FARM ENTRY

import math

import time

import matplotlib.pyplot as plt

import numpy as np

from matplotlib.patches import Polygon

import matplotlib.transforms as transforms

from farm\_safety import SafetyModule

safety = SafetyModule()

# --- Constants ---

STEP = 0.2 # Increased for faster navigation

TOLERANCE = 0.5 # Increased tolerance for reaching targets

MAX\_ATTEMPTS = 200 # Increased maximum attempts

DEBUG = False

ANIMATION\_SPEED = 0.05 # Rotation animation speed (lower is faster)

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.")

class Rover:

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

self.x = 0.0

self.y = 0.0

self.heading = 0.0

self.history = []

self.command\_count = 0

self.waypoint = None

self.geofence = None

self.inside\_fence = False

self.entry\_point = None

self.blocked\_directions = set()

self.stuck\_count = 0 # Counter for detecting when rover is stuck

self.position\_history = [] # To detect cycles and stuck conditions

self.rover\_patch = None # Visual representation of the rover

self.fence\_locked = False # Track if rover is locked within the fence

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

"""Set rover position with optional heading"""

if self.geofence and not force:

# 1) Check if we're at (or within tolerance of) the entry point

if self.entry\_point and self.is\_entry\_point(x, y):

# Entering through entry point: allow and lock inside

self.inside\_fence = True

self.fence\_locked = True

print(f"🔓 Entering farm at entry point — rover locked inside.")

else:

# 2) Perform standard polygon check

in\_fence = self.is\_point\_in\_polygon(x, y, self.geofence)

# 3) Prevent exit once locked inside

if self.fence\_locked and self.inside\_fence and not in\_fence:

print(f"🔒 Movement blocked: Rover is locked inside the farm")

return False

# 4) Block any crossing unless it is the first entry

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

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

return False

# Apply new position/heading

self.x = x

self.y = y

if heading is not None:

self.heading = heading % 360

if add\_to\_history:

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

return True

def set\_waypoint(self, x, y):

"""Set target waypoint"""

self.waypoint = (x, y)

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

"""Set geofence polygon and entry point"""

self.geofence = vertices

self.entry\_point = entry\_point

self.inside\_fence = self.is\_point\_in\_polygon(self.x, self.y, vertices)

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

"""Move rover forward in current heading direction"""

if distance <= 0:

print("⚠️ Invalid distance value <= 0")

return False

rad = math.radians(self.heading)

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

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

# Smooth intermediate animation

if ax and fig and rover\_patch and distance > STEP:

steps = min(int(distance / (STEP/2)), 5)

if steps > 1:

step\_x = (target\_x - self.x) / steps

step\_y = (target\_y - self.y) / steps

for \_ in range(steps-1):

nx, ny = self.x + step\_x, self.y + step\_y

if not self.set\_position(nx, ny, add\_to\_history=False):

return False

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

plt.pause(ANIMATION\_SPEED/2)

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

if success:

self.command\_count += 1

print(f"Cmd #{self.command\_count}: MOVE\_FWD {distance:.2f}m → ({self.x:.3f}, {self.y:.3f})")

if self.waypoint:

print(f" 📏 Distance to waypoint: {self.distance\_to(\*self.waypoint):.2f}m")

if self.entry\_point and not self.inside\_fence:

print(f" 📏 Distance to entry point: {self.distance\_to(\*self.entry\_point):.2f}m")

return True

else:

rounded = int(self.heading/10)\*10

self.blocked\_directions.add(rounded)

print(f"⚠️ Movement in direction {rounded}° blocked")

return False

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 distance\_to(self, tx, ty):

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

def is\_point\_in\_polygon(self, x, y, verts):

n = len(verts)

inside = False

p1x, p1y = verts[0]

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

p2x, p2y = verts[i%n]

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

if p1y!=p2y:

