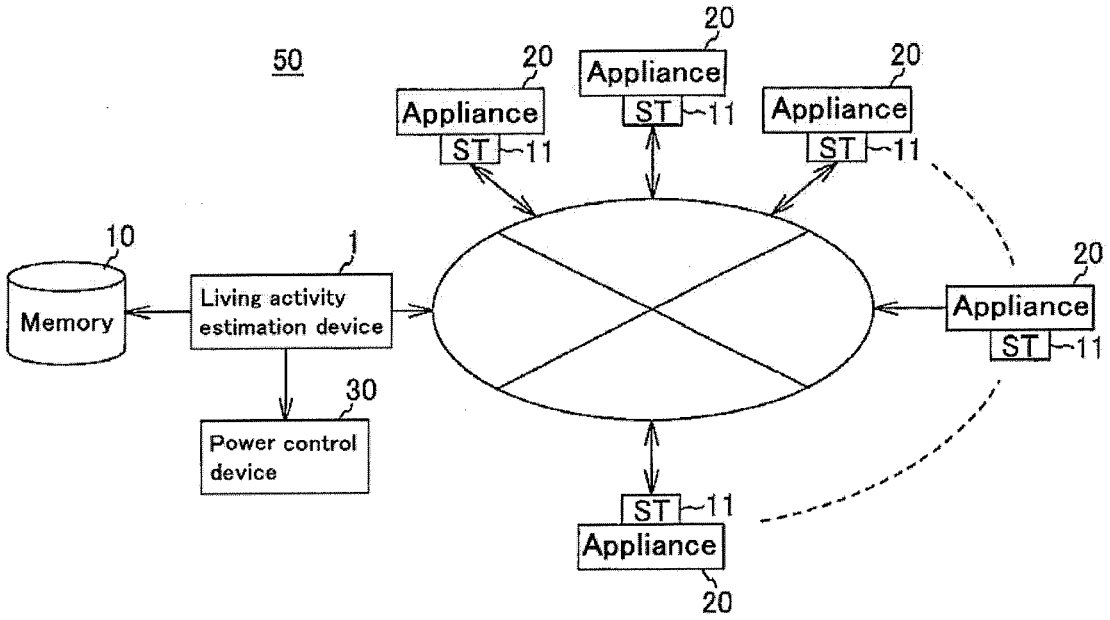
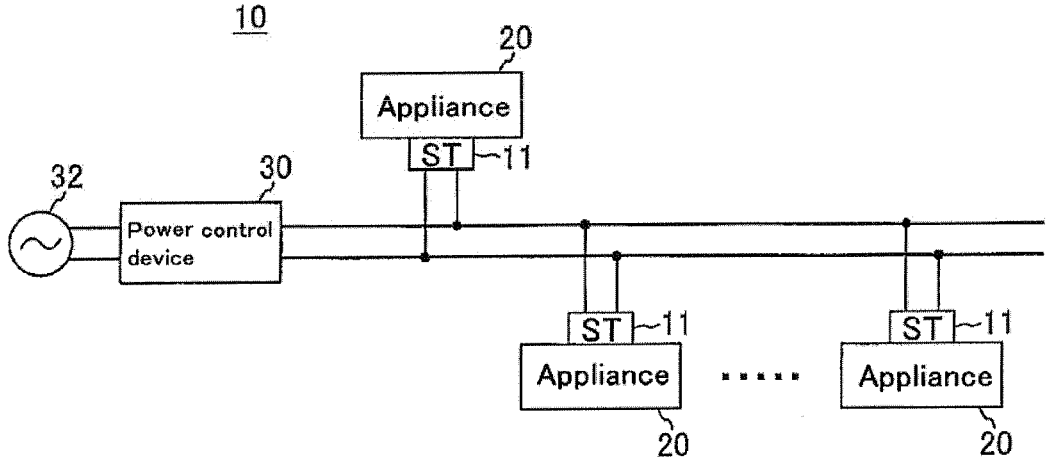
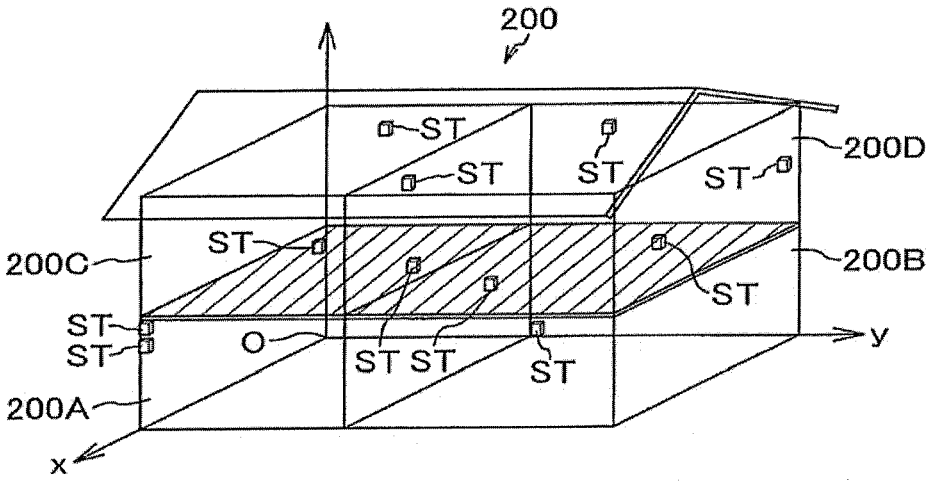
[Fig.1]



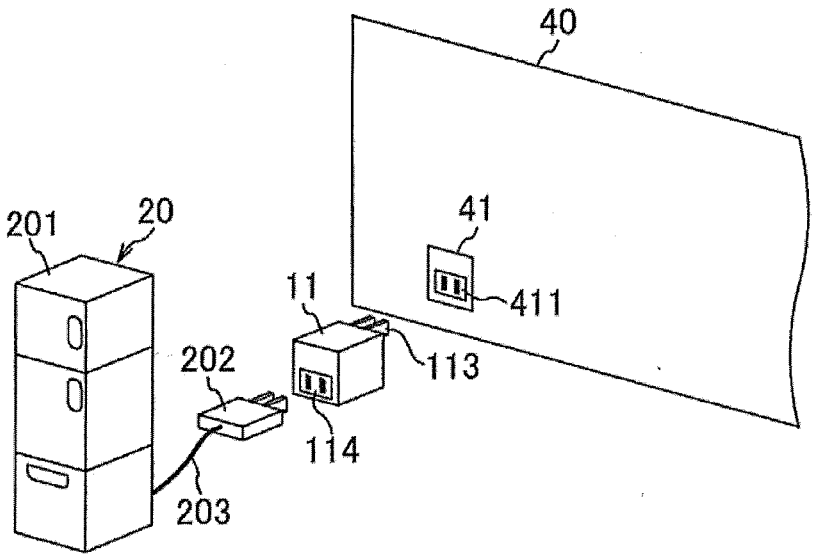
[Fig.2]



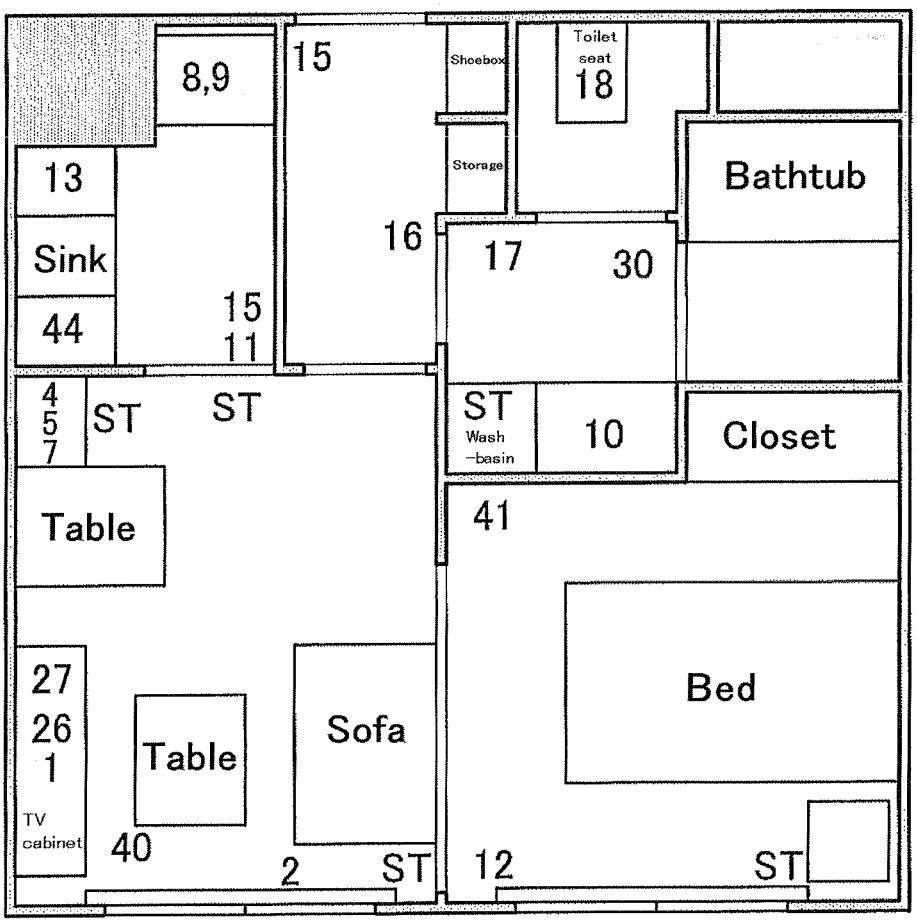
[Fig.3]



[Fig.4]

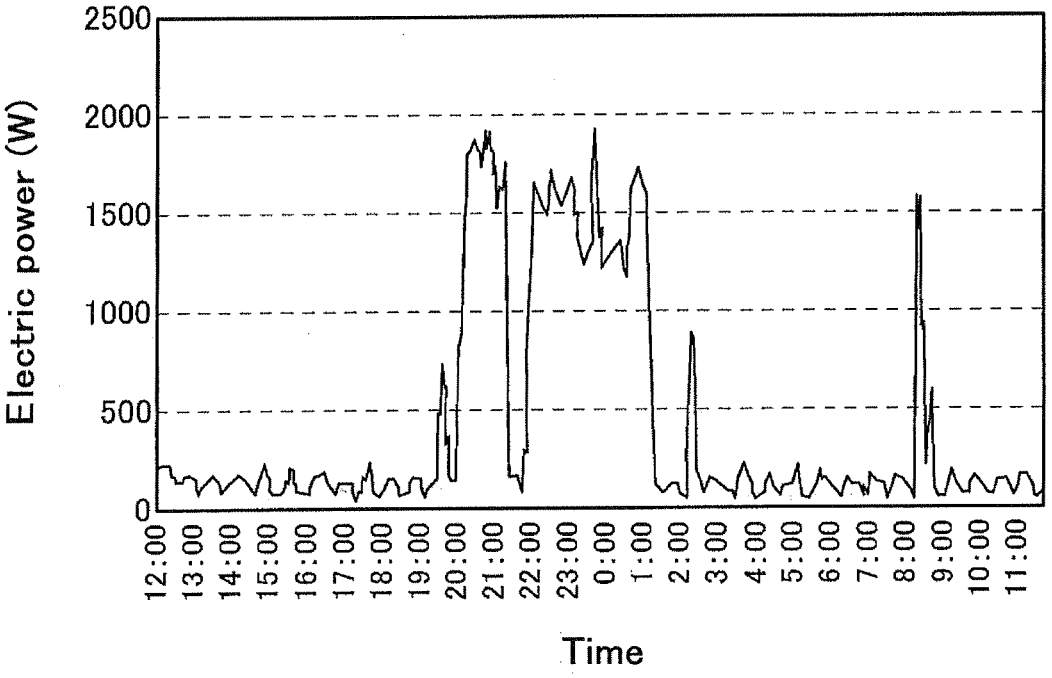


[Fig.5]

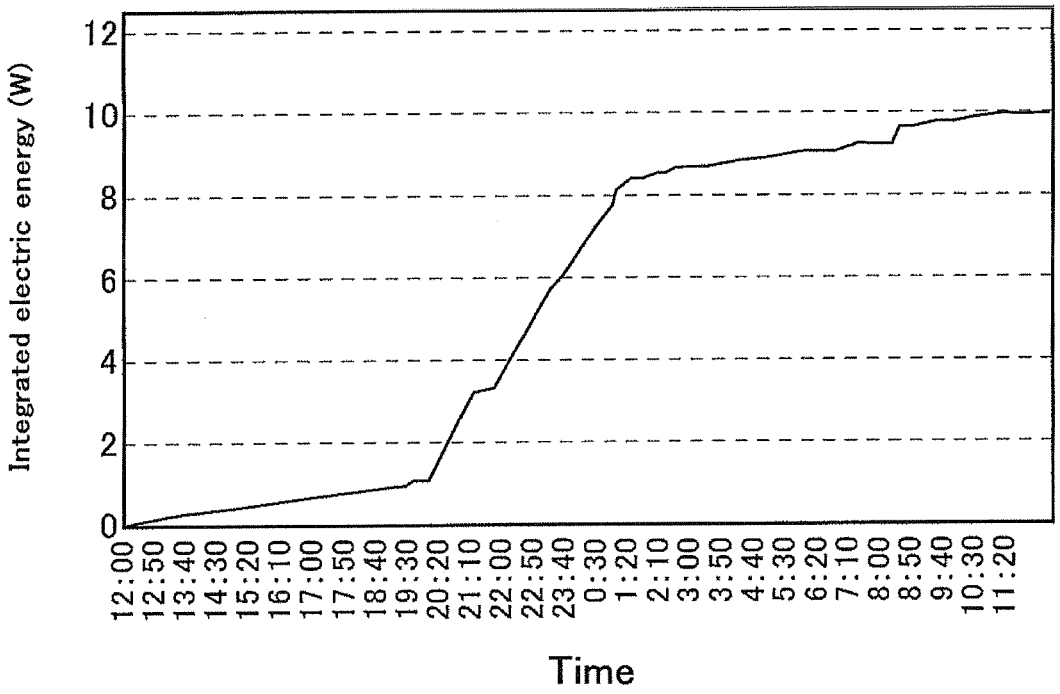


Layout of a home appliance

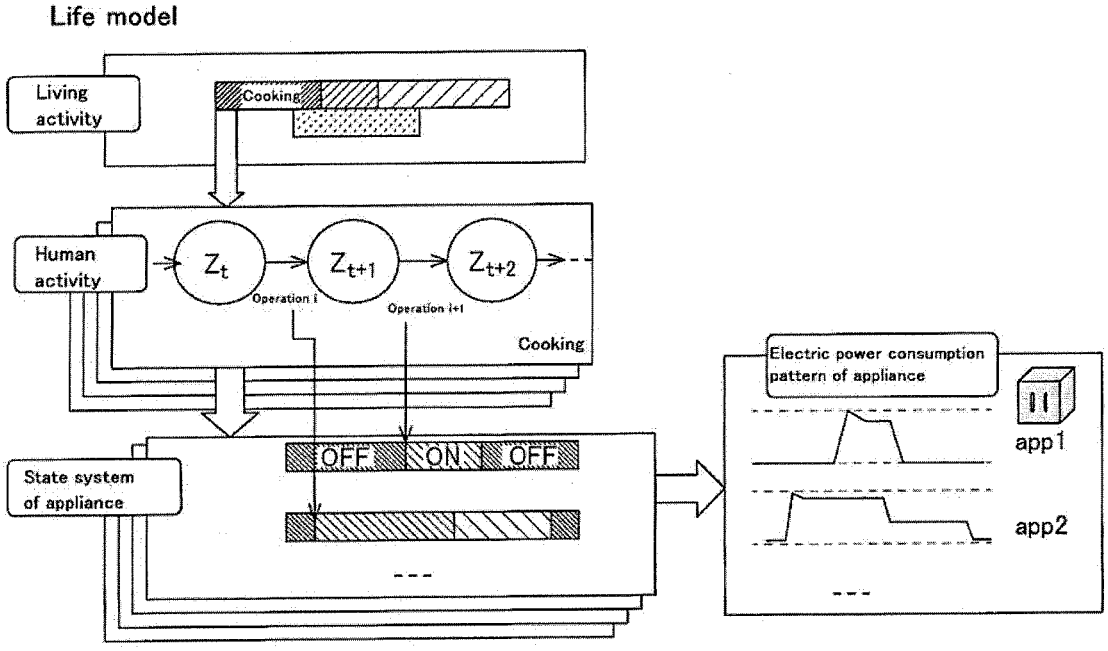
[Fig.6]


