An Exercise Recommendation System While Performing Daily Activities Based on Contextual Information

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Lab introduction and Authors' mini-bio

Daily Life Computing Laboratory (DLCL)

http://tuat-dlcl.org/welcome_en/

- Established in 2007 by Prof. Dr. Kaori Fujinami
- Research topics
  - Ubiquitous computing, Tangible User Interfaces
  - Human-Computer Interaction, Human-Agent Interaction
  - Human/Animal activity recognition
  - Augmented/Virtual/Mixed Reality
  - Behavioral changing systems

Authors

Ms. Mizuki Kobayashi

- Received her B.E and M.E in computer science from TUAT in March 2021 and 2023, respectively.
- Now working in industry
- Research interest
  - Activity recognition
  - Behavioral changing systems

Prof. Dr. Kaori Fujinami

- Received his B.E. and M.E. degrees in electrical engineering and his Ph.D. degree in computer science from Waseda University in 1993, 1995, and 2005, respectively.
- From 1995 to 2003, he worked for NTT and NTT Comware Co., as a software engineer.
- From 2007 to 2017, he was an associate professor in the Department of Computer and Information Sciences at TUAT.
- Since 2018, he has been a professor at TUAT.
- Established DLCL in 2007 and is leading now.

Background

Background

- Benefits of Exercise
  - Decreases risk of heart disease, diabetes, cancer, etc.
  - Delays the onset of dementia
- Over 1.4 billion people worldwide do not exercise[1]
  - No improvement since 2001
- Reasons for not increasing exercise[2]
  1. Too busy with work or housework
  2. Too troublesome
  3. I am old.
  4. No particular reason
  5. I cannot afford exercise.

To increase the opportunity of exercise,
it is important to incorporate exercise into daily life that can be performed while working or doing housework.

[1] Regina Guthold, et al. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. The Lancet Global Health, Vol. 6, No. 10, pp. e1077–e1086, 2018.
[2] Japan Sports Agency, "Public opinion poll on the status of sports implementation, etc.," https://www.mext.go.jp/sports/content/20220310- spt_kensport01-0000204871.pdf.

Proposed method

Recommendation based on contextual information

Concept of “Exercise Recommendation System While Performing Daily Activities”

