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Multi-action Detection System Using Infrared Omnidirectional Cameras

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A short resume of the presenter

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Researcher @ Iwate Monodukuri Software Information Technology Center (i-MOS), Iwate Prefectural University in Japan. My research interests include “Computer Vision”, “Image Processing” and “Virtual Reality”.

2018 – Now	Researcher, i-MOS, Iwate Prefectural University
2016 – 2019	Student of doctor degree program, Graduate school of Information and Science, Iwate Prefectural University
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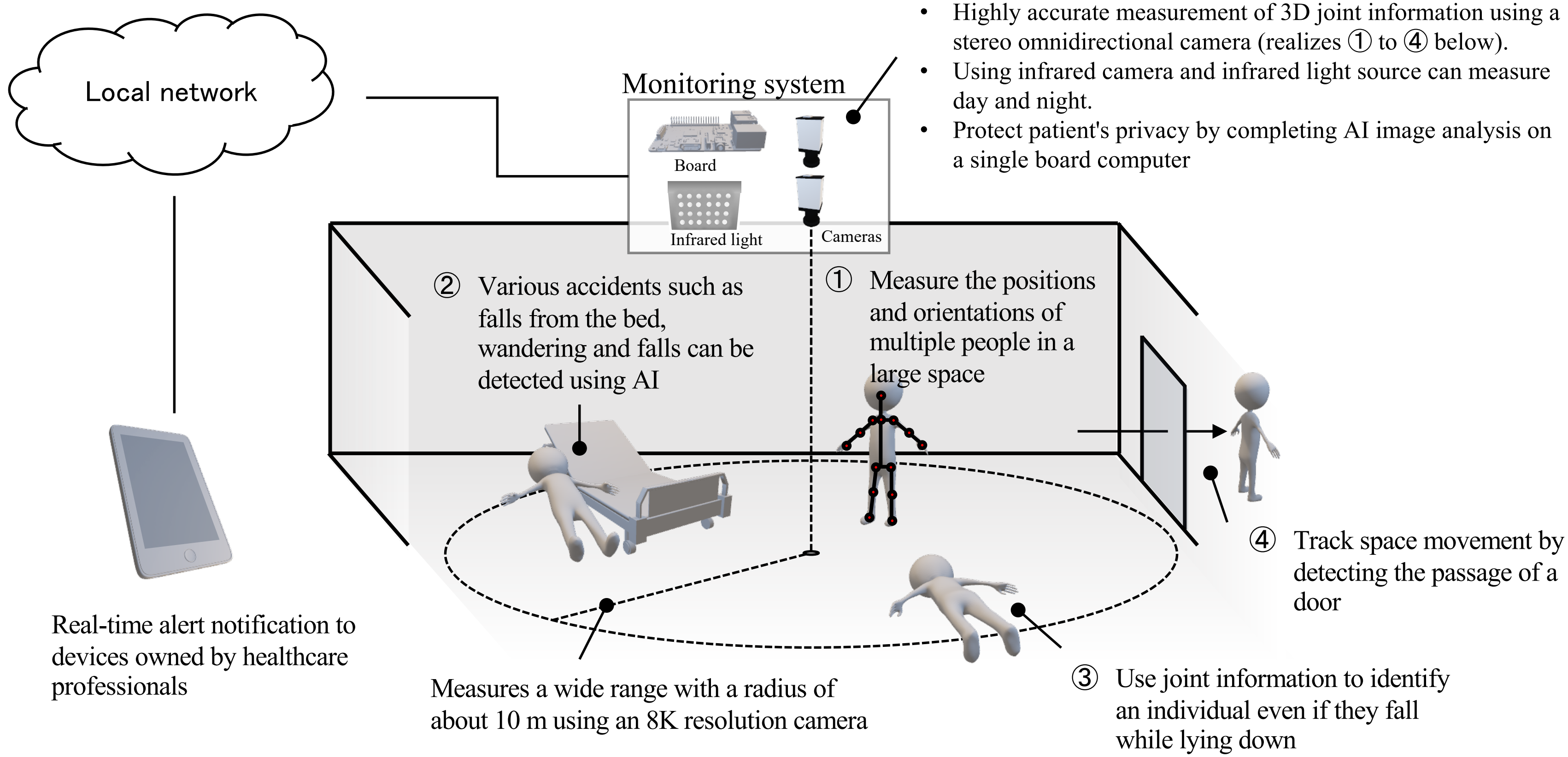
2010 – 2014	Student, Faculty of Information and Science, Iwate Prefectural University

The aim of our study

Development of monitoring system detecting actions that can be dangerous accident for patients using infrared omnidirectional stereo camera for reducing the burden on healthcare workers.

