Efficient Sensors Selection Algorithm in Cyber Physical System

Ma-Wubin,Deng-Su,Huang Hongbin,Chen-Jian,Wu-Yahun,Li-zhuo

Abstract—Cyber physical system (CPS) for target tracking, military surveillance, human health monitoring, and vehicle detection all require maximizing the utility and saving the energy. Sensor selection is one of the most important parts of CPS. Sensor selection problem (SSP) is concentrating to balance the tradeoff between the number of sensors which we used and the utility which we will get. In this paper, we propose a performance constrained slide windows (PCSW) based algorithm for SSP in CPS. we present results of extensive simulations that we have carried out to test and validate the PCSW algorithms when we track a target, Experiment shows that the PCSW based algorithm improved the performance including selecting time and communication times for selecting.

Keyword—cyber physical system; sensor selection problem; PCSW based algorithm

I. INTRODUCTION

CPS has been used for many fields such as military surveillance, human health monitoring, and vehicle detection. The National Science Foundation (NSF) defined the CPS as "the tight conjoining of and coordination between computational and physical resources" [2]. In many of these applications in CPS, the CPS units, including the sensors and actuators, first observe the physical space or phenomenon of interest and report data to the fusion center, then process these data and change the physical space through the consequence of process.

In CPS, there may be several CPS units that should be selected for the user to control. Apparently, there is a cost associated with using some CPS units by users. It may be desired that the economy for using a set of CPS units for getting the prospective purpose with the lowest cost possible.However, the lowest cost CPS unit selection may be very hard because of three reasons:

1: The process of selection is dynamic. In most case, we need the CPS units should connect or leave the system in any time.

2: The selection of the CPS units should meet real time request. The selection time should be short as much as possible.

3: Energy is the key problem we should consider for selection.

MaWubin. Author is with information system and engineering, Changsha China (phone: +8607314576609; e-mail: mawubin417@ gmail.com).

DengSu. Author is with information integration and decision support system, Changsha China (phone: +8607314576609; e-mail: DengSu086@ gmail.com). .

Huang Hongbin. Author is with information system and engineering, Changsha China (phone: +8607314576609; e-mail: Huanghongbin@ gmail.com). .

ChenJian. Author is with information system and engineering, Changsha China (phone: +8607314576609; e-mail: ChenJian0413@ gmail.com). .

WuYahui. Author is with information system and engineering, Changsha China (phone: +8607314576609; e-mail: WuYahui0731@ gmail.com). .

LiZhuo. Author is with Chinese Philology, Changsha China (phone: +8614789790756; e-mail: lizhuo0903@ gmail.com). .
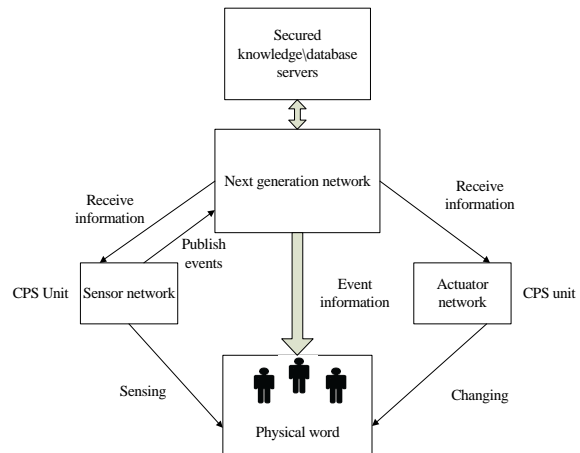
Fig. 1 The framework of CPS

Although it is well-known that the cost minimization of CPS depends on the selection of CPS units, there have been relatively few contributions to the optimal experimental design for CPS on the condition of distributed computing and diversity of units. This paper focus on the sensors of the CPS unit, discusses the selection cost minimization problem in the condition of distributed sensors network in CPS, uses an efficient selection algorithm to solve it. The paper is organized as follows: In Section 1 we introduce the sensor selection problem in CPS and related work of this problem. In Section 2 we formulate the sensor selection problem. Section 3 presents our PCSW based algorithm. Section 4 brings experimental results that compare the cost function and communication time of both our algorithms and some algorithms proposed in [9]. Finally, Section IV provides concluding remarks and discussions of future directions of research.

