Safety: Stopping and Collision Avoidance Tests

version 1.0/12-Aug-2025/ZH

Purpose

This test evaluates a robot's ability to detect, localise and respond to both human and non-human obstacles under realistic conditions, for robots within a defined size range. The goal is to ensure operational safety, navigation accuracy and reliable obstacle response. The primary capabilities considered are: *object detection*, *response timing*, *safe stopping* and *collision avoidance* behaviours.

Precondition: The robot system must have passed the separate **HRI: Off-line Detection and Tracking Test** and the **HRI: Live Detection Test** before attempting the test procedure described herein. Refer to the **Annex B** for detailed instructions. The two detection pre-tests cover:

- **Obstacle Detection:** A static obstacle such as a trolley is presented in the robot's field of view.
- **Human Detection:** A person moves across or stands in front of the stationary robot; the person may carry items or be partially obscured.

Test Facility

The test is designed for evaluating an unmanned ground vehicle (UGV) with obstacle detection system intended for use in agricultural environments. The test procedure applies to small and medium-sized mobile platforms (< 2m^2 footprint) suitable for safe operation in semi-structured environments such as polytunnels, greenhouses, glasshouses or drilled fields. No specific numeric mass or footprint thresholds are enforced unless constrained by the test location or documented standards, e.g. spacing within rows of a polytunnel.

The **Test Site** is a semi-controlled outdoor environment simulating typical deployment (e.g., strawberry polytunnel), with the following properties:

- **Size and Layout:** Straight path 10–20 m long, 2–4 m wide with randomized obstacle placements.
- **Boundary Marking Method:** Cones or flags at edges; painted centreline and lateral offset markers (or none).
- **Ground Conditions:** Paved, gravel, or grass (firm, dry), coefficient of friction between 0.6–1.0 (ISO 18646-2:2019).
- **Lighting:** 100–1,000 lux for vision-based systems (ISO 18646-2:2019).
- **Temperature/Humidity:** 10–30 °C, 0–80% RH.
- **Obstacles** (for the collision avoidance test):
  - **Human Obstacles:**
    - Standing dummy height: 1.6–1.8 m; width: 0.4–0.6 m (based on ISO 13482:2014 dummy anthropometry).
    - Moving dummy on caster platform/trolley (simulates pedestrian crossing). Dynamic obstacles enter robot path 5s prior to robot arrival.
  - **Non-Human:**
    - Static trolley (height around 1.2 m).

  - Cubical block – cardboard boxes (side: 0.4–0.8 m).
- Obstacle examples align with experimental setups in agricultural robot studies (see PMCID: PMC8434662, MDPI Sensors 2021).
- Obstacles will be introduced either stationary or moving laterally at up to 1 m/s (pedestrian approximation per ISO 13855:2024).
- Only one obstacle is used every trial.

The following **Test Equipment** and **Robot Configuration** are expected:

- Nominal speeds: e.g., 0.5–1.0 m/s depending on manufacturer-rated operation and test safety scope (aligned with ISO 18497:2024 typical platform motion ranges).
- Fully autonomous mode enabled.
- Safety monitoring system active.
- Logging: onboard time-synced logs; external motion capture/video. (Optional)

Test Procedure

The **Test Setup** is as follows:

- Insert one obstacle at each interval (distance between robot starting point and the obstacle can be changed)
- Each trial: Robot travels down the path; obstacle appear stationary or are remotely introduced 5 sec before the robot's arrival.