System features

- Highly accurate measurement of 3D joint information using a stereo omnidirectional camera (realizes ① to ④ below).
- Using infrared camera and infrared light source can measure day and night.
- Protect patient's privacy by completing AI image analysis on a single board computer



What are the issues in healthcare field

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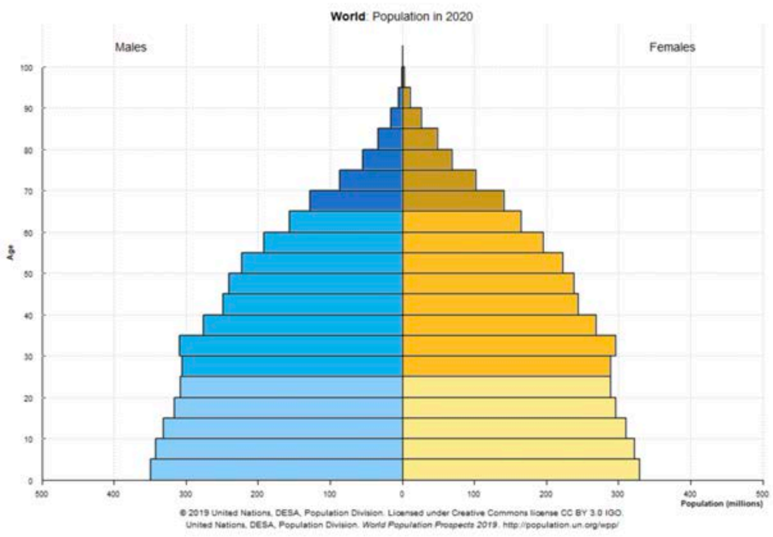
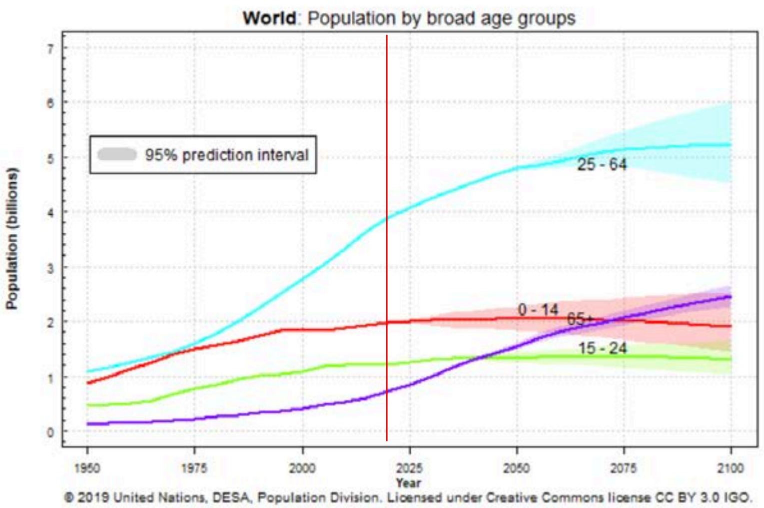
The increasing percentage of elderly people in many national populations lead to … [1]



Medium-variant data is shown as coloured bars, and uncertainty is shown in gray for 95 per cent prediction intervals.



→ increasing number of functionally impaired hospitalized patients.

→ increasing risk of falling and wandering consequently injuring themselves.

→ Increasing the burden on healthcare workers and deterioration in both the quality of care and patient's QOL (Quality of Life).

※https://population.un.org/wpp/

Existing healthcare support equipment

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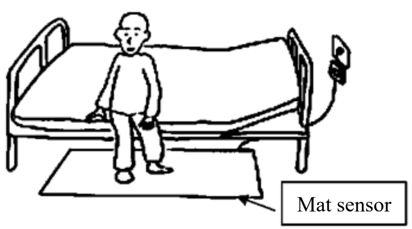
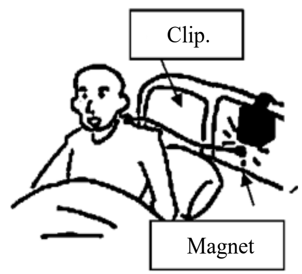
Several measures have been introduced in healthcare settings to detect patient actions, but their effectiveness is limited. [2]

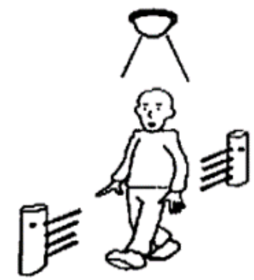
- Detecting rising from the bed and leaving the bed for preventing fall down from the bed
- Detecting and notifying patient's moving for preventing wandering



