RF-ARP: RFID-based Activity Recognition and Prediction in Smart Home

Yegang Du

Japan Advanced Institute of Science and Technology (JAIST)
1-1 Asahidai, Nomi, Ishikawa, Japan
Email: duyegang@jaist.ac.jp

Dec 5, 2019

Internet of Things (IoT)

IoT in Industry 4.0

- Over the past several years, IoT has been well developed in both academe and industry. All kinds of IoT systems improved the production efficiency and security in different areas, greatly.

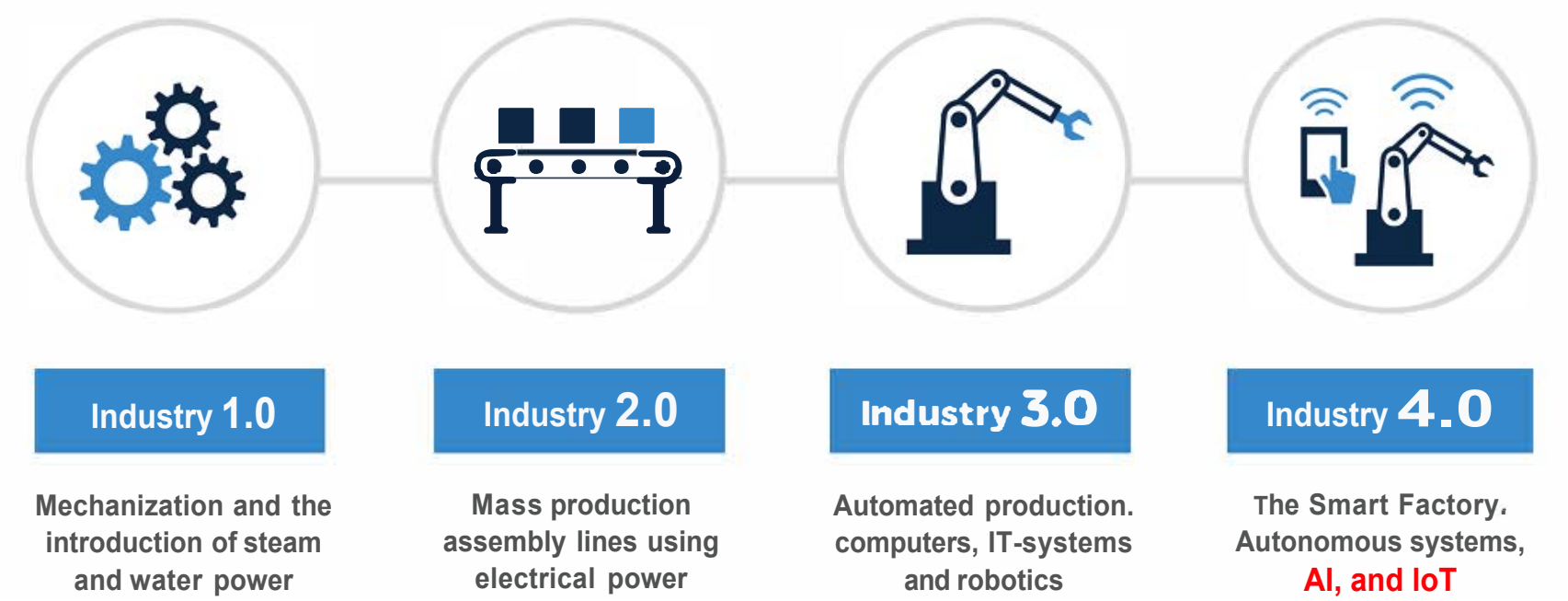


Figure 1: After the past three industrial revolutions, we come to industry 4.0.[1]

[1] https://www.spectralengines.com/articles/industry-4-0-and-how-smart-sensors-make-the-difference

The Trend of IoT

Smart Industry

- When Industrial Internet of Things (IIoT) hugs intelligence, that enables content-aware data processing to improve the efficiency of manufacturing and save more energy.

Smart Agriculture

- IoT applications are used to collect the data of temperature, rainfall, humidity, wind speed and so on, to provide automatic decision in the farm management.

Smart City

- IoT applications are usually utilized to build smart city, which can continuously monitor and automatically control the infrastructures like railway, bridges, parking lots, etc.

IoT Around Human

Then, how can IoT provide ***smart*** services to human?

