Solving Airport Gate Allocation Problem Using Angle Modulated Simulated Kalman Filter

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Abstract—In order to solve discrete optimization problem, the SKF algorithm is combined with angle modulated approach. Airport gate allocation problem refers to the search for optimal assignment of flights to gates at an airport. Assignment of flight to gates has become very complex nowadays, especially for a big size airport. In this study, the airport gate allocation problem is solved using a recently introduced angle modulated simulated Kalman filter (AMSKF). The objective of this study is to minimize the total walking distance. A small case study with 14 flights and 16 gates has been chosen. Preliminary results show that SKF is a promising algorithm for solving the airport gate allocation problem.

Keywords—airport schedule, gate assignment, angle modulated, simulated Kalman filter, walking distance

1. INTRODUCTION

Various approaches have been employed for solving airport gate allocation problems (AGAP) such as linear programming [1], tabu search [2], simulated annealing [3], coevolutionary [4], and genetic algorithm [5-7]. Inspired by the estimation capability of Kalman filter, a novel estimation-based optimization algorithm called simulated Kalman filter (SKF) has been introduced [8]. Then, a number of fundamental improvements of SKF have been proposed, such as hybrid simulated Kalman filter with particle swarm optimization [9] and binary simulated Kalman filter [10]. The SKF also has been applied to solve engineering problems [11-12]. In this paper, an application of SKF algorithm in solving AGAP is presented.

The objective of AGAP is to find the optimal assignment of flights to gates at an airport. The quality of the assignment can be evaluated based on certain objectives, such as to minimize the total connection times by passengers [2,11] or to minimize the total walking distance [4].

2. SIMULATED KALMAN FILTER AND ANGLE-MODULATED SIMULATED KALMAN FILTER

Every agent in SKF is regarded as a Kalman filter. Based on the mechanism of Kalman filtering and measurement process, every agent estimates the global minimum/maximum. Measurement, which is required in Kalman filtering, is mathematically modelled and such simulated. Agents communicate among them to update and improve the solution during the search process. The simulated Kalman filter (SKF) algorithm is illustrated in Fig. 1.

Consider n number of agents, SKF algorithm begins with initialization of n agents, in which the states of each agent are given randomly. The maximum number of iterations, $t_{\max}$, is defined. The initial value of error covariance estimate, $P(0)$, the process noise value, Q, and the measurement noise value, R, which are required in Kalman filtering, are also defined during initialization stage.

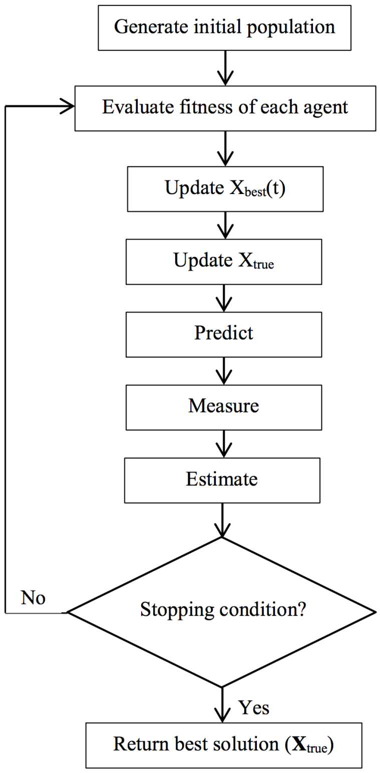

Figure 1: The original simulated Kalman filter (SKF) algorithm.

Then, every agent is subjected to fitness evaluation to produce initial solutions $\{\boldsymbol{X}_1(0), \boldsymbol{X}_2(0), \boldsymbol{X}_3(0), \ldots, \boldsymbol{X}_{n-2}(0), \boldsymbol{X}_{n-1}(0), \boldsymbol{X}_n(0)\}$. The fitness values are compared and the agent having the best fitness value at every iteration, t, is registered as $\boldsymbol{X}_{\mathbf{best}}(t)$. For function minimization problem,

$$\boldsymbol{X}_{\mathbf{best}}(t) = \min_{i \in 1,\ldots,n} fit_i(\boldsymbol{X}(t)) \tag{1}$$

whereas, for function maximization problem,

$$\boldsymbol{X}_{\mathbf{best}}(t) = \max_{i \in 1,\ldots,n} fit_i\big(\boldsymbol{X}(t)\big) \tag{2}$$