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

if p1x==p2x or x<=xin:

inside = not inside

p1x,p1y = p2x,p2y

return inside

def is\_entry\_point(self, x, y, tolerance=TOLERANCE):

if self.entry\_point:

return self.distance\_to(\*self.entry\_point) <= tolerance

return False

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

self.position\_history.append((self.x,self.y))

if len(self.position\_history)>10:

self.position\_history.pop(0)

if len(self.position\_history)>=5:

maxd = max(math.hypot(self.x-px,self.y-py) for px,py in self.position\_history)

if maxd < TOLERANCE/2:

self.stuck\_count += 1

print(f"⚠️ Possible stuck condition detected ({self.stuck\_count}/3)")

if self.stuck\_count>=3:

print("🔄 Taking recovery action - making a significant turn")

self.blocked\_directions.clear()

self.stuck\_count=0

return (self.heading+120)%360

else:

self.stuck\_count=0

return None

# Visualization helpers (unchanged)

def safe\_remove(element):

if element:

try:

element.remove()

return True

except:

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

return False

def create\_rover\_patch():

verts = np.array([[0.7,0],[-0.3,0.4],[-0.3,-0.4]])

return Polygon(verts, closed=True, fc='blue', ec='black')

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

if rover\_patch is None:

rover\_patch = create\_rover\_patch()

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(0.01)

return rover\_patch

def visualize\_turn(rover, new\_heading, ax, fig, rover\_patch=None):

current = rover.heading

diff = (new\_heading-current+180)%360 - 180

if abs(diff)<5:

rover.heading = new\_heading

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

rover.command\_count += 1

print(f"Cmd #{rover.command\_count}: ROTATE\_TO {new\_heading:.1f}° ({diff:.1f}° turn)")

if rover.waypoint:

print(f" 📏 Distance to waypoint: {rover.distance\_to(\*rover.waypoint):.2f}m")

steps = max(5, min(int(abs(diff)/5), 36))

step\_ang = diff/steps

try:

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(ANIMATION\_SPEED)

except Exception as e:

if DEBUG: print(f"Turn viz error: {e}")

rover.heading = new\_heading

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

# Path planning (unchanged)

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

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

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 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

# --- MAIN ---

def main():

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

rover = Rover()

print("🔧 Enter farm rectangle coordinates:")

min\_x = get\_float(" Min X: ")

max\_x = get\_float(" Max X: ")

min\_y = get\_float(" Min Y: ")

max\_y = get\_float(" Max Y: ")

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

entry = verts[0]

print(f"🚪 Entry point set to bottom-left corner: ({entry[0]:.2f}, {entry[1]:.2f})")

rover.set\_geofence(verts,entry)

print("🔧 Enter starting position:")

while True:

x1=get\_float(" x1: "); y1=get\_float(" y1: ")

if rover.is\_point\_in\_polygon(x1,y1,verts):

print("⚠️ Starting point must be outside the farm. Please enter new coordinates.")

else: break

print(f"✅ Valid starting position: ({x1:.2f}, {y1:.2f})")

print("🔧 Enter waypoint coords:")

while True:

wx=get\_float(" wx: "); wy=get\_float(" wy: ")

if not rover.is\_point\_in\_polygon(wx,wy,verts):

print("⚠️ Waypoint must be inside the farm. Please enter new coordinates.")

else: break

print(f"✅ Valid waypoint: ({wx:.2f}, {wy:.2f})")

rover.set\_waypoint(wx,wy)

try:

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

xs=[v[0] for v in verts]+[x1,wx,entry[0]]; ys=[v[1] for v in verts]+[y1,wy,entry[1]]

mxx, Mxx = min(xs)-2, max(xs)+2; myy, Myy = min(ys)-2, max(ys)+2

ax.set\_xlim(mxx,Mxx); ax.set\_ylim(myy,Myy); ax.grid(True)

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

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

ax.add\_patch(fence)

# Place entry point marker on top (zorder=10)

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

ax.scatter(x1,y1,c='green',s=80,label='Start (Outside)')

ax.scatter(wx,wy,c='red',s=120,marker='\*',label='Waypoint')

pl,=ax.plot([],[], 'b-',alpha=0.5,label='Path'); ax.path\_line=pl; ax.legend(loc='upper left')

fig.canvas.draw\_idle(); plt.pause(0.5)

except Exception as e:

print(f"Error in plot setup: {e}")

fig, ax = plt.subplots(figsize=(8,6)); pl,=ax.plot([]); ax.path\_line=pl; ax.set\_title("Rover Navigation (Limited View)")

rover.set\_position(x1,y1,force=True,add\_to\_history=False)

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

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

print("\n🚜 Moving rover from outside farm to entry point...\n")

print(f"📏 Initial distance to entry point: {rover.distance\_to(\*entry):.2f}m")

for attempt in range(1,4):

print(f"\n🔄 Entry point navigation attempt {attempt}/3...")