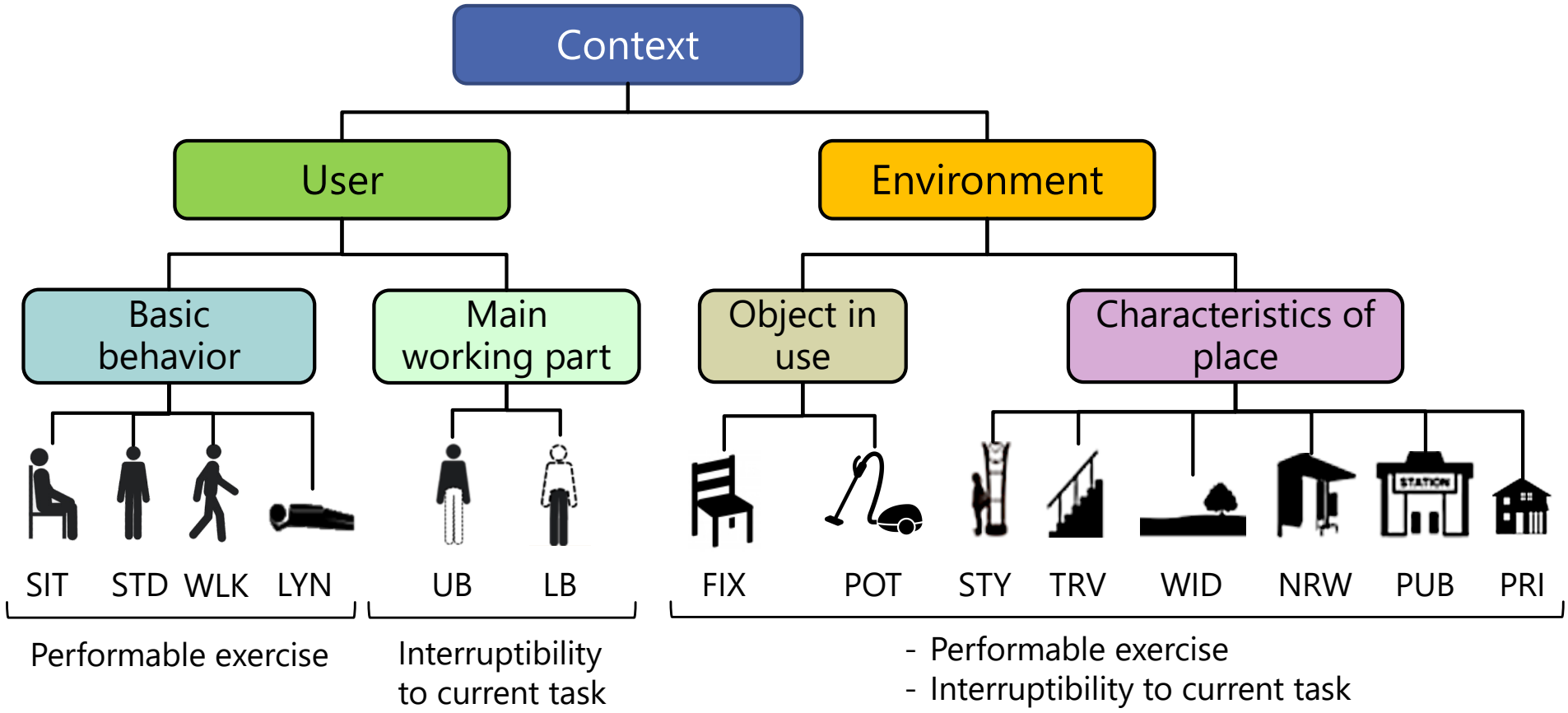
Acquiring user’s contextual information from user him/herself and surrounding environments (objects and places)

