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A Fuzzy Method for Fault Tolerance in Mobile Sensor Network

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Abstract

Faults occurring to sensor nodes are common due to the limitation sensors and the harsh environment sensor networks. The fault sensors lowest effect in network efficiency or in others word sensor network has fault tolerance. In this paper is studied the fault tolerance problem from the coverage point of view for sensor networks. In the proposed methods missing regions with faulty sensors recoup by its neighbors and using minimum redundant sensors. After, a sensor node becomes fault, coverage loss caused covered by its neighbors moving to failure node. Major problem elected neighbor node for movement. The priority of neighbor nodes for movement and coverage missing regions determines overlapping sensing range and its distance from faulty node. In this paper priority of neighbors determine by two methods, in first method priority determines by an equation. It is included overlapping and distance but in second method priority of neighbors obtained by a fuzzy system with inputs overlapping and distance, and its output priority of neighbors. The target of proposed methods is decrement redundant sensors for replacement faulty sensors in network sensor. The propose methods compared with themselves and previous methods which used only from redundant sensors.

Keywords: Mobile Wireless Sensor Network, Fault Tolerance, Coverage, Fuzzy Logic, Movement.

I. Introduction

Mobile sensor networks are a new paradigm of wireless sensor networks; they obtained particularity by node mobility. Recent increasing growth of interest in wireless sensor networks has provided us a new design wireless environmental monitoring applications. Mobile nodes are able to take intelligent physical actions like escaping from dangerous situations or responding to interesting events by executing sophisticated protocols, mobile sensor networks are more flexible and adaptive to unknown or hazardous environments than static wireless sensor networks [21].

However, applications and network operational environment has put strong impact on sensor network systems to maintain high service quality. Therefore one challenge is to design efficient fault management solutions to recover network systems from various unexpected failures. In sensor networks, sensing coverage is an important QoS factor. It is

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measured by the overall area that a sensor network is currently monitoring. The larger the coverage, the better service the network can provide. As a sensor network operates, its coverage decreases because of node failures. The reasons why nodes fail are multifold. For example, a node may run out of battery power and stop functioning at any time, and it may suddenly die because of hardware defects or due to harsh environment conditions like extreme temperature. In these cases, to maintain quality of service, a sensor network must have the capability of preserving its coverage in the presence of node failures [16].

Fault tolerance is a critical issue for sensors deployed in places where are not easily replaceable, repairable and rechargeable. The failure of one node shouldn't incapacitate the entire network. In this paper fault tolerance problem are studied the coverage from the point of view. So aforesaid, Coverage characterizes the monitoring quality provided by a sensor network in a designated region and different applications require different degrees of sensing coverage and while more applications only require that every location in a region be monitored by one node. Also, degree of coverage depends on the number of faults that must be tolerated. A network with a higher degree of coverage [7] can maintain acceptable coverage in face of higher rates of node failures, but higher degree of coverage produce duplicate data and also increment consumption energy, acutely. Therefore higher degree coverage for fault tolerance is expense, relatively.

Also, [11],[9],[18],[19] propose methods for fault tolerance in network sensor, they named Sensor Relocation Protocols; they be employed as a fault tolerance approach to reduce or complement coverage loss caused by node failures. Four sensor relocation protocols WCP [18], WCPZ [19], ZONER [9], and MSRP [11] were proposed for mobile sensor networks. They all require redundant sensors same happen faulty sensors in sensor network, and also all rely on global/cross-network message transmissions for discovering nearby replacement sensors. There protocols compared to the proposed methods in this paper, for variety of reasons.

Algorithm [19] grid-quorum based relocation protocol (referred to as WCPZ) for mobile sensor networks. This protocol employs the quorum based location service [13], [17], in modified forms, to find replacement for failed sensors.

Algorithm [11] is Mesh Based Relocation Protocol (MSRP), it constitute a novel localized structure, information mesh, for publishing and retrieving distance sensitive data like location information. Based on the concept of information mesh, propose MSRP. This protocol maintains a sensor network's overall sensing coverage by replacing failed sensors with nearby redundant ones using minimized time delay and balanced energy consumption.