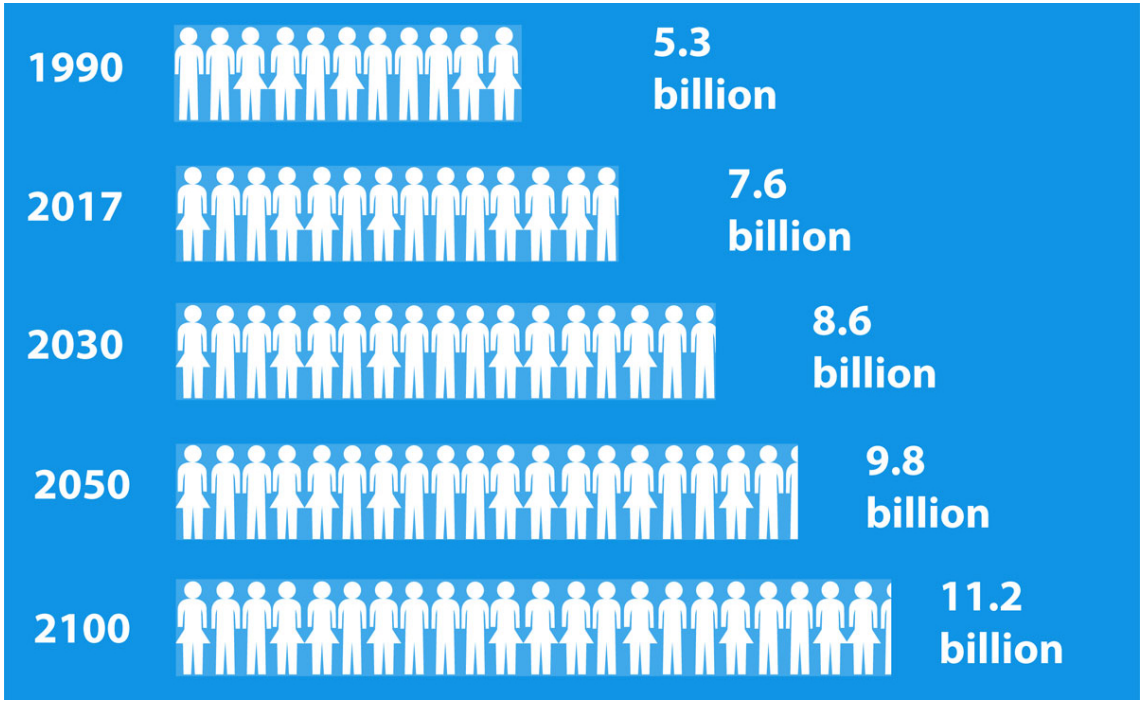


Figure 2: The fast-growing population yields a big market of smart environments.[2]

The smart environment around human in the future should not act as a tool, but a reliable partner of human.

[2] https://www.un.org/en/sections/issues-depth/population/index.html

Smart Environments

Smart Environments

- Smart environments can be considered to be a kind of context-aware system that provides services **AUTOMATICALLY** based on the knowledge it sensed.

Current Smart Environments

- Smart homes typically utilize a home gateway to connect the controlled devices and sensors. And now the users can control the system through different kinds of remote terminals, such as tablet, computers, and mobile phones.
- Many companies have produced their own smart home platforms to take the lead, e.g. Apple Home-Kit, Samsung SmartThings, Google Nest, etc. A typical scenes of such smart home platforms is to allow users to remote control the home devices through voice assistant.

Human-Oriented Services

Smart Services

- Health care
- Living conditions control
- Personalized recommendation
- ...