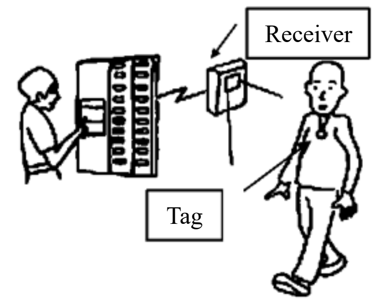
Mat sensor



Clip-type sensor



Heat and infrared sensor



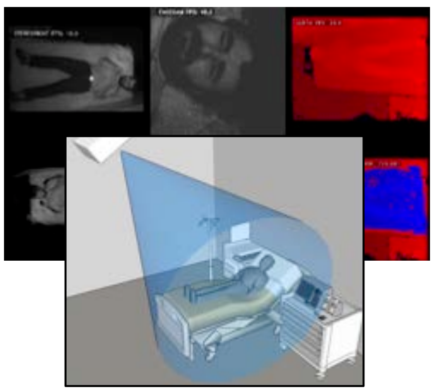
Tag sensor

Major issues

Patient moves sensor intentionally	Patient intentionally removes sensor	Patient intentionally avoids sensor	Patient intentionally removes sensor
False detection of visitor causes	miss detections due to unintentional movement	False detection of visitor causes	Monitor is always required to prevent falls

Related work using optical sensors

At the research level, many efforts developed non-invasive monitoring using optical sensors.



Automated Multi-Camera System (Martinez et al.) [3]

Developing a monitoring system for patients on the bed in a healthcare facility using an infrared camera.

It can only detect a patient leaving the bed; it cannot detect wandering or falling. Furthermore, the monitoring area is limited to a bed and its immediate area.

A multi-action monitoring system (Murata et al.) [4]

Developing a multi-action monitoring system for healthcare facilities that uses MS-KINECT sensors.

It cannot detect a person lying on a bed because they cannot detect differences in the depth between a patient and a bed.

Moreover, their coverage is limited to a bed and the surrounding area.

Requirements for a monitoring system

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We considered the following requirements to be essential for developing a patient monitoring system.

- Monitoring both day and night (i.e., 24-hour monitoring). ……①
- Locating and identifying multiple patients. ……①
- Monitoring entire multi-patient room using a minimum amount of easy-to-install equipment. ……①
- Detecting multiple actions, including rising from the bed, leaving the bed, falling down, and wandering. ……②
- Notifying hospital staff of abnormal patient actions. …… ③
- Protecting privacy. …… ②・③

On the basis of these requirements, We developed multi-action detection system that have has following features.

① The system capture the room using only infrared omnidirectional camera.
② We employing "OpenPose" library[5] and use only patient joint information.
③ The system enable to detect multi-action and send to the healthcare workers.

Overview of the proposed system

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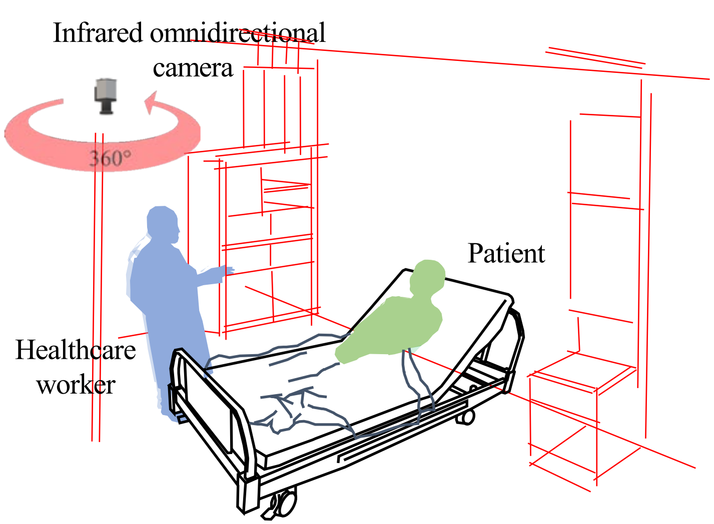
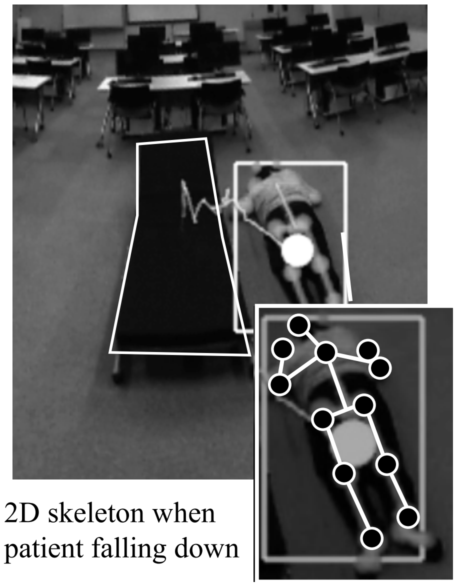
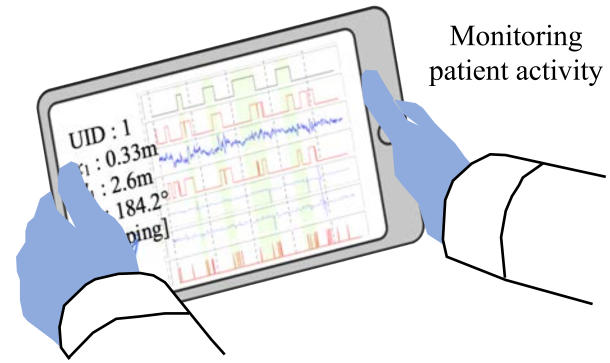
In this paper





2D skeleton when patient falling down



Capturing multiple patient using infrared omnidirectional camera through day and night.