reached, rover\_patch = navigate\_to\_point(rover, entry[0],entry[1],ax,fig,rover\_patch, step\_size=STEP\*attempt, tolerance=TOLERANCE)

if reached:

break

if attempt<3:

rover.blocked\_directions.clear(); print("🔄 Retrying entry point navigation with new parameters...")

if reached:

try:

# Remove the "point reached" visualization marker - just draw and pause

fig.canvas.draw\_idle(); plt.pause(0.5)

# Notice we removed the scatter() call that would add a marker

except: pass

rover.blocked\_directions.clear(); rover.position\_history.clear()

print("\n🚜 Moving rover to waypoint inside farm...\n")

print(f"📏 Initial distance to waypoint: {rover.distance\_to(\*rover.waypoint):.2f}m")

for attempt in range(1,4):

print(f"\n🔄 Waypoint navigation attempt {attempt}/3...")

ok, rover\_patch = navigate\_to\_point(rover, wx,wy,ax,fig,rover\_patch, step\_size=STEP\*attempt, tolerance=TOLERANCE)

if ok: break

if attempt<3:

rover.blocked\_directions.clear(); print("🔄 Retrying waypoint navigation with new parameters...")

if ok:

try:

ax.scatter(rover.x,rover.y,c='magenta',s=100,marker='o',label='Final Position'); ax.legend(loc='upper left'); fig.canvas.draw\_idle(); plt.pause(0.5)

except: pass

print(f"\n✅ Mission complete! Reached waypoint in {rover.command\_count} commands.")

else:

print("\n⚠️ Could not reach waypoint after multiple attempts.")

print(" Consider adjusting sim parameters or waypoint location.")

else:

print("\n⚠️ Could not reach farm entry point after multiple attempts.")

print(" Consider adjusting sim parameters or entry point location.")

try:

plt.ioff(); plt.title("Rover Farm Navigation Simulation"); plt.show(block=True)

except Exception as e:

print(f"Error in final plot display: {e}")

print("Simulation completed without final visualization.")

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

try:

main()

except KeyboardInterrupt:

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

except Exception as e:

print(f"\n❌ Simulation error: {e}")

if DEBUG:

import traceback; traceback.print\_exc()

ROW NAVIGATION

import matplotlib.pyplot as plt

import numpy as np

from scipy.interpolate import CubicSpline

import math

import time

from farm\_safety import SafetyModule

safety = SafetyModule()

class RowNavigator:

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

self.rover = rover

self.current\_waypoint\_index = 0

self.interpolated\_path = [] # Path of discrete waypoints

self.waypoint\_threshold = 0.1 # Keep the precise threshold

self.column\_spacing = 1.5

self.column\_height = 15

self.zigzag\_pattern = True # This only affects waypoint generation pattern

self.movement\_speed = 0.10 # Increased from 0.05 to 0.2 for faster movement

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 = []

for i in range(num\_strips):

x = start\_x + i \* spacing

# Generate waypoints for the vertical segment

if i % 2 == 0:

# Even columns: bottom to top

y\_points = np.linspace(bottom\_y, top\_y, 5)

else:

# Odd columns: top to bottom

y\_points = np.linspace(top\_y, bottom\_y, 5)

# Add all waypoints for this column

for y in y\_points:

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

# Add horizontal transition to the next column (except for the last column)

if i < num\_strips - 1:

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

transition\_y = top\_y if i % 2 == 0 else bottom\_y

# Use fewer intermediate points for horizontal transitions

intermediate\_points = 3 # Reduced from 5 for faster movement

for j in range(1, intermediate\_points):

interp\_x = x + (next\_x - x) \* j / intermediate\_points

self.interpolated\_path.append((interp\_x, transition\_y))

# Add the transition point explicitly

self.interpolated\_path.append((next\_x, transition\_y))

return self.interpolated\_path

def distance(self, p1, p2):

"""Calculate Euclidean distance between two points"""

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

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

"""Calculate heading angle between two points (in degrees)"""

return math.degrees(math.atan2(p2[1] - p1[1], p2[0] - p1[0])) % 360

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

"""Calculate the difference between current and target heading"""

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

return diff

def find\_closest\_waypoint(self):