The-best-so-far solution in SKF is named as $\boldsymbol{X}_{\mathbf{true}}$. The $\boldsymbol{X}_{\mathbf{true}}$ is updated only if the $\boldsymbol{X}_{\mathbf{best}}(t)$ is better (($\boldsymbol{X}_{\mathbf{best}}(t) < \boldsymbol{X}_{\mathbf{true}}$ for minimization problem, or $\boldsymbol{X}_{\mathbf{best}}(t) > \boldsymbol{X}_{\mathbf{true}}$ for maximization problem) than the $\boldsymbol{X}_{\mathbf{true}}$. The subsequent calculations are largely similar to the predict-measure-estimate steps in Kalman filter. In the prediction step, the following time-update equations are computed.

$$\boldsymbol{X}_{\boldsymbol{i}}(t|t) = \boldsymbol{X}_{\boldsymbol{i}}(t) \tag{3}$$

$$P(t|t) = P(t) + Q \tag{4}$$

where $\boldsymbol{X}_i(t)$ and $\boldsymbol{X}_i(t|t)$ are the current state and current transition/predicted state, respectively, and $P(t)$ and $P(t|t)$ are the current error covariant estimate and current transition error covariant estimate, respectively. Note that the error covariant estimate is influenced by the process noise, Q.

The next step is measurement, which is a feedback to estimation process. Measurement is modelled such that its output may take any value from the predicted state estimate, $\boldsymbol{X}_i(t|t)$, to the true value, $\boldsymbol{X}_{\mathrm{true}}$. Measurement, $\boldsymbol{Z}_i(t)$, of each individual agent is simulated based on the following equation:

$$\boldsymbol{Z}_{\boldsymbol{i}}(t) = \boldsymbol{X}_{\boldsymbol{i}}(t|t) + \sin(rand \times 2\pi) \times |\boldsymbol{X}_{\boldsymbol{i}}(t|t) - \boldsymbol{X}_{\boldsymbol{true}}| \tag{5}$$

The $\sin(rand \times 2\pi)$ term provides the stochastic aspect of SKF algorithm and $rand$ is a uniformly distributed random number in the range of $[0,1]$. The final step is the estimation. During this step, Kalman gain, $K(t)$, is computed as follows:

$$K(t) = \frac{P(t|t)}{P(t|t)+R} \tag{6}$$

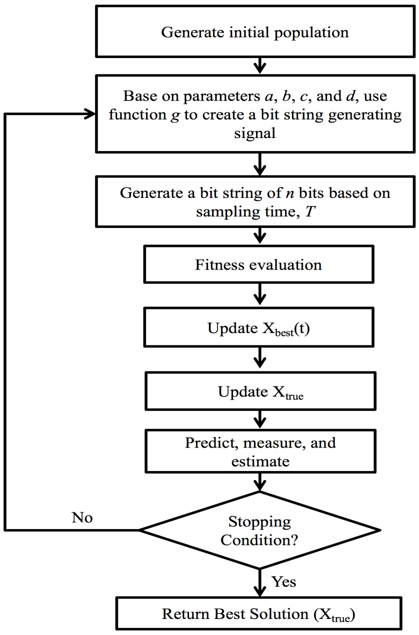

Figure 2**:** The angle modulated SKF (AMSKF) algorithm.

Then, the estimation of next state, $\boldsymbol{X}_i(t+1)$, and the updated error covariant are computed based on (7) and (8), respectively.

$$\boldsymbol{X}_i(t+1) = \boldsymbol{X}_i(t|t) + \Delta_i \tag{7}$$

$$P(t+1) = \left(1 - K(t)\right) \times P(t|t) \tag{8}$$

where $\Delta_i = K(t) \times (\boldsymbol{Z}_i(t) - \boldsymbol{X}_i(t|t))$.

Finally, the next iteration is executed until the maximum number of iterations, t_{max}, is reached. Fig. 2 shows the angle modulated SKF (AMSKF) for solving combinatorial optimization problem by using function, $g(x)$, to create a continuous signal. The shape of signal $g(x)$ is determined by 4 variables, namely a, b, c, and d as shown in (9).

$$g(x) = \sin(2\pi(x-a)\times b\times \cos(A)) + d \tag{9}$$

where $A = 2\pi(x-a)\times c$

The main advantage of angle modulated approach is that complex calculation in producing high dimensional bit string can be avoided. The search process in solving a combinatorial optimization problem can be done by tuning the values of a, b, c, and d only. In this work, the tuning is done by the SKF algorithm.