Context as a key to find suitable exercise

Cosine similarity-based item (candidate) comparison

Recommendation of exercises that should match to the context

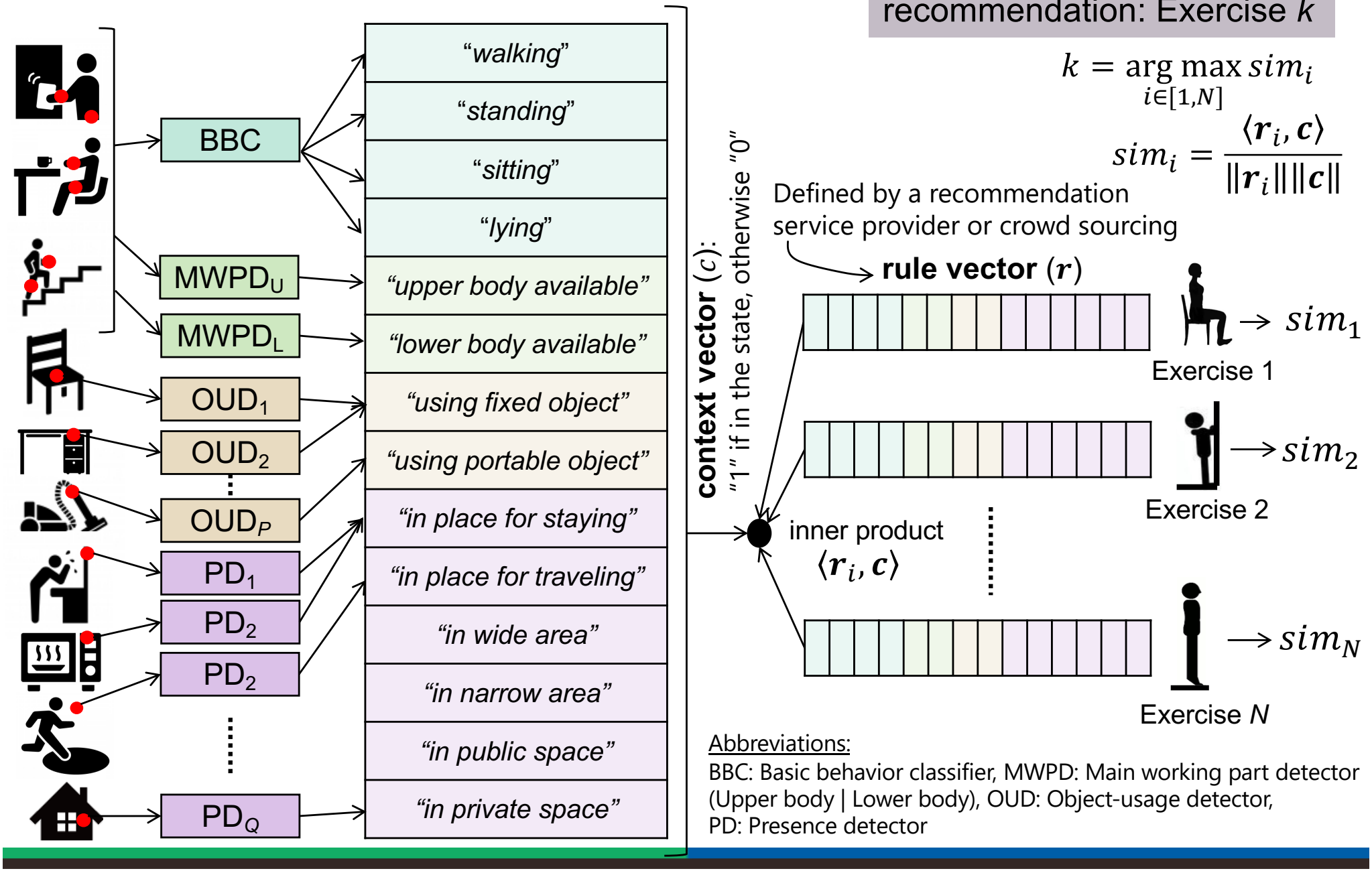
Categories of contextual information and specific values



Abbreviations:
SIT: Sitting, STD: Standing, WLK: Walking, LYN: Lying, UB: Upper body, LB: Lower body, FIX: Fixed objects, POT: Portable objects, STY: Place for staying, TRV: Place for traveling, WID: Wide area, NRW: Narrow area, PUB: Public area, PRI: Private area

Detail of recommendation

Cosine similarity-based item selection using 14-bit context and rule vectors



Abbreviations:
BBC: Basic behavior classifier, MWPD: Main working part detector (Upper body | Lower body), OUD: Object-usage detector, PD: Presence detector