"""Find the closest waypoint in the path"""

if not self.interpolated\_path:

print("⚠️ No valid path")

return None

min\_dist = float('inf')

closest\_idx = 0

for i, point in enumerate(self.interpolated\_path):

dist = self.distance((self.rover.x, self.rover.y), point)

if dist < min\_dist:

min\_dist = dist

closest\_idx = i

self.current\_waypoint\_index = closest\_idx

print(f"🔍 Found closest waypoint: #{closest\_idx}")

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

print(f" Waypoint position: ({self.interpolated\_path[closest\_idx][0]:.3f}, {self.interpolated\_path[closest\_idx][1]:.3f})")

print(f" Distance: {min\_dist:.3f}m")

return self.interpolated\_path[closest\_idx]

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

"""Align rover heading to the direction of the next waypoint"""

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

print("⚠️ No active path or at end of path")

return False

# Get current position and next waypoint

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

next\_pt = self.interpolated\_path[self.current\_waypoint\_index + 1]

# Calculate desired heading to next waypoint

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

if ax and fig and rover\_patch:

from farm\_entry import visualize\_turn

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

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

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

else:

self.rover.heading = desired\_heading

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

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

return True

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

"""Move precisely to a specific point using larger, faster steps"""

from farm\_entry import update\_rover\_visualization, visualize\_turn

max\_attempts = 100 # Reduced from 200 for faster execution

attempts = 0

step\_size = self.movement\_speed # Larger step size for faster movement

while attempts < max\_attempts:

# Calculate distance to target

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

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

# Check if we've reached the target

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

# Force exact position to ensure precision

self.rover.x = target\_point[0]

self.rover.y = target\_point[1]

if ax and fig and rover\_patch:

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

plt.pause(0.01) # Faster visualization update

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

return True

# Align heading precisely to target

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

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

if abs(heading\_diff) > 1: # Keep the strict heading alignment

if ax and fig and rover\_patch:

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

else:

self.rover.heading = desired\_heading

# Move a larger step toward the target

move\_dist = min(step\_size, dist\_to\_target)

# Calculate the target position based on heading and move distance

target\_x = self.rover.x + move\_dist \* math.cos(math.radians(self.rover.heading))

target\_y = self.rover.y + move\_dist \* math.sin(math.radians(self.rover.heading))

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

# Check safety before moving

from farm\_safety import safety # Make sure this is imported at the top of the file

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

if status == 'safe':

if ax and fig and rover\_patch:

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

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

plt.pause(0.01) # Faster updates for quicker animation

else:

success = self.rover.move\_forward(move\_dist)

elif status == 'drift':

# Handle drift scenario

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

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

# Update rover position and heading

self.rover.x, self.rover.y = pos

self.rover.heading = heading

success = True

if ax and fig and rover\_patch:

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

plt.pause(0.01)

print(f"🔄 Drift corrected: New heading {heading:.1f}°")

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

# Handle no-go zone or boundary violation

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

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

# Update rover position and heading

self.rover.x, self.rover.y = pos

self.rover.heading = heading

success = False # Mark as unsuccessful to trigger alternative path finding

# Update visualization if available

if ax and fig and rover\_patch:

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

plt.pause(0.01)

print(f"⚠️ Safety violation handled: {violation\_status}")

if not success:

print("⚠️ Movement blocked, attempting to adjust")

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

# Try a very small sidestep and continue

sidestep\_angle = (desired\_heading + 90) % 360

if ax and fig and rover\_patch:

rover\_patch = visualize\_turn(self.rover, sidestep\_angle, ax, fig, rover\_patch)

self.rover.move\_forward(0.1, ax, fig, rover\_patch)

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

else:

self.rover.heading = sidestep\_angle

self.rover.move\_forward(0.1)

self.rover.heading = desired\_heading

attempts += 1

# Only print status updates every 5 steps to reduce console output

if attempts % 5 == 0:

print(f" Moving: distance remaining = {dist\_to\_target:.3f}m")

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

print(f"⚠️ Failed to reach point after {max\_attempts} attempts")

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

return False

def navigate\_direct\_to\_closest(self, ax=None, fig=None, rover\_patch=None):

closest\_point = self.find\_closest\_waypoint()

if not closest\_point:

return False

print(f"\n🚜 Navigating directly to closest point on path: ({closest\_point[0]:.3f}, {closest\_point[1]:.3f})")