Electric power (W)
2500
2000
1500
1000
500
0
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
1:00
2:00
3:00
4:00
5:00
6:00
7:00
8:00
9:00
10:00
11:00
Time

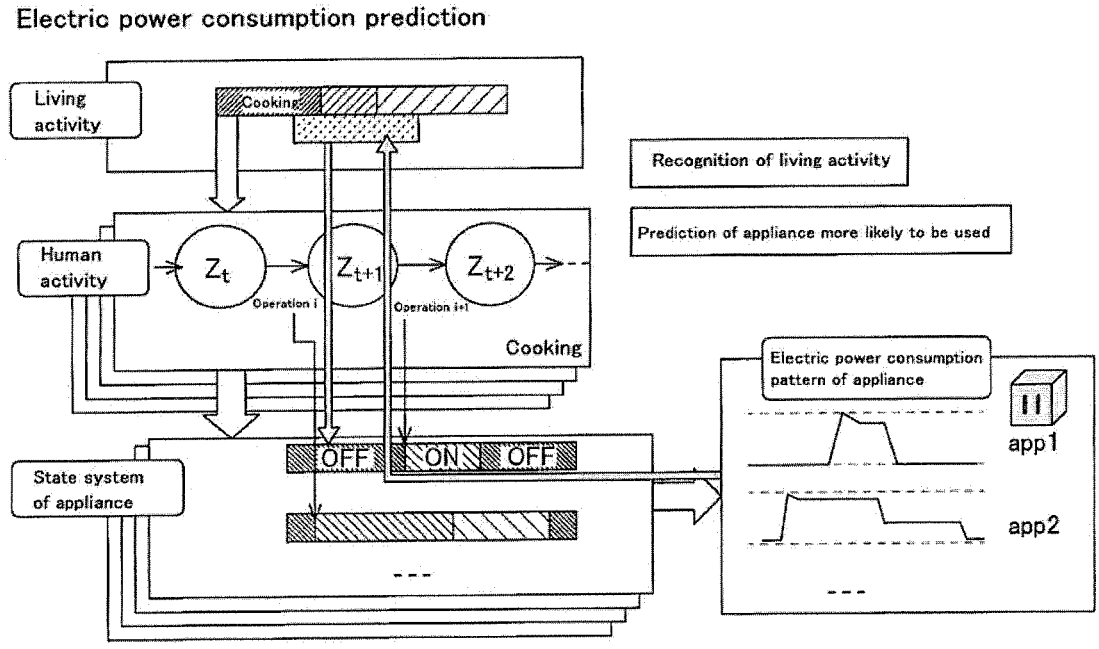
[Fig.7]


Integrated electric energy (W)
12
10
8
6
4
2
0
12:00
12:50
13:40
14:30
15:20
16:10
17:00
17:50
18:40
19:30
20:20
21:10
22:00
22:50
23:40
0:30
1:20
2:10
3:00
3:50
4:40
5:30
6:20
7:10
8:00
8:50
9:40
10:30
11:20
Time

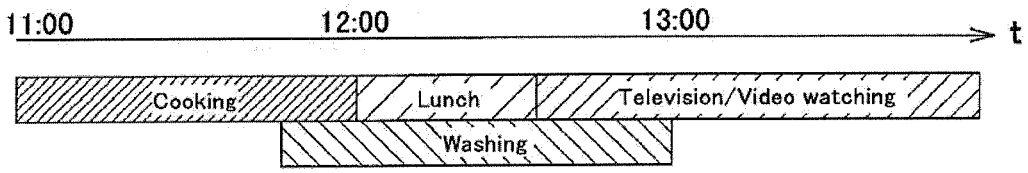
[Fig.8]



[Fig.9]



[Fig.10]



[Fig.11]

Living activity

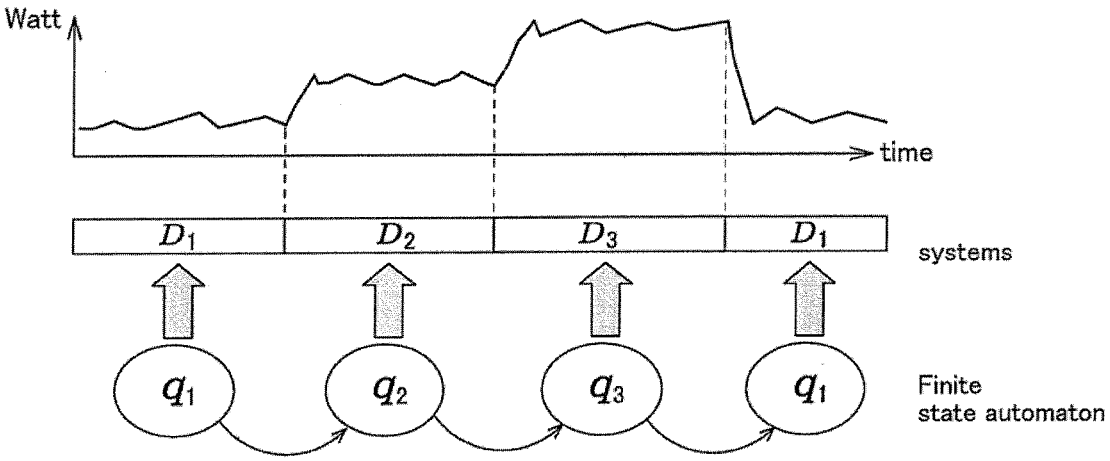
(a) People's life time survey by NHK

Sleep	Professional relationship	Care of children	Conversation/association	Television	Video/DVD
Meal	Class/school activity	Household chore	Sport	Radio	Rest
Personal care	Study outside school	Commute	Fun trip/stroll	Newspaper	Others
Cure/rest	Cooking/washing/cleaning	Commute to school	Hobby/entertainment/culture	Magazine/comic/book	Unknown
Work	Shopping	Social involvement	Internet	CD (compact disc)/tape	—

(b)

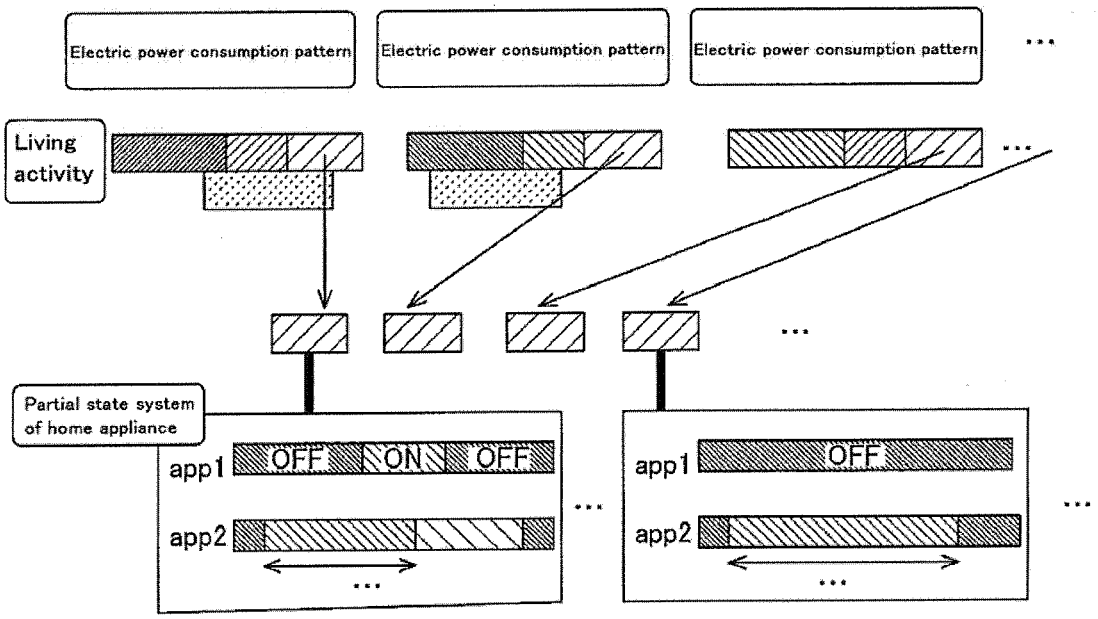
Sleep	Bathing	Child raising/ household chore
Meal	Parsonal care (wash up and the like)	Work/ academic learning
Cooking		Cooking
Washing	Rest	Others
Cleaning	Hobby/entertainment/TV	Going out

[Fig.12]



[Fig.13]

Learning of living activity – home appliance relationship model (2)

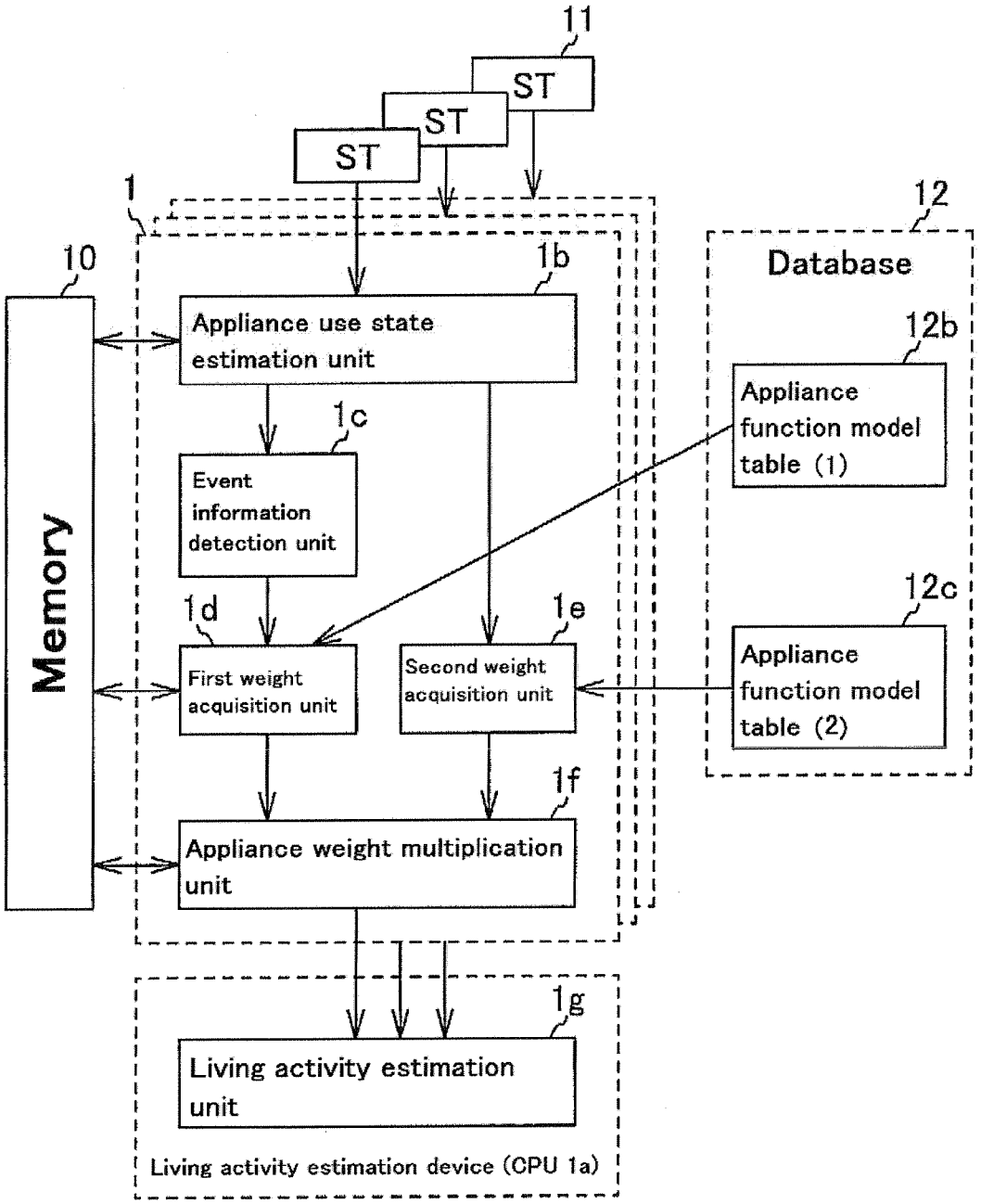


[Fig.14]