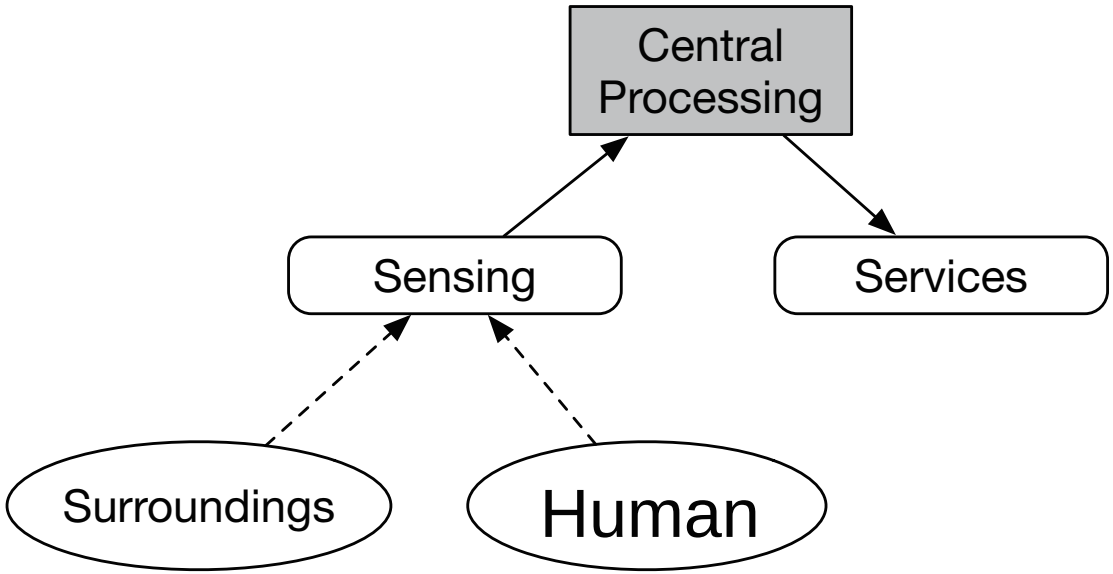


Figure 3: A simplified architecture of human-centered smart environment.

★ To provide **Human-Oriented** services automatically, the state of human has to be taken into consideration in an active way.

Purposes and Objectives

★ This research is to propose scalable frameworks to recognize and predict human activity in smart homes.

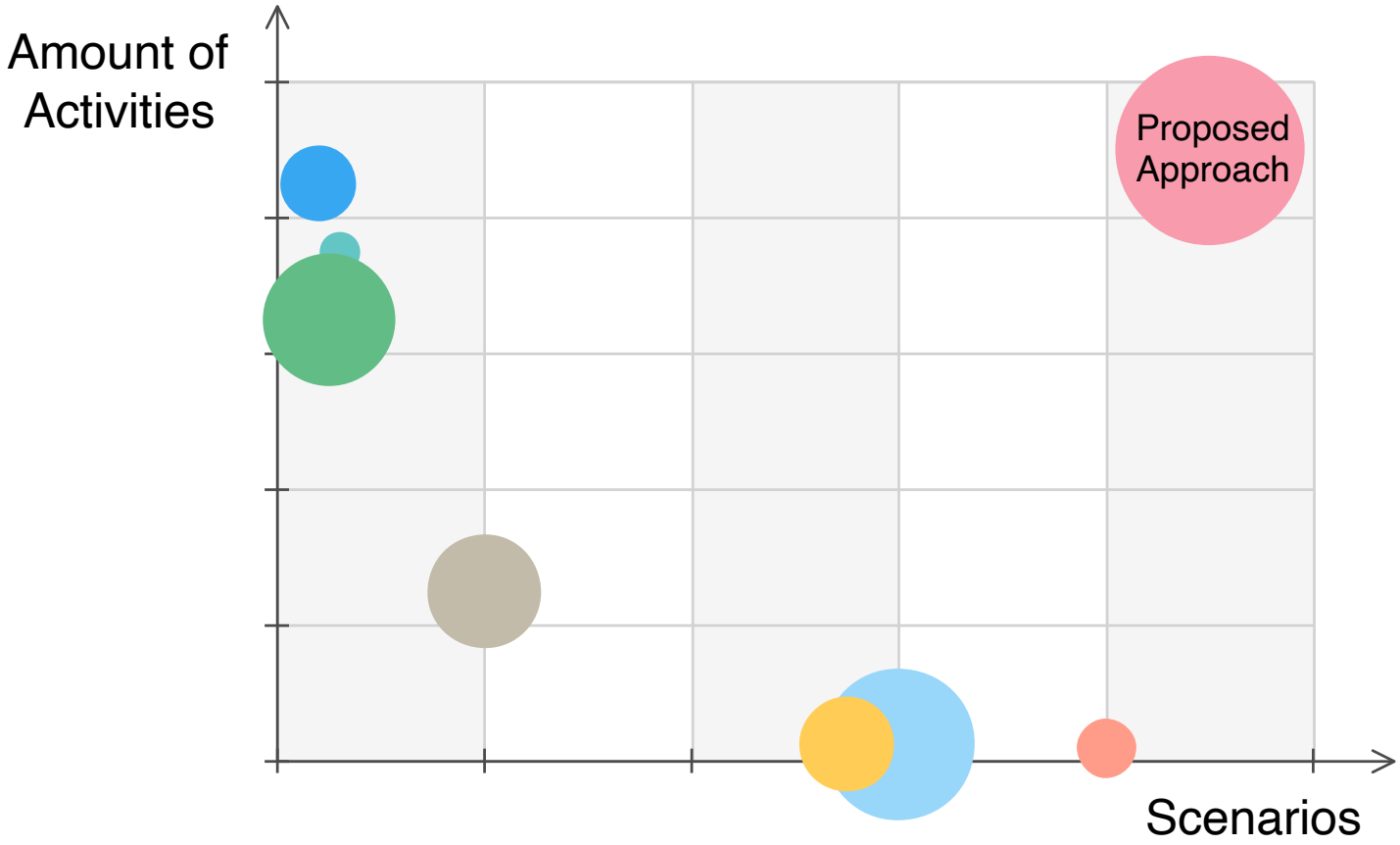


Figure 4: The proposed approach is scalable in two dimensions.