Protocol MSRP fulfills by Distance Sensitive Node Discovery (DSND). Algorithm DSND is node relocation task by a shifted node relocation method. That is, establish a path between a failed node and a redundant node in a localized way, and shift all the nodes' position along the path toward the failed node. This method uses a localized relocation path discovery mechanism, and generates constant relocation delay and balanced energy consumption.

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It is the basic idea proposed methods in this paper, when as a sensor become faulty its neighbors compensate missing region by move toward faulty sensor. But it is fundamental problem, which elected neighbor for move? In proposed methods, in each stage elect a neighbor according to amount its overlapping sensing range with its neighbors and distance faulty sensor and it. In first method priority of neighbors obtained by an equation with two mentioned variables, but in second method priority of neighbors obtained by a fuzzy system with inputs overlapping and distance, and its output priority of neighbors. In two methods, after elect a neighbor with high priority, it moves toward faulty sensor and a part of missing region. The second proposed method is based on a novel use of fuzzy functions and operators for devising weighting cost functions that are employed in solving determine priority of neighbors' problem. Fuzzy Logic is a mathematical discipline invented to express human reasoning in rigorous mathematical notation. Unlike classical reasoning which a proposition is either true or false, fuzzy logic establishes approximate truth value of a proposition based on linguistic variables and inference rules.

II. Methods

A. Network Model And Parameters sensor

In this paper is assumed that sensor nodes are located in two dimensions plan and shape square. Also all sensor nodes spread in environment randomly. But knowing the physical position location of each sensor, it can compute by GPS [3] or some GPS-less techniques such as [19].

Sensing model: Each sensor node in proposed method is associated with a sensing area which is represented by a circle with radius r_s (radius sensing) whereas sensor node resided in its center. This circular area is called Sensing Range and depends on several factors in the network. In this paper accepted binary sensing model. Under the binary sensing model [20], [8], a sensor node can detect all the events in its sensing range.

Radio range: Apart from sensing range, each sensor has a Communication Range. Communication range same sensing range is represented by a circle with radius r_c (radius communication) whereas sensor node resided in its center. But communication range usually is longer than sensing range. In this paper is assumed communication range is double sensing range ($r_c=2r_s$). When a node broadcasts a message, all the sensor nodes in its communication range will receive this message. In [21], it is proven that if all the active sensor nodes have the same parameters and the radio range is at least twice of the sensing range $r_c \geq 2r_s$, complete coverage of an area implies connectivity among the nodes. Therefore, under this assumption, the connectivity problem reduces to the coverage problem.

Neighbor sensors: Two sensors are neighbor when in range connection each other. Therefore each sensor which its distance with another sensor lower r_c are neighbor. Furthermore because $r_c=2r_s$, if sensors are neighbor their sensing range have overlapping.

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Sensor equipment: All sensors have ability movement in different direction, perceptively. Each sensor can move in accordance with formulas and coordination its neighbors [9],[12].

Boundary sensor: If sensor distances whit boundary line lower r_s named boundary sensor. Therefore in sensors boundary, a section sensing range is out of environment boundary.

Faulty sensor: Sensors with abnormal readings are called faulty sensors. A sensor of reading is abnormal when it different other readings of its neighbor, significantly. Faulty sensors can communicate with other sensors, no problem. Approaches for determine faulty sensors presented in [6],[12], in this paper is assumed determine faulty sensors, previously.

B. Dissect Problem And Proposed Methods

After sensors diffuse in the environment or after constitute sensor network march of time, some sensors will fail due to increment energy or impact obstacles and etc. If a sensor become faulty, region which by sensor is covered will become uncovered. The basic idea proposed methods in this paper is when a sensor become faulty its neighbors compensate missing region by move toward faulty center. But it is fundamental problem, which elective neighbor for move. In proposed methods in each stage implement, faulty sensor neighbors redress some area uncovered, by movement to faulty sensor and movement neighbors continue so long as missing region covered by faulty sensor neighbors. It is possible some faulty sensors of missing region don’t cover by proposed method, completely. In that case use redundant sensors and replace faulty sensors, similarly [11],[9],[19]. Therefore goal of proposed methods is decrement redundant sensor in sensor network with faulty sensors.
The methods elect neighbor in each stage implement according to amount overlapping its sensing range with its neighbors and distance faulty sensor. The sensor movement has cost in sensor network, therefore methods, distance election neighbor is important factor, because by lower movement coverage loss caused faulty sensor. Also in proposed methods election neighbor has more density, when sensors density is high in environment, several coverage has in a little part of environment and produce duplicate data and also increment consumption energy, acutely. Therefore a neighbor with more density or more overlapping is better for movement.