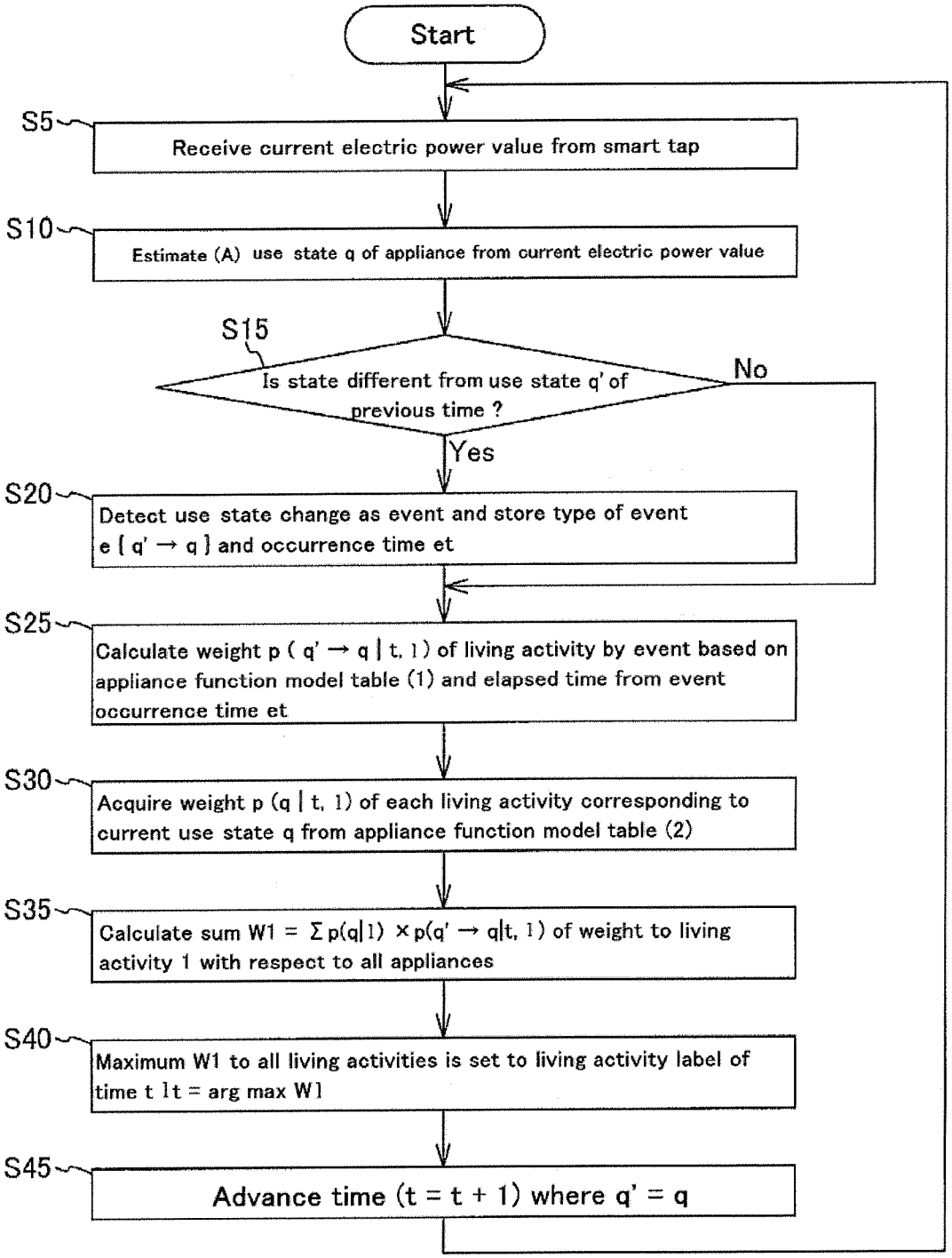
Ex)ON of television

Hobby/ entertainment/ TV	Rest	Cooking	Meal	Cleaning	Parsonal care	Bathing	Sleep	Work/ academic learning	...
1	0.5	0.5	0.5	0.5	0.5	0	0	0	

[Fig.15]


11
ST
ST
ST
1
12
10
1b
Database
Appliance use state estimation unit
12b
Appliance function model table (1)
1c
Event information detection unit
Memory
1d
1e
12c
First weight acquisition unit
Second weight acquisition unit
Appliance function model table (2)
1f
Appliance weight multiplication unit
1g
Living activity estimation unit
Living activity estimation device (CPU 1a)

[Fig.16]


Start
S5
Receive current electric power value from smart tap
S10
Estimate (A) use state q of appliance from current electric power value
S15
Is state different from use state q' of previous time ?
No
Yes
S20
Detect use state change as event and store type of event e [q' → q] and occurrence time et
S25
Calculate weight p (q' → q | t, l) of living activity by event based on appliance function model table (1) and elapsed time from event occurrence time et
S30
Acquire weight p (q | t, l) of each living activity corresponding to current use state q from appliance function model table (2)
S35
Calculate sum W1 = Σ p(q|l) × p(q' → q|t, l) of weight to living activity l with respect to all appliances
S40
Maximum W1 to all living activities is set to living activity label of time t lt = arg max W1
S45
Advance time (t = t + 1) where q' = q

[Fig.17]

Appliance function model table (1)

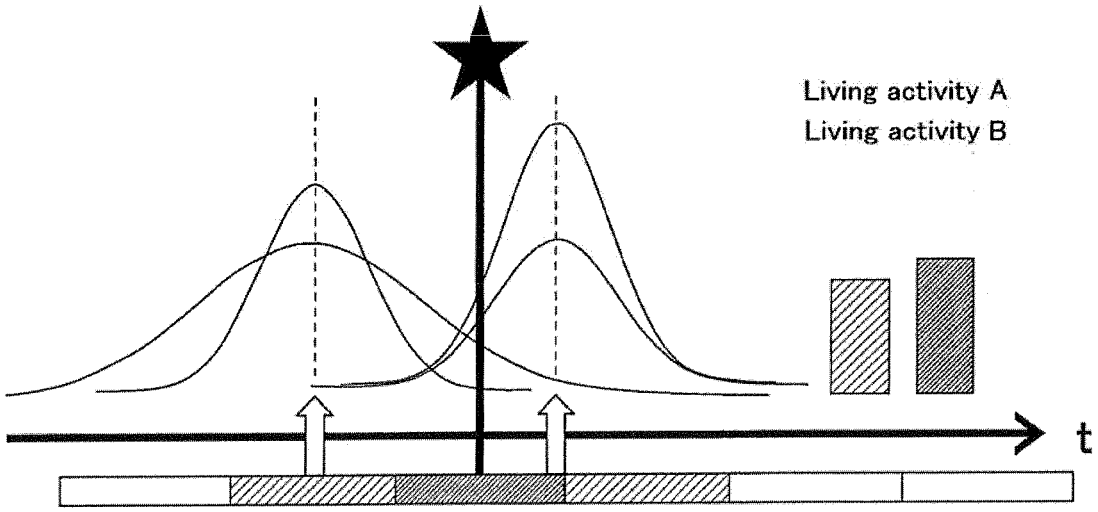
Home appliance	Previous state → next state	Cooking	Washing	Entertainment	Learning	···
Living room lighting	OFF → ON	0	0	0.5	0.5	···
	ON → OFF	0.5	0	0	0	···
Washing machine	OFF → ON	1	0	0	0	···
	ON → OFF	1	0	0	0	···

[Fig.18]

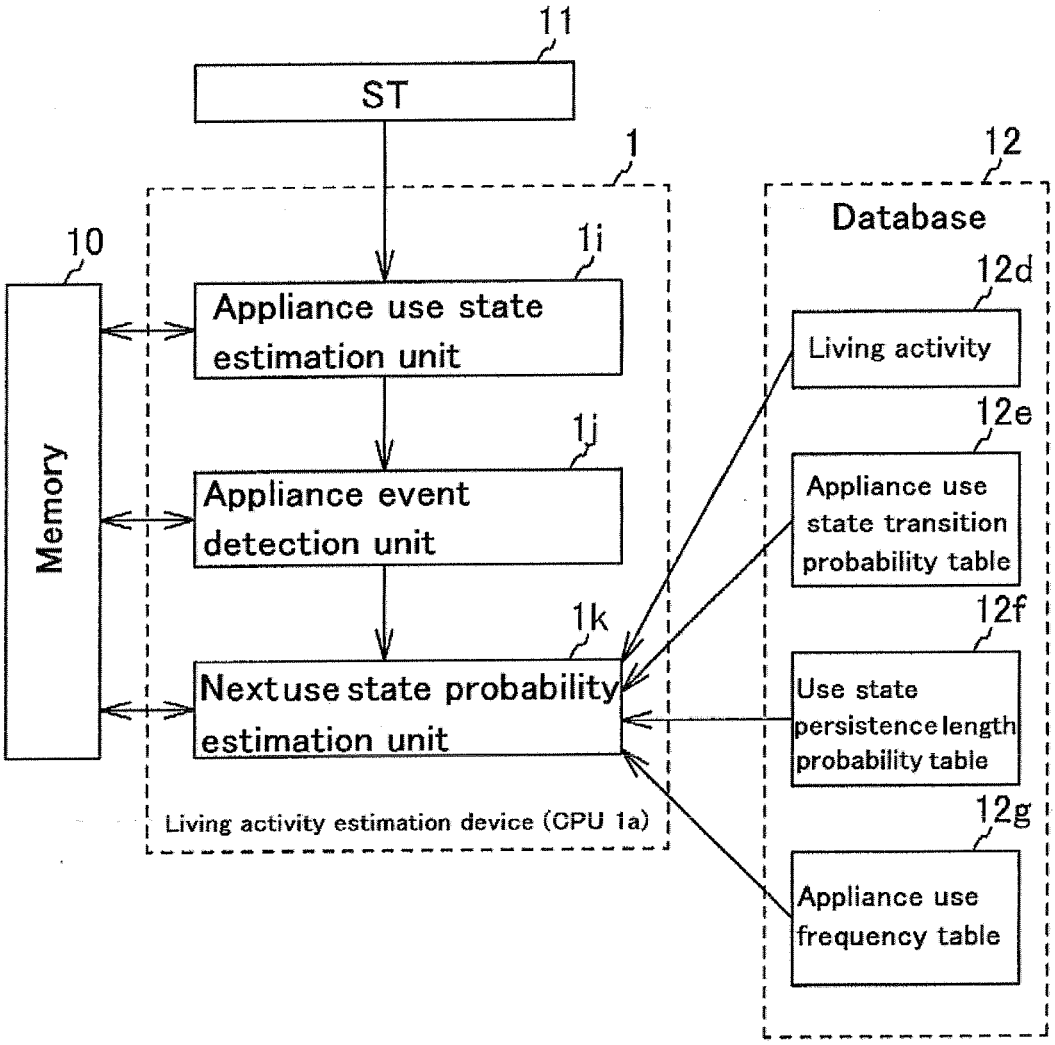
Appliance function model table (2)

Home appliance	Previous state → next state	Cooking	Washing	Entertainment	Learning	···
Living room lighting	Bright	0.2	0.2	0.8	0.8	···
	Middle	0.5	0.2	0.8	0.8	···
	Dark	0.2	0.2	0.6	0.6	···
Television	ON	0.2	0.2	0.9	0.2	···

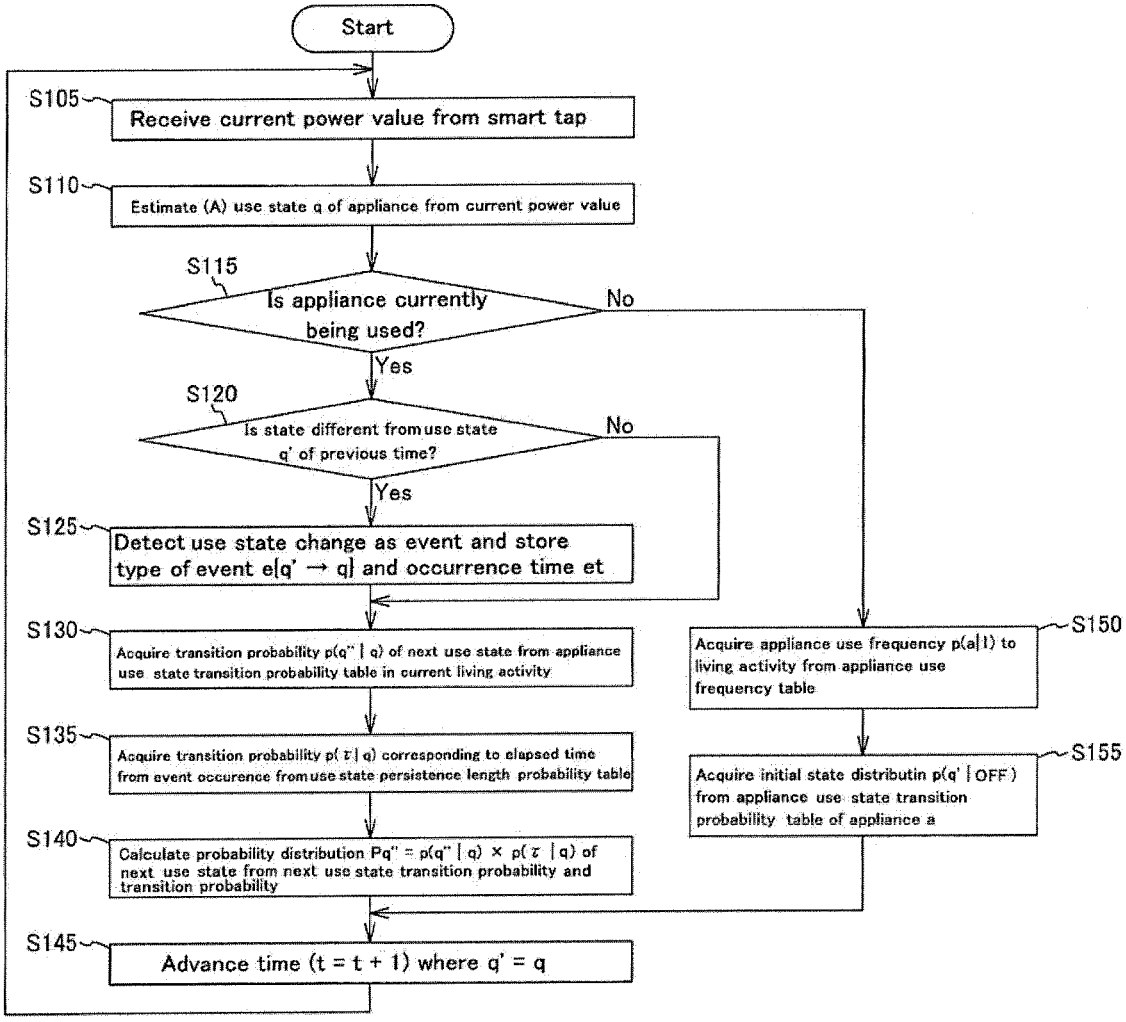
[Fig.19]