# Set the rover position directly to the closest point (teleport)

self.rover.x = closest\_point[0]

self.rover.y = closest\_point[1]

# Update visualization if available

if ax and fig and rover\_patch:

from farm\_entry import update\_rover\_visualization

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

plt.pause(0.01)

print(f"✅ Successfully reached the closest waypoint #{self.current\_waypoint\_index}")

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

return True

def determine\_next\_task(self):

"""Task 2.i: Determine the next task (next waypoint in the row)"""

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

print("⚠️ No more waypoints available")

return None

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

next\_point = self.interpolated\_path[next\_idx]

print(f"\n📋 Task 2.i: Determined next task - waypoint #{next\_idx}")

print(f" Next waypoint: ({next\_point[0]:.3f}, {next\_point[1]:.3f})")

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

print(f" Distance: {self.distance((self.rover.x, self.rover.y), next\_point):.3f}m")

return next\_point

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

"""Task 2.ii: Align rover direction to the orientation of next task"""

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

if not next\_point:

return False

# Get current position

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

# Calculate desired heading to next waypoint

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

print(f"\n🔄 Task 2.ii: Aligning rover to next task orientation")

if ax and fig and rover\_patch:

from farm\_entry import visualize\_turn

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

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

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

else:

self.rover.heading = desired\_heading

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

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

return True

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

"""Navigate through the path with the updated task structure"""

print(f"\n🚜 Starting navigation of path...\n")

if not self.interpolated\_path:

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

return False

# Task 1: Navigate directly to the closest point (no intermediate points)

print("\n📋 Task 1: Navigate directly to closest point on path")

if not self.navigate\_direct\_to\_closest(ax, fig, rover\_patch):

print("⚠️ Failed to reach the closest waypoint. Aborting.")

return False

# Now at closest point (start of row), proceed with next tasks

# Task 2.i: Determine next task

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

if not next\_point:

print("⚠️ No next task available. Ending navigation.")

return False

# Task 2.ii: Align to next task orientation

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

print("⚠️ Failed to align to next task. Attempting to continue anyway.")

# Task 3: Navigate through the identified row

print("\n📋 Task 3: Start navigating in the identified row")

return self.navigate\_path(ax, fig, rover\_patch)

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

"""Task 3: Navigate through the path, strictly following all waypoints"""

from farm\_entry import update\_rover\_visualization, visualize\_turn

import matplotlib.pyplot as plt

print(f"\n🚜 Task 3.i: Navigating path with {len(self.interpolated\_path) - self.current\_waypoint\_index - 1} remaining waypoints...\n")

# Start from current waypoint and visit all remaining waypoints

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

# Task 3.ii: Read the current location

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

print(f"\n📍 Task 3.ii: Current location: ({self.rover.x:.3f}, {self.rover.y:.3f})")

# Task 3.iii: Find the closest next waypoint in the row

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

next\_point = self.interpolated\_path[next\_idx]

dist\_to\_next = self.distance(current\_pos, next\_point)

print(f"🎯 Task 3.iii: Found next waypoint #{next\_idx}: ({next\_point[0]:.3f}, {next\_point[1]:.3f})")

print(f" Distance to next waypoint: {dist\_to\_next:.3f}m")

# Use the precise movement method to reach the exact waypoint

reached = self.move\_precisely\_to\_point(next\_point, ax, fig, rover\_patch)

if reached:

self.current\_waypoint\_index = next\_idx

print(f"✅ Reached waypoint #{next\_idx} exactly")

else:

print(f"⚠️ Failed to reach waypoint #{next\_idx}")

# Even if we can't reach it perfectly, we still advance to the next waypoint

self.current\_waypoint\_index = next\_idx

print(f"✅ Reached end of path")

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

return True

FARM SAFETY

import math

import random

import numpy as np

class SafetyModule:

"""

A module to handle drift and no-go zone safety checks for farm rover navigation.

Combines logic from both drift recovery and geofence enforcement.

