Data Recovery and Alerting Schemes for Faulty Sensors in IWSNs

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Abstract. In monitoring and alerting industrial system, industrial wireless sensor networks play an important role. However, we usually have to face one critical issue that is to recover the data and emergency treatment schedule for the faulty sensors. In this paper, we target on monitoring industrial environments and deal with the problems caused by the failure or faulty sensors nodes. Firstly, based on industrial private cloud, an architecture of industrial environment monitoring system is proposed. Furthermore, a hierarchical support vector machines is adopted for faulty nodes' data recovery. Unlike most previous works, we intend to address the problem from global and local data perspectives. Using the first layer Support Vector Machines is adopted to judge the types of missing data based on the monitoring system. In second layer of SVM is responsible for finishing the recovery local data in the light of the history records. Performance of the proposed SVM data recovery strategies are evaluated in terms of networks self-healing competence, and energy consumption. We also implement our schemes in a real-life monitoring and alerting network system to demonstrate the feasibility and validate the network detection capability of emergency events.

Keywords: Data recovery · Hierarchical support vector machines · IWSNS · Alerting system

1 Introduction

In the past decade, with the increasingly developments of information, computer and communication technologies, and wireless sensors networks (WSNs) have significantly encouraged advances. Because in a WSN there are many advantages such as no wires, flexibility, mobility, low cost etc. Furthermore, in different applicable fields for WSNs, many challenges have to face for academic and engineering. So WSNs become a hot issue in research domain. Meanwhile, we usually encounter that a WSN is widely used for smart home, medical health, military fence and agriculture [1–4]. In these WSNs application, environmental monitoring and alerting system occupy a great share.

In industrial fields, usually WSNs are adopted to monitor environment performances such as temperature, humidity, light intensity vibrations, heats, noise and other parameters [5–9]. Moreover, IWSN working environments are not friendly and full of

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water, metal, high humidity and temperature. It is easy to cause node failure and monitoring data missing. If the vital monitoring sensors nodes are lose their functions such as communications, sensing data, the imponderable disaster will happen, and there are amount of economic loss [10, 11].

As shown in Fig. 1, in a monitoring IWSNs system, wireless sensor nodes are deployed in an industrial domain. It is common that sensor nodes are placed with maximums coverage as Fig. 1(a). In the industrial environment, as above discussing wireless sensor nodes have to face many challenging. So nodes failures are very common like Fig. 1(b). Once the faulty nodes exist in WSNs, it maybe forms some sensing void holes for example in Fig. 1(c). If the emergent events happen in area of the sensing holes, it must be unreliable for this kind system. How to recover the missing data and emergency treatment of faulty nodes in the sensing void holes become an important way to deal these challenge with the lowest cost and real time. These are motivation and goal problem of this paper.

In this work, we do not intent to study the improvement of processing of node design for overcoming the hostile environment or longing network working life, nor nodes deployment with amount of sensor to achieve certain degree of sensing coverage. Rather, based on the historical record of global and local sensing data, we are from the data prediction perspectives to deal with the urgent event, and avoiding this disaster caused by node failure. Our ultimate goal is to realize industrial WSNs for monitoring and alerting system so that detection application of various emergency events with few nodes faulty can be practically implanted.

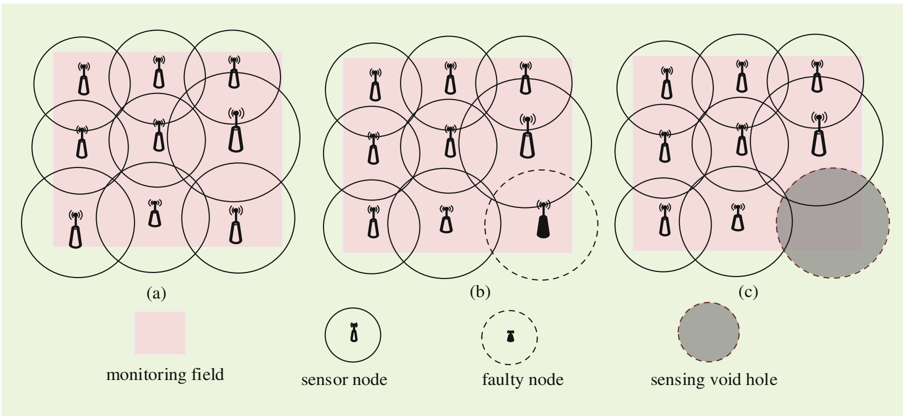

Fig. 1. Sensing void holes in IWSN

The remainder of the paper is organized as follows. In Sect. 2, related works are introduced for solving the faulty sensor nodes. Also, several prior research efforts and summarize our works contributions. Then, Sect. 3 give architecture of monitoring system based on Industrial private cloud and Industrial WSNs. In Sects. 4 and 5, the hierarchical SVM data recovery and emergency treatment strategies are proposed.