3. AIRPORT GATE ALLOCATION PROBLEM

The AGAP involves a number of parameters as follows:

n number of flights
m number of gates
w number of time windows
ω_k walking distance between gate k and entrance/exit

Once a flight arrived at an assigned gate, the passengers have to walk from the date to the entrance/exit hall. In this study, the objective is to minimize the total walking distance between gates and an entrance/exit. This objective is mathematically represented as

$$min \sum_{i=1}^{w} x_{ik}\, \omega_k \tag{10}$$

where
$x_{ik} \in \{0,1\}$ 1 iff time window i is assigned to gate k;
0 otherwise.

Table 1: Flight arrival from Penang.

Depart (PEN)	Arrive (KLIA)	Flight's code
6:50	7:50	F0300
8:35	9:35	F0200
11:20	12:20	F0100
13:10	14:10	F0400
14:10	15:10	F0301
17:10	18:10	F0401
18:20	19:20	F0101
19:25	20:25	F0201
20:55	21:55	F0402
23:30	00:20	F0102

Table 2: Flight arrival from Kota Kinabalu.

Depart (KBK)	Arrive (KLIA)	Flight's code
7:10	9:40	F0800
9:30	12:10	F0700
10:55	13:25	F0600
12:30	15:00	F0500
15:45	18:15	F0900
18:30	21:00	F0801
18:55	21:25	F0701
19:25	21:55	F0601
20:10	22:45	F0501
21:30	23:50	F0901

In this paper, only flights arrive from Penang, Kota Kinabalu, and Kuching at KLIA are considered as a case study. The arrival and departure time of those flights are tabulated in Table 1, Table 2, Table 3, Table 4, Table 5, and Table 6. This information is obtained from Malaysian Airlines website (http://www.malaysiaairlines.com). Based on this case study, the number of flights, n = 15. Also, number of gates, m = 16, is considered and the distance between gates (in meter) to entrance/exit is shown in Table 7.

In this study, a time window is defined as a duration (from the arrival to the next departure) of a flight at an airport. The time windows are obtained based on the departure and arrival information. The time windows associated to flights are shown in Table 8. The transit data of the flights and passengers are tabulated in Table 9, Table 10, Table 11, and Table 12.

4. ANGLE MODULATED SIMULATED KALMAN FILTER TO SOLVE AIRPORT GATE ALLOCATION PROBLEM

Fig. 3 shows the use of angle modulated simulated Kalman filter to solve airport gate assignment problem. The experimental setting is shown in Table 13. Fig. 4 and Fig. 5 show two examples of convergence curve based on different maximum iteration values. The convergence curves show that the generation of better gate assignment can be obtained using AMSKF algorithm. Example of solution produced by AMSKF algorithm is shown in Table 14, Table 15, and Table 16.

5. CONCLUSION

This paper introduced the application to AMSKF in AGAP. The original SKF algorithm is extended such that it can be used for solving combinatorial optimization problems such as AGAP. The angle modulated approach generates a bit string that is required to represent solution. A small scale problem which consists of 14 flights, 16 gates, and an entrance/exit is considered in the experiments. Simulation results show that the SKF algorithm is able to minimize the total walking distance and optimal matching between flights and gates can be obtained. The next step is to consider larger scale of problem with more flights and gates. Also, the fitness function used for the evaluation of flight-gate matching shall be improved to obtain robust solution.

Table 3: Flight arrival from Kuching.

Depart (KCH)	Arrive (KLIA)	Flight's code
7:00	8:45	F1000
9:20	11:00	F1100
10:40	12:25	F1200
11:55	13:45	F1300
15:05	16:45	F1001
16:15	17:55	F1101
17:35	19:20	F1201
18:30	20:15	F1301
19:10	21:00	F1400
19:45	21:25	F1102
22:50	00:50	F1202

Table 4: Flight departure to Penang.