II. RELATED WORK

CPS consists of a large number of sensors and actuators that have the capability to change and take various measurements of their environment. An important class of application for the WSN is to observe physical systems, where the sensor networks together with the physical processes are considered as part of CPS[1]. Sensors which are scattered around a field to sense the environment and send the information back have different ability and should be selected to use. Some works have been down for the sensor selection problem in coverage schemes, target tracking and localization schemes. A general sensor selection problem is formulated [2] ,it is solved by relaxing to a convex programming problem. A multitude studies along this line try to obtain a performance level with the lowest cost for target localization[3,11]. [4] develops an analytical model for probabilistic area coverage in terms of the target detection probability. [5, 6] focuses on a central issue of

active information fusion, their goal is selecting a subset of sensors which are most decision relevant and cost effective, [7] proposes a method to select sensors with trusted and relevant information by fusing data from a multitude of heterogeneous, distinct, but possibly unreliable or irrelevant sensors. [8] proposes prediction-based sleep scheduling method sensor selection problem for target tracking, it reduces the number of computing sensors as well as their active by precisely predicting the target movement based on kinematics and probability, Sensor selection also has been studied in sensor network management[9], hypothesis testing in a sensor network[10], and discrete-event systems[11]. The sensor selection problem formulation we use in this paper can be found in [1], [1] has important contribution for SSP in CPS, for the first time it presents the SSP in CPS for the target detection, and proposes the elimination-based convex optimal method, uses the Fisher information matrix (FIM) as the unifying framework for SSP.

However, all of them ignore efficiency of sensor selection problem caused by dynamic target tracking. Their selection algorithm is not suitable for the sensors which have different ability such as in radar target tracking. We believe that the ideas behind our algorithm will be more efficient for sensor selection in tracking dynamic target.

III. FORMULATION OF SENSOR SELECTION

We consider a linear system with m linear measurements:

$$x_{k+1} = Ax_k + w_k, k = 1, ..., n$$
$$y_i = a_i^T x + v_i, i = 1, ..., m \tag{1}$$

Where $x \in R^n$ is a vector of parameters and $x = \{x_1, , , x_n\}$, $x_i \sim N(0, \Sigma)$, $v_1, ..., v_n$ are independent and $v_i \sim N(0, \sigma_i^2)$. We assume that $y_k = [y_{k,1}, y_{k,2}, , , y_{k,m}]^T$, $y_{k,m}$ indicates what the sensors estimate in time k. where we also assume that A and a_i^T is detectable,

From [12], the maximum-likelihood estimate of x :

$$\hat{x} = \left(\sum_{i=1}^m a_i a_i^T \right)^{-1} \sum_{i=1}^m y_i a_i \tag{2}$$

Then the covariance of the estimation error $x - \hat{x}$ is:

$$\Sigma = \sigma^2 \left(\sum_{i=1}^m a_i a_i^T \right)^{-1} \tag{3}$$

The sensor selection problem is based on D-optimality which can be described as follows:

$$\text{Maximize} \quad \log \quad \det \left(\sum_{i=1}^m r_i a_i a_i^T \right)$$

$$\text{Subject to } 1^T r = k , r_i \in \{0, 1\}, i = 1, ..., m$$

There are other optimality criteria available, such as E-optimality criterion, A-optimality criterion et al. The D-optimality is more commonly used by SSP because the result of the D-optimality is not affected by linear transforms compared with other criterion and it is differentiable. Our performance function for PCSW algorithm is also based on the D-optimality.

r_i indicates the ith sensor which is selected or unselected by assigning value with 0 or 1, in order to more factual, a normalized sampling rate $p_i[k]$ is assigned to indicate the possibility of selected. That is,

$$p_i[k] \in [0, 1], \sum p_i[k] = 1$$

Then the SSP can be described as follows:

$$\text{Maximize} \quad \log \quad \det \left(\sum_{i=1}^m p_i a_i a_i^T \right) \tag{4}$$

$$\text{Subject to } 1^T p = 1, p \geq 0$$

Much work has been done on this problem[2], [2]proved it is a NP hard problem, most of research tried to solve the problem with heuristic method or relaxations of the sensing model.