Detecting multi-action in accordance with predefined rules.

Notify the patient's accident to the medical staff's terminal.

a. Panorama expansion from images captured by the camera.
b. Detection and tracking of patients using 2D skeletal images obtained using the OpenPose library.
c. Joint angle calculation, and action classification.

a. Panorama expansion

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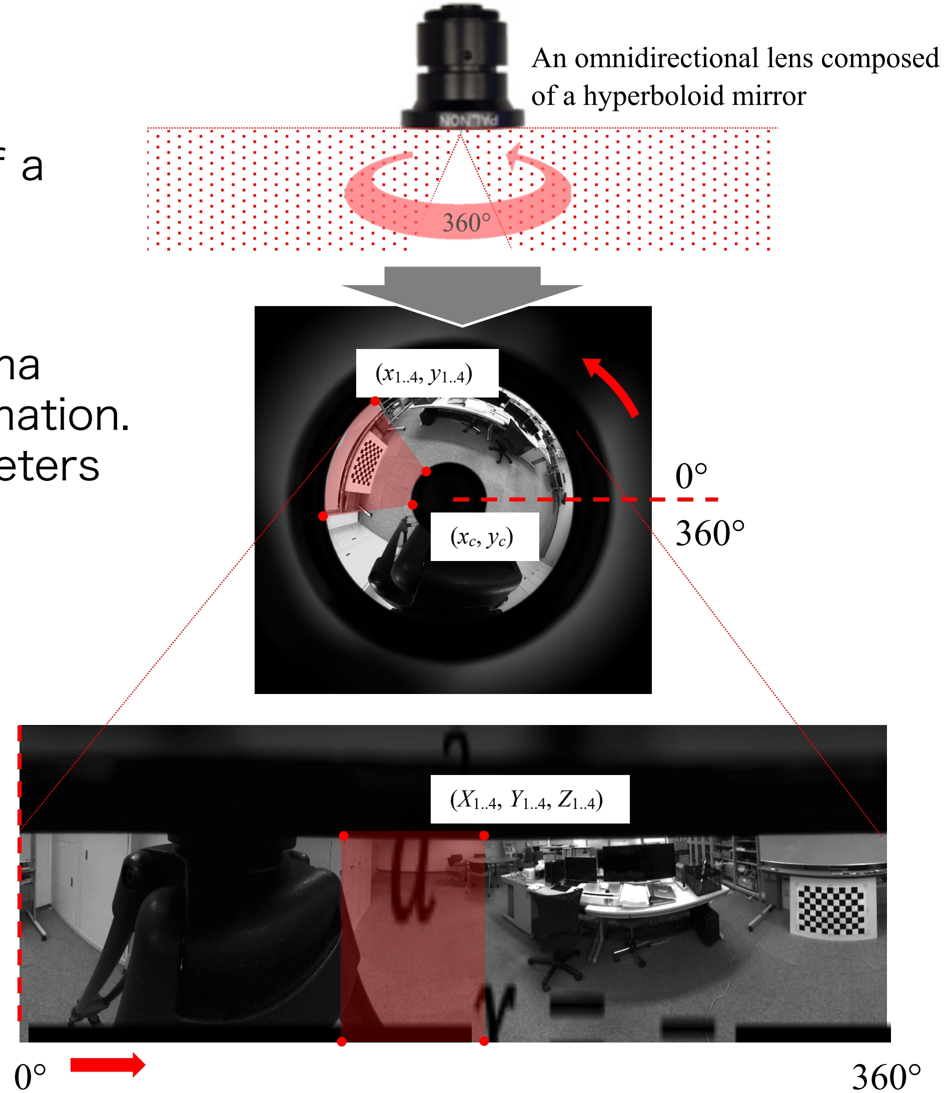
An omnidirectional lens composed of a hyperboloid mirror enables the capture of a 360° image from the projection of the hyperboloid mirror.

Captured image is expanded to a panorama image by perspective projection transformation. Four vertex pairs are calculated as parameters using following equations.