Meanwhile, the performance and comparison are presented, while a real-life industrial monitoring network are implemented for demonstrating the proposed schemes. At last, we draw our concluding remarks in Sect. 6.

2 Related Work

For finishing the goal (environment monitoring), most of earlier study works in WSNs applications and researches, focus on the low real-time environments such as greenhouses, forests, refineries and so on. It is known that these fields are not easy to access and nodes are amounted limited energy [12, 13]. These kinds of WSNs have to meet remote communication, large-scale monitoring range, especially for saving energy of the whole networks. In many related works, the energy conservation schemes are proposed. Among them, the most classical strategies that ordinary nodes switch between sleep and waking, extending sleeps time, or turn off the wireless radio module. It is obvious that these schemes are not suitable for industrial applications because of higher real-time and being sensitivity to emergencies.

With the deepening of WSN research, it is possible to deploy node with some effective and special schemes. So in some literatures [14, 15], various deployment strategies have been presented to enhance the sensing void hole. One important and common way is that deploying redundant nodes in monitoring fields. It get an effective means to deal with this challenge. However, such redundant deployment means higher cost and it is hard to judge the position for placing the redundant nodes. Furthermore, it is vulnerable to sensing void holes, particularly in industrial domain.

Consequently, a plenty of research efforts begin to transfer to the mobility WSNs, by mobile sensors nodes to large sensing range and fill the sensing nodes, given any number of randomly placed sensors nodes. However, in these WSNs, for finishing effective moving the networks have to transfer related data or information to all moving nodes. Moreover, a lot of energy must use to finish mechanical moving.

We observe that previous works explore these strategies only partially, leaving issues such as energy conservation and high latency, data recovery, sensing void holes, dealing the emergent event. However, in practice, data recovery of sensor failures should be resolved as an effective solution to achieve an operative WSN with high self-healing for void holes. In light of this, we investigate the sensor data, and based on Global SVM divided the data into different type for meaning the different level of industrial condition. Based the value of different level, IWSNs could drive different services. Then, for getting missing data of sensor nodes failure, local SVM is adopted to forecast the single nodes missing data. We summarize our contributions as follows. Firstly, we develop a double SVM for dealing sensing void holes. Secondly, our system could quickly respond to emergent event. At last, a real-life WSN adopting our strategies are implanted.

3 Industrial WSNs Architecture for Monitoring and Alerting System

It is known that WSNs having many advantages are applied in industrial domain. Among of these IWSN, most of applications is targeted to monitoring industrial environment and machine conditions. Once the sensing environment parameters are beyond the normal ranges, the alerting systems are driven, and some appropriate measures will be taken, such turning off power, evacuating the workmen etc.

3.1 Architecture of Industrial WSNs for Monitoring

As above discussing, a complete industrial monitoring system has several functions: monitoring, processing data, judging urgent event and give corresponding warning. As Fig. 2 shown, in our industrial WSNs monitoring and alerting system architecture, the framework contains four parts: sensor nodes, backbone networks, data servers and services.

In an industrial monitoring and alerting system are based on WSNs. The nodes are deployed in different places as certain schemes. Sensor nodes collect the data, periodically. Then the nodes send the node to sinker or base stations, according to certain communication protocols such as MAC. In the paper, TDMA is adopted to transmit the sensing data. Thereafter, sinking data are unloading to servers or industrial private clouds. At last, some relevant services were supported from the server to mobile users, workmen and management system.