IV. EFFICIENT SENSOR SELECTION ALGORITHM

We will introduce two important definitions which are the foundation of the algorithm. We define the performance constrained windows and λ -strategy as follows:

Define1: Performance Constrained Slide Windows (PCSW), it is indicated with three tuples $(L, P(L), t_i)$, L means the length of the windows, it indicates the number of the sensors which have been selected in SSP, and P is the function about L , it denotes the performance of selected sensors; $t_i \in T$ indicates the time of windows. Time has been separated to discrete time segment in SSP, $T = \{t_1, t_2, ..., t_k\}$.

Let the performance function, according to (3) and (4),

$$f(s_i) = -\log \det \left(\sum_{i=1}^m a_i \sigma_i^{-2} a_i^T \right) \tag{5}$$

We also define the update strategy for PCSW based algorithm:

Define2: λ -Strategy: For the discrete stages in sensor selection problem, we select λn new sensors and discard some sensors from stage i to stage j in the condition of enough tracking performance. λ is a rate parameter which indicates the update degree between the stages.
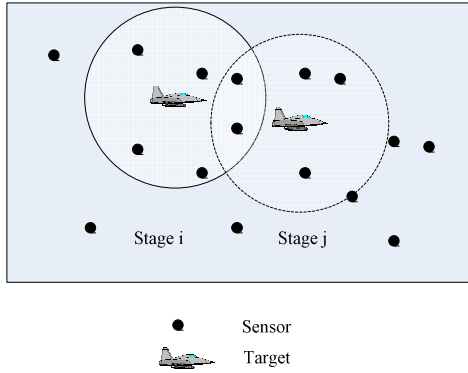
Fig. 2 Update from Stage i to Stage j by λ -strategy , λ =0.5

Based on the form of SSP formulation, we will propose a sensor selection algorithm for target tracking and parameter estimation. It divides sensors to two states: selection state and tracking state.

The pseudocode of the PCSW based algorithm

Algorithm 1.1 *PCSW based algorithm:*

Input: PCSW constrain condition; Target' moving; network distribution; λ -

strategy

Output: The selected sensors sequence p_{ii} for the target;

1: On sensor computing:

For each round t=1,2,3,…do

  For each sensor

    Receive parameter time slot of stage and other sensor simples from sink;

    Wait for a small random time, then send sensor sample information to sink;

  End For

End For

2: On sink computing:

For each sensor in radio range:

  Compute $f(s_i)$;

  Put $f(s_i)$ in DCSW;

End For

Sort(DCSW) by ascending ;

For each stage

  If(target moving)

  Update DCSW by λ -strategy;

    Send the information to the proper sensor;

End for

Exit the state selecting

V. EXPERIMENT

We use the OMNeT++4.1[13] simulator for the simulation of the SSP. 15 nodes and 1 target were uniform random distribution in an area of 500m and 500m. The nodes have the same radio range and they are initialed fixed in the area, the signal noise ratio (SNR) of each sensor is 15db, the target appears in the area at a random corner. It chooses the direction to center and moves in a straight line along the direction, at a

speed of 1.5m/s, the target will come back when it arrive the bound of area. We also assume that there is a sink can communicate with each sensor in network. The simulation stops when the target comes back to starting place. We divided the whole simulation to some stages by following ruler:

When the selected sensors set was changed, stage change.

Obvious the stage have characters as follows:

a) Stages might have different time interval and every stage has its' own selected sensors set;

b) Neighbor stages have different selected sensors set.

