Towards a New Era of Smart Wheelchair Navigation: Estimating Door Opening Direction with a 360-Degree Camera

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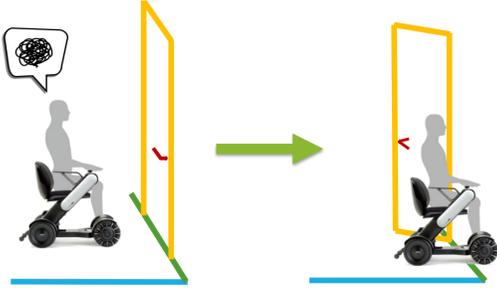Presentation Video of This Research

## 1 Background

Social Issues

- Labor shortages are rapidly increasing in caregiving and related fields.
- Autonomous wheelchairs are being deployed in hospitals and airports to help mitigate workforce shortages.

Required Technologies

- Current autonomous wheelchairs cannot open or pass through standard doors, which limits the range of autonomous navigation. Therefore, enabling autonomous door opening and passage is required.
- To achieve this capability, doors must be detected accurately and in real time. Specifically, the following elements must be identified:
  1. Door region
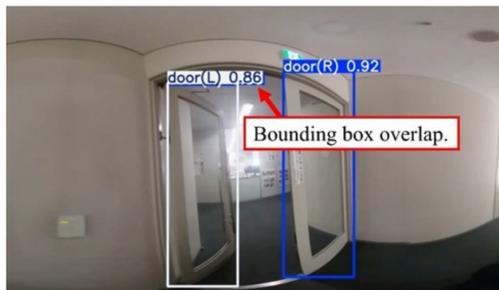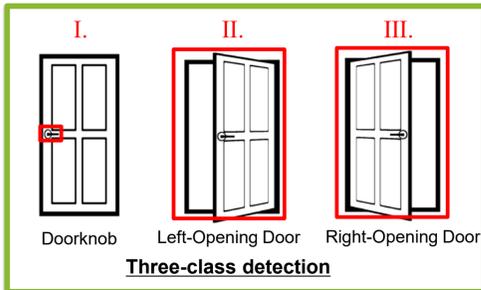 2. Door handle position
  3. Door-opening direction (left/right)

or

Left-Opening Door   Right-Opening Door
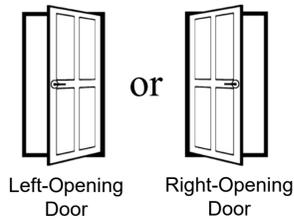
2 Challenges and Objective

Limitations of Conventional Methods

- Increased computational cost due to more detection classes, making real-time processing difficult.
- Higher misclassification rates for visually similar objects such as left- and right-opening doors.
- Low detection accuracy for small objects such as door handles.

I.   II.   III.

Doorknob   Left-Opening Door   Right-Opening Door

Three-class detection

door(L) 0.86   door(R) 0.92

Bounding box overlap.

Objective

- **Accurate Door-Opening Direction Detection Without Increasing Computational Cost**

Proposed Method

- Reduce computational cost by limiting detection to two classes.
- Estimate the door-opening direction (left/right) using the spatial relationship between the detected door and handle.
- Estimate door-opening direction in real time from a single omnidirectional camera.
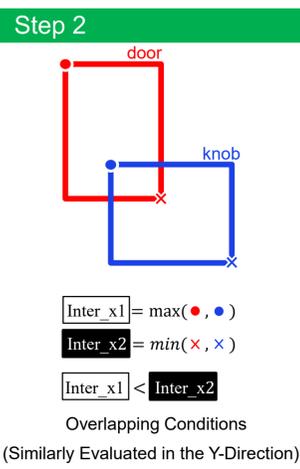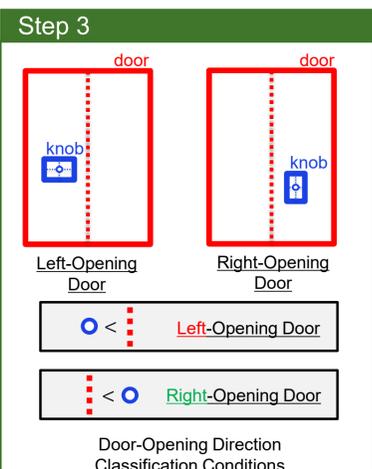- Improve small-object detection accuracy through dataset and training improvements.