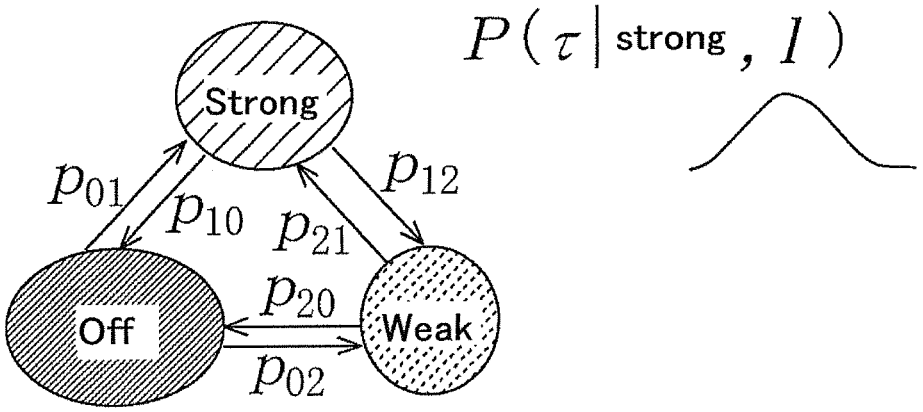
[Fig.20]


11
ST
1
12
Database
10
1i
12d
Appliance use state estimation unit
Living activity
1j
12e
Appliance event detection unit
Appliance use state transition probability table
Memory
1k
12f
Next use state probability estimation unit
Use state persistence length probability table
Living activity estimation device (CPU 1a)
12g
Appliance use frequency table

[Fig.21]


Start
S105
Receive current power value from smart tap
S110
Estimate (A) use state q of appliance from current power value
S115
Is appliance currently being used?
No
Yes
S120
Is state different from use state q' of previous time?
No
Yes
S125
Detect use state change as event and store type of event e[q' → q] and occurrence time et
S130
Acquire transition probability p(q'' | q) of next use state from appliance use state transition probability table in current living activity
S135
Acquire transition probability p(τ | q) corresponding to elapsed time from event occurence from use state persistence length probability table
S140
Calculate probability distribution Pq'' = p(q'' | q) × p(τ | q) of next use state from next use state transition probability and transition probability
S145
Advance time (t = t + 1) where q' = q
S150
Acquire appliance use frequency p(a|l) to living activity from appliance use frequency table
S155
Acquire initial state distributin p(q' | OFF) from appliance use state transition probability table of appliance a

[Fig.22]


$P(\tau \mid \text{strong}, l)$
Strong
Off
Weak
p_{01}
p_{10}
p_{12}
p_{21}
p_{20}
p_{02}

[Fig.23]

Appliance use state transition probability table

(a)

Living room lighting		Next use state			
		Off	Weak	Middle	Strong
Previous use state	Off		0.1	0.2	0.7
	Weak	0.3		0.5	0.2
	Middle	0.2	0.4		0.4
	Strong	0.1	0.3	0.7	

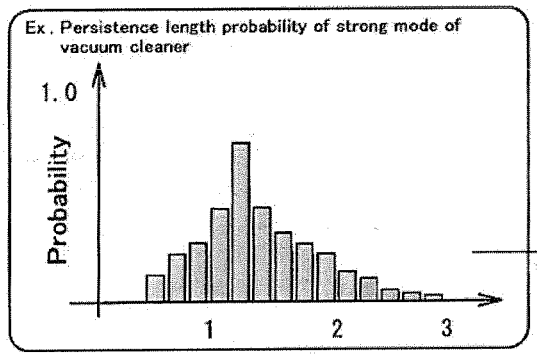
(b)

Vacuum cleaner		Next use state			
		Off	Weak	Middle	Strong
Previous use state	Off		0.1	0.2	0.7
	Weak	0.3		0.5	0.2
	Middle	0.2	0.4		0.4
	Strong	0.1	0.3	0.7	

[Fig.24]

Use state persistence length probability table

(a)



(b)

Vacuum cleaner		Persistence time (sec.)			
		0.2	0.4	0.6	···
State	Weak	0.1	0.2	0.2	···
	Middle	0.02	0.1	0.1	···
	Strong	0.01	0.05	0.09	···

[Fig.25]

Appliance use frequency table

(a) Use probability of IH

Sleep	0
Breakfast	0
Lunch	0
Bathing	0
Personal care	0
Cooking	0. 67
Work / academic learning	0
Hobby / entertainment	0
Televideo	0

(b) Use probability of television

Sleep	0
Breakfast	1
Lunch	1
Bathing	0
Personal care	0. 66
Cooking	1
Work / academic learning	0
Hobby / entertainment	1
Televideo	1

[Fig.26]

Use probability and contribution of appliance

(a) Use probability of IH

Sleep	0
Breakfast	0
Lunch	0
Bathing	0
Personal care	0
Cooking	0.67
Work / academic learning	0
Hobby / entertainment	0
Televideo	0

(b) Use probability of television

Sleep	0
Breakfast	1
Lunch	1
Bathing	0
Personal care	0.66
Cooking	1
Work / academic learning	0
Hobby / entertainment	1
Televideo	1

(C) Contribution of televison

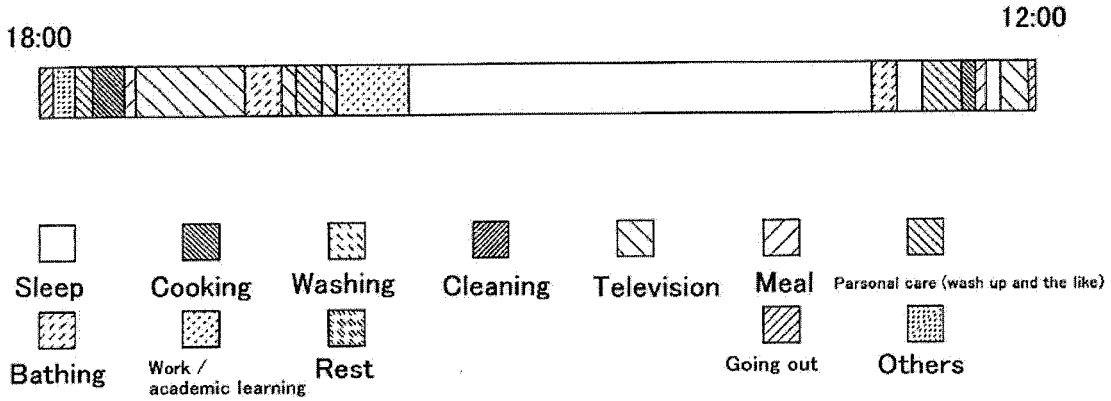
Sleep	0
Breakfast	1.72
Lunch	1.72
Bathing	0
Personal care	1.06
Cooking	1.72
Work / academic learning	0
Hobby / entertainment	1.72
Televideo	1.72

(d) Contribution with respect to cooking

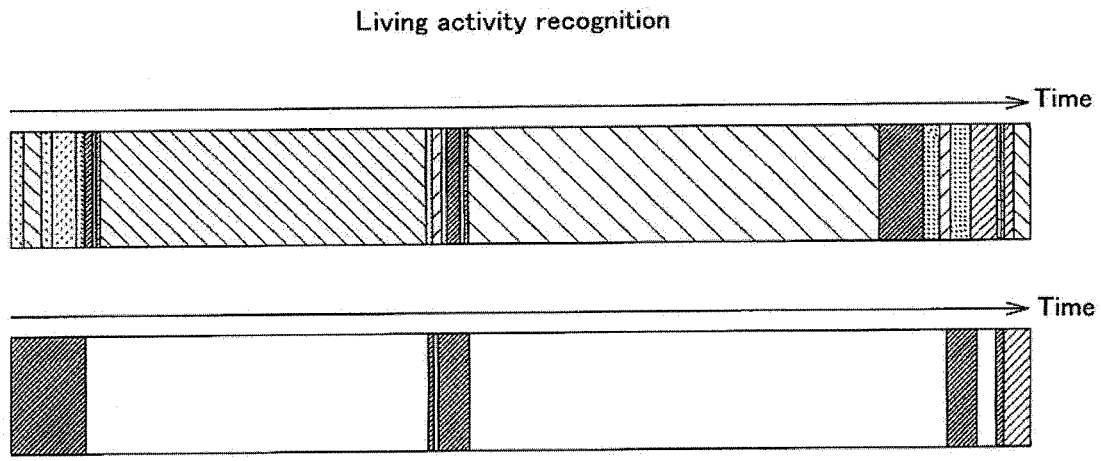
TV	1.72
Living	1.15
Refrigerator	1
Corridor	0
Kitchen1	4.9
Pot	4.84
Washlet	1
Restroom	0
Bath1	0
Kitchen2	1.78
CoffeeMaker	3.76
MicrowaveOven	6.88
IH	5.8
Bath2	0
notePC	0

[Fig.27]

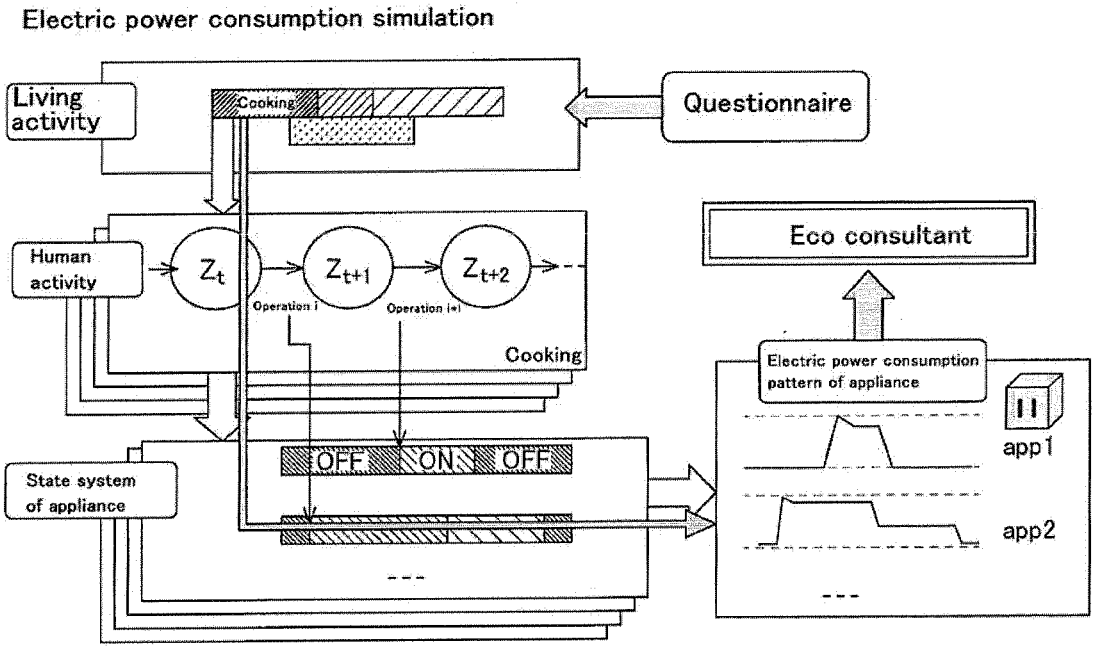
Living activity recognition result



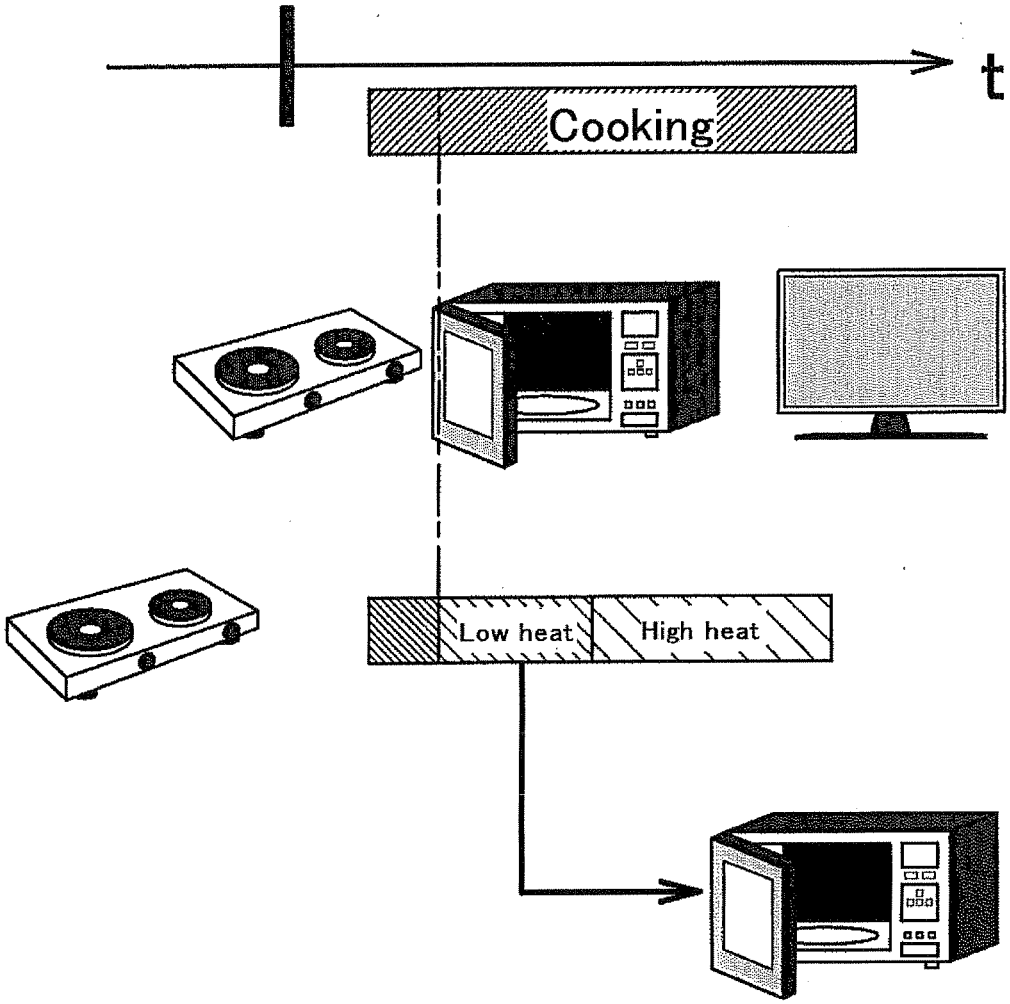
[Fig.28]