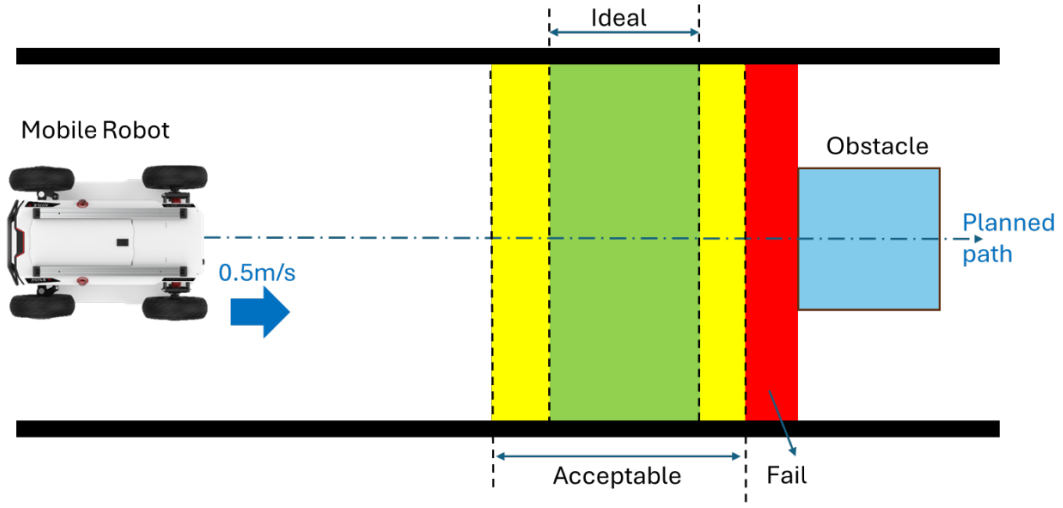


Figure 1: Test Scenario Example

The **Test Steps** are outlined below, for each trial, where each trial should be repeated at least 5 times:

(1) Reaction Time and Stop Distance Test

- Objective: Evaluate system response time and final clearance after stopping.
- Setup: Position static obstacle at various positions and distances along the robot path during different trials.
- Procedure:

  - Trigger an obstacle detection event (static or manually moving).
  - Measure time between detection and stop initiation.
  - Measure total stop time and distance from obstacle after full stop.
- Output: Reaction time, braking time, final stop distance away from the obstacle.

(2) Collision Avoidance Trajectory Test

- Objective: Evaluate lateral deviation strategies and safety margin.
- Setup: Same obstacle layout as in 4.1. Robot attempts to navigate around instead of stopping.
- Requirements: Use external tracking (e.g., motion capture or SLAM log) to trace path.
- Procedure:
  - Robot approaches obstacle at nominal speed.
  - If equipped with avoidance logic, allow rerouting behaviour.
  - Record full path and calculate minimum clearance from obstacle.
- Output: Minimum clearance from obstacle edge, trajectory analysis.

Evaluation Criteria and Error Conditions

Success is measured as:

- **Detection Rate**: ≥ 95% of trials [3]
- **Reaction Time**: ≤ 0.5 s from detection to control action [2, *T-response component*]
- **Clearance**: ≥ 300 mm stop distance or lateral deviation [5]
- **Stop Accuracy**: ±50 mm of calculated stop point [4, *Annex B (measured deceleration)*]
- **No Collisions**