"""

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

# 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

# No-go zone configuration

self.no\_go\_zones = [] # list of no-go zones [(x0, y0, x1, y1), ...]

self.geofence = None # farm boundary polygon vertices

self.violations\_history = [] # track violation incidents

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

def set\_geofence(self, vertices):

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

self.geofence = vertices

def add\_no\_go\_zone(self, x0, y0, x1, y1):

"""Add a rectangular no-go zone"""

self.no\_go\_zones.append((x0, y0, x1, y1))

def clear\_no\_go\_zones(self):

"""Clear all no-go zones"""

self.no\_go\_zones = []

def is\_in\_no\_go\_zone(self, pos):

"""Check if position is in any no-go zone"""

for zone in self.no\_go\_zones:

x0, y0, x1, y1 = zone

if x0 <= pos[0] <= x1 and y0 <= pos[1] <= y1:

return True

return False

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

"""Check if position is outside the geofence"""

if not self.geofence:

return False

# Ray casting algorithm for point-in-polygon test

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):

if 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 current position and heading are safe.

Returns:

- safety\_status: 'safe', 'drift', 'no-go', or 'outside'

- recovery\_data: Data needed for recovery (if applicable)

"""

# Check for no-go zone

if self.is\_in\_no\_go\_zone(pos):

self.violations\_history.append(('no-go', pos.copy(), heading))

return 'no-go', {'violation\_type': 'no-go', 'pos': pos.copy(), 'heading': heading}

# Check for outside geofence

if self.is\_outside\_geofence(pos):

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

return 'outside', {'violation\_type': 'outside', 'pos': pos.copy(), 'heading': heading}

# Check for potential drift (random occurrence)

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

# Find closest point on path for reference

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

# Only drift if we have enough path ahead

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

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

# Calculate drift parameters

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

lookahead = self.lookahead\_steps

# Calculate recovery parameters

trigger\_idx = closest\_idx

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

# Drift direction calculation

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 != 0 else (1.0, 0.0)

# Rotate drift direction

rad = math.radians(drift\_angle)

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

rx = ux \* c + uy \* s

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

# Calculate recovery index

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

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

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

recovery\_target = path[recovery\_idx]

# Return drift data

drift\_data = {

'trigger\_idx': trigger\_idx,

'drift\_angle': drift\_angle,

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

'recovery\_idx': recovery\_idx,

'recovery\_target': recovery\_target,

'path': path

}

return 'drift', drift\_data

# If all checks pass, we're safe

return 'safe', None

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

"""

Handle a drift event by simulating drift and computing recovery path.

Returns:

- updated\_pos: Position after drift or during recovery

- updated\_heading: Heading after drift or during recovery

- status: 'drifting', 'recovering', or 'recovered'

- recovery\_path: Path to follow for recovery

"""

# Extract drift parameters

drift\_vector = drift\_data['drift\_vector']

recovery\_target = drift\_data['recovery\_target']

drift\_len = 1.0

drift\_steps = 20

# Calculate how far to drift in each step

drift\_delta = (drift\_vector[0] \* drift\_len/drift\_steps,

drift\_vector[1] \* drift\_len/drift\_steps)

# Apply drift to position

pos[0] += drift\_delta[0]

pos[1] += drift\_delta[1]

# Determine if we need to start recovery

drift\_steps\_done = drift\_data.get('drift\_steps\_done', 0) + 1

drift\_data['drift\_steps\_done'] = drift\_steps\_done

if drift\_steps\_done >= drift\_steps:

# Calculate recovery heading

desired = self.head(pos, recovery\_target)

dh = self.diff\_h(heading, desired)

# Apply heading correction

turn\_step = self.turn\_rate\_per\_cm \* self.distance\_per\_step

if abs(dh) > 5:

heading += turn\_step if dh > 0 else -turn\_step

return pos, heading, 'recovering', drift\_data

else:

# Move toward recovery point

pos[0] += self.distance\_per\_step \* math.cos(math.radians(heading))

pos[1] += self.distance\_per\_step \* math.sin(math.radians(heading))

# Check if we've recovered

d = self.dist(pos, recovery\_target)

if d < 0.5:

return recovery\_target, heading, 'recovered', None

return pos, heading, 'recovering', drift\_data

else:

return pos, heading, 'drifting', drift\_data

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

"""

Handle a no-go zone violation by backing away from the zone.