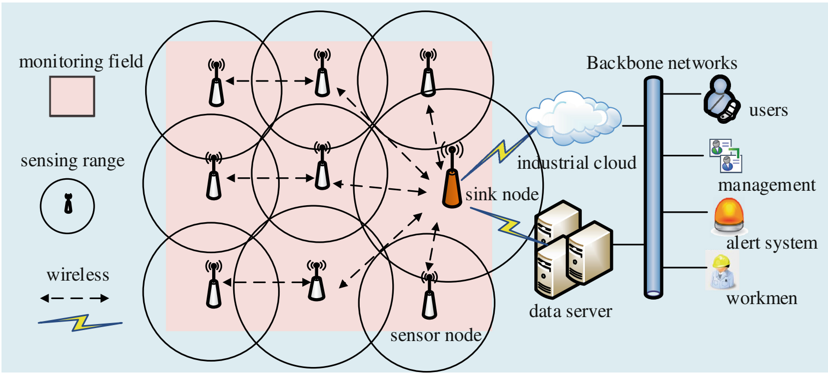

Fig. 2. Architecture of monitoring and alerting system in IWSN

3.2 IWSNs Monitoring Working Algorithm with Dealing with Emergent Events

It is known that in an industrial environment emergency mechanism for emergent event such fires, accidents are very important. A good IWSNs monitoring system should have an effective way for dealing with the emergent events. Usually, the traditional monitoring system would transmit the alerting information after the emergent event taking place. Obviously, it is not suitable for the modern industrial environment system. So in this section, we give an algorithm for deal with the emergent events based on the prediction with the historical data records about the monitoring system.

Table 1. Summary of notations used in IWSNs monitoring working algorithm

Notation	Description
k	Loops of sensor nodes worked
T_s	Time of sensor nodes start working
T_{cyc}	Time of sensor nodes cycle working
Tc	Time of current
S_i	The *i*th sensor nodes
$D_{i,k}$	The *i*th node sensing data in the *k*th loops
Max	Max loops
e_i	The *i*th emergent event

Table 1 gives the description of notation of our IWSN working steps. Algorithm 1 provides the pseudocode for IWSNs monitoring operations. Note that in the end of the *k*-th loop, sensor node *Si* sensing data *Di*, *k* is judged whether it is beyond the emergent set {*e*1, *e*2, *e*3, …, *en*}. Then system performs the alerting or normal operations, based on the judged results. For giving a clear description of IWSNs monitoring system, we give an algorithm about the working processing. The system working principle as following:

Algorithm 1. IWSNs monitoring working algorithm with dealing with emergent events.

set $k = 0$;
set $T_s = T_{cyc}$; //initial sensing time
while ($k < Max$) && ($Tc = Ts$) **do**
  for each sensor $s_i \in \{s_1, s_2, s_3, \ldots, s_n\}$ **do**
    sensing data;
    transmit data to servers or cloud by WSNs.
  End for
  Server saving and judging these sensing data $D_{i,k}$
  if ($D_{i,k} \in !\ \{e1, e2, e3, \cdots, en\}$) **then**
    perform normal strategies
  else
    perform alerting strategies
  end if
  set $k = k+1$;
end while

4 Hierarchical SVM for Node Faulty Data Classification and Recovery

Wireless sensors nodes operate in industrial fields have to face different formidable challenges, such as signal interferences, obstacles, dusts, high humidity and temperature. So wireless sensors are inherently unreliable. The sensor depletions or unexpected failures will cause missing data, disaster and sensing void holes. To prevent accident taking place and recover the missing data, one alternative namely hierarchical SVM strategy is to perform.