Depart(KLIA)	Arrive(PEN)	Flight's code
7:15	8:10	F0403
8:15	9:10	F0103
10:00	10:55	F0304
12:50	13:45	F0204
14:35	15:30	F0105
15:45	16:45	F0405
17:00	17:55	F0306
19:35	20:30	F0406
21:00	21:55	F0106
22:00	22:55	F0206

Table 5: Flight departure to Kota Kinabalu.

Depart(KBK)	Arrive(KLIA)	Flight's code
6:30	9:05	F0702
7:50	10:30	F0602
9:30	12:05	F0502
10:20	12:55	F0902
12:50	15:20	F0803
15:35	18:10	F0703
16:25	19:00	F0603
17:10	19:45	F0503
18:35	21:05	F0903
21:25	23:59	F0804

Table 6: Flight departure to Kuching.

Depart(KCH)	Arrive(KLIA)	Flight's code
7:00	8:45	F1000
9:20	11:00	F1100
10:40	12:25	F1200
11:55	13:45	F1300
15:05	16:45	F1001
16:15	17:55	F1101
17:35	19:20	F1201
18:30	20:15	F1301
19:10	21:00	F1400
19:45	21:25	F1102
22:50	00:50	F1202

Table 7: Distance between gates to entrance/exit.

Gate Number	**Distance**
GATE 0	1019.5m
GATE 1	1328.6m
GATE 2	1650.0m
GATE 3	2015.6m
GATE 4	2405.2m
GATE 5	2809.0m
GATE 6	3221.6m
GATE 7	3640.1m
GATE 8	1019.5m
GATE 9	1328.6m
GATE 10	1650.0m
GATE 11	2105.6m
GATE 12	2406.22m
GATE 13	2809.0m
GATE 14	3221.6m
GATE 15	3640.1m

Table 8: Example distance between gate assigned to gate.

GATE	**GATE 0**	**GATE 1**	**GATE……**	**GATE 15**
GATE 0	0m	437.5m	………………	3657.7m
GATE 1	437.5m	0m	………………	3300m
GATE 2	875m	437.5m	………………	2964m
GATE 3	1312.5m	875m	………………	2657.5m
GATE 4	1750m	1312.5m	………………	2392.2m
GATE 5	2187.5m	1750m	………………	2183m
GATE 6	2625m	2187.5m	………………	2047.3m
GATE 7	3062.5m	2625m	………………	2000m
GATE 8	2000m	3062.5m	………………	3062.5m
GATE 9	2047.3m	2000m	………………	2625m
GATE 10	2183m	2047.3m	………………	2187.5m
GATE 11	2392.2m	2183m	………………	1750m
GATE 12	2657.5m	2392.2m	………………	1312.5m
GATE 13	2964m	2657.5m	………………	875m
GATE 14	3300m	2964m	………………	437.5m
GATE 15	3657.7m	3300m	………………	0m

Table 9: Number of passenger to transits for connecting flight.

Flight's code	No of Passenger
F0300	40
F0200	40
F0100	40
F0400	100
F0301	80
F0401	90
F0101	80
F0201	100
F0402	X
F0102	X
F0800	80
F0700	80
F0600	100
F0500	120
F0900	130
F0801	100
F0701	50
F0601	X
F0501	X
F0901	X
F1000	70
F1100	70
F1200	70
F1300	150
F1001	100
F1101	180
F1201	100
F1301	50
F1400	X
F1102	X
F1202	X

Table 10: Total Number of passenger arrive at KLIA go to entrance after do transits.

Flight's code	No of Passenger
F0300	160
F0200	160
F0100	160
F0400	100
F0301	70
F0401	60
F0101	70
F0201	50
F0402	100
F0102	100
F0800	120
F0700	120
F0600	100
F0500	80
F0900	20
F0801	50
F0701	50
F0601	100
F0501	100
F0901	X
F1000	130
F1100	130
F1200	130
F1300	50
F1001	50
F1101	30
F1201	50
F1301	100
F1400	100
F1102	100

Table 11: Number of passenger from transits for connecting flight.

Flight's code	No of Passenger
F0304	100
F0204	150
F0105	100
F0405	80
F0306	80
F0406	80
F0106	80
F0206	150
F0403	X
F0103	X
F0803	120
F0703	100
F0603	80
F0503	90
F0903	140
F0804	50
F0702	90
F0602	150
F0502	X
F0902	X
F1002	120
F1104	100
F1204	60
F1303	50
F1003	90
F1105	80
F1205	70
F1302	X
F1402	X
F0103	X
F0304	100

Table 12: Number of passenger go to entrance after transits.