The Characteristic of Human Activity

Difficulties

- Concurrency.
- Multiplicity.
- Complexity.
- Diversity.
- Randomness.

Proposed approach should

- deal with concurrent activities.
- recognize full-grain-size activities.
- define activity with discrimination.
- scalable for different houses.
- model the behavioral habits.

(a) The result of existing HAR approaches.

(b) The activities in real world.

Figure 5: The comparison between existing HAR approaches and ground truth activities in real world.

From Action to Activity

Hierarchy of Activity

- The actions contain very basic semantic information, while the higher level activities contain much more complex semantic information.
- Thus, the HAR problem can be unwrapped into two problems.
  - How to sense the lower level actions?
  - How to combine the actions to infer the higher level activity?

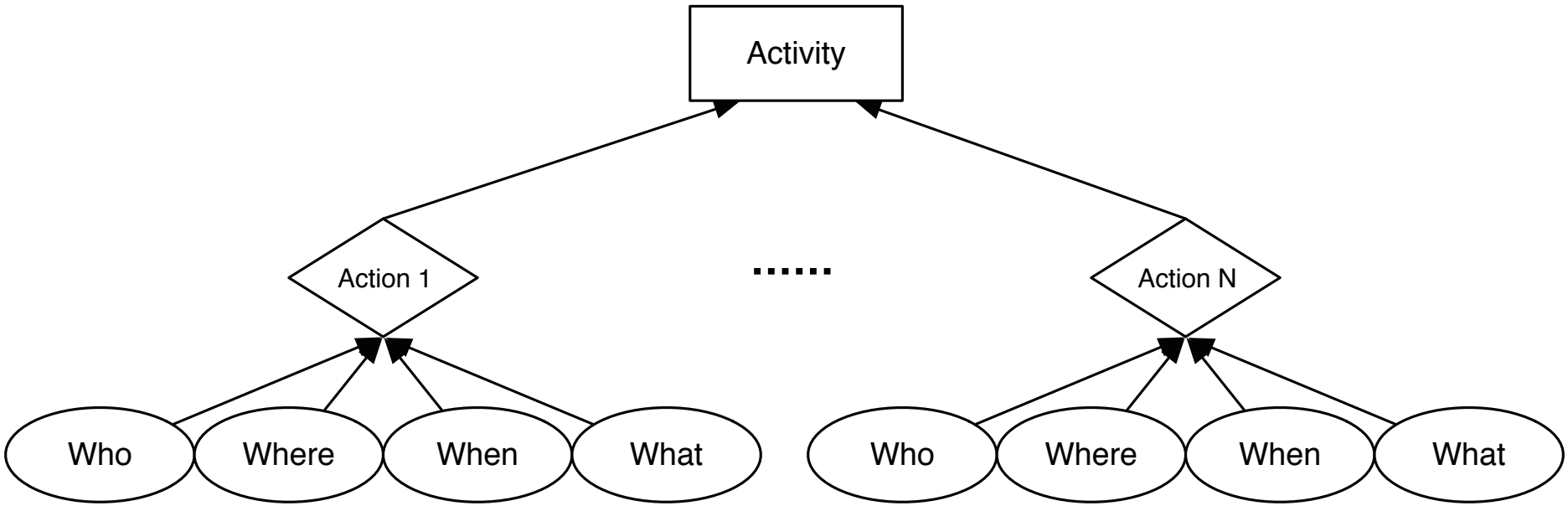


Figure 6: Modification of activity theory.

Interaction-based HAR

Indoor human activity

- High level human activity sensing should be the key to make the IoT systems smart enough to understand the demand of human.
- The difference between high level and low level activity is semantic meaning.

Action, interaction, and activity

- Here, action is treated as low level activity. And the interaction between human and objects entrusts semantic meaning on action. Thus, high level activity could be inferred accordingly.
- So the task becomes how can we detect the interaction in an *appropriate* way?

★ The answer in this research is passive Radio Frequency IDentification (**RFID**).

Inspiration

Passive RFID

- Passive RFID is a kind of wireless sensing technology, which achieves great success in several areas, such as: logistics, storage, and retail.
- The characteristics of passive RFID inspire us to recognize the human activity with tagged objects.