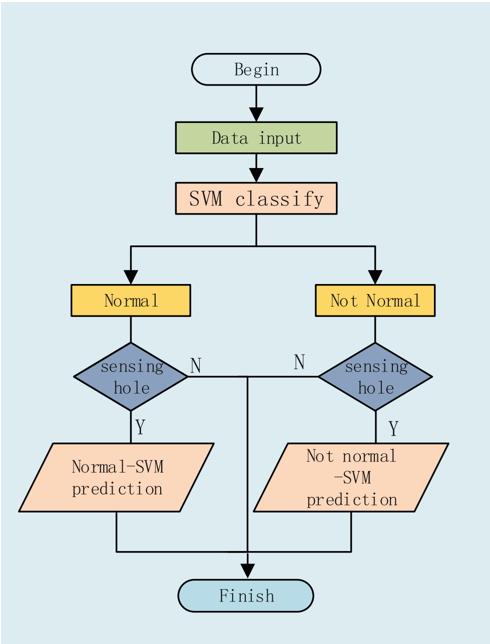

Fig. 3. Hierarchical SVM for dealing with data classification and data recovery

In this section, we use hierarchical SVM for dealing with data classification and data recovery. As in Fig. 3, the first one-class SVMs classifier will be used to classify the environment of industrial working fields. Usually we divide the data in safe and unsafe, it is mean that no emergent event and emergent event happen in the monitoring domain. If the domain has emergent event, the handling mechanisms are triggered. Secondly, as soon as there are faulty nodes (sensing holes) in the monitoring area, the mechanisms of data prediction are called for. The data prediction is based on the SVM and historical data records. SVM prediction uses the SVM classifier to judge the previous data of faulty nodes to predict.

4.1 Global SVM Data Classification

In the present context, one-class SVMs classifier will be used to detect monitoring data in an industrial sensor network. SVM classifier could divide these data into different level of the monitoring industrial field. One-class approach based on the fact that usually monitoring system draws more attention to whether the monitoring environment is in safety. Hence the output set have two values, not-normal and normal. As Fig. 4 shown that for simply to compute, we use +1 to label normal and −1 to label not-normal. The SVM working mechanism is to search the optimal plane for divide the data in different classifications.

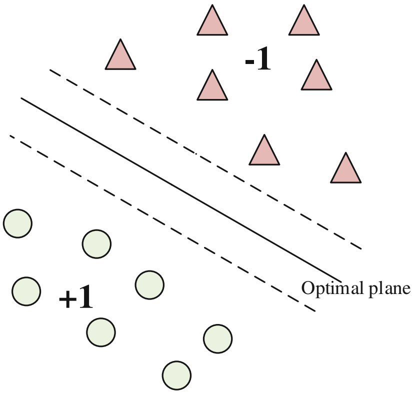

Fig. 4. Linear separation of the industrial monitoring data into two classes

Related SVM problem is formulated as follows: Given that the training set is

$$T_{\mathrm{set}} = \{(x_1, y_1), (x_2, y_2), \ldots, (x_{\mathrm{N}}, y_{\mathrm{N}})\} \in (X \times Y)^{\mathrm{N}}$$

$$\text{where}\, x_{\mathrm{i}} \in \mathrm{R}^{\mathrm{dL}},\ \mathrm{i} = 1, 2, \ldots, \mathrm{N}$$

And X denotes the input space, Y denotes the output space. d_L is the dimension of input space. N is the size of training set. In light of this training set a decision function is constructed.

$$\mathrm{y(x)} = \mathrm{sgn}\left[\omega^{\mathrm{T}} \varphi(x) + \mathrm{b}\right] \mathrm{y}(x) = \mathrm{sgn}\left[\omega^{\mathrm{T}} \varphi(x) + \mathrm{b}\right]$$

Where ω is the weight vector and b is the bias. This may construct the one-class SVM primal problem.

$$\min_{\omega, b, \varepsilon} f(\omega, b, \varepsilon) = \frac{1}{2} \parallel \omega \parallel + C \sum\nolimits_{i=1}^{n} \varepsilon_i + b$$

$$s.t.\begin{cases} \omega^T \varphi(x_i) + b \geq -\varepsilon_i \\ \varepsilon \geq 0 \end{cases}$$

Where C is some constant and ε is a vector of slack variables. It is known that the first term is a regularization term for preventing overfitting. The second is an empirical risk estimation function, and the final term is included to bias the result to detecting the industrial working environment. For giving a clear description of global-SVM data classification, we give an algorithm about the working processing. The system working principle as following:

Algorithm 2. Global SVM data classification.

```
1:  Input:
2:  //training dataset represented by N blocks:
3:  (x1,y1),(x2,y2),...,(xN,yN)
4:  // constant C > 0 for tuning errors and margin size
5:  Training:
6:  -create the weight vector ω
7:  - obtain the optimal plane (ω, b)
8:  Classification of new data x based on the plane is:
9:  y(x) = sgn[ω^T φ(x)+b]
10  end Training
```

4.2 Local SVM Data Recovery

For deal with the sensing data holes in industrial WSN monitoring system, we propose a SVM algorithm to predict the missing data. The whole working steps of local SVM data recovery is divided into two stages. Table 2 give the notation used in algorithm 3.