Living activity recognition
Time
Time

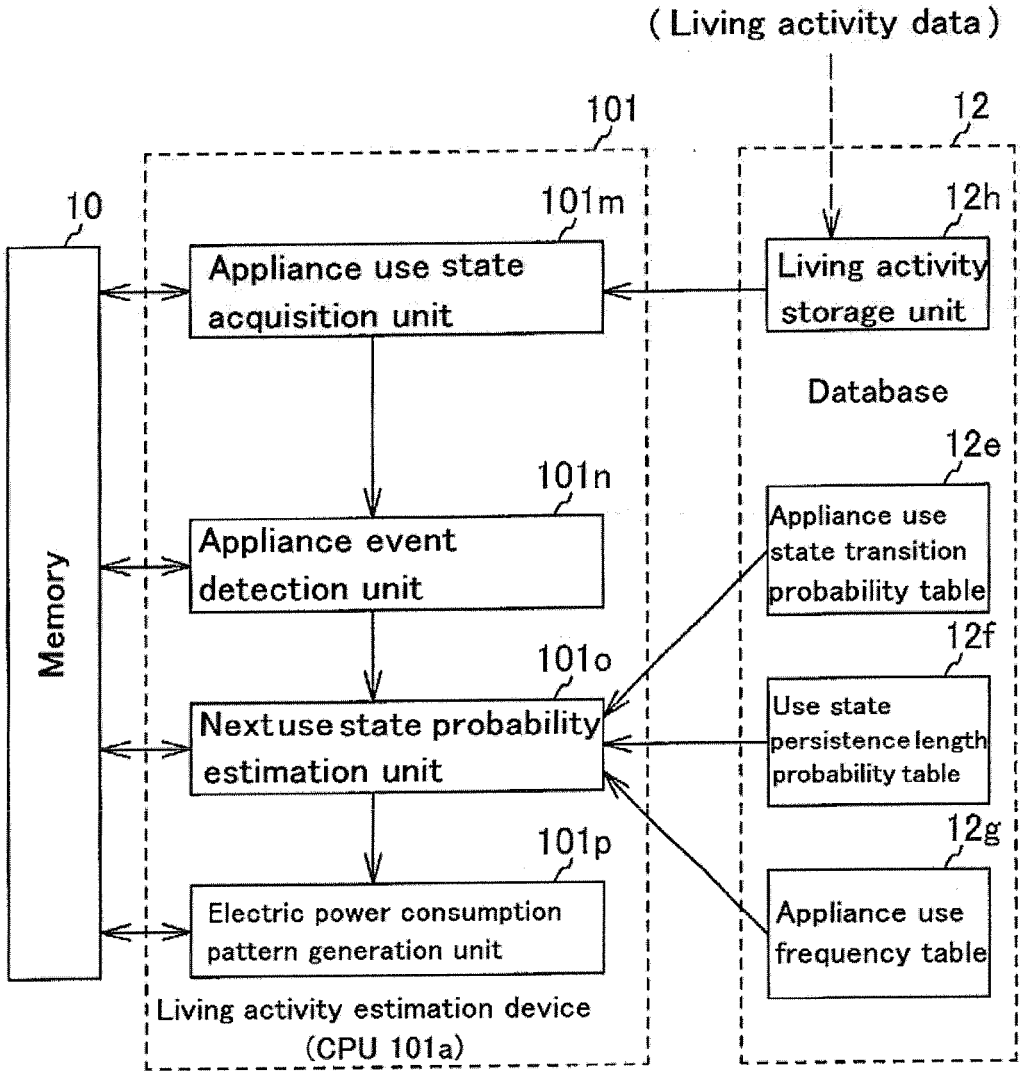
[Fig.29]


Electric power consumption simulation
Living activity
Cooking
Questionnaire
Human activity
Zt
Zt+1
Zt+2
Operation i
Operation (i+1)
Cooking
Eco consultant
Electric power consumption pattern of appliance
app1
app2
State system of appliance
OFF
ON
OFF

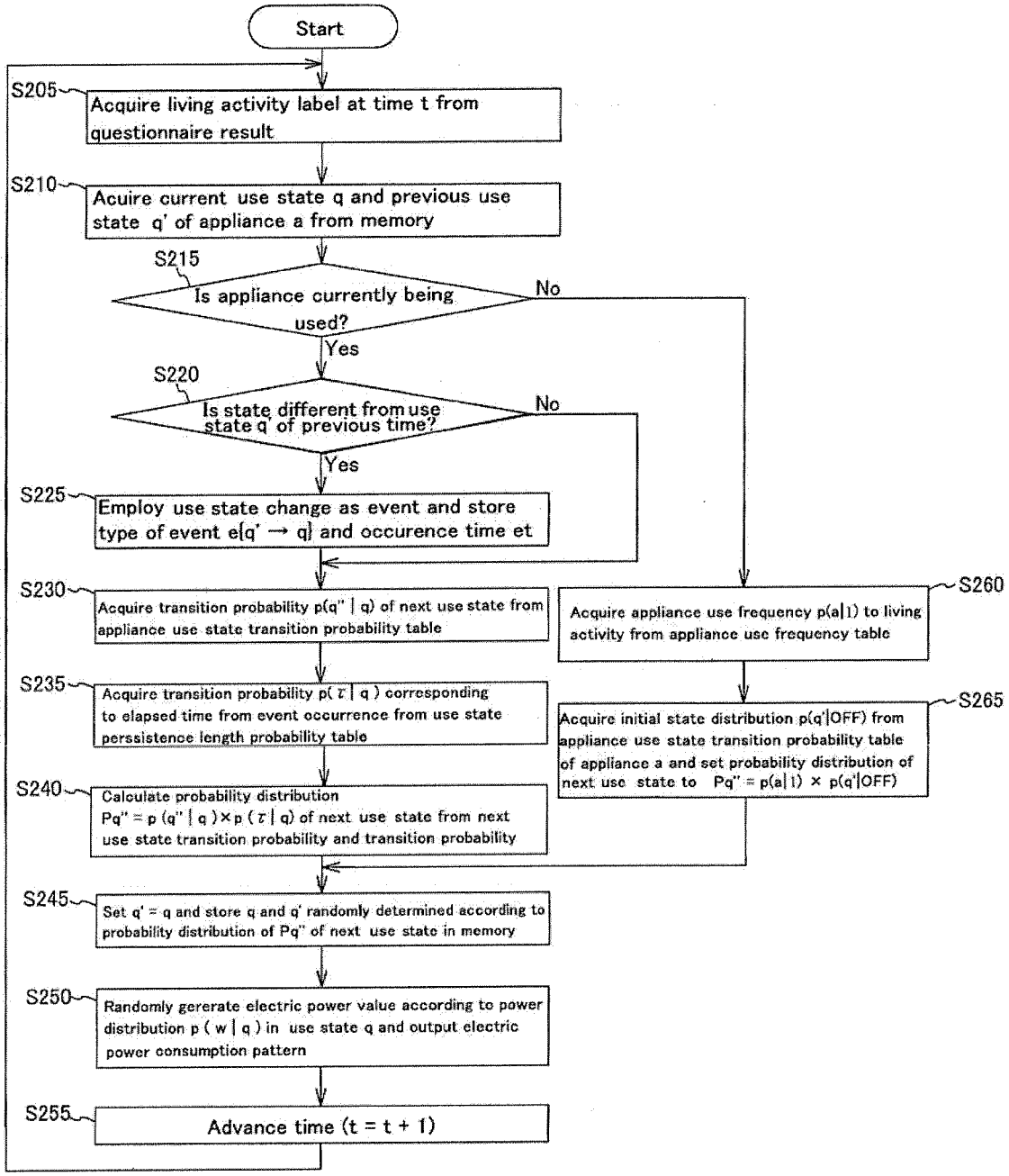
[Fig.30]



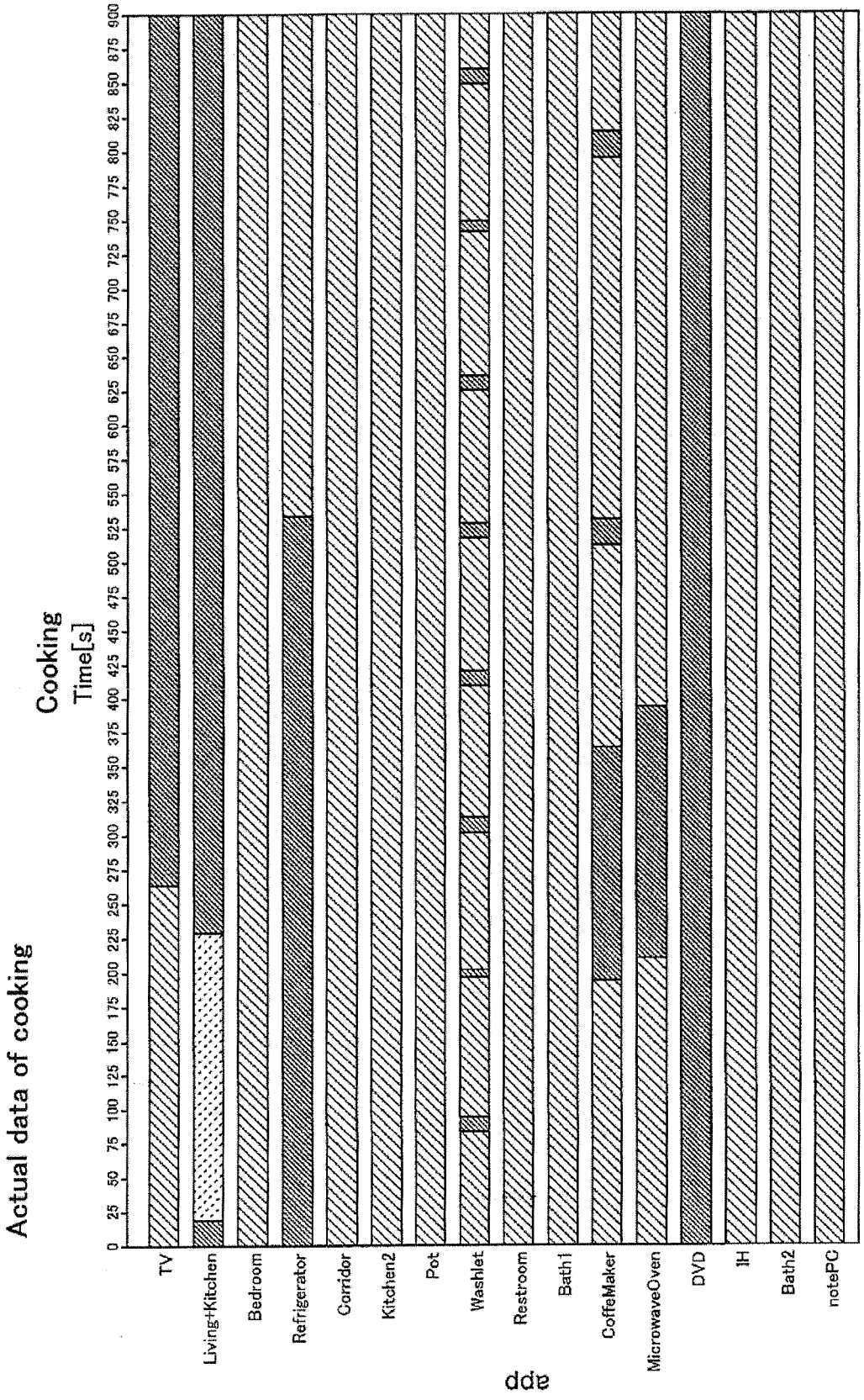
[Fig.31]


(Living activity data)
101
12
10
101m
12h
Appliance use state acquisition unit
Living activity storage unit
Database
12e
101n
Appliance event detection unit
Appliance use state transition probability table
12f
101o
Next use state probability estimation unit
Use state persistence length probability table
12g
101p
Electric power consumption pattern generation unit
Appliance use frequency table
Memory
Living activity estimation device
(CPU 101a)

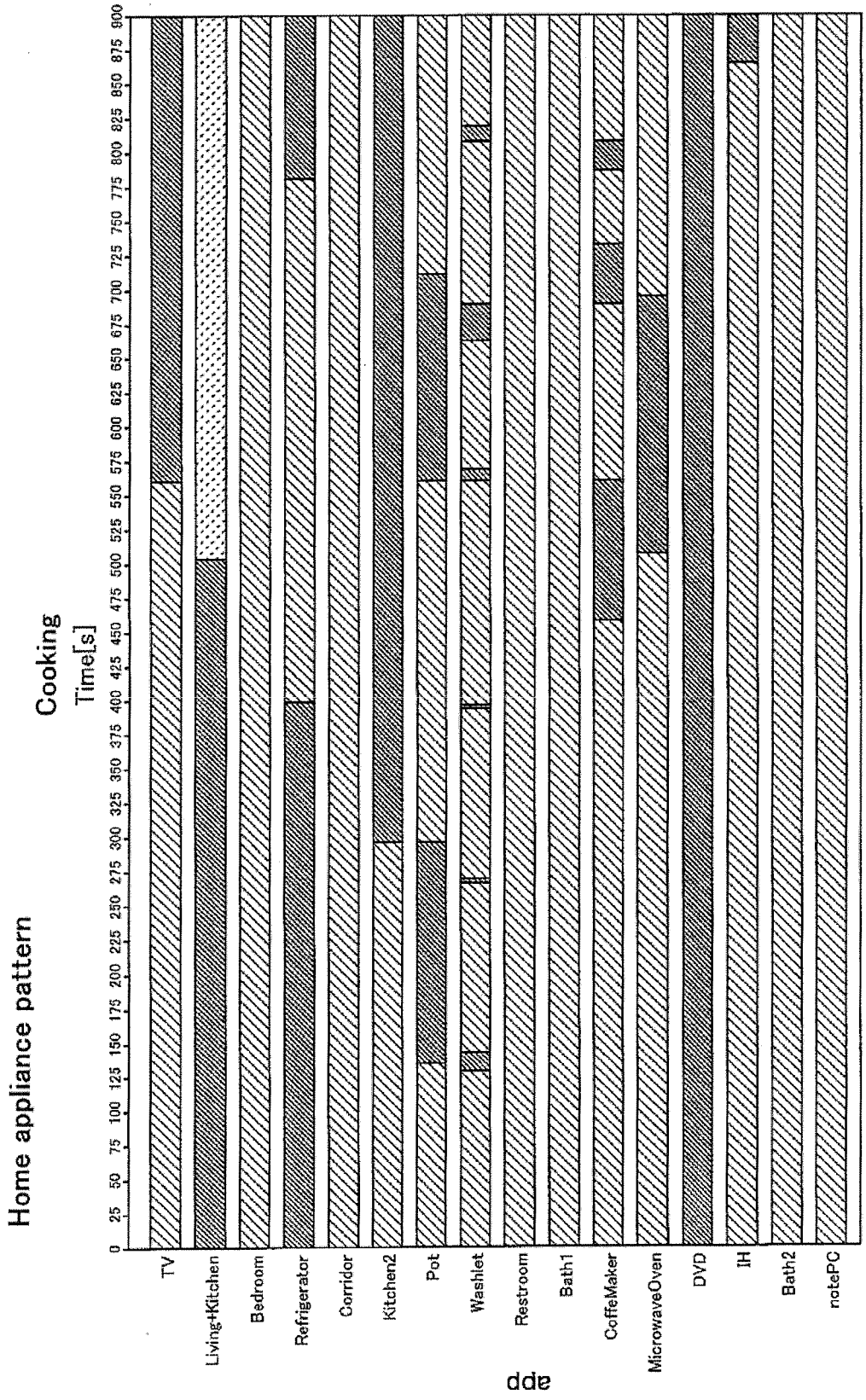
[Fig.32]