The methods consist two phases: First gathering information of neighbors and determining the priority of mobile sensor node to move and second movement election neighbor. In methods after determine faulty sensor, each one faulty sensor neighbors computes its conditions, such as position compared with as faulty sensor, its overlapping with its neighbors and its distance with faulty sensor and then each neighbor sends its factors to faulty sensor.

In first method, priority of neighbors determine by an equation which used of overlapping of neighbors and their distance for compute their priority. But in second method, overlapping of neighbors and their distance are inputs of a fuzzy system which it determine their priority in its output.

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B1. Compute neighbors conditions

In this part, compute methods of inputs for determination priority faulty sensor neighbors, such as distance, overlapping, position neighbor compared with as faulty sensor.

Distance two neighbor sensors: Denote distance two neighbors sensor s_i and s_j located in positions (x_i, y_i) and (x_j, y_j), respectively, by (1)[5]:

$$d(s_i, s_j) = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2} \quad (1)$$

Compute overlapping sensing range two neighbor sensors: When sensors are neighbor; their sensing ranges have overlapping (Figure.1). Overlapping area two sensors compute by (2):

$$overlop(s_i, s_j) = |area - sectors - area\_rhombus| \quad (2)$$

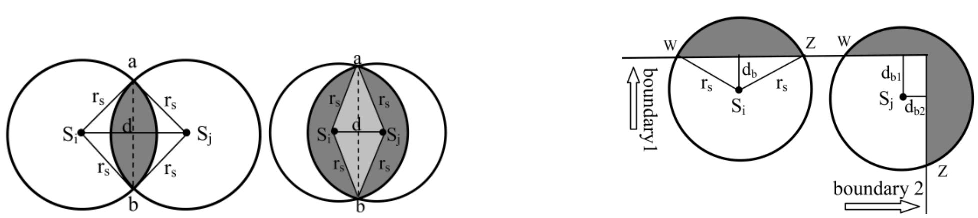
area_sectors in (2) compute by equation (3):

$$area\_sectors = 2 \times (\frac{1}{180} \times \arccos \langle \frac{d(s_i,s_j)}{2r_s} \rangle) \quad (3)$$

Also *area_rhombus* in (2) compute by (4):

$$area\_rhombus = d(s_i, s_j) \times \left[2r_s \times \sin\left(\arccos \langle \frac{d(s_i,s_j)}{2r_s} \rangle\right)\right] \quad (4)$$

Equation (2) use for two cases of neighbors, since $d(s_i,s_j) \geq r_s$, since $d(s_i,s_j) \leq r_s$ and sensors resided in sensing range together (Figure.1a).



(a) (b)

(a) overlapping sensing range neighbors sensors. *(b)* different positions boundary sensors.

Figure.1.overlapping sensing range

Compute section area of range sensing boundary sensors out of environment: in proposed methods range sensing area out of environment of boundary is important factor. It is possible two cases for boundary sensors (Figure1b), boundary sensor range sensing is cross one boundary (in Figure1b, s_i sensor) or cross two boundaries (sensors near corner,

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for example in Figure1a, s_j sensor). However, part area of range sensing boundary sensors out of boundary computes by (5):

$$area_{out} = \left[\frac{arccos\,\langle\frac{d_b}{r_s}\rangle}{180} \times \pi r^2\right] - \left[d_b \times r_s \times \sin(arccos\,\langle\frac{d_b}{r_s}\rangle\right] \quad (5)$$

d_b in (5) is distance boundary sensor with environment boundary, it obtained by sensor coordinate. Equation (5) obtained by different area sector and triangle created with boundary. Also, area out of boundary of range sensing boundary sensor is crossing two boundaries, equal sum area out two boundaries.