Table 2. Summary of notations used in Algorithm 3

Notation	Description
i	ID of faulty nodes
D_{now}	Current sensing data of node
D_j	Previous historical data of faulty nodes
Nor_i	The ith neighbor nodes of faulty nodes
D_{miss}	Missing data
S_{sink}	Sink sensor nodes
$D_{i,k}$	The ith node sensing data in the kth loops
y	The result of algorithm 2
m_{Max}	Max allowing cycle of the faulty nodes stop working
m	After the m-th sensing cycle of the faulty nodes stop working

First, the WSNs looking for faulty sensing nodes, and transmit the nodes is to server or industrial private clouds. Second, the server predicts the monitoring area whether to normal or not-normal based on the Algorithm 2 with previous historical data. Furthermore, based on the result of above, the server begins to predict the data using SVM. At last, the prediction data are transmitted to nodes or sink and neighbor nodes.

Algorithm 3. Local SVM data recovery when faulty sensing data stop working.

```
set m = 0;
Sensor node transmitting data to sink S_sink
Sink nodes inform the server or clouds
if (D_now = void) do
input: D_1, D_2 D_3 ,..., D_j
call for the Algorithm 2.
output y;
while (m < m_Max)
    if (y = +1)
        D_miss = SVM for normal prediction
    else
        D_miss = SVM for NOT-normal prediction
    end if
    Transmitting D_miss to Nor_i and S_sink
    m = m+1;
end while
else
    break;
end if
```

5 Experiment and Result Analysis

In order to verify these above discussing algorithms, we construct an IWSN prototype in lab. So in this section, we briefly report our prototyping experiences on an industrial environment system.

Figure 6 illustrate the hardware architecture and communication protocols used in the prototype. The sensor node is basically a temperature and humidity node with relevant sensor and wireless radio module. ZigBee is adopted in communication protocols. The laptop acts a server, while the nodes transmitting the data to server by ZigBee. Meanwhile, the laptop is used to restore and execute SVM prediction and classification algorithms.

In this set of real-life of experiments, we combine four monitoring parameters in an industrial field (Machinery Factory) to test the performance of the proposed algorithms. We collect the temperature from 13:30 to 17:00, while using the SVM algorithm. As Fig. 5 shown, the experimental temperature of using SVM and real-time measuring temperature are given.