The advantages of passive RFID

- Low-cost
- Perceptive
- Multi-function
- Non-invasive
- Easy to implement

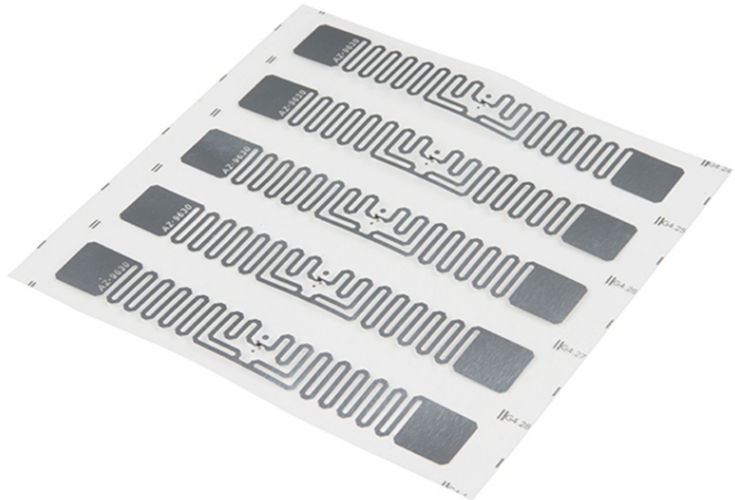


Figure 7: Example of passive RFID tag[3].

[3] https://www.alientechnology.com/products/tags/

RFID Interface

Interaction and RFID

- As introduced before, RFID phase changes according to the specific interactions with the tags. Thus, it is practicable to infer the interactions of human.

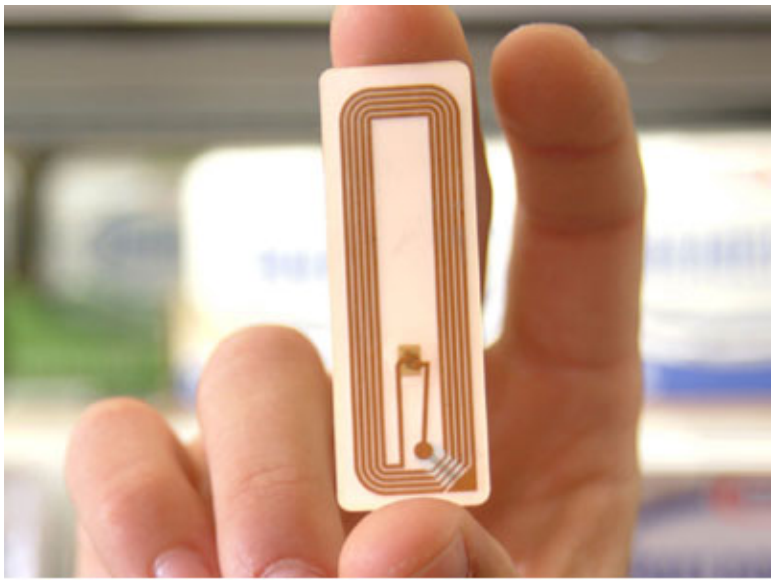


Figure 8: RFID tags can be attached everywhere. And this enables a fine-grained activity recognition.