Compute position neighbors and faulty sensor: position neighbors compared with as faulty sensor show by connection line angle neighbor and faulty sensor with horizon-line. It computes by coordinates sensor nodes.

If S_f is faulty sensor and S_i is its neighbors. S_i's connection line angle computes by equation (6):

$$\alpha_i = arc\tan\langle\frac{y_f - y_i}{x_f - x_i}\rangle \quad (6)$$

B2. First method: Fault Tolerance Common (FTC)

In this method, then detection faulty sensors, first by Eligibility Rule based on Perimeter Coverage (ERPC) algorithm in [14] assign each faulty sensor sensing range covered by its neighbors of sensing range. When sensors deployment in environment randomly, it is possible some sensor sensing range covered by its neighbors sensing range, completely. In such cases if sensor becomes fault, region doesn't remain uncovered and therefore it isn't necessary implement FTC method. Also, ERPC performed then each FTC stage; FTC for faulty sensor is finishing since missing region covered, completely.

In FTC, then detection faulty sensors and implement ERPC and detection missing region, for coverage it used faulty sensor neighbors. FTC divide neighbors of faulty sensor in four groups and in each performance stage, one neighbor of one group elect for movement to faulty sensor and covered section of missing region. Clustering in FTC executes in attention their position compared with as faulty sensor. The neighbor sensors which their line connection angle in [0,90) are in one group and line in second group is in [90,180), and connection angle third and fourth groups are in [180,270) and [270,360), respectively.

In each stage FTC elect one neighbor of one group for movement. The each neighbor priority of groups specified by its distance with faulty sensor and amount its neighbors overlapping. Therefore neighbors with distance lesser from faulty sensor have high priority, because with minimum movement obtained maximum area of missing region. Also, each neighbor with more range sensing overlapping increment its neighbor priority, because neighbor movement, decrement its overlapping with their neighbors and

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increment coverage missing region so the neighbor with more overlapping has more priority. Furthermore, in FTC, if a neighbor is boundary sensor its priority increase with amount area of range sensing out of boundary, because its area out of boundary covered any region in network environment. However election priority in FTC assigned by equation (7):

$$priority(S_m) = [\sum_{i=1}^{n} overlap(S_m, S_i)]/d(s_m, s_f) \quad (7)$$

In (7) S_f is faulty sensor and S_m is one of its neighbors, S_is are S_m's neighbors and n is their number. *Overlap*(S_m, S_i) compute range sensing overlapping S_m and S_i, furthermore, if S_m is boundary sensor area out of boundary add *overlap*(S_m, S_i). Also, $d(S_m,S_f)$ define distance neighbor and faulty sensor. Therefore in (7) neighbors priority increment by increment overlapping and decrement by increment distance with faulty sensor.

In FTC compute priority all neighbor in a group then a neighbor elect with maximum priority for movement. The election neighbor of movement vector should development its overlapping neighbor sensing range with missing area. In FTC, orientation of movement vector is direction connection line neighbor and faulty sensor and toward faulty sensor. Also, size of movement vector determines proportionate distance election neighbor and faulty sensor. Size of movement vector is low cover any section of missing region and if size of movement vector is high, neighbor move senselessly, and effective coverage loss and increment overlapping its sensing range with its neighbors. Therefore, in FTC size of movement vector determines half distance faulty sensor and election neighbor in each stage.

B3. Second method: Fuzzy Based Fault Tolerance (*FBTF*)

In this method, similar FTC when a sensor determined faulty, first it implements ERPC and determine its sensing range is covered by sensing range of its neighbors or no. since it is full coverage, impalement any stage FBTF. Furthermore in FBTF method, in end each stage and movement a neighbor, implements ERPC and if sensing range is full coverage FBTF don't implement after this time. Also in FBTF similar FTC, neighbors of faulty sensor divide in four groups and in each implement stage, one neighbor of one group elect for movement to faulty sensor and covered section of missing region.