Start
S205
Acquire living activity label at time t from questionnaire result
S210
Acuire current use state q and previous use state q' of appliance a from memory
S215
Is appliance currently being used?
No
Yes
S220
Is state different from use state q' of previous time?
No
Yes
S225
Employ use state change as event and store type of event e{q' → q} and occurence time et
S230
Acquire transition probability p(q'' | q) of next use state from appliance use state transition probability table
S235
Acquire transition probability p(τ | q) corresponding to elapsed time from event occurrence from use state perssistence length probability table
S240
Calculate probability distribution Pq'' = p (q'' | q) × p (τ | q) of next use state from next use state transition probability and transition probability
S245
Set q' = q and store q and q' randomly determined according to probability distribution of Pq'' of next use state in memory
S250
Randomly gererate electric power value according to power distribution p (w | q) in use state q and output electric power consumption pattern
S255
Advance time (t = t + 1)
S260
Acquire appliance use frequency p(a|1) to living activity from appliance use frequency table
S265
Acquire initial state distribution p(q'|OFF) from appliance use state transition probability table of appliance a and set probability distribution of next use state to Pq'' = p(a|1) × p(q'|OFF)

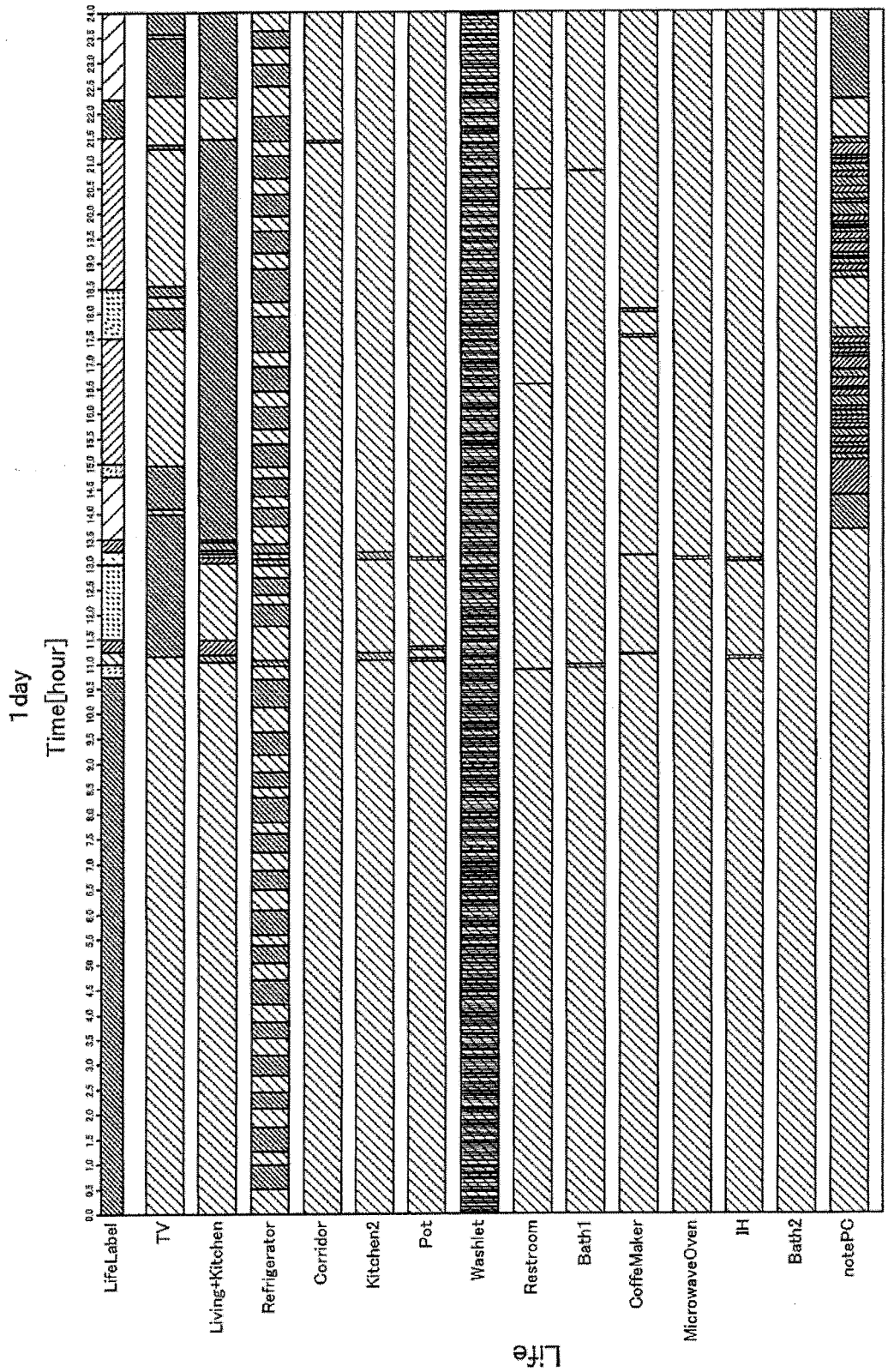
[Fig.33]


Actual data of cooking
Cooking
Time[s]
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 575 600 625 650 675 700 725 750 775 800 825 850 875 900
app
TV
Living+Kitchen
Bedroom
Refrigerator
Corridor
Kitchen2
Pot
Washlet
Restroom
Bath1
CoffeMaker
MicrowaveOven
DVD
IH
Bath2
notePC

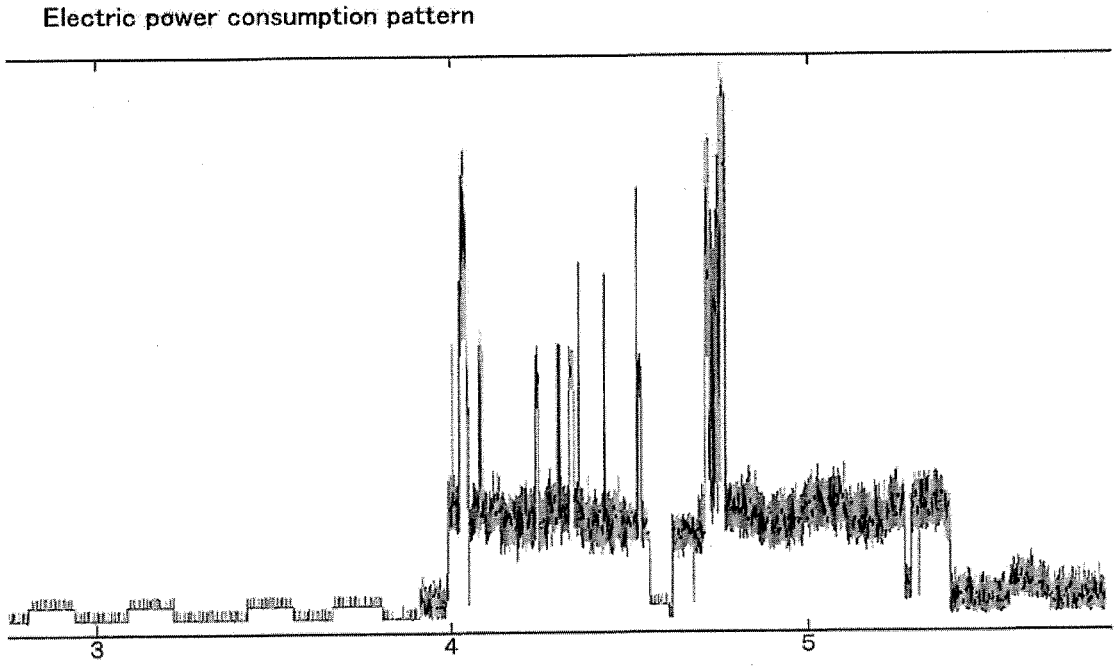
[Fig.34]


Home appliance pattern
Cooking
Time[s]
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500 525 550 575 600 625 650 675 700 725 750 775 800 825 850 875 900
app
TV
Living+Kitchen
Bedroom
Refrigerator
Corridor
Kitchen2
Pot
Washlet
Restroom
Bath1
CoffeMaker
MicrowaveOven
DVD
IH
Bath2
notePC

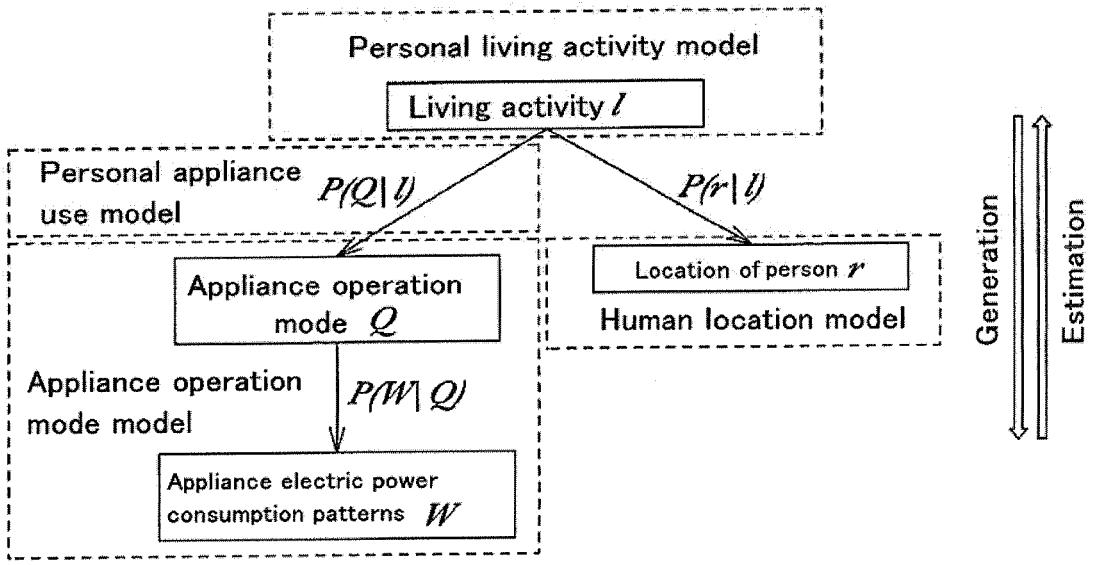
[Fig.35]


1 day
Time[hour]
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0 10.5 11.0 11.5 12.0 12.5 13.0 13.5 14.0 14.5 15.0 15.5 16.0 16.5 17.0 17.5 18.0 18.5 19.0 19.5 20.0 20.5 21.0 21.5 22.0 22.5 23.0 23.5 24.0
LifeLabel
TV
Living+Kitchen
Refrigerator
Corridor
Kitchen2
Pot
Washlet
Restroom
Bath1
CoffeMaker
MicrowaveOven
IH
Bath2
notePC
Life

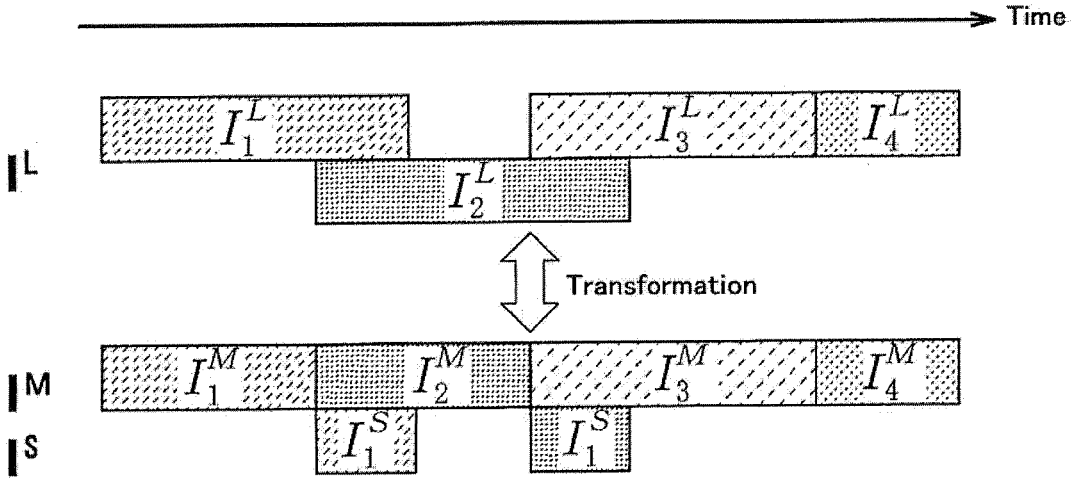
[Fig.36]