Returns:

- updated\_pos: Position after backing away

- updated\_heading: Heading after backing away

- status: 'backing', 'redirecting', or 'recovered'

"""

# Back up in the opposite direction of current heading

backup\_heading = (heading + 180) % 360

# Back up by a small amount

backup\_dist = self.distance\_per\_step \* 2 # Back up by twice the normal step size

new\_pos = [

pos[0] + backup\_dist \* math.cos(math.radians(backup\_heading)),

pos[1] + backup\_dist \* math.sin(math.radians(backup\_heading))

]

# Check if we're still in a no-go zone

if self.is\_in\_no\_go\_zone(new\_pos) or self.is\_outside\_geofence(new\_pos):

# Try a different direction if backing up doesn't work

for angle\_offset in [45, -45, 90, -90]:

try\_heading = (backup\_heading + angle\_offset) % 360

try\_pos = [

pos[0] + backup\_dist \* math.cos(math.radians(try\_heading)),

pos[1] + backup\_dist \* math.sin(math.radians(try\_heading))

]

if not self.is\_in\_no\_go\_zone(try\_pos) and not self.is\_outside\_geofence(try\_pos):

return try\_pos, try\_heading, 'redirecting'

# If all attempts fail, just back up a tiny bit and hope for the best

return [

pos[0] + 0.1 \* math.cos(math.radians(backup\_heading)),

pos[1] + 0.1 \* math.sin(math.radians(backup\_heading))

], backup\_heading, 'backing'

else:

# Successfully backed out

return new\_pos, backup\_heading, 'recovered'

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

"""Find the closest point on a path to the given position"""

min\_dist = float('inf')

min\_idx = 0

min\_point = None

for i, point in enumerate(path):

d = self.dist(pos, point)

if d < min\_dist:

min\_dist = d

min\_idx = i

min\_point = point

return min\_idx, min\_point

# Utility functions

def dist(self, a, b):

"""Calculate Euclidean distance between points a and b"""

return math.hypot(b[0] - a[0], b[1] - a[1])

def head(self, a, b):

"""Calculate heading from point a to point b in degrees"""

return math.degrees(math.atan2(b[1] - a[1], b[0] - a[0])) % 360

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

"""Calculate the minimal angle difference between headings c and t"""

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

# At the end of your file, add:

safety = SafetyModule()

FARM SIMULATION

import matplotlib.pyplot as plt

import numpy as np

import math

import time

# Import our modules

from farm\_entry import Rover, update\_rover\_visualization, visualize\_turn, navigate\_to\_point

from row\_navigation import RowNavigator

from farm\_safety import SafetyModule

safety = SafetyModule()

# Set farm boundary

# Add any no-go zones

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 run\_simulation():

print("🚜 Farm Rover Navigation Simulation 🚜")

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

# Create the rover

rover = Rover()

# Setup the geofence (farm boundaries)

print("\n🔧 Enter farm rectangle coordinates:")

min\_x = get\_float(" Min X: ")

max\_x = get\_float(" Max X: ")

min\_y = get\_float(" Min Y: ")

max\_y = get\_float(" Max Y: ")

# Create vertices for the farm boundary

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

entry\_point = verts[0] # Bottom-left corner as entry point

print(f"🚪 Entry point set to bottom-left corner: ({entry\_point[0]:.3f}, {entry\_point[1]:.3f})")

# Set geofence in rover

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

# Set farm boundary in safety module

safety.set\_geofence(verts)

# Add no-go zones if needed

# For example, to 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)

# Get rover starting position (outside farm)

print("\n🔧 Enter starting position (must be outside the farm):")

while True:

x1 = get\_float(" x1: ")

y1 = get\_float(" y1: ")

if rover.is\_point\_in\_polygon(x1, y1, verts):

print("⚠️ Starting point must be outside the farm. Please enter new coordinates.")

else:

break

print(f"✅ Valid starting position: ({x1:.3f}, {y1:.3f})")

# Initialize visualization

plt.ion()

fig, ax = plt.subplots(figsize=(12, 10))

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)

# Mark entry point and start position

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

ax.scatter(x1, y1, c='green', s=80, label='Start (Outside)')

# Setup plot limits and grid

xs = [v[0] for v in verts] + [x1, entry\_point[0]]

ys = [v[1] for v in verts] + [y1, entry\_point[1]]

margin = 3 # Add more margin

mxx, Mxx = min(xs) - margin, max(xs) + margin

myy, Myy = min(ys) - margin, max(ys) + margin

ax.set\_xlim(mxx, Mxx)

ax.set\_ylim(myy, Myy)

ax.grid(True)

# 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

rover.set\_position(x1, y1, force=True, add\_to\_history=False)

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

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

# --- TASK 1: Enter the farm at entry point ---

print("\n🚜 TASK 1: Moving rover from outside farm to entry point...\n")

print(f"📏 Initial distance to entry point: {rover.distance\_to(\*entry\_point):.3f}m")

# Navigate to entry point

reached\_entry = False

for attempt in range(1, 4):

print(f"\n🔄 Entry point navigation attempt {attempt}/3...")