Experiment and Analysis

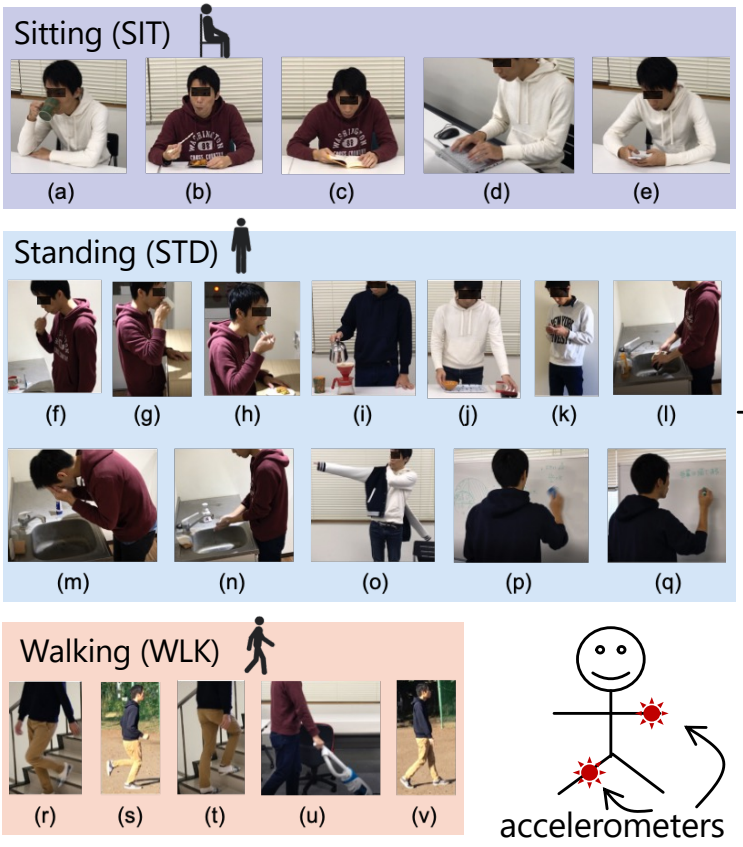
Offline (= simulation-based) experiment

1. Basic behavior classification performance
2. Performance of detecting availability of body parts
3. Overall recommendation

User study with working prototype

Offline experiment 1: Basic behavior classification

Q: How well can daily activities be classified into one of four BBCs?



Dataset of 22 daily activities collected from 14 people*

*: People in the training and test datasets were different.

Method

Dataset of 4 basic behaviors (sitting, standing, walking, and lying) collected from 10 people*

Training

Test (input) → RandomForest Classifier → Result (output)

Table:
Basic behavior classification performance metrics

Basic behavior	Recall	Precision	F-measure
SIT	0.763	0.998	0.865
STD	0.940	0.937	0.939
WLK	0.867	0.902	0.884
LYN	N/A	N/A	N/A
Macro average	0.857	0.946	0.896

Basic behavior (output)

Daily activity (input)

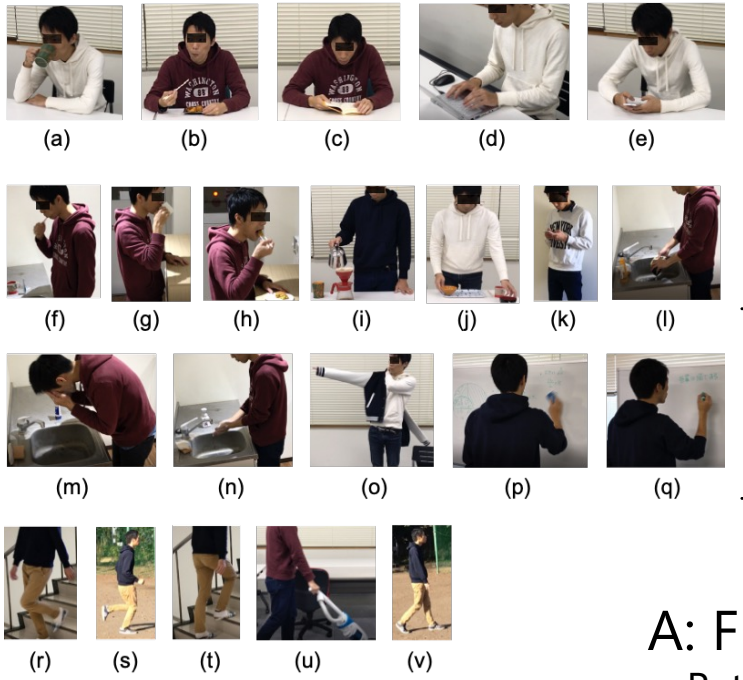
# of instances	SIT	STD	WLK	LYN
(a) DK_SIT	2718	300	12	903
(b) ET_SIT	3012	2	1	976
(c) RB	2618	3	3	1380
(d) UC	3475	1	2	483
(e) SP_SIT	3337	0	7	635
(f) BT	0	3987	5	8
(g) DK_STD	9	3936	2	11
(h) ET_STD	0	3969	0	11
(i) MC	0	3552	3	22
(j) ST	0	1526	1322	700
(k) SP_STD	0	3945	0	1
(l) WD	0	3953	0	1
(m) WF	0	3828	15	1
(n) WH	0	3739	8	0
(o) WJ	7	3012	413	8
(p) EW	0	3870	50	27
(q) WW	9	3310	2	83
(r) DS	0	0	3695	1
(s) RN	0	0	4003	0
(t) US	0	1	4057	0
(u) VC	3	2538	1296	87
(v) WK	0	0	4032	0