I.   II.

Doorknob   Door   or   Left-Opening Door   Right-Opening Door

Two-class detection
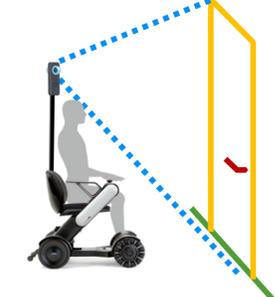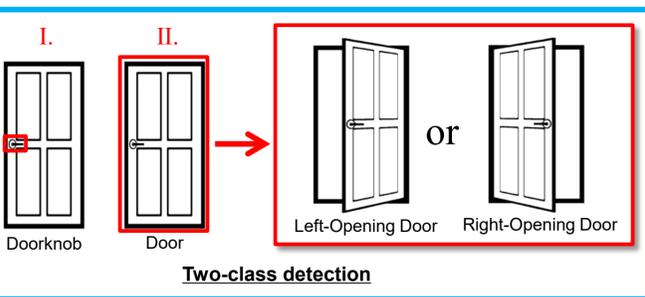
3 Methods

Left/Right Door-Opening Classification

Step 1

Object Detection Using Deep Learning (YOLOv11)

Detect two classes (door and door handle) using YOLOv11.

Video: Door-Opening Direction Detection Using the Proposed Method

Step 2

door

knob

$Inter\_x1 = max(\bullet, \bullet)$
$Inter\_x2 = min(\times, \times)$
$Inter\_x1 < Inter\_x2$

Overlapping Conditions
(Similarly Evaluated in the Y-Direction)

Determine the overlap between the door and door-handle bounding boxes.

Step 3

door   door

knob   knob

Left-Opening Door   Right-Opening Door

$O < $ | Left-Opening Door
$ < O$ | Right-Opening Door

Door-Opening Direction Classification Conditions

Infer the door-opening direction using a geometric rule based on the handle's relative position to the door (and their overlap relationship).

4 Architecture

360-degree camera

1.5m

Dual fisheye image   Equirectangular Image

Image Input   Stitching Processing   Object Detection   Left–Right Classification (Geometric Inference)
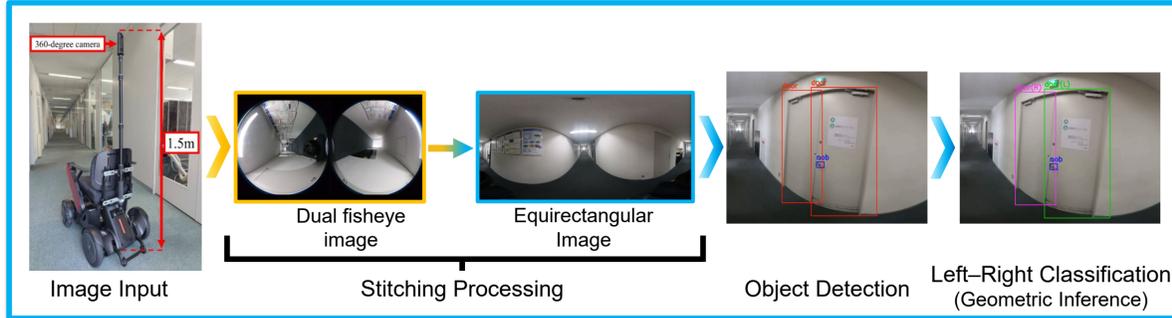
Key Design Ideas

- Computational cost is reduced by using a single omnidirectional camera instead of multiple cameras.
- Stable detection is achieved by fixing the camera height during both dataset acquisition and experiments.
- Image distortion is reduced by converting stitched images to an equirectangular projection, improving detection accuracy.
- Lightweight processing is achieved by detecting only two classes: door and door handle.
- Door-opening direction (left/right) is determined using a simple geometric rule based on the handle's position relative to the door, without deep learning.