For each stage in the simulation, we record the value of selected number. the entries of matrix A are drawn independently from $N(0,1)$ [7],the sensors with size of observation vectors m= 4.
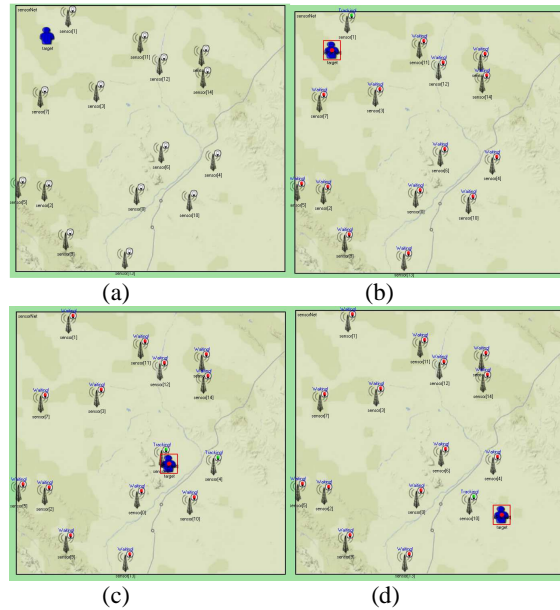

Fig. 3 The topology of 15 sensors and 1 target for experiment (a) It is initialized location of the sensors and target in this experiment. (b) It indicates that the target begin to move, the sensor[1] with green light means that it has been selected and would track the target.(c) When target moves to the place in the picture, the sensor[6] and sensor[4] has been selected with PCSW based algorithm for tracking .(d) When the target move to some corner, it would change the direction and come back to original place

After the experiment, we record the subset of selected sensors of each stage. We split off the whole process of experiment to 14 stages according to the change of selected sensors. Then each stage has a subset of selected sensors. In the Table 1, the subset (1,2) indicates that sensor[1] and sensor[2] have been selected.

TABLE I
SUBSET OF SELECTED SENSORS OF EACH STAGE

Stage of target moving	The subset of selected sensors	Stage of target moving	The subset of selected sensors
1	(1)	8	(10,4)
2	(3,7)	9	(10,4,6)
3	(3,6)	10	(4,6)
4	(6,0)	11	(6)

5	(4,0)	12	(3,6)
6	(4,10)	13	(3)
7	(10)	14	(1)

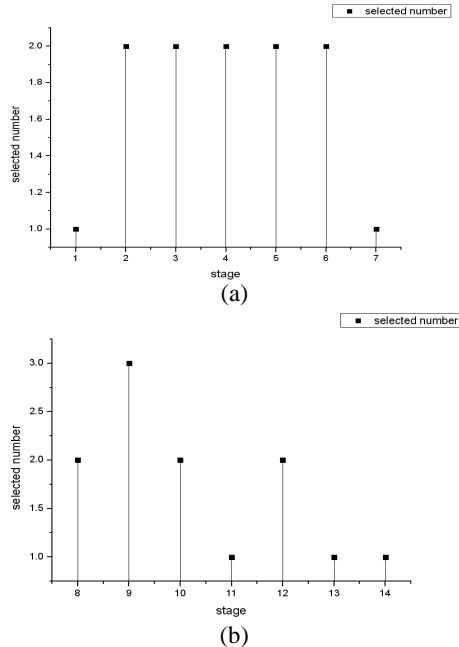The number of selected sensors in each stage is shown in Fig. 4.

(a)

(b)

Fig. 4 Number of selected sensors in whole experiment . (a)Number of selected sensors in coming stage,(b) Number of selected sensors in back coming stage

Next, we compare performance function which defined in (4) for PCSW based, entropy based and hypothesis based method. The performance function we defined is inverse proportion with Mean Squire Error (MSE). From the Figure 5, there is not very apparently difference among these three algorithms.
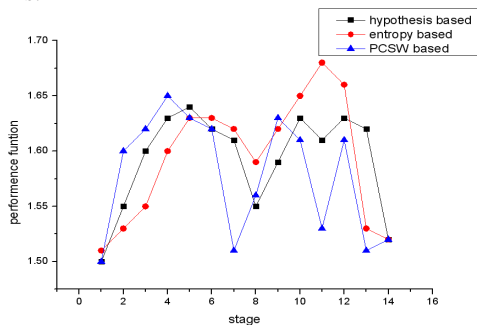