In FTC, priority neighbors of faulty sensor in each group determined by amount overlapping and their distance from faulty sensor and by equation (7). But In FBTF determine priority of neighbors in groups by a fuzzy system. The inputs of fuzzy system are amount overlapping sensing range of neighbor and its distance from faulty sensor.

The distance neighbor and faulty sensor similar FTC compute by equation (1). But in FBTF for overlapping of neighbors aspect by present, for compute it, first compute sum overlapping all faulty sensor of neighbors and their area out of boundary (They compute by equation (4) and (5)) and then amount overlapping each neighbor equal ratio its overlapping with all neighbors of faulty sensor which normalize between 0-100; So in FBTF overlapping of neighbors express by is an amount between 0-100 and its distance is in (0-2r_s].

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The linguistic variables to represent the distance of neighbors and faulty sensor are divided into three levels: *far, mean,* and *near*; and those to represent the percent overlapping are also divided into five levels: *very high, high, middle, low* and *very low*. The consequent or priority of neighbors is divided into five levels: *very good, good, accept, bad* and *very bad*. Table 1 summaries the rules and consequents.

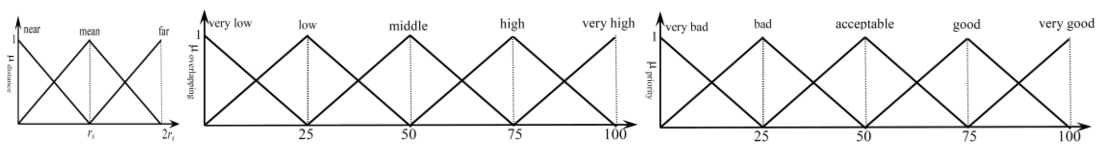
One example of rules is as follows:

IF the distance of neighbor and faulty sensor is *near* **AND** its percent of overlapping is *high* **THEN** its priority for movement is *very good*

TABLE 1. RULE BASE OF THE PROPOSED FUZZY METHOD

overlap / distance	*very high*	*High*	*Middle*	*Low*	*very low*
near	very good	very good	good	accept	bad
mean	very good	good	accept	bad	bad
far	Good	accept	bad	very bad	very bad

Figure.2 shows input and output membership functions of proposed fuzzy method.



(a) (b) (c)

Figure.2. Membership functions of the proposed Fuzzy method
(a) Distance neighbor and faulty sensor membership function. *(b)* Present of overlapping neighbor and faulty sensor membership function. *(c)*Priority membership function.

After fuzzy system determined priority all neighbors in a group, the neighbor with most priority elect for movement and coverage missing region by faulty sensor. The election neighbor of movement vector in FBTF is similar FTC; therefore, in FBTF size of movement vector determines half distance faulty sensor and election neighbor in each stage.

B4. localized proposed methods

The sensor networks usually have more sensors in large environment. Implement algorithms in sensor networks locally, decrement energy consumption and data traffic in network. Proposed methods in this paper can implement by base station or unused it and locally.

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In centralized implement, since a sensor become faulty, base station informed faulty sensors and implements clustering neighbor sensors and computed them priority in groups and elected a neighbor with most priority of each group for movement. The base station sends a message to election neighbor for movement direction. Also, in centralized implement ERPC algorithm in termination each stage implement by base station.

In locally implement, when a sensor become faulty detect it by algorithm [6]. Also, by [6] all faulty sensor neighbors informed faulty sensor. In localization all neighbors send distance with faulty sensor and sensing range overlapping with their sensing range neighbors. Faulty sensor implements clustering neighbor sensors and computed them priority in groups by FTC or FBTF and elect a neighbor with most priority of each group for movement. The faulty sensor sends a message to most priority neighbor for movement direction. In localization, it is possible several faulty sensors elect one sensor for movement, in case faulty sensor movement direction with minimum distance accept by it.

III. Results and Analysis

In this part, proposed methods FTC and FBTF simulate by C++ language. They implement for election and movement faulty sensors neighbors in different networks and compare with MSRP [11]&WCPZ [19] and together. The proposed methods and previous methods implement in same network with same environment and number sensors and faulty sensors, but with different fault percent. Each metric obtained by methods implement under different parameter, 10 experiments based on different initial distribution and different faulty sensors are run and the average results reported.