Electric power consumption pattern
3
4
5

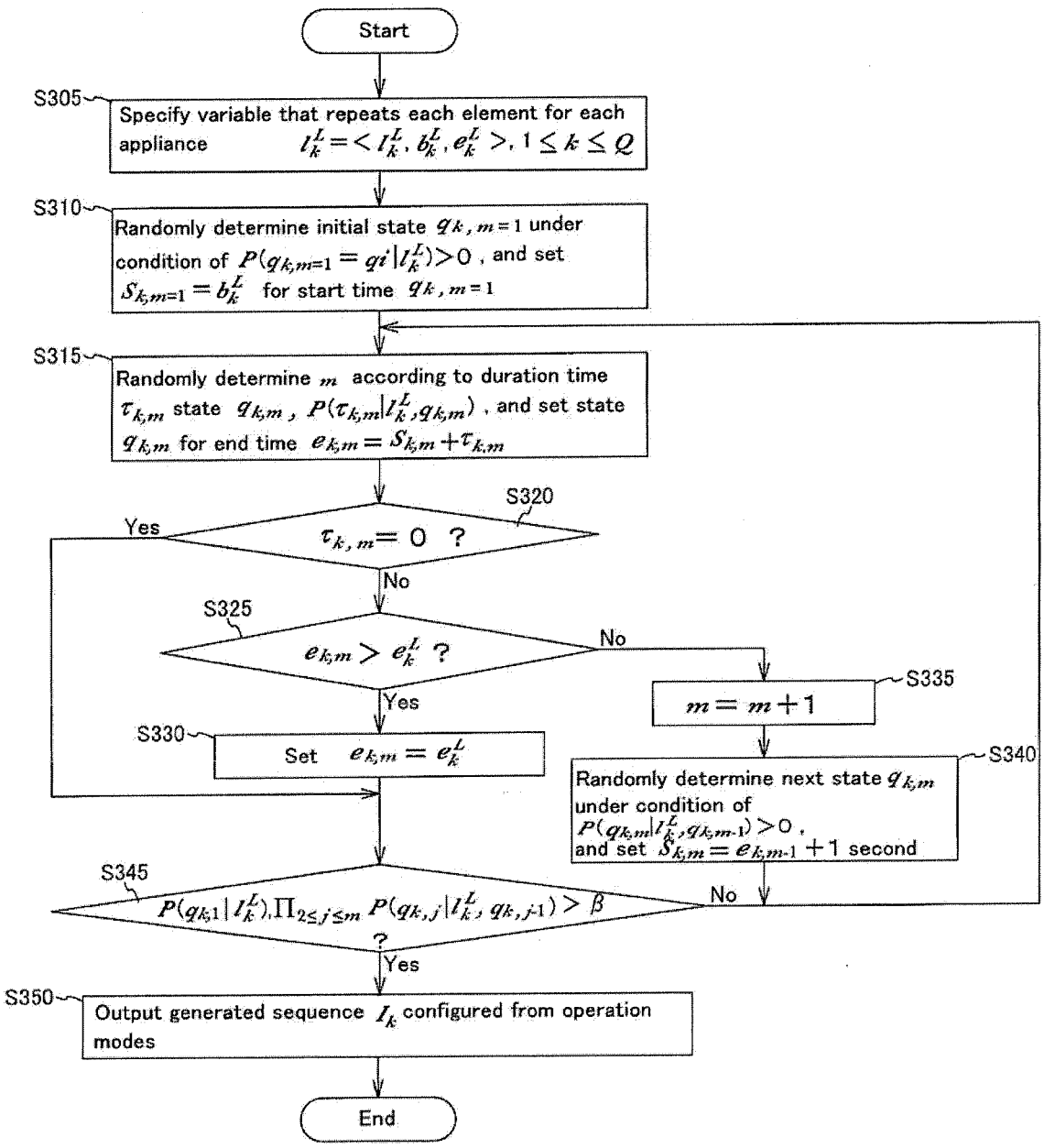
[Fig.37]


Personal living activity model
Living activity l
Personal appliance use model
P(Q|l)
P(r|l)
Appliance operation mode Q
Location of person r
Human location model
Appliance operation mode model
P(W|Q)
Appliance electric power consumption patterns W
Generation
Estimation

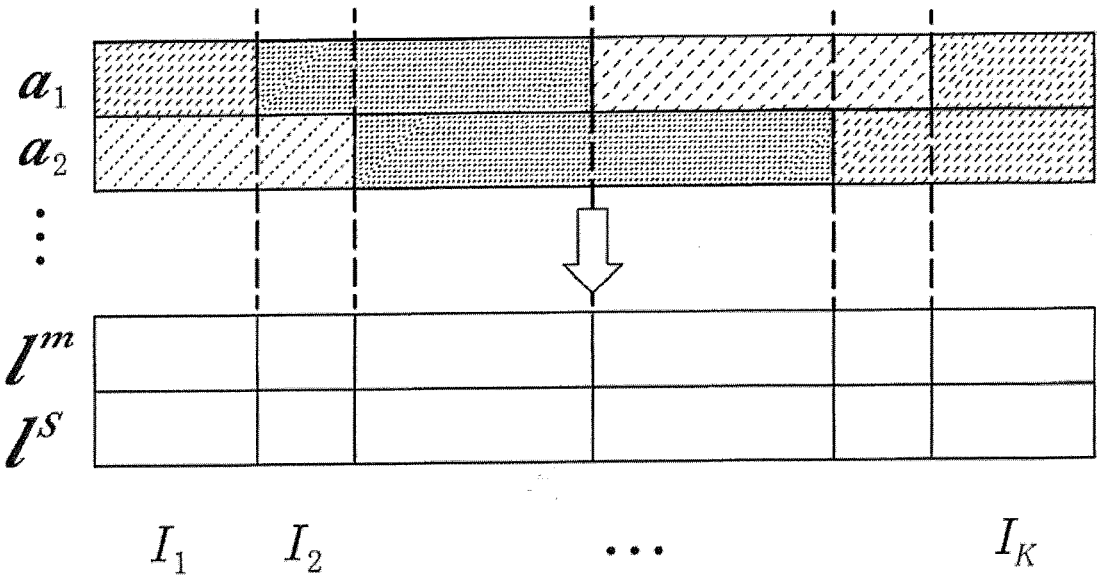
[Fig.38]


Time
L
I_1^L
I_2^L
I_3^L
I_4^L
Transformation
M
S
I_1^M
I_2^M
I_3^M
I_4^M
I_1^S
I_1^S

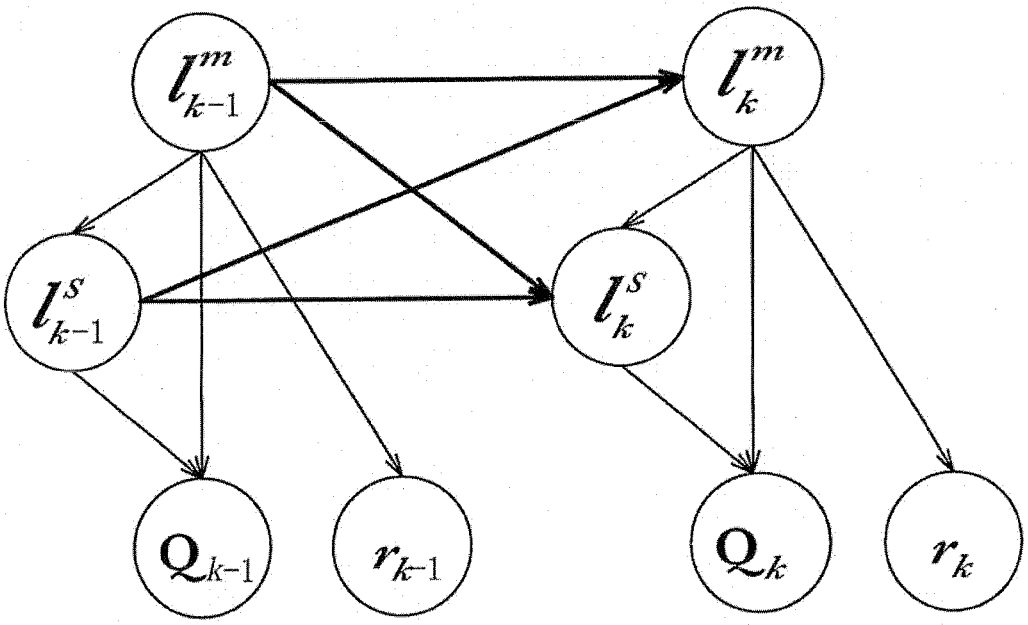
[Fig.39]


Start
S305
Specify variable that repeats each element for each appliance $I_k^L = < I_k^L, b_k^L, e_k^L >, 1 \leq k \leq Q$
S310
Randomly determine initial state $q_{k,m=1}$ under condition of $P(q_{k,m=1} = qi | I_k^L) > 0$, and set $S_{k,m=1} = b_k^L$ for start time $q_{k,m=1}$
S315
Randomly determine m according to duration time $\tau_{k,m}$ state $q_{k,m}$, $P(\tau_{k,m} | I_k^L, q_{k,m})$, and set state $q_{k,m}$ for end time $e_{k,m} = S_{k,m} + \tau_{k,m}$
S320
$\tau_{k,m} = 0$?
Yes
No
S325
$e_{k,m} > e_k^L$?
No
Yes
S330
Set $e_{k,m} = e_k^L$
S335
$m = m + 1$
S340
Randomly determine next state $q_{k,m}$ under condition of $P(q_{k,m} | I_k^L, q_{k,m-1}) > 0$, and set $S_{k,m} = e_{k,m-1} + 1$ second
S345
$P(q_{k,1} | I_k^L) \cdot \Pi_{2 \leq j \leq m} P(q_{k,j} | I_k^L, q_{k,j-1}) > \beta$?
No
Yes
S350
Output generated sequence I_k configured from operation modes
End

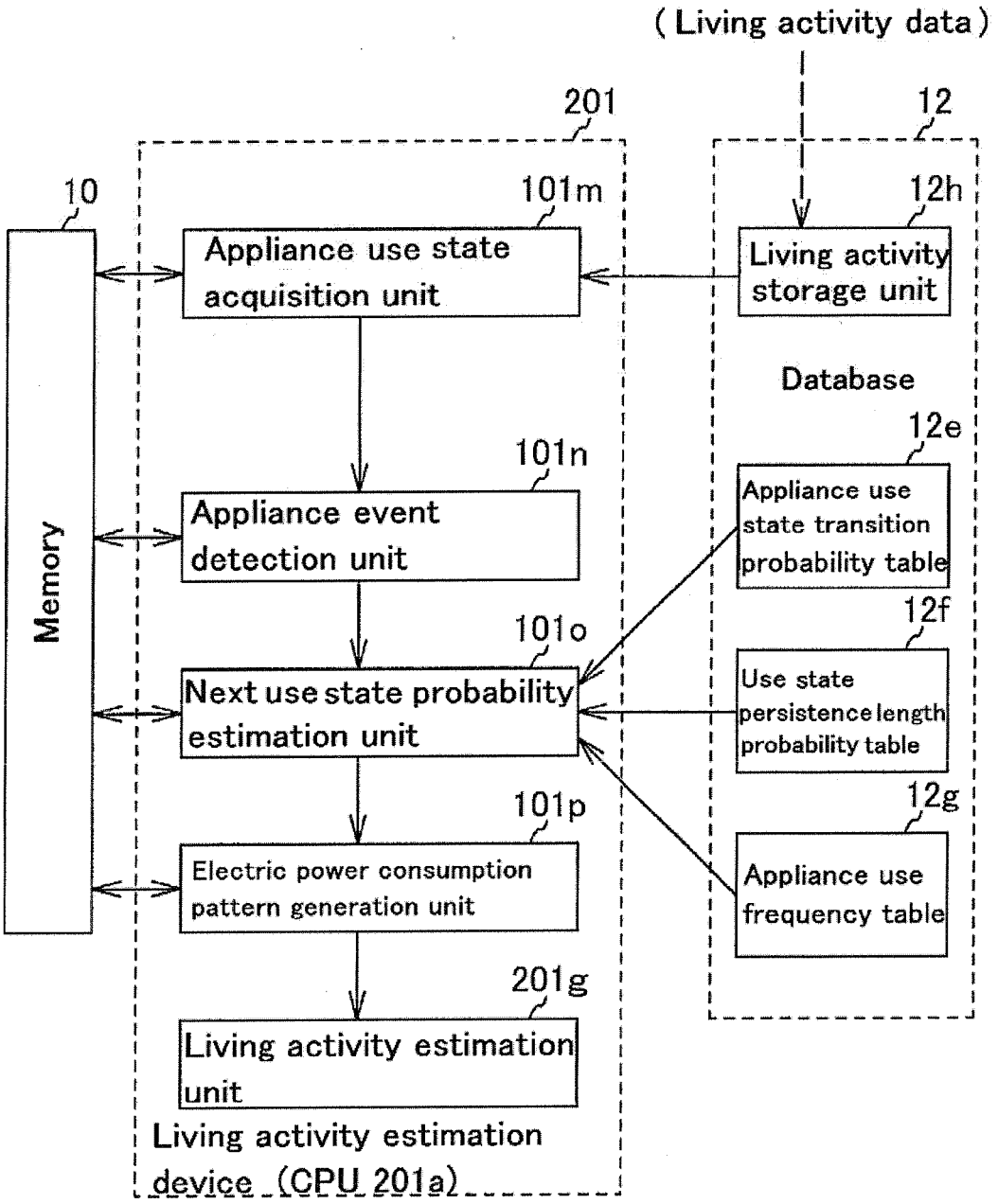
[Fig.40]



[Fig.41]



[Fig.42]