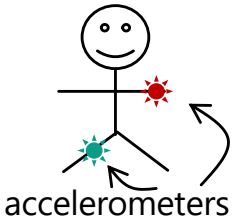
A: Satisfactory as a context detector.

- High average F-measure (=0.896) ↑
- Confusion matrix also followed intuition. →

Offline experiment 2: Availability of body parts

Q: How well are the main working parts of daily activities detected?





Dataset of 22 daily activities collected from 14 people

Rule-based detection

if variance of a window > *th*

→ 0: used, i.e., unavailable

otherwise

→ 1: not used, i.e., available

$MWPD_U$ (left wrist)

$MWPD_L$ (right thigh)

Ratio of "1: not used" to total # of instances

The closer to the value is 1.0, the more cases are judged as "the part is available for exercise."

Daily activity (input)	LW	RT
(a) DK_SIT	0.88	0.93
(b) ET_SIT	0.81	0.98
(c) RB	0.93	0.98
(d) UC	0.97	0.98
(e) SP_SIT	0.97	0.97
(f) BT	0.72	0.64
(g) DK_STD	0.86	0.72
(h) ET_STD	0.74	0.82
(i) MC	0.58	0.65
(j) ST	0.57	0.09
(k) SP_STD	0.96	0.86
(l) WD	0.08	0.54
(m) WF	0.07	0.58
(n) WH	0.04	0.63
(o) WJ	0.01	0.30
(p) EW	0.74	0.13
(q) WW	0.97	0.64
(r) DS	0.01	0.00
(s) RN	0.00	0.00
(t) US	0.03	0.00
(u) VC	0.17	0.00
(v) WK	0.09	0.00

A: Findings…

- Ratio of LW for "both-hands"-dominated movement, e.g., WD and WF, showed low availability. ☺
  - Inevitable in misjudgment in single (dominant)-hand activities, e.g., DK_SIT and ET_SIT, due to data from sensors on opposite hand. ☹ But…the system should recommend exercises that can be done when the upper and lower body are free, respectively, to allow the user to make the final decision. ☺
- Ratio of both RT and LW were low when the arms and legs were moved together, e.g., WK, WD, and VC. ☺