System Design

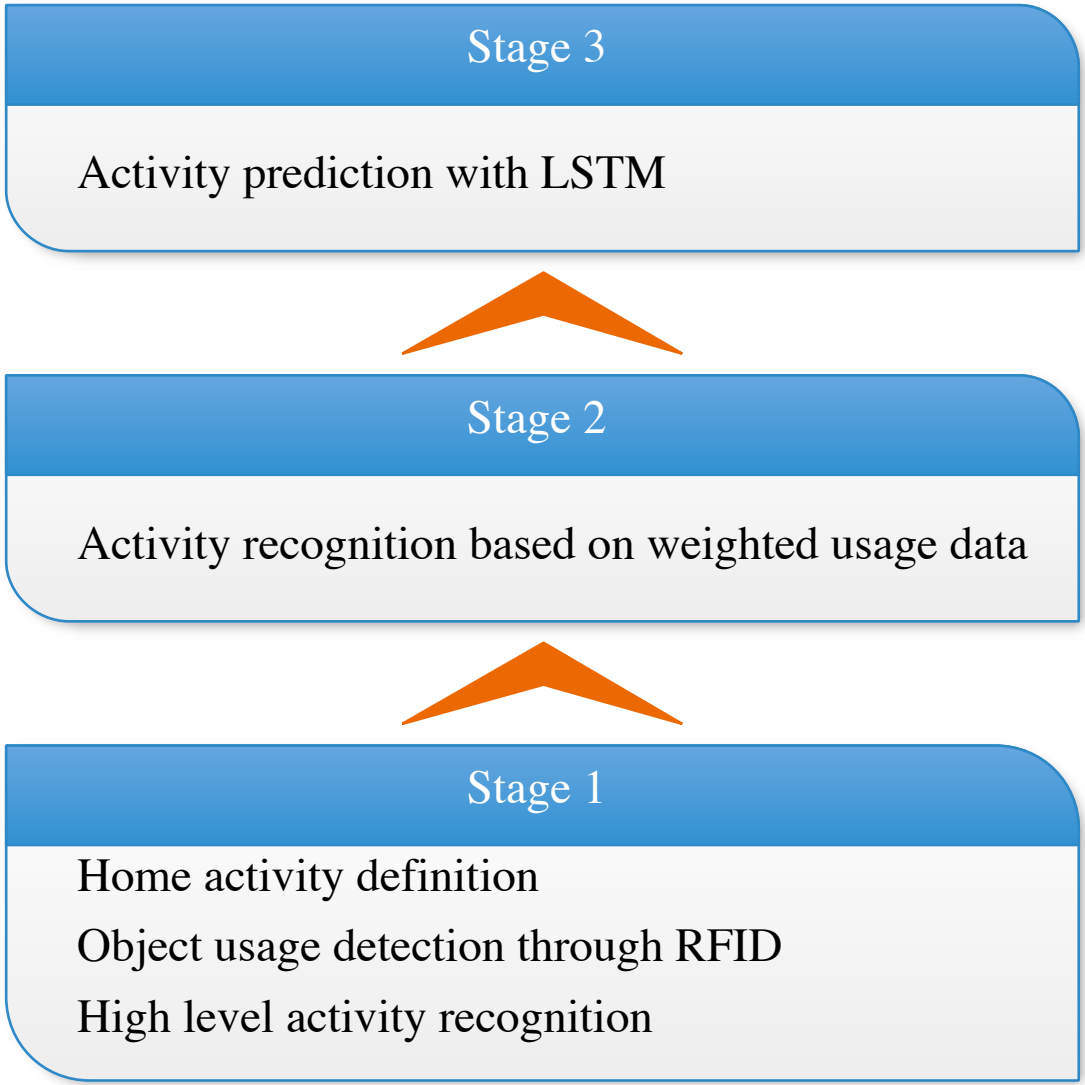


Figure 9: Three-stage framework to recognize and predict human activity.

The First Stage

Human activity definition

- We define the activity and its corresponding objects based on priori knowledge. This ensure the framework could be extend in the future.

Object usage detection

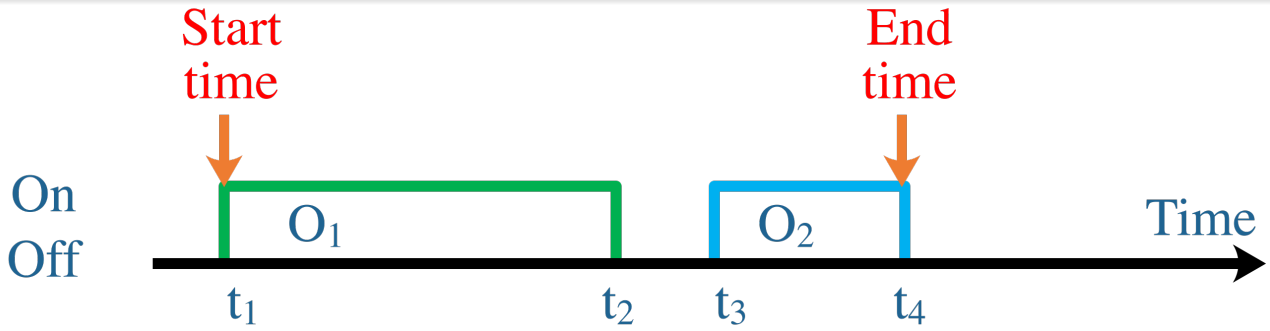
Figure 10: Object usage detection via interaction.

Usage	Tag State	Interaction	Objects
1	Covered	Sitting, lying, blocking	Chair, bed, sofa, switch, etc.
	Picked up	Picking up	Knife, toothbrush, chopsticks, etc.
0	Interfered	Passing by	All
	Still	Absence	All