Fig. 5 performance function

However, Figure 6 shows that sensors total working time in PCSW based algorithm is less than other two in the experiment. Sensors total working time is calculated by the sum of all sensors' tracking time and communication time for target.
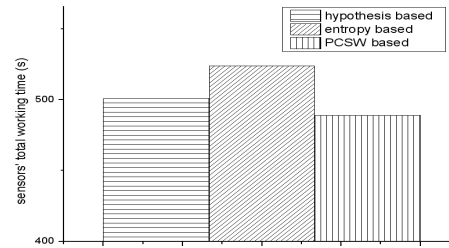

Fig. 6 sensors' total working time

VI. CONCLUSION, DISCUSSION AND FUTURE WORK

We have shown in this paper that the sensor selection problem underlying the now very popular Cyber Physical System can essentially solved efficiently by PCSW based algorithm. We formulate the problem and performance function, propose an efficient algorithm. Experiment shows that it has less communication times with the guarantee of performance. Because the CPS includes not only sensors, but also some actuators, our immediate future work is going to research the actuators' selection method in CPS. After that, we want to implement the CPS to our real life with the selection of sensors and actuators.

REFERENCES

[1] Z. Song, et al., Optimal Observation for Cyber-physical Systems. London: Spinger, 2009.
[2] S. Joshi and S. Boyd, "Sensor Selection via Convex Optimization," IEEE Transactions on signal processing, vol. 57, pp. 451-460, 2009.
[3] H. Godrich and A. Petropulu, "A Combinatorial Optimization Framework for Subset Selection in Distributed Multiple-Radar Architectures," in International conference on acoustics speech and signal processing, 2011.
[4] R. Rajagopalan, "Spatial correlation based sensor selection schemes for probabilitic area coverage," International Journal of Computer Networks & Communications, vol. 3, pp. 233-249, 2011.
[5] Y. Zhang and Q. Ji, "Efficient Sensor Selection for Active Information Fusion," IEEE Transactions on systems,man,and cybernetics, pp. 1-10, 2009.
[6] M. Naeem, et al., "Cross-Entropy Optimization for Sensor Selection Problems," in International Symposium on communications and information, 2009.
[7] V. Kekatos and G. B. Giannakis, "Slececting reliable sensors via convex optimization," in international workshop on signal processing advance in wireless communicaitons, 2010.
[8] B. Jiang and B. Ravindran, "Completely Distributed Particle Filters for Target Tracking in Sensor Networks," Doctor, Faculty of the Virginia Polytechnic Institute and State University, Virginia 2010.
[9] H. Rowaihy, et al., "A Survey of Sensor Selection Schemes in Wireless Sensor Networks," in Proc. SPIE, 2007, 2007.
[10] D. Bajoví´c, et al., "Sensor Selection for Event Detection in Wireless Sensor Networks," 2010.
[11] S. Jiang, et al., "Optimal sensor selection for discrete-event systems with partial observation," IEEE Trans. Autom.Control, vol. 48, 2003.
[12] F. Bian, et al., "Utilitybased Sensor Selection," in IPSN2006, Nashville, Tennessee, USA, 2006.
[13] A. Varga, "The OMNeT++ discrete event simulation system," in The European Simulation Multiconference, Prague, Czech Republic, 2001.

Mawubin (S'09) received the Bachelor's degree in information system and engineering in 2008 and M.Sc. degree in 2010 from the Department of Information System and Management, National University of Defence Technology, ChangSha, China. From 2011 to 2012, he was a PhD student in information system and engineer laboratory in National University of Defence Technology, ChangSha, China, researching on cyber physical system and WSN, he has been working towards the Ph.D. degree. Her current research focuses on sensor selection problem and cyber physical system.