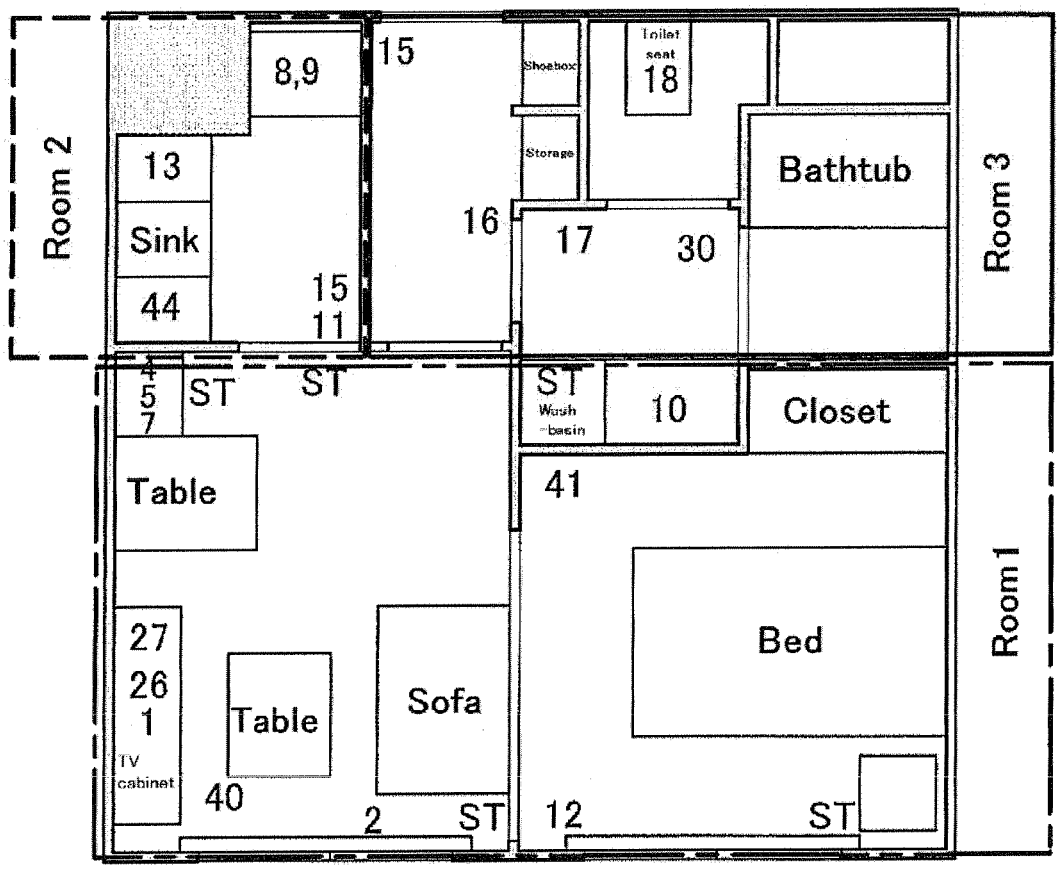

(Living activity data)
201
12
10
101m
12h
Appliance use state acquisition unit
Living activity storage unit
Database
12e
101n
Appliance use state transition probability table
Appliance event detection unit
Memory
12f
101o
Use state persistence length probability table
Next use state probability estimation unit
12g
101p
Appliance use frequency table
Electric power consumption pattern generation unit
201g
Living activity estimation unit
Living activity estimation device (CPU 201a)

[Fig.43]

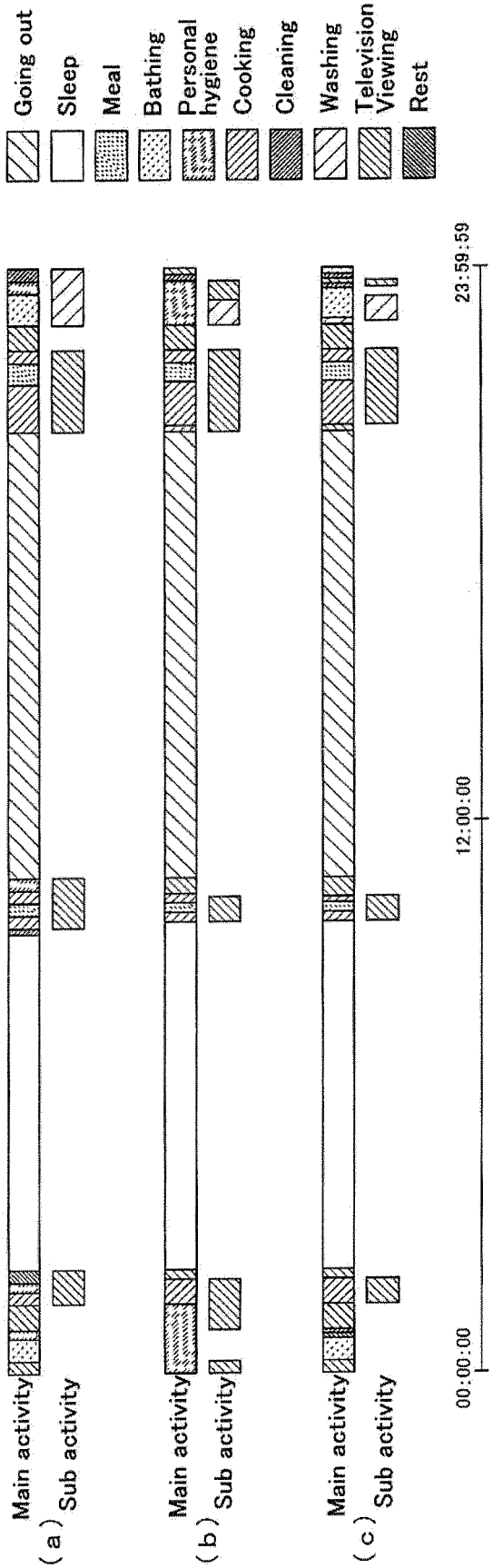
Probabilities based on appliance function / learned probabilities

$P(a_c \mid I_g)^*$	Going out	Sleep	Meal	Bathing	Personal hygiene	Cooking	Cleaning	Washing	Chore	Work/ academic learning	Entertainment	Television viewing	Rest	Conversation	$\lambda(c)$
Television	0/0	0/0	0/0.10	0/0.03	0/0.01	0/0.02	0/0.04	0/0.02	0/0	0/0.01	0.25/0.20	0.75/0.25	0/0	0/0	0.10
Air conditioner	0/0	0/0	0.50/0.18	0/0.01	0.04/0.06	0/0.01	0.07/0.06	0/0.01	0.11/0.11	0.13/0.11	0.13/0.09	0.13/0.11	0.33/0.25	0.50/0.50	0.02
Living room light	0/0	0/0	0/0.05	0/0.06	0.04/0.07	0/0.01	0.07/0.09	0/0.05	0.11/0.11	0.13/0.16	0.13/0.13	0.13/0.14	0.33/0.25	0.50/0.50	0.11
Bedroom light	0/0	0/0	0/0	0/0	0.04/0.06	0/0	0.07/0.06	0/0	0.11/0.11	0/0	0/0	0/0	0.33/0.25	0/0	0
Refrigerator	0/0	0/0	0/0.09	0/0.03	0/0.02	0.04/0.05	0/0	0/0.04	0/0	0/0.02	0/0.05	0/0.06	0/0	0/0	0.09
Corridor light	0/0	0/0	0/0	0/0	0.04/0.06	0/0	0.07/0.06	0/0	0.11/0.11	0/0	0/0	0/0	0/0	0/0	0
Kitchen light1	0/0	0/0	0/0.07	0/0.04	0/0.02	0.22/0.23	0.07/0.09	0/0.03	0.11/0.11	0/0.05	0/0.03	0/0.05	0/0	0/0	0.10
Kitchen light2	0/0	0/0	0/0.12	0/0	0/0.01	0.22/0.24	0.07/0.04	0/0	0.11/0.11	0/0	0/0	0/0.10	0/0	0/0	0.25
Pot	0/0	0/0	0/0	0/0	0/0	0.07/0.08	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0
Microwave	0/0	0/0	0.50/0.25	0/0	0/0.02	0.22/0.15	0/0	0/0	0/0	0/0	0/0	0/0.04	0/0	0/0	0.52
IH cooker	0/0	0/0	0/0.14	0/0	0/0	0.22/0.18	0/0	0/0	0/0	0/0	0/0	0/0.09	0/0	0/0	0.43
Wash-basin light	0/0	0/0	0/0	0/0	0.26/0.11	0/0.02	0.07/0.02	0/0	0.11/0.11	0/0	0/0.02	0/0.08	0/0.25	0/0	0.73
Restroom light	0/0	0/0	0/0	0.25/0.17	0.26/0.33	0/0	0.07/0.06	0.14/0.08	0.11/0.11	0/0	0/0	0/0	0/0	0/0	0
Bathroom light	0/0	0/0	0/0	0.75/0.50	0.04/0.07	0/0	0.07/0.03	0/0.15	0.11/0.11	0/0	0/0	0/0	0/0	0/0	0.41
Dryer	0/0	0/0	0/0	0/0	0.26/0.11	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0.83
Vacuum cleaner	0/0	0/0	0/0	0/0	0/0	0/0	0.40/0.35	0/0.08	0/0	0/0	0/0	0/0	0/0	0/0	0.83
Washing machine	0/0	0/0	0/0	0/0.16	0/0.03	0/0	0/0.11	0.86/0.47	0/0	0/0.04	0/0.08	0/0.02	0/0	0/0	0.32
Notebook PC	0/0	0/0	0/0	0/0	0/0.01	0/0.01	0/0	0/0.07	0/0	0.75/0.61	0.50/0.40	0/0.07	0/0	0/0	0.35

[Fig.44]


Room 2
8,9
15
Shoebox
Toilet seat
18
Storage
Bathtub
Room 3
13
Sink
44
15
11
16
17
30
4
5
7
ST
ST
ST
Wash basin
10
Closet
Table
41
27
26
1
TV cabinet
Table
Sofa
Bed
Room 1
40
2
ST
12
ST

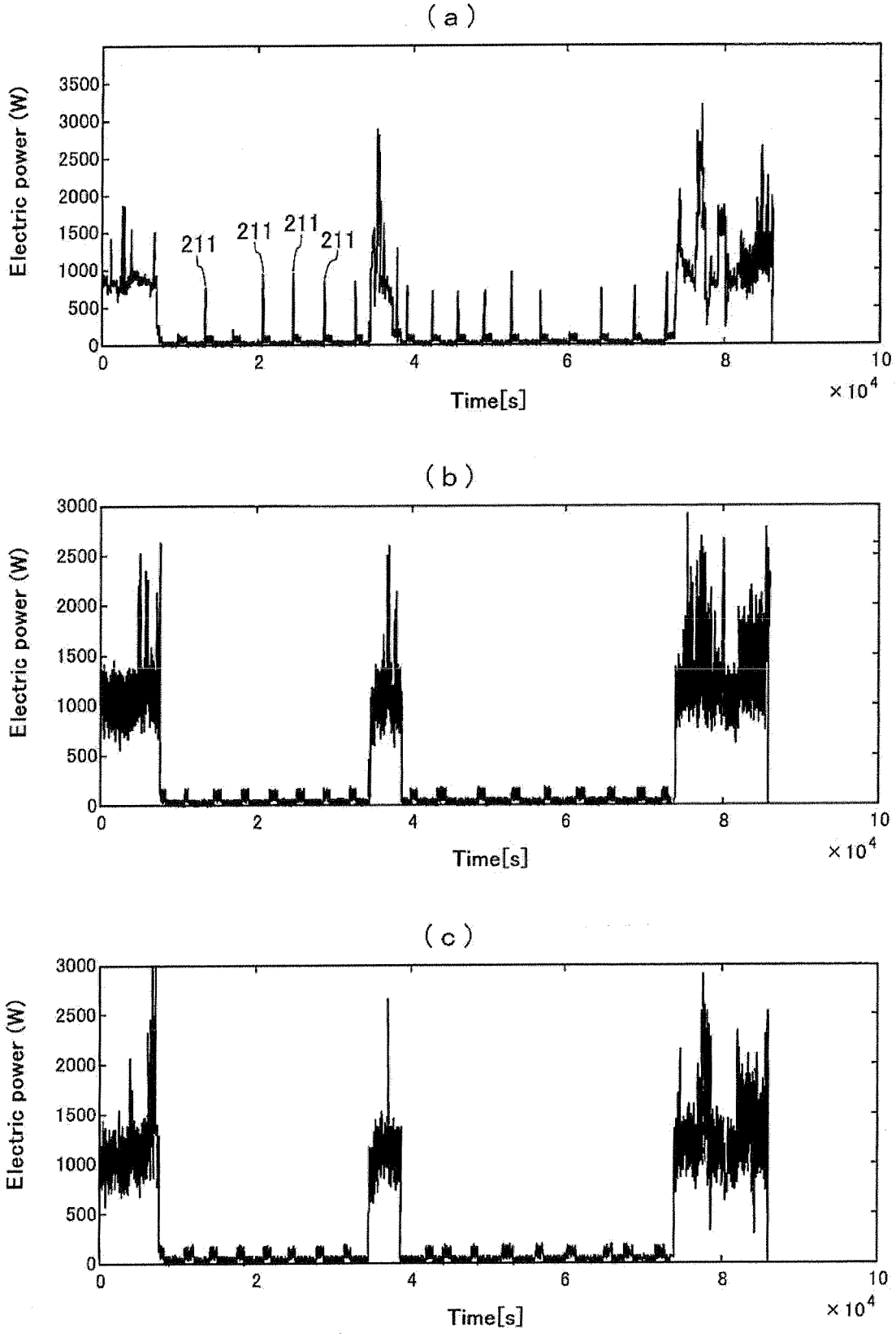
[Fig.45]


Going out
Sleep
Meal
Bathing
Personal hygiene
Cooking
Cleaning
Washing
Television Viewing
Rest
(a)
Main activity
Sub activity
(b)
Main activity
Sub activity
(c)
Main activity
Sub activity
00:00:00
12:00:00
23:59:59

[Fig.46]

		A-1	A-2	A-3	A-4	B-1	B-2	C-1	C-2	C-3	C-4	C-5	Average value
wo / learning	Recall	20/26=0.77	15/18=0.83	20/22=0.91	15/18=0.83	9/14=0.64	7/9=0.78	6/12=0.5	10/12=0.83	13/19=0.68	10/19=0.53	16/21=0.76	0.746
	Precision	23/24=0.96	22/25=0.88	26/28=0.93	22/26=0.85	9/16=0.56	7/12=0.58	9/12=0.75	14/14=1.0	18/21=0.86	11/17=0.65	25/33=0.76	0.784
	F-measure	0.85	0.85	0.92	0.84	0.60	0.67	0.60	0.91	0.76	0.58	0.76	0.758
w / learning	Recall	22/26=0.85	15/18=0.83	19/22=0.86	15/18=0.83	9/14=0.64	8/9=0.89	6/12=0.5	10/12=0.83	14/19=0.74	10/19=0.53	16/21=0.76	0.771
	Precision	28/31=0.9	20/20=1	24/27=0.88	21/30=0.7	10/21=0.48	8/11=0.73	9/13=0.69	14/14=1.0	22/25=0.88	13/16=0.81	24/28=0.86	0.786
	F-measure	0.87	0.91	0.87	0.76	0.55	0.80	0.58	0.91	0.80	0.64	0.81	0.773

[Fig.47]


(a)
Electric power (W)
3500
3000
2500
2000
1500
1000
500
0
211
211
211
211
0
2
4
6
8
10
Time[s]
×10^4
(b)
Electric power (W)
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
Time[s]
×10^4
(c)
Electric power (W)
3000
2500
2000
1500
1000
500
0
0
2
4
6
8
10
Time[s]
×10^4