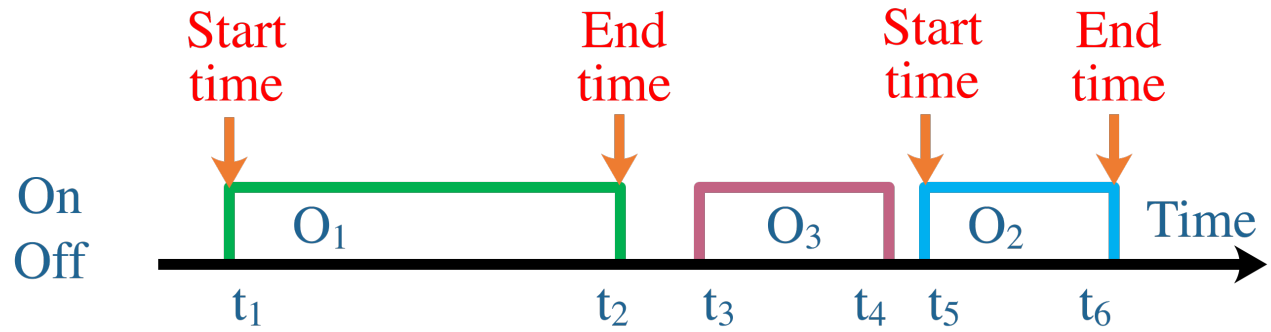
The First Stage

High level activity recognition

In this part, we propose two strategies to determine the start time and end time: activity fusion and activity segmentation.



(a) No interruption between two objects.



(b) Interruption between two objects.

Figure 11: We propose two strategies to determine the start time and end time. O_1 and O_2 are objects that belong to one activity, and O_3 belongs to some other activity.

The Second Stage

Recognition in Progress

- In this stage, we introduce an online approach based on $tf - idf$ that recognizes the activity in progress.

The term frequency tf_i^j can be calculated using the follow equation:

$$tf_i^j = \frac{g_i^j}{\sum_{i=1}^{n} g_i^j}. \tag{1}$$

Moreover, the inverse document frequency idf_i^j can be calculated using Equations (**??**) and (**??**)

$$idf_i^j = log(\frac{m}{\sum_{j=1}^{m} f_{i,j}(T)}), \tag{2}$$

$$f_{i,j}(T) = \begin{cases} 0, & g_i^j = 0, \\ 1, & otherwise. \end{cases} \tag{3}$$

After obtaining tf_i^j and idf_i^j, the tf-idf_i^j then can be calculated as follows:

$$tf - idf_i^j = tf_i^j * idf_i^j. \tag{4}$$

The Third Stage

Activity prediction with LSTM[4]

- We treat human activity prediction as a time sequence prediction problem. We believe that the inhabitants perform different activities in a relatively fixed pattern.
- Moreover, the next activity is related with not only the current activity but also the previous ones.

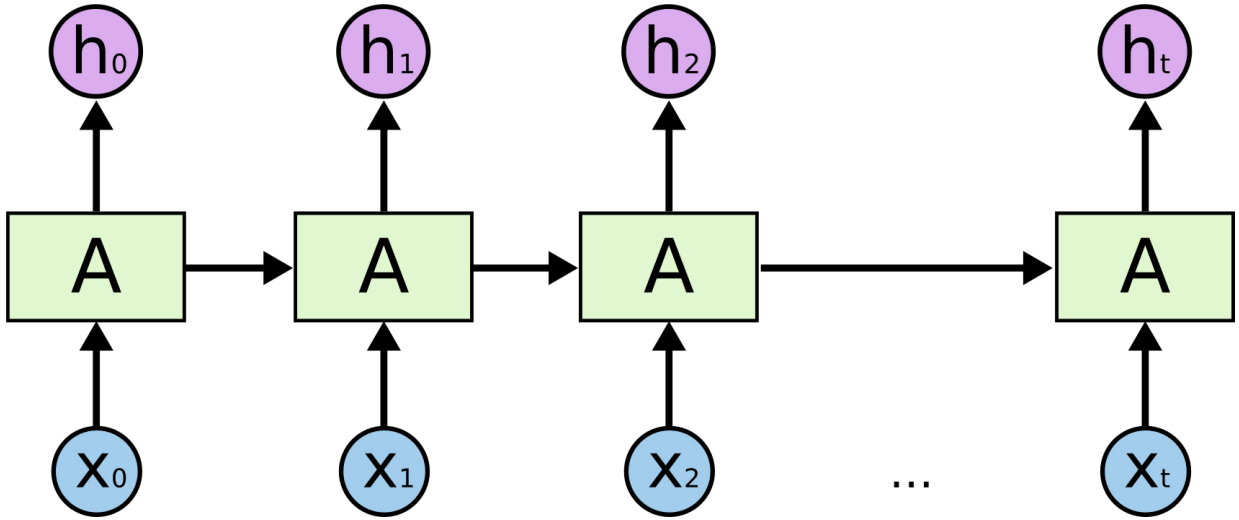


Figure 12: Activity sequence and recurrent neural network (RNN) model.

[4] Hochreiter, Sepp, and Jürgen Schmidhuber. "Long short-term memory." Neural computation 9.8 (1997): 1735-1780.

Experiment and Evaluation

Result of object usage detection

Figure 13: Result of object usage detection.