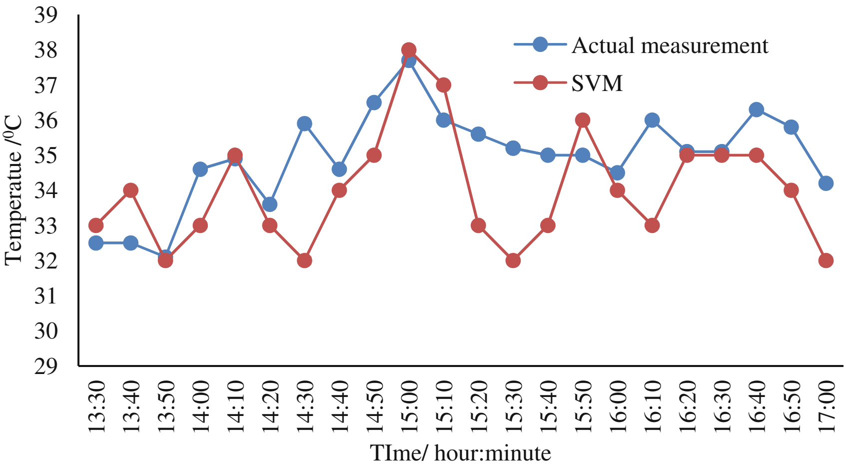

Fig. 5. Using SVM to measure temperature

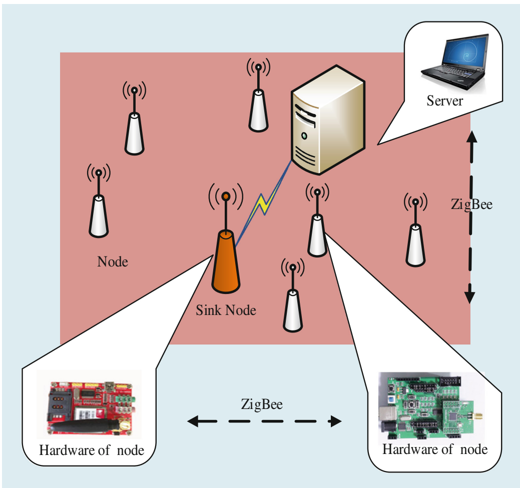

Fig. 6. Implement a real-world industrial WSNs via hardware components

6 Conclusions and Future Work

In this paper, for deal with sensing void holes in IWSNs, we propose a hierarchical support vector machines to recovery data with the objective of providing effective ways for smart sensing industrial environment. The algorithm divides the global data into different levels that means different environmental security levels. Then based on the schemes could recover the missing data of node failure with second layer SVM based on the latest historical records. We attempt to realize a practical system with the prosed algorithm. In the future, based on different other communication protocols such as SMAC, CSMA, and other routing mechanism like LEACH, the proposed way need to verify its feasibility.

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References

1. Li, X., Li, D., Wan, J., Vasilakos, A., Lai, C., Wang, S.: A review of industrial wireless networks in the context of industry 4.0. Wirel. Netw. (2015). doi:10.1007/s11276-015-1133-7
2. Zhang, D., Wan, J., Liu, Q., Guan, X., Liang, X.: A taxonomy of agent technologies for ubiquitous computing environments. KSII Trans. Internet Inf. Syst. **6**(2), 547–565 (2012)
3. Liu, J., Wang, Q., Wan, J., Xiong, J.: Towards real-time indoor localization in wireless sensor networks. In: Proceedings of the 12th IEEE International Conference on Computer and Information Technology, Chengdu, China, pp. 877–884, October 2012
4. Al Ameen, M., Liu, J., Kwak, K.: Security and privacy issues in wireless sensor networks for healthcare applications. J. Med. Syst. **36**(1), 93–101 (2012)
5. Fontana, E., et al.: Sensor network for monitoring the state of pollution of high-voltage insulators via satellite. IEEE Trans. Power Delivery **27**(2), 953–962 (2012)
6. Shu, Z., Wan, J., Zhang, D., Li, D.: Cloud-integrated cyber-physical systems for complex industrial applications. ACM/Springer Mobile Netw. Appl. (2015). doi:10.1007/s11036-015-0664-6
7. Yi, J.M., Kang, M.J., Noh, D.K.: SolarCastalia: solar energy harvesting wireless sensor network simulator. Int. J. Distrib. Sens. Netw. **2015**, 1–10 (2015)
8. Liang, W., et al.: Survey and experiments of WIA-PA specification of industrial wireless network. Wirel. Commun. Mobile Comput. **11**(8), 1197–1212 (2011)
9. Nguyen, K.T., Laurent, M., Oualha, N.: Survey on secure communication protocols for the internet of things. Ad Hoc Netw. **32**, 17–31 (2015)
10. Wan, J., Zou, C., Zhou, K., Rongshuang, L., Li, D.: IoT sensing framework with inter-cloud computing capability in vehicular networking. Electron. Commer. Res. **14**(3), 389–416 (2014)
11. Wan, J., Zhang, D., Sun, Y., et al.: VCMIA: a novel architecture for integrating vehicular cyber-physical systems and mobile cloud computing. Mobile Netw. Appl. **19**(2), 153–160 (2014)
12. Wan, J., Zou, C., Ullah, S., et al.: Cloud-enabled wireless body area networks for pervasive healthcare. IEEE Netw. **5**, 56–61 (2013)
13. Wu, J., Yang, S.: SMART: a scan-based movement-assisted sensor deployment method in wireless sensor networks. In: Proceedings of IEEE INFOCOM, pp. 2313–2324, March 2005
14. Zou, Y., Chakrabarty, K.: Sensor deployment and target localization based on virtual forces. In: Proceedings of IEEE INFOCOM, pp. 1293–1303, April 2003
15. Lin, T.-Y., Santoso, H.A., Wu, K.-R.: Global sensor deployment and local coverage - aware recovery schemes for mart environments. IEEE Trans. Mobile Comput. **14**(7), 1382–1396 (2015)