Offline experiment 3: Recommendation (1): Method

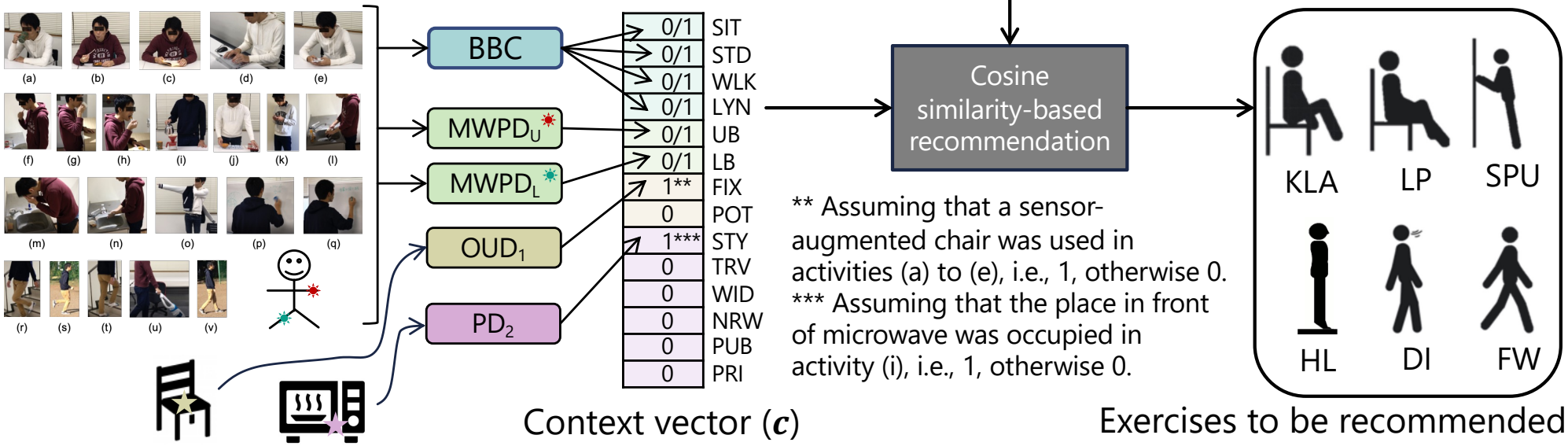
Q: How well do recommended exercises match to the current context?

Table:
Rule vector ($\boldsymbol{r}_i$) representing the rules of exercise recommendation*

* S. Nagano, "Get rid of your busy schedule and get some exercise! One-minute exercise diet," PHP Institute, 2003.

Exercise[a]	Basic behavior				Main working part		Object in use		Characteristics of place					
	SIT	STD	WLK	LYN	UB	LB	FIX	POT	STY	TRV	WID	NRW	PUB	PRI
KLA	1	0	0	0	0	1	1	0	0	0	0	0	0	0
LP	1	0	0	0	1	0	1	0	0	0	0	0	0	0
SPU	0	1	0	0	0	1	0	0	1	0	0	0	0	0
HL	0	1	0	0	1	0	0	0	1	0	0	0	0	0
DI	0	0	1	0	0	1	0	0	0	0	0	0	0	0
FW	0	0	1	0	1	0	0	0	0	0	0	0	0	0

[a] KLA: knee lift abdominal exercise, LP: leg-pushing exercise, SPU: standing push-up exercise, HL: heel lift-up exercise, DI: drawing-in exercise, and FW: striding with a large belly and fast walking.



Context vector ($\boldsymbol{c}$)

Exercises to be recommended

Offline experiment 3: Recommendation (2): Result

- LP () and KL () were recommended more frequently for sitting-related daily activities the others, especially, LP.
  - KLA was defined as an exercise suitable in upper-body availability, and upper-body movements seem to be detected in theses activities.
- SPU () and HL () were recommended more frequently for standing-related daily activities.
  - Especially, HL was more often recommended for activities using both hands because of upper-body's unavailability.
  - Activities with more chance of recommendation of SPU were due to the "non-dominant hand" problem. The sensor on LW was not moved enough to detect as "being used."
  - Walking-related exercise DI () was recommended for ST (setting table for meal), which might be because walking might happen during preparing for meal.
- DI () and FW () were recommended more frequently for mobility-related activities, especially, DI.

