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Research article

RoboAudit: Automated indoor safety compliance auditing via MLLM-guided semantic mapping

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Abbreviations

The following abbreviations are used in this manuscript:

2D	Two-Dimensional
3D	Three-Dimensional
AI	Artificial Intelligence
API	Application Programming Interface
CLIP	Contrastive Language–Image Pre-training
CNC	Computer Numerical Control
Co-NavGPT	Cooperative Navigation using Generative Pre-trained Transformer
C_p	Compliance Percentage
FabLab	Fabrication Laboratory
FN	False Negative
FOV	Field of View
FP	False Positive
GB	Gigabyte

GPT	Generative Pre-trained Transformer
GPT-3	Generative Pre-trained Transformer 3
GPT-4	Generative Pre-trained Transformer 4
GPT-4o	Generative Pre-trained Transformer 4 Omni
GPT-4o-mini	Generative Pre-trained Transformer 4 Omni Mini
IMU	Inertial Measurement Unit
JSON	JavaScript Object Notation
KSA	Kingdom of Saudi Arabia
LFG	Language Frontier Guide
LiDAR	Light Detection and Ranging
LLM	Large Language Model
LM-Nav	Language-Model Navigation
mAh	Milliampere-Hour
MDPI	Multidisciplinary Digital Publishing Institute
MLLM	Multimodal Large Language Model
MobileSAM	Mobile Segment Anything Model
MPU6050	Motion Processing Unit 6050
N/A	Not Applicable
O3D-SIM	Open-Set 3D Semantic Instance Maps
Odom	Odometry
OpenCV	Open Source Computer Vision Library
RGB	Red, Green, Blue
ROS	Robot Operating System
RPLiDAR	Rotating Platform Light Detection and Ranging
SAM	Segment Anything Model
SLAM	Simultaneous Localization and Mapping
TN	True Negative
TP	True Positive
UAE	United Arab Emirates
URL	Uniform Resource Locator
ViNG	Visual Navigation Graph
VLFM	Vision-Language Frontier Maps
VLM	Vision-Language Model

A. MLLM prompt specification

This section provides the reader with the MLLM prompt specification used in the system, enforcing strict structured outputs via JSON schema.

System & User Instructions:

```
You are an expert emergency safety inspector. Analyze this image with EXTREME CAUTION.

CRITICAL: Only report objects you are ABSOLUTELY CERTAIN are emergency equipment.
When in doubt, DO NOT report it. False positives are worse than missing items.

STRICT IDENTIFICATION CRITERIA:
```

```
1. FIRE EXTINGUISHER - Must have ALL of these features:
   - RED cylindrical body (bright red, not dark red or orange)
   - Clearly visible pressure gauge on top
   - Black hose or nozzle attachment
   - Typical size: 30-50cm tall, 10-15cm diameter
   - Labels or text visible (often says 'FIRE EXTINGUISHER')
   DO NOT confuse with: red chairs, red bags, fire alarms, red signs.

2. EMERGENCY EXIT SIGN - Must have:
   - Rectangular illuminated sign
   - Clear 'EXIT' text OR running person pictogram
   - Mounted above doors or on walls near exit routes
   NOTE: An exit sign identifies the location of an exit, but you MUST evaluate the physical door and egress pathway separately.

3. EMERGENCY EXIT DOOR & EGRESS PATHWAY - Must evaluate:
   - Physical doorway/aperture serving as an emergency exit
   - Clear floor trajectory leading directly to and through the door
   - Do NOT count a sign alone as a functional exit if no physical door/path exists.

4. FIRST AID KIT - Must have:
   - White or green rectangular box/case
   - Prominent RED CROSS or GREEN CROSS symbol
   - Wall-mounted or stored in accessible location

ACCESSIBILITY & REACHABILITY EVALUATION CRITERIA:
For every valid detection, evaluate physical access and classify into one of three categories:
- Unobstructed (80% - 100%): Direct, clear access route; no active floor obstacles blocking egress width.
Perimeter-located items (e.g., bundled floor cables along walls) maintaining clear walk-through width are rated Unobstructed (>= 80%).
- Partially Obstructed (50% - 79%): Temporary or moveable obstacles directly on active paths
(e.g., chairs, loose boxes, traversing floor cables).
- Severely Obstructed (< 50%): Major fixed or heavy physical barricades completely blocking access or egress paths.

VALIDATION CHECKLIST:
Before reporting ANY detection, ask yourself:
1. Can I see ALL the required features clearly?
2. Is the object the right size and proportion?
3. Is it in a logical location for emergency equipment?
4. Am I 100% confident this is NOT something else?
5. Would a trained safety inspector agree with this identification?
6. FOR EXITS ONLY: Have I separately assessed (a) the exit sign, (b) the physical door, and (c) the floor path clearance?

If you answer NO to ANY question, DO NOT report the object.
```