$$x = -\frac{a^2 f X}{(b^2 + c^2)Z - 2bc\sqrt{X^2 + Y^2 + Z^2}} + x_c$$

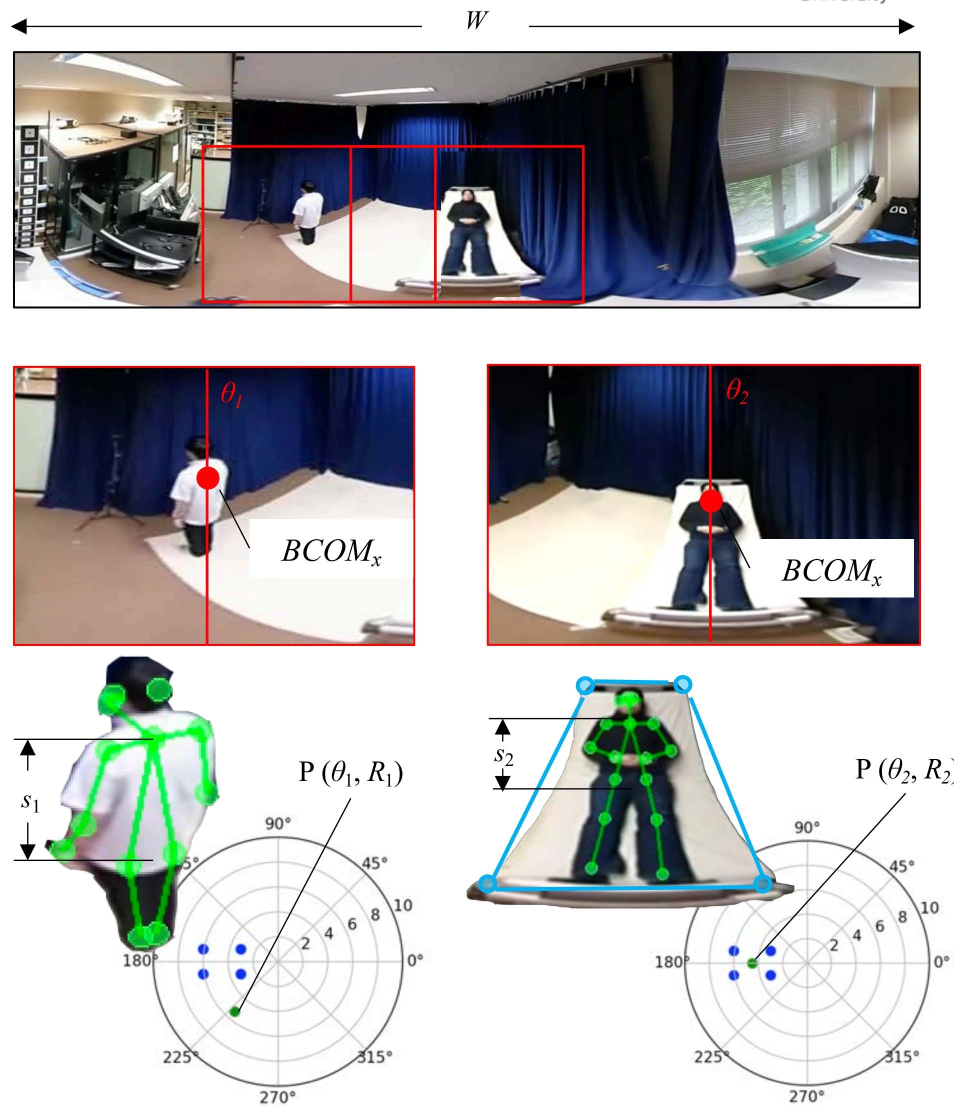
$$y = -\frac{a^2 f Y}{(b^2 + c^2)Z - 2bc\sqrt{X^2 + Y^2 + Z^2}} + y_c$$

a, b, c : parameters for the hyperboloid mirror satisfying $c^2 = a^2 + b^2$
f : focal length



b. Detecting and tracking patient location

The location of the patient is defined as a polar coordinate $P(\theta, R)$, which is calculated using skeletal coordinate $Joint\,(j_{1..}j_n)$.



Azimuth θ

$$\theta = 360 \cdot \frac{BCOM_x}{W}$$

the horizontal coordinate of the BCOM (Body Center Of Mass)

$$BCOM_x = \frac{j_{1x} + j_{2x} + j_{3x} \cdots j_{nx}}{n}$$

Distance R

$$R = s \cdot dist_w$$

c. Calculation of joint angles and action classification

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Patient actions are classified using several parameters calculated from the skeletal information.

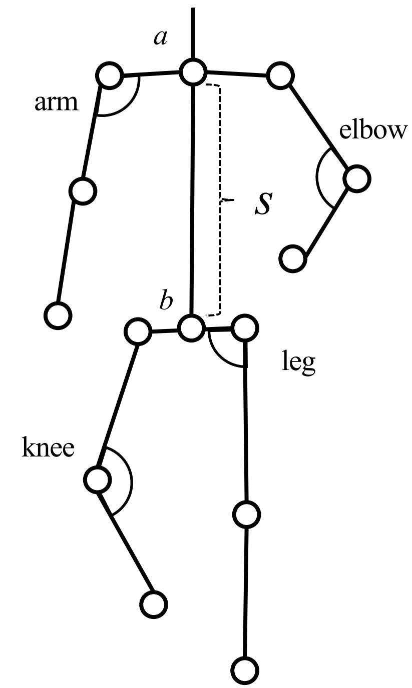
Patient's movement: standard deviation of BCOM

$$Var_{bcom} = \sqrt{\frac{1}{m}\sum_{j=1}^{m}\left(BCOM_{j(x,y)} - \overline{BCOM}_{(x,y)}\right)^2}$$