Ratio of recommended items per activity (output)

Daily activity (input)	KLA	LP	SPU	HL	DI	FW
DK_SIT	0.37	0.63	0.00	0.00	0.00	0.00
ET_SIT	0.43	0.57	0.00	0.00	0.00	0.00
RB	0.45	0.55	0.00	0.00	0.00	0.00
UC	0.40	0.60	0.00	0.00	0.00	0.00
SP_SIT	0.41	0.59	0.00	0.00	0.00	0.00
BT	0.00	0.00	0.34	0.66	0.00	0.00
DK_STD	0.00	0.00	0.72	0.28	0.00	0.00
ET_STD	0.00	0.00	0.53	0.47	0.00	0.00
MC	0.00	0.00	0.35	0.65	0.00	0.00
ST	0.00	0.00	0.38	0.00	0.62	0.00
SP_STD	0.00	0.00	0.75	0.25	0.00	0.00
WD	0.00	0.00	0.19	0.81	0.00	0.00
WF	0.00	0.00	0.09	0.91	0.00	0.00
WH	0.00	0.00	0.17	0.83	0.00	0.00
WJ	0.00	0.00	0.02	0.90	0.00	0.08
EW	0.00	0.00	0.88	0.09	0.03	0.00
WW	0.00	0.00	0.96	0.04	0.00	0.00
DS	0.00	0.00	0.00	0.00	0.77	0.23
RN	0.00	0.00	0.00	0.00	0.60	0.40
US	0.00	0.00	0.00	0.00	1.00	0.00
VC	0.00	0.00	0.43	0.00	0.57	0.00
WK	0.00	0.00	0.00	0.00	1.00	0.00

User study (1): Method

Objective: To evaluate if the recommendation matches the context when it is received.

Method:

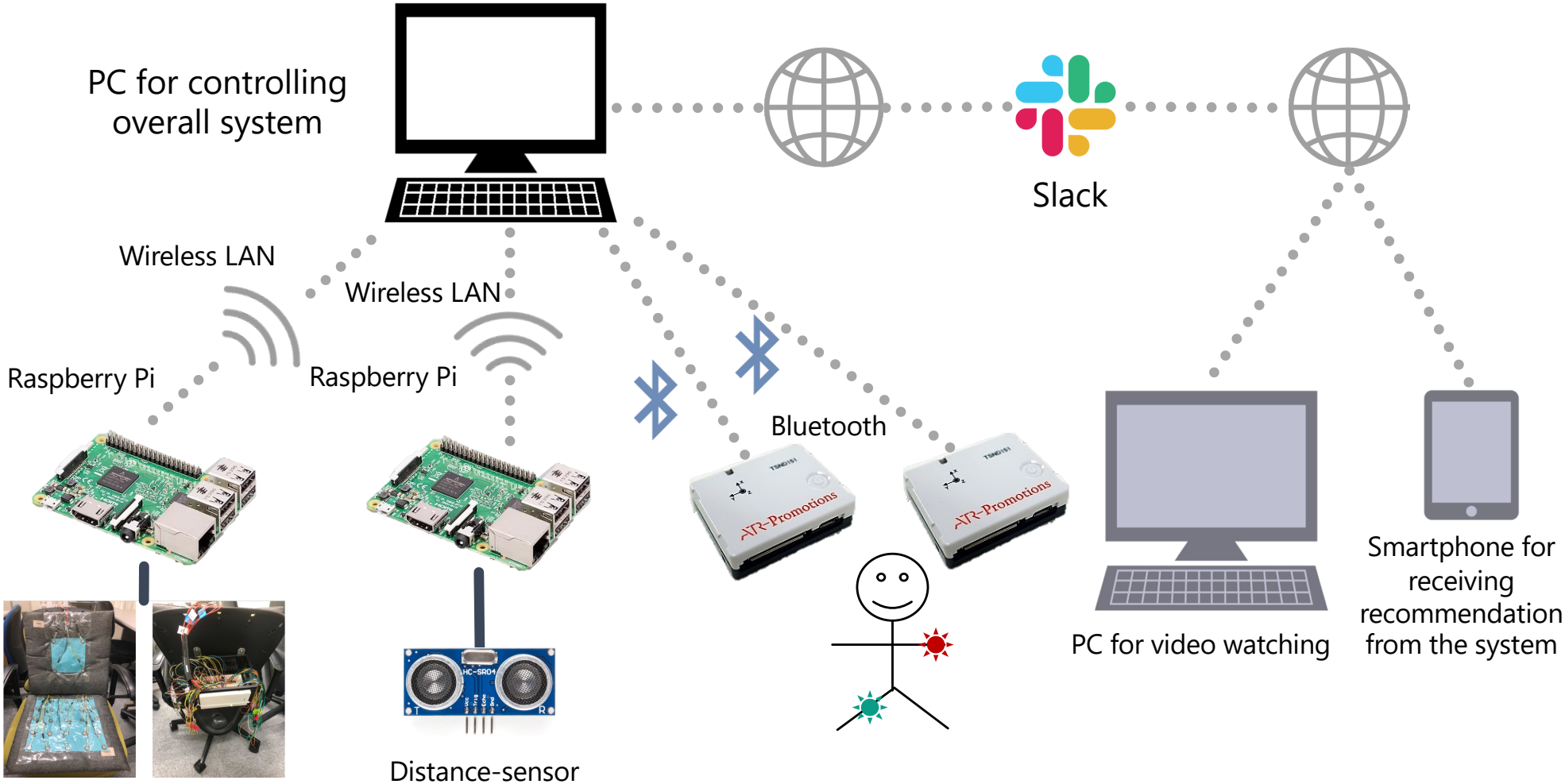
- 15 participants (different from the providers of the offline experiment)
  - Accelerometer on LW and RT, sensor-augmented chair, and motion sensor on microwave
  - Recommended through slack on their own smartphones
- Two conditions of activities: *Specified* and *Free*
  - Watching videos on a PC as SIT ( )
  - Waiting for snacks to warm up in front of microwave as STD ( )
  - Entering and leaving a laboratory room as WLK ( )