Objects	TP	TN	FP	FN
Chair	50	49	1	0
Toothbrush	49	47	3	1

- The average object usage detection accuracy can be calculated as 97.5%. Moreover, the precision and recall are 96.1% and 99%, respectively. The usage detection performance is sufficiently good to prove that RFID tags can be used to detect the object usage.

Experiment and Evaluation

Result of activity recognition based on $tf - idf$

Figure 14: Confusion matrix of recognized activities.

Activity ID	1	2	3	4	5	6	7	8	9	10
1	37	0	0	0	0	0	0	0	0	2
2	0	91	0	0	0	0	0	0	0	0
3	0	0	11	0	0	0	0	0	0	0
4	0	0	0	28	0	0	0	0	0	0
5	0	0	0	0	22	0	0	0	1	0
6	0	0	0	0	0	11	3	0	0	0
7	0	0	0	0	0	3	13	1	0	0
8	0	0	0	0	0	1	1	45	0	0
9	1	0	0	0	0	0	0	2	98	1
10	2	0	0	0	0	0	0	0	0	92

- According to the calculation, the average precision of our framework in the second stage is 85.0%, and the average recall is 87.9%.

Experiment and Evaluation

Result of activity prediction based on LSTM

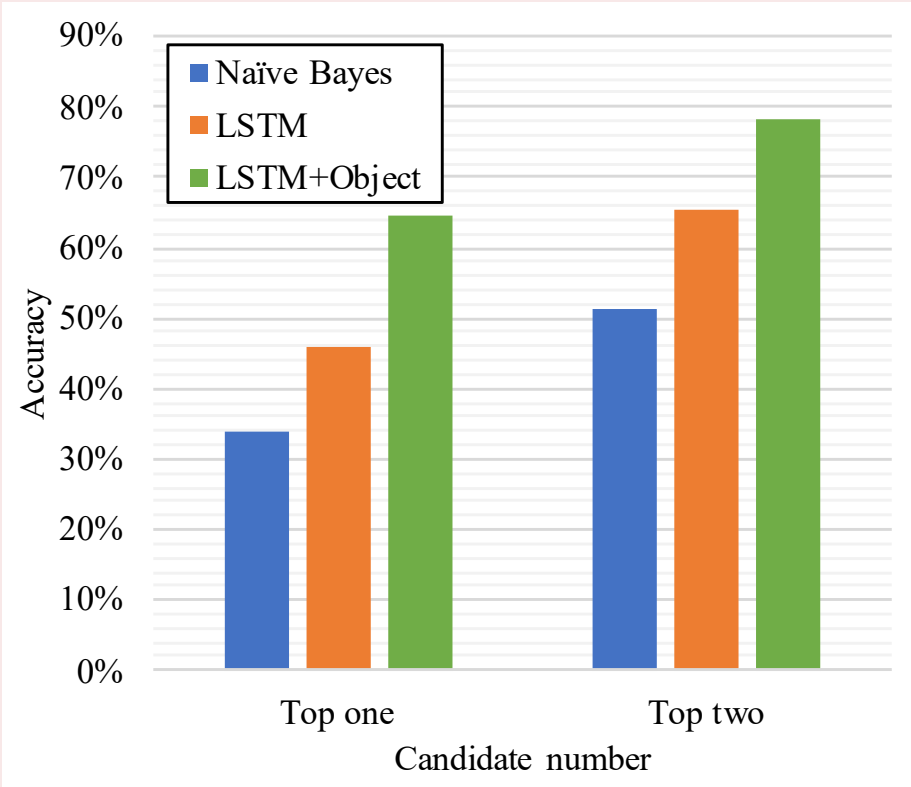


Figure 15: Accuracy of Naive Bayes and LSTM solution.

- The top two prediction accuracy reaches 65.2%. Moreover, when we apply the method to the process of prediction in the second stage, the accuracy will be as high is 78.3%.

Conclusion

Conclusion

- This research proposed a novel scalable interaction-based HAR approach in smart home. The approach can monitor full-grain human activity in real time, and further predict next activity.

Innovations

- The approach utilizes the advantages of both data-driven and knowledge driven approaches.
- The approach unwrapped the task of HAR in smart home, achieving a high flexible approach
- It is the first approach which can predict human activity in smart home.

Future Work

More Scenarios

- HAR in different scenarios may provide different knowledge to build human-centered smart environments.
- Among the smart environments, how to insert the knowledge to existing systems to enable the automation still need more work.

More Precision

- The proposed approach can detect the human activity, however, it can not tell how well the activity is performed.
  - E.g. in the gym, how to help the user avoid incorrect posture?

More Applications

- This research focuses on the off-line human activity, which can be combined with on-line activity to build more applications.
  - E.g. application can not only know the user is watching TV, but also know what the user is watching.

Thanks for your attention!

duyegang@jaist.ac.jp