Flight's code	No of Passenger
F0304	300
F0204	350
F0105	300
F0405	280
F0306	280
F0406	280
F0106	350
F0206	100
F0403	100
F0103	100
F0803	220
F0703	200
F0603	280
F0503	290
F0903	340
F0804	250
F0702	290
F0602	350
F0502	150
F0902	150
F1002	320
F1104	300
F1204	260
F1303	250
F1003	290
F1105	280
F1205	270
F1302	100
F1402	100

Table 13: Experimental setting parameters.

SKF Parameters	
Parameter	**Value**
Error covariant, P	1000
Process noise, Q	0.5
Measurement noise, R	0.5
rand	[0,1]
$x_{\min}$	-100
$x_{\max}$	100
Number of agents	100

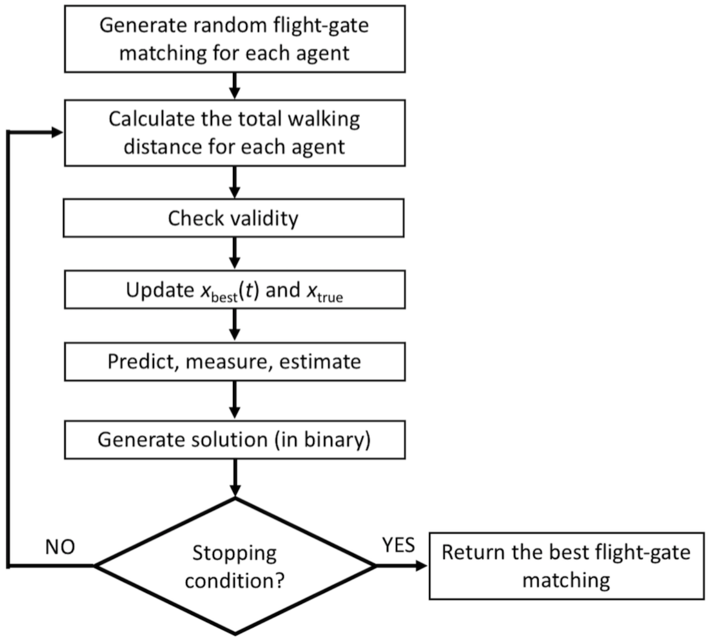

Figure 3**:** Algorithm to solve airport gate assignment problem.

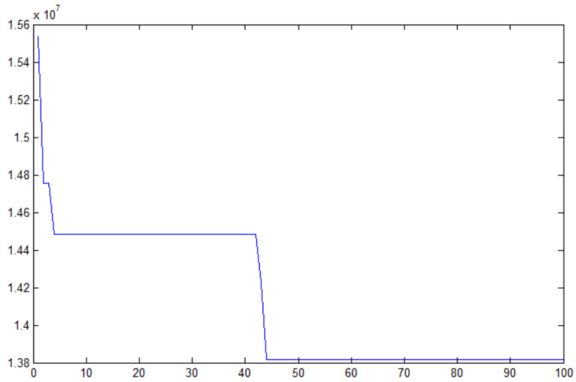

Figure 4: Convergence curve based on 100 iterations. In this figure, the y-axis is the total walking distance in meter (m) and x-axis is the iteration number.

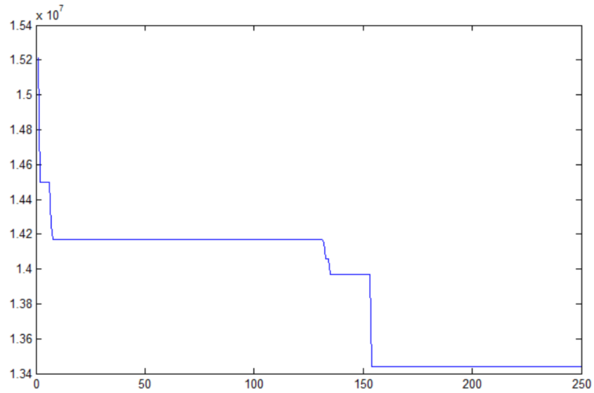

Figure 5: Convergence curve based on 250 iterations. In this figure, the y-axis is the total walking distance in meter (m) and x-axis is the iteration number.