Joint angle (elbow, arm, keg, knee)

$$\theta_{joint} = 180° - \frac{\bar{u} \cdot \bar{v}}{|\bar{u}| \cdot |\bar{v}|}$$

Each joint angle is calculated separately for the left and right sides



Pre-defined action classification rules

	Inside the bed	Moving	Tilt angle [°]	Joint angles [°]	head position
Rising from the bed	Yes	No	<±30	-	high → low
Leaving the bed	Yes → No	Yes	±30<= → <±30	leg<45 → 150<=leg	-
Falling down	No	Yes → No	±45<=	-	-
Wandering	No	Yes	<±30	160<kne, 150<=elbow	-

Experiment Ⅰ

- Experiment setting -

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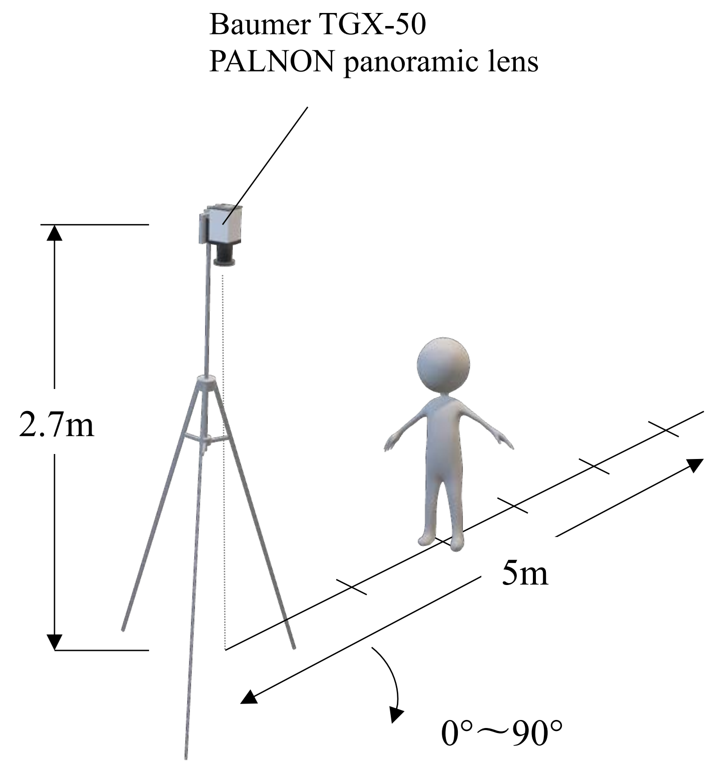
Aim:
Measurement the accuracy of patient location estimation.

Participants:
12 participants

Equipment:
Baumer TGX-50 (2840 × 2040, 30 fps)
PALNON panoramic lens (elevation 66°, depression 0°)

Experiment contents:
We measured the position of each participant at a total of 35 points in increments of 15° up to 90°, 1 to 5 m in increments of 1 m.

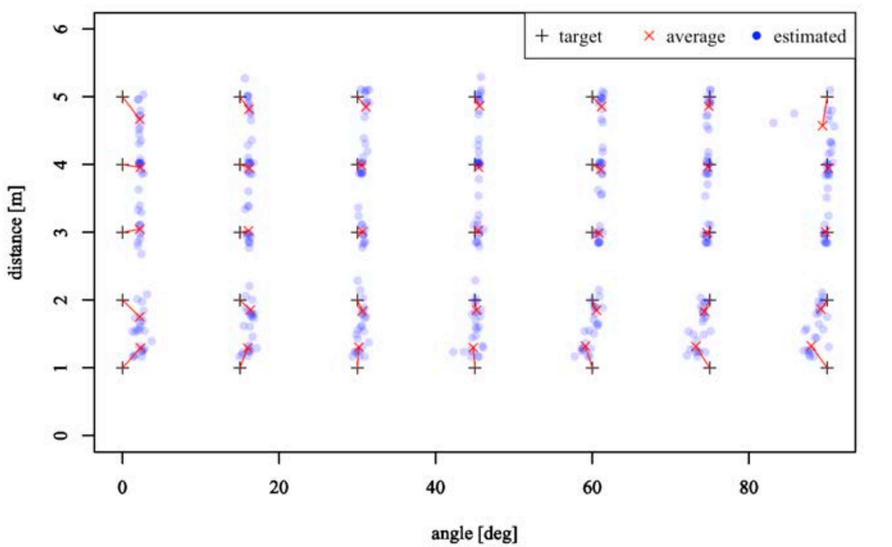
Evaluation index:
Root Mean Square Error (RMSE)