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

rover, entry\_point[0], entry\_point[1], ax, fig, rover\_patch)

if reached\_entry:

break

if attempt < 3:

rover.blocked\_directions.clear()

print("🔄 Retrying entry point navigation with new parameters...")

if not reached\_entry:

print("\n⚠️ Could not reach farm entry point after multiple attempts.")

print(" Try adjusting simulation parameters or entry point location.")

return

# Force rover position to exactly match entry point

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

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

# Mark entry point reached

# Mark entry point reached

ax.scatter(entry\_point[0], entry\_point[1], c='cyan', s=80, marker='^', label='Entry Reached')

ax.legend(loc='upper left')

fig.canvas.draw\_idle()

plt.pause(1)

print("\n✅ TASK 1 COMPLETE: Successfully entered the farm")

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

# --- TASK 2: Generate zigzag row pattern and identify closest row ---

print("\n🚜 TASK 2: 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

row\_start\_x = min\_x + 2 # Start rows 2 units from left edge

row\_start\_y = min\_y + 2 # Start rows 2 units from bottom edge

row\_spacing = 1.5

num\_strips = max(3, min(10, int((max\_x - min\_x - 4) / row\_spacing))) # Calculate number of strips based on farm width

# Generate rows and visualize them

rows = navigator.generate\_rows(

row\_start\_x, row\_start\_y,

num\_strips=num\_strips,

strip\_length=max\_y - min\_y - 4 # Strip height based on farm height

)

# 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

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

ax.scatter(navigator.interpolated\_path[-1][0], navigator.interpolated\_path[-1][1], c='red', s=50, marker='o', label='Path End')

fig.canvas.draw\_idle()

plt.pause(0.5)

# --- TASK 2.i: Determine the closest row ---

print("\n🚜 TASK 2.i: Determining closest point on path...\n")

navigator.find\_closest\_waypoint()

# Mark the closest point

closest\_point = navigator.interpolated\_path[navigator.current\_waypoint\_index]

ax.scatter(closest\_point[0], closest\_point[1], c='yellow', s=60, marker='\*', label='Closest Point')

ax.legend(loc='upper left')

fig.canvas.draw\_idle()

plt.pause(0.5)

print(f"✅ TASK 2.i COMPLETE: Identified closest point on path")

# --- TASK 2.ii: Navigate to the closest point on the path ---

print("\n🚜 TASK 2.ii: Moving to the closest point on the path...\n")

target\_point = navigator.interpolated\_path[navigator.current\_waypoint\_index]

print(f"🎯 Target point: ({target\_point[0]:.3f}, {target\_point[1]:.3f})")

print(f"📏 Distance to target: {rover.distance\_to(\*target\_point):.3f}m")

# Navigate to the closest point

reached\_point = False

for attempt in range(1, 4):

print(f"\n🔄 Point navigation attempt {attempt}/3...")

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

rover, target\_point[0], target\_point[1], ax, fig, rover\_patch)

if reached\_point:

break

if attempt < 3:

rover.blocked\_directions.clear()

print("🔄 Retrying point navigation with new parameters...")

if not reached\_point:

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

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

return

# Force rover position to exactly match target point

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

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

# Mark point reached

ax.scatter(target\_point[0], target\_point[1], c='magenta', s=80, marker='\*', label='Point Reached')

ax.legend(loc='upper left')

fig.canvas.draw\_idle()

plt.pause(1)

print("\n✅ TASK 2.ii COMPLETE: Successfully reached closest point")

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

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

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

navigator.align\_to\_path(ax, fig, rover\_patch)

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

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

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

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

# 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}")

if 'DEBUG' in globals() and DEBUG:

import traceback

traceback.print\_exc()