Table 14: Gate combination for Penang's flight.

Flight's code	Best gate assigned
F0300	Gate 5
F0200	Gate 6
F0100	Gate 12
F0400	Gate 2
F0301	Gate 13
F0401	Gate 1
F0101	Gate 10
F0201	Gate2
F0402	Gate 7
F0102	Gate 1

Table 15: Gate combination for Kota Kinabalu's flight.

Flight's code	Best gate assigned
F0800	Gate 3
F0700	Gate 9
F0600	Gate10
F0500	Gate 1
F0900	Gate 11
F0801	Gate 5
F0701	Gate 9
F0601	Gate 13
F0501	Gate 12
F0901	Gate 7

Table 16: Gate combination for Kuching's flight.

Flight's code	Best gate assigned
F1000	Gate 2
F1100	Gate 15
F1200	Gate 6
F1300	Gate 0
F1001	Gate 4
F1101	Gate 3
F1201	Gate 14
F1301	Gate 8
F1400	Gate 1
F1102	Gate 2
F1202	Gate 9

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REFERENCES

[1] R. A. Bihr, "A conceptual solution to the aircraft gate assignment problem using 0, 1 linear programming," Comput. Ind. Eng., vol. 19, no. 1, pp. 280–284, 1990.

[2] Jiefeng Xu and G. Bailey, "The airport gate assignment problem: mathematical model and a tabu search algorithm," Proceedings of the 34th Annual Hawaii International Conference on System Sciences, 2001.

[3] A. Drexl and Y. Nikulin, "Multicriteria airport gate assignment and Pareto simulated annealing," IIE Trans., vol. 40, no. 4, pp. 385–397, Feb. 2008.

[4] A. G. D. S. Garza and A. P. T. C. Licastro, "A coevolutionary method for automating airport gate scheduling," Proceedings of the Fourth Mexican International Conference on Computer Science, pp. 200–206, 2003.

[5] W. Li and X. Xu, "Optimized assignment of airport gate configuration based on immune genetic algorithm," Meas. Technol. Mechatronics Autom. Electr. Eng., pp. 347–355, 2012.

[6] X.-B. Hu and E. Di Paolo, "An efficient genetic algorithm with uniform crossover for the multi-objective airport gate assignment problem," Proceedings of the IEEE Congress on Evolutionary Computation, pp. 55–62, 2007.

[7] Y. Gu and C. A. Chung, "Genetic algorithm approach to aircraft gate reassignment problem," J. Transp. Eng., vol. 125, pp. 384–389, 1999.

[8] Z. Ibrahim, N. H. Abd Aziz, N. A. Ab Aziz, S. Razali, M. I. Shapiai, S. W. Nawawi, and M. S. Mohamad, "A Kalman filter approach for solving unimodal optimization problems," ICIC Express Lett., vol. 9, no. 12, pp. 3415–3422, 2015.

[9] B. Muhammad, Z. Ibrahim, K. H. Ghazali, K. Z. Mohd Azmi, N. A. Ab Aziz, N. H. Abd Aziz, and M. S. Mohamad, "A new hybrid simulated Kalman filter and particle swarm optimization for continuous numerical optimization problems," ARPN J. Eng. Appl. Sci., vol. 10, no. 22, pp. 17171–17176, 2015.

[10] Z. Md Yusof, I. Ibrahim, S. N. Satiman, Z. Ibrahim, N. H. Abd Aziz, and N. A. Ab Aziz, "BSKF : Binary simulated Kalman filter," Third International Conference on Artificial Intelligence, Modelling and Simulation, pp. 77–81, 2015.

[11] Z. Md Yusof, S. N. Satiman, K. Z. Mohd Azmi, B. Muhammad, S. Razali, Z. Ibrahim, Z. Aspar, and S. Ismail, "Solving Airport Gate Allocation Problem using Simulated Kalman Filter," Int. Conf. Knowl. Transf., 2015.

[12] A. Adam, Z. Ibrahim, N. Mokhtar, M. I. Shapiai, M. Mubin, I. Saad, "Feature selection using angle modulated simulated Kalman filter for peak classification of EEG signals, SpringerPlus," Vol. 5, No. 1580, 2016.