configuration

self.turn\_rate\_per\_cm = 20 # degrees per cm of turn capability

self.distance\_per\_step = 0.2 # cm traveled per simulation step

self.lookahead\_steps = 5 # baseline lookahead for drift recovery

self.drift\_probability = 0.05 # probability of drift occurring per check

# Geofence

self.geofence = None # farm boundary polygon vertices

# Waypoint tracking for revisit prevention

self.waypoints = [] # list of (x,y) waypoints

self.visited\_wp\_indices = set() # indices of waypoints already visited

self.revisit\_threshold = revisit\_threshold

# History logs

self.violations\_history = [] # track no-go incidents

self.drift\_history = [] # track drift incidents

def set\_geofence(self, vertices):

"""Set the farm boundary as a polygon"""

self.geofence = vertices

def set\_waypoints(self, waypoints):

"""Provide the ordered list of navigation waypoints"""

self.waypoints = waypoints

self.visited\_wp\_indices.clear()

def is\_outside\_geofence(self, pos):

"""Check if a position is outside the farm boundary polygon"""

if not self.geofence:

return False

x, y = pos

inside = False

n = len(self.geofence)

p1x, p1y = self.geofence[0]

for i in range(1, n+1):

p2x, p2y = self.geofence[i % n]

if y > min(p1y, p2y):

if y <= max(p1y, p2y) and x <= max(p1x, p2x):

if p1y != p2y:

xinters = (y - p1y) \* (p2x - p1x) / (p2y - p1y) + p1x

if p1x == p2x or x <= xinters:

inside = not inside

p1x, p1y = p2x, p2y

return not inside

def check\_safety(self, pos, heading, path):

"""

Check if a planned move is safe.

Returns:

- status: 'safe', 'drift', or 'no-go'

- data: info for recovery or violation handling

"""

# Candidate next position

next\_pos = path[-1]

# 1) No-go: revisiting an already visited waypoint

for idx, wp in enumerate(self.waypoints):

if math.hypot(next\_pos[0]-wp[0], next\_pos[1]-wp[1]) <= self.revisit\_threshold:

if idx in self.visited\_wp\_indices:

self.violations\_history.append(('no-go-revisit', next\_pos, heading))

return 'no-go', {

'violation\_type': 'revisit',

'pos': next\_pos,

'heading': heading

}

else:

# mark this waypoint as visited now

self.visited\_wp\_indices.add(idx)

break

# 2) No-go: exiting farm boundary

if self.is\_outside\_geofence(next\_pos):

self.violations\_history.append(('no-go-boundary', next\_pos, heading))

return 'no-go', {

'violation\_type': 'boundary',

'pos': next\_pos,

'heading': heading

}

# 3) Potential drift

if path and random.random() < self.drift\_probability:

closest\_idx, \_ = self.find\_closest\_point\_on\_path(pos, path)

if closest\_idx < len(path) - self.lookahead\_steps:

self.drift\_history.append(('drift', pos.copy(), heading))

drift\_angle = 45 if random.choice([True, False]) else -45

trigger\_idx = closest\_idx

end\_idx = min(trigger\_idx + self.lookahead\_steps, len(path)-1)

dx = path[end\_idx][0] - path[trigger\_idx][0]

dy = path[end\_idx][1] - path[trigger\_idx][1]

mag = math.hypot(dx, dy)

ux, uy = (dx/mag, dy/mag) if mag else (1.0, 0.0)

rad = math.radians(drift\_angle)

c, s = math.cos(rad), math.sin(rad)

rx = ux\*c + uy\*s

ry = -ux\*s + uy\*c

turn\_dist = abs(drift\_angle) / self.turn\_rate\_per\_cm

extra\_skip = int(turn\_dist / self.distance\_per\_step)

recovery\_idx = min(trigger\_idx + self.lookahead\_steps + extra\_skip, len(path)-1)

recovery\_target = path[recovery\_idx]

return 'drift', {

'trigger\_idx': trigger\_idx,

'drift\_angle': drift\_angle,

'drift\_vector': (rx, ry),

'recovery\_idx': recovery\_idx,

'recovery\_target': recovery\_target,

'path': path

}

# 4) Safe to proceed

return 'safe', None

def handle\_drift(self, pos, heading, drift\_data):

"""(Unchanged) Simulate drift and guide recovery."""

# ... existing drift handler code ...

raise NotImplementedError

def handle\_no\_go\_violation(self, pos, heading, violation\_data):

"""(Unchanged) Back away from forbidden position."""

# ... existing no-go handler code ...

raise NotImplementedError

def find\_closest\_point\_on\_path(self, pos, path):

"""Find the path index closest to pos."""

min\_dist, min\_idx = float('inf'), 0

for i, p in enumerate(path):

d = math.hypot(p[0]-pos[0], p[1]-pos[1])

if d < min\_dist:

min\_dist, min\_idx = d, i

return min\_idx, path[min\_idx]

def diff\_h(self, c, t):

return (t - c + 540) % 360 - 180