5 Results

Dataset Composition

	Number of Images	Door (R) Instances	Door (L) Instances	Doorknob Instances	All Instances
Training	3000	5465	4544	3623	13632
Validation	804	750	705	512	1967

Improved Small-Object Detection Accuracy

640×320pix   Precision−Recall Curve   0.4

1400×700pix   Precision−Recall Curve   0.9
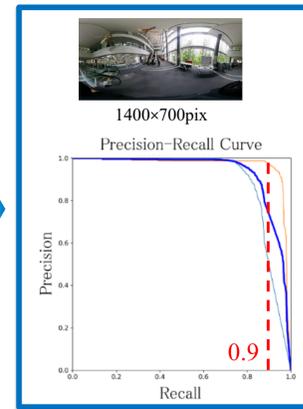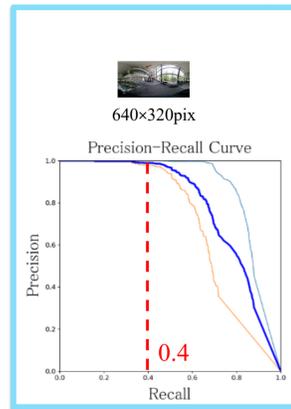
- Model: YOLOv11
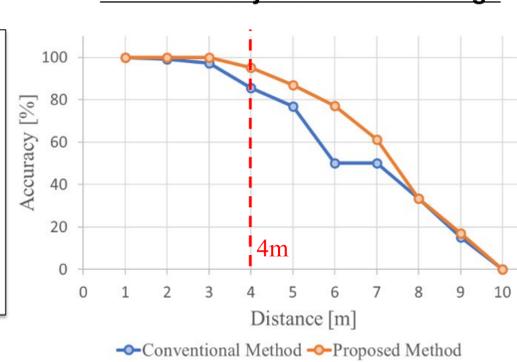- Epoch: 200
- Batch : 16
- Learning Rate: 0.01

— Door
— Doorknob
— Average

- Improved small-object detection (e.g., door handles) by using higher-resolution training images.

Confusion Matrix for Door Opening Direction and Door Handle Detection

Conventional Method (3 class)

	719	35	0	138
	6	458	0	119
	0	0	496	36
	53	39	46	

Proposed method (2 class)

	763	0	0	129
	0	468	0	115
	0	0	507	25
	26	19	32	

3 Classes — Conventional Method
2 Classes — Proposed method

Extended Object Detection Range

Accuracy [%] vs Distance [m]

4m

Conventional Method   Proposed Method

Improved Detection Accuracy

	Precision [%]		Recall [%]		F1-Score [%]		Accuracy [%]	
	3-CLASS	2-CLASS	3-CLASS	2-CLASS	3-CLASS	2-CLASS	3-CLASS	2-CLASS
Door(R)	92.4	96.7	80.6	85.5	86.1	90.8	78.0	83.4
Door(L)	86.1	96.1	78.6	80.3	82.2	87.5	78.0	83.4
Doorknob	91.5	94.1	93.2	95.3	92.4	94.7	78.0	83.4

+10%   +4~5%

3-CLASS : Conventional Method
2-CLASS : Proposed method

Runtime Performance

	fps	Output Delays [ms]	mAP50
Conventional Method (3 Classes)	11.05	749	0.907
Proposed method (2 Classes)	11.40	727	0.932

6 Conclusion and Future Work

- We proposed a method to estimate door-opening direction in real time using an omnidirectional camera, YOLO-based door and handle detection, and a geometric rule based on their spatial relationship.
- Compared with conventional multi-class detection, the proposed method improves processing speed and detection accuracy, demonstrating its feasibility for autonomous wheelchairs in real environments.
- Future work will focus on implementing automated door-opening and door-passage functions for autonomous wheelchairs using the proposed method, and on accurately distinguishing sliding doors and push doors through image processing.