  → "specified"
  - Performed freely in the same room for 10 minutes → "free"

Evaluation

- Questionnaire survey with 5 levels at the end of each activity in specified condition and after 10 min's activity
  1: inappropriate recommendation for current context,
  2: slightly inappropriate,
  3: neither appropriate nor inappropriate
  4: slightly appropriate,
  5: appropriate
- Calculated the ratio of each score of participants' reply to total number of replies
- Compared the contribution of the element of contextual information

User study (2): Experimental system



User study (3)

Result

- More than 80% of the recommendations were evaluated as "appropriate recommendation", i.e., score = 5.
- Using both contextual information from user and environment (object and place) were better than individual contextual information.

Table:
Relative frequency of the user evaluation scores on the recommended exercises
(= ratio of each score of participants' reply to total number of replies)

Score	Specified			Free		
	User	Environment	All	User	Environment	All
1	0.014	0.000	0.005	0.014	0.012	0.014
2	0.032	0.022	0.014	0.041	0.012	0.010
3	0.045	0.034	0.032	0.041	0.043	0.024
4	0.104	0.134	0.127	0.092	0.092	0.077
5	0.805	0.810	0.824	0.812	0.840	0.876
N_{rec}*	221	179	221	218	163	209

* Total number of recommendation

Conclusion

Conclusion

- Proposed exercise recommendation based on contextual information of user's activities, availability of body working parts for exercise, objects in use, and place.
- Simulation-based experiment
  - Classification performance of 22 daily activities into 3 classes of basic behaviors showed high macro average F-measure (=0.896) even against test data from unseen people. Confusion matrix also followed intuition. (Slide p. 11)
  - Evaluation on detecting the availability of body working parts was basically as expected with an exception of "non-dominant hand" problem. (Slide p. 12)
  - Overall recommendation was also mostly intuitively correct. (Slide pp. 13-14)
- User study with working prototype (Slide pp. 15-17)
  - More than 80% of the recommendations were evaluated as "appropriate recommendation."
  - Using both contextual information from user and environment were better than individual contextual information.
- Future work
  - Investigating rule generation with participation of users based on interactive genetic algorithm (IGA)