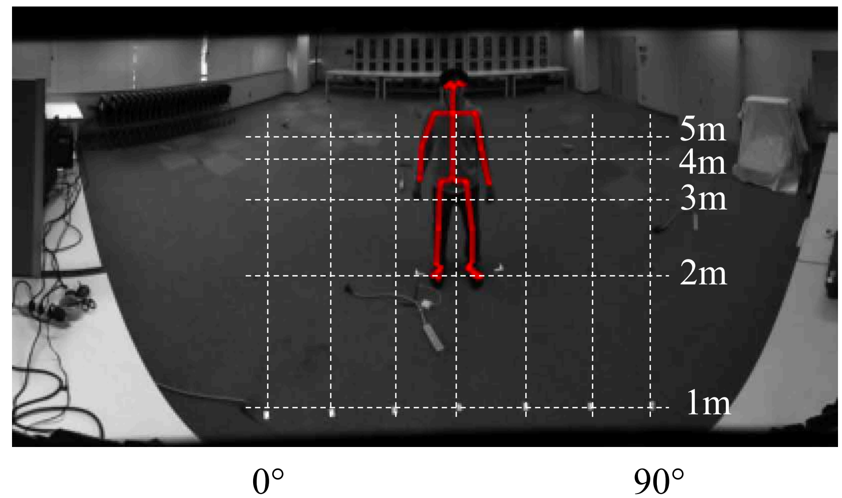


Experiment Ⅰ

- Result -

The RMSE for the azimuth was **1.30**°, the RMSE for the distance was **0.27m**.





→ Sufficiently accuracies for the proposed system to be used in practical situations.

→ No significant error was observed for up to 5 m, indicating that a single omnidirectional camera can effectively cover a large multi-patient room.

Experiment Ⅱ

- Experiment setting -

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Aim:
Evaluation the accuracy of the proposed action classification method.

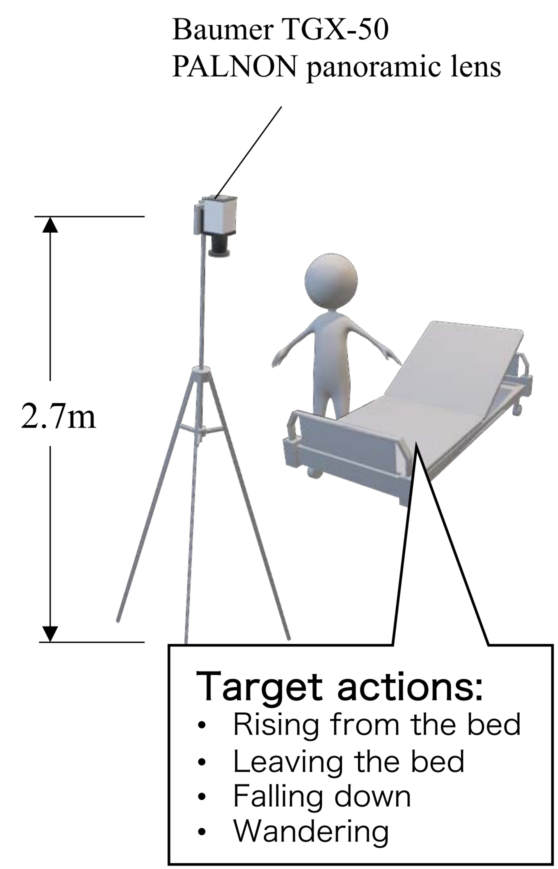
Participants:
8 participants

Equipment:
Same as Experiment Ⅰ

Experiment contents:
Patient actions were collected as video data by having the participants perform the four target actions three times each for each participant.

The correct data was manually annotated while the video was being checked.

Evaluation index:
A confusion matrix showing how well the actions were correctly estimated for all frames in the video.



Experiment Ⅱ

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- Result -

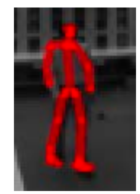
[frame]

	Confusion matrix					
	True positive	False positive	False negative	True negative	Accuracy	Precision
Rising from the bed	601	3366	959	22511	84.24%	15.15%
Leaving from the bed	1087	539	828	24983	95.02%	66.85%
Falling down	2216	961	449	23811	94.86%	69.75%
Wandering	3727	2012	2231	19467	84.54%	64.94%

Leaving the bed

Rising from the bed

Falling down



Wandering

The accuracy of estimating each action exceeded 80%. The precision was 60~70% except for rising from the bed. The number of false detections was high for each action.

→ It is difficult to measure depth information for the joint coordinate occulted by other body parts and difficult to estimate correct body orientation.

→ We found that our rule-based action classification using 2D skeletal images has limitations.