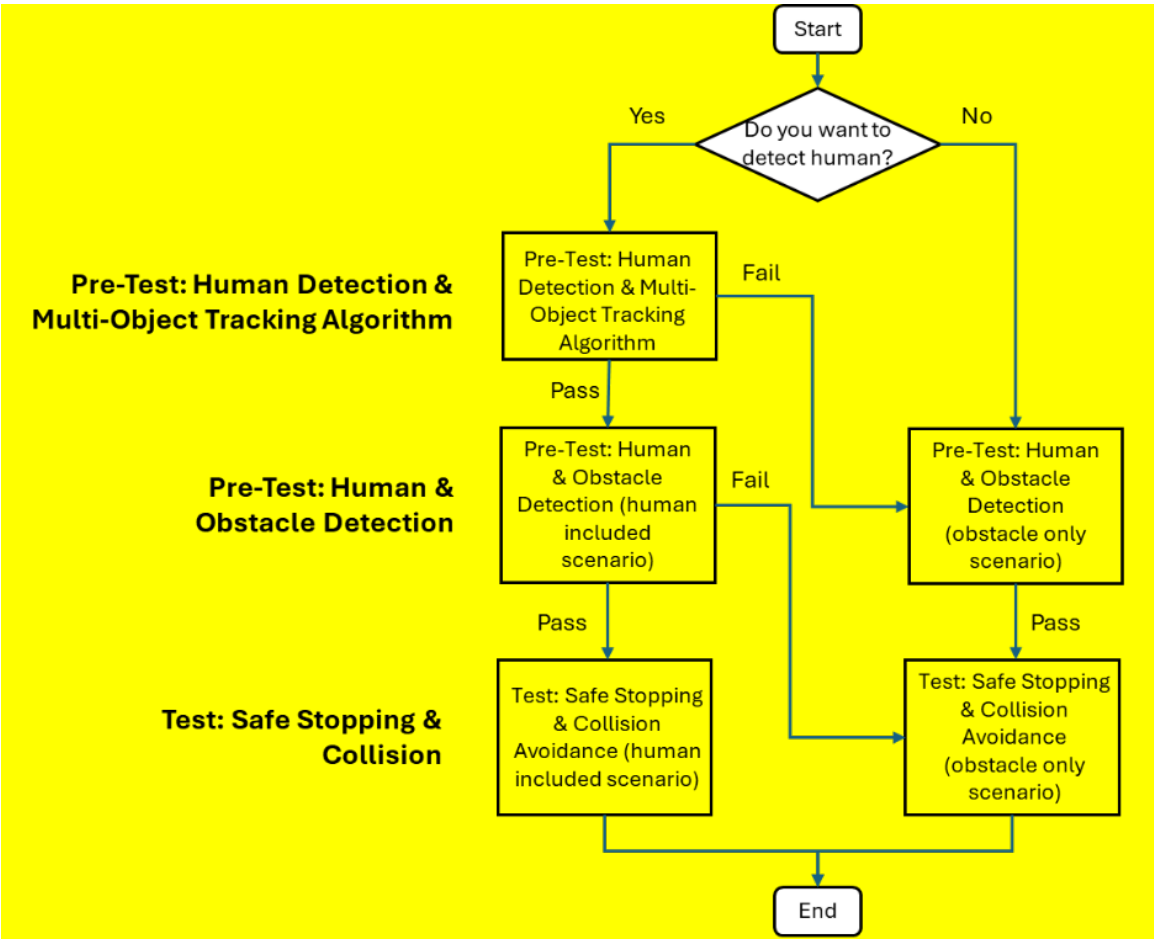
Conditions

- Use consistent trial conditions for comparison.

Test Result

The following shall be recorded and included in the test report:

- Test facility conditions, as above, including:
  - Size, layout and boundary marking method
  - Ground conditions, lighting, temperature and humidity
  - Obstacles: type, size, number and position of each (within the layout)
- For each trial:
  - Obstacle type, position, and behaviour (static/dynamic).
  - Detection time and distance (between robot and obstacle).
  - Reaction time and response type (stop/deviation).
  - Final stop/clearance distance.
  - Missed and false detections (number and notes on false/missed detections).
  - Video and sensor log correlation.
  - Trajectory logs (e.g. GNSS/IMU/SLAM).



References

1. ISO 18646-2:2019 – Performance requirements for service robots in outdoor environments.
2. ISO 13855:2024 – Positioning of safeguards and safe separation distances. Used to calculate human-safe stop margins.
3. ISO 18497:2024 – Safety of highly automated agricultural machines. Sets expectations for safe detection and response.
4. ISO 10218-1:2011 Annex B – Stopping distance/time measurement method in robotics.
5. Klimenda, Frantisek, Roman Cizek, Matej Pisarik, and Jan Sterba. "Stopping the mobile robotic vehicle at a defined distance from the obstacle by means of an infrared distance sensor." Sensors 21, no. 17 (2021): 5959.
6. Pilz & ReeR Safety Guidelines – Industry applications of ISO 13855 for separation distance design.