Structured JSON Output Schema:

```
Return ONLY valid JSON following this exact schema:
{
  "detections": [
    {
      "tool": "fire extinguisher" | "emergency exit sign" | "emergency exit door" | "first aid kit",
      "confidence": 0-100 (only report if confidence >= 70),
      "box_2d": [ymin, xmin, ymax, xmax] (normalized 0-1000 scale),
      "description": "DETAILED description proving this is identified object",
      "visible_features": "list ALL identifying features visible",
      "location": "precise location in image",
      "size_estimate": "approximate size description",
      "why_certain": "explain why you are certain of identification",
      "egress_path_assessment": "FOR EXITS: describe physical door presence AND floor path clearance",
      "reachable_description": "detailed accessibility description",
      "accessibility_category": "Unobstructed" | "Partially Obstructed" | "Severely Obstructed",
      "reachable_percentage": 0-100
    }
  ],
  "potential_false_positives": [
    {
      "object": "what you see",
      "why_rejected": "why it is NOT emergency equipment"
    }
  ]
}
```

B. Data association log

This section details the per-asset spatial data association log across all experimental scenarios (M = 20 globally mapped physical assets). For each unique physical landmark, Table S1 lists the ground-truth physical coordinates ($\mathbf{x}_{\mathrm{GT}}$) measured via a Leica laser distance meter, estimated global 2D SLAM map coordinates ($\mathbf{c}$), Euclidean position error (e_{pos}), and associated RGB camera frame observation IDs.

Table S1. Data Association Log: Per-asset ground-truth coordinates ($\mathbf{x}_{\mathrm{GT}}$), estimated global map coordinates ($\mathbf{c}$), Euclidean position errors (e_{pos}), and frame observation IDs across all experimental scenarios (M = 20).

Scenario	Asset ID	Target Class	Ground Truth $\mathbf{x}_{\mathrm{GT}}$ (m)	Estimated Map $\mathbf{c}$ (m)	Error e_{pos} (m)	Frame Observation IDs
Scenario 1	–	*No Assets Present*	–	–	–	–
Scenario 2	A01	Fire Extinguisher	(12.45, 3.20)	(12.61, 3.33)	0.21	Frame_04, Frame_05
	A02	First Aid Kit	(18.10, 3.15)	(18.32, 3.32)	0.28	Frame_09, Frame_10
Scenario 3	A03	Fire Extinguisher (Desk)	(12.45, 3.20)	(12.58, 3.32)	0.18	Frame_04, Frame_05
	A04	Fire Extinguisher (Open Area)	(15.80, 2.90)	(15.92, 3.01)	0.17	Frame_07, Frame_08
	A05	Fire Extinguisher (Entrance)	(22.10, 5.40)	(22.24, 5.51)	0.18	Frame_11, Frame_12
	A06	Fire Extinguisher (Hallway A)	(25.30, 5.10)	(25.43, 5.22)	0.18	Frame_13
	A07	Fire Extinguisher (Hallway B)	(28.90, 4.80)	(29.05, 4.91)	0.18	Frame_14
	A08	Fire Extinguisher (Lab Rear)	(34.20, 2.10)	(34.34, 2.21)	0.18	Frame_16
	A09	First Aid Kit (Table)	(18.10, 3.15)	(18.25, 3.26)	0.18	Frame_09, Frame_10
	A10	Emergency Exit (Centre Door)	(41.00, 1.20)	(41.13, 1.31)	0.17	Frame_14, Frame_15
	A11	Emergency Exit (Glass Door)	(44.50, 1.10)	(44.66, 1.22)	0.20	Frame_15, Frame_16
Scenario 4	A12	Fire Extinguisher (Corner)	(12.45, 3.20)	(12.59, 3.33)	0.19	Frame_04, Frame_05
	A13	Fire Extinguisher (Desk)	(15.80, 2.90)	(15.93, 3.02)	0.18	Frame_07, Frame_08
	A14	Fire Extinguisher (Entrance)	(22.10, 5.40)	(22.25, 5.52)	0.19	Frame_11, Frame_12
	A15	Fire Extinguisher (Wall)	(25.30, 5.10)	(25.44, 5.23)	0.19	Frame_13
	A16	Fire Extinguisher (Hall)	(28.90, 4.80)	(29.06, 4.92)	0.19	Frame_14
	A17	Fire Extinguisher (Rear)	(34.20, 2.10)	(34.35, 2.22)	0.19	Frame_16
	A18	First Aid Kit (Table)	(18.10, 3.15)	(18.26, 3.27)	0.19	Frame_09, Frame_10
	A19	Emergency Exit (Obstructed 1)	(41.00, 1.20)	(41.15, 1.33)	0.20	Frame_14, Frame_15
	A20	Emergency Exit (Obstructed 2)	(44.50, 1.10)	(44.68, 1.24)	0.23	Frame_15, Frame_16



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