Experiment Ⅱ

- Result -

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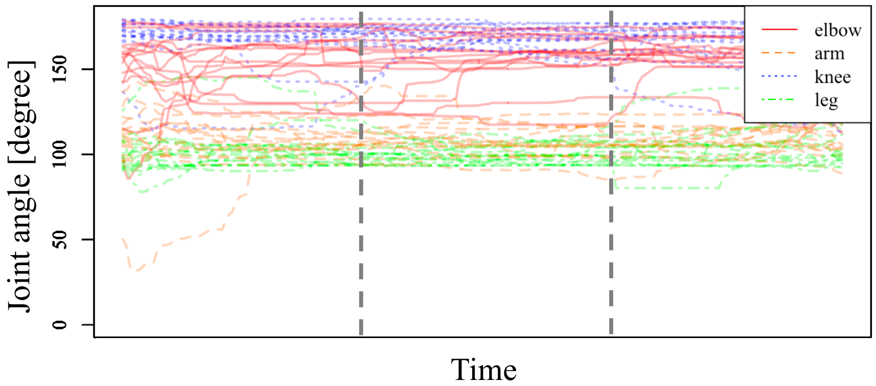
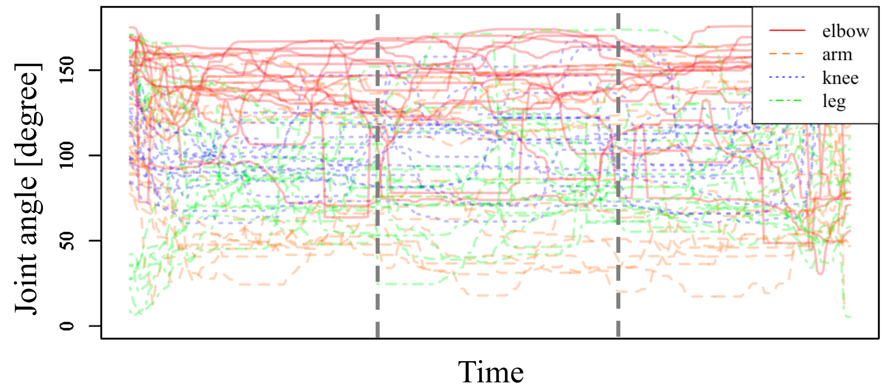
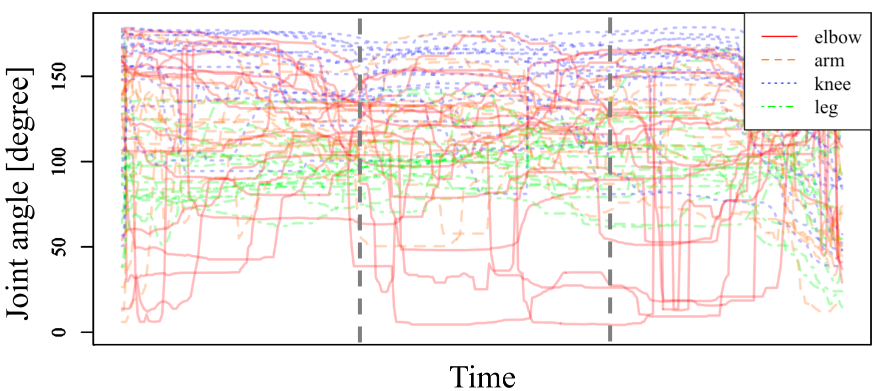


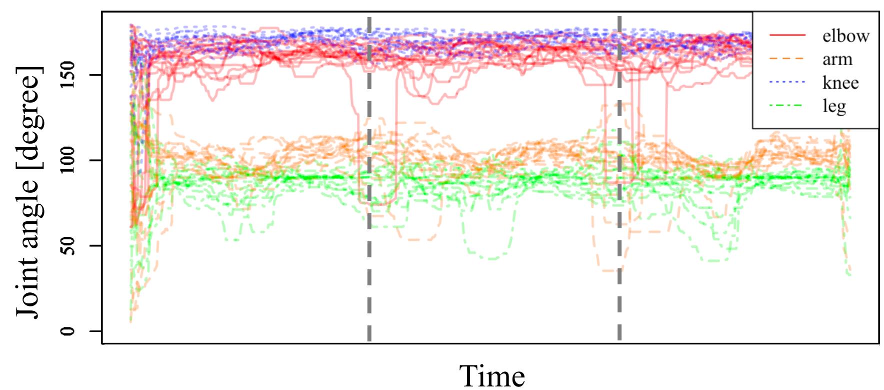
Rising from the bed



Leaving the bed



Falling down



Wandering

The change in the joint angle for each action was quite similar for all participants.
→ This shows the possibility of classification by time-series deep learning.

Conclusion

In this study

We proposed novel patient monitoring system using an infrared omnidirectional camera for healthcare facilities.

- Enables detection and classification of various actions that can be dangerous for patients.
- Can accurately estimate the locations of multiple patients enabling each patient action to be identified in a wide area.
- Can be applicable not only to healthcare facilities but also to facilities that have wide areas

Future work

- Investigating the effect on classification accuracy of the use of machine learning to estimate the changes in joint angles and the effect of using a stereo camera to obtain 3D images.
- Implementation a single-board computer for easy equipment installation and privacy protection.
- Integrating the system with our developed alert notification systems.

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6. Baummer, https://www.baumer.com/ch/en/ [retrieved: Febrary, 2020]

That’s all, Thank you.

For any question or comment, please contact the following.

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