A. Objectives and Metrics

In simulation assumed all sensors are same and deployment in 50×50m or 100×100m environment, randomly. But for better deployment similar [12], environment divided minor field and partly sensors deployment in its field, randomly. Also, sensing range radius (r_s) each sensor assumed 5m and so sensing range radius (r_c) equal 10m.
Experiments implement for number different sensors and number different faulty sensor. In each experiment, after deployment sensors, assume number sensors in network fault randomly, and proposed methods implement for them. In the end of each stage method and move a neighbor, ERPC [14] check number full coverage missing region.

The proposed methods compare tougher and with MSRP & WPCZ as three aspects: sum movement all sensors in environment, number redundant sensors or number faulty sensors with full coverage missing region after implement each method and sum overlapping sensing range of all sensors. The sum movement sensors in environment are important because movement needs energy, and energy of sensors is limit. Also, the sum overlapping of sensors show useful region which covered sensing range of sensors. Since sum overlapping is low show more useful region coverage and missing region with faulty sensors covered efficiently. MSRP&WCPZ and previous methods [11],[9],[14],[19] only use redundant sensors and replacement them with faulty sensors in network, but in FTC and FBTF some faulty sensors and their missing regain covered by their neighbors and decrement redundant sensors, so methods compare with number redundant sensor used.

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B. Simulation Results

Simulation proposed methods and results average report in figure 3. Experiments try covered different condition such as different number sensor and number faulty sensor and environment. Experiments in four cases below and percent different faulty sensor performed:

1. environment 50×50 and 100 sensors
2. environment 50×50 and 300 sensors
3. Environment 100×100 and 200 sensors
4. Environment 100×100 and 700 sensors

In figure 3 shows average results for number redundant sensors used and amount moving sensors and area overlapping sensing range them. The point of view number redundant sensors used both methods FTC and FBTF use a few redundant sensors also moving sensors in them lesser proportion DSND & WCPZ. FTC and FBTF reduced overlapping sensing range which signified more coverage by a few sensors.

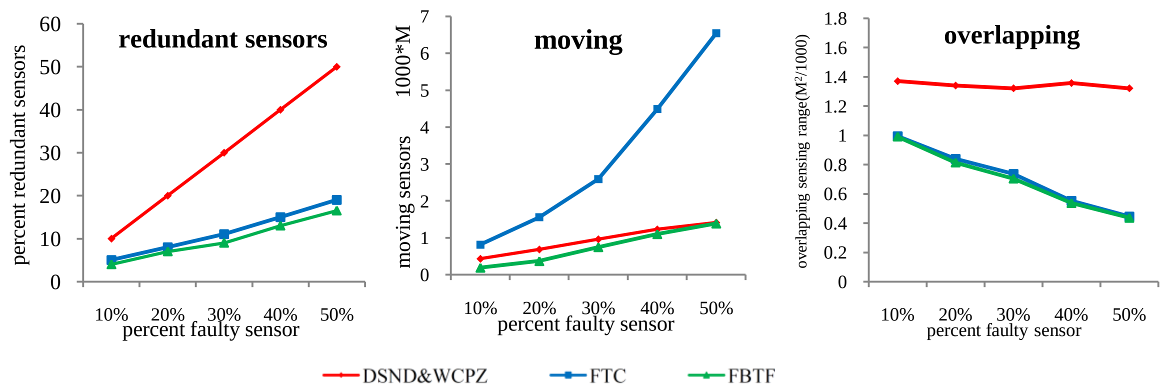

Figure.3. simulation results average

IV. CONCLUSION

In this paper, the new fault tolerant methods are proposed for unattended mobile sensor networks. Proposed methods by approximate neighbors of faulty sensor try cover missing region by faulty sensor, they use overlapping of neighbors and their distance from faulty sensor for determine priority of neighbors for movement. The methods run completely distributed by each node based only on local communications. Simulation results show that proposed methods decrement redundant sensors used for replacing with faulty sensors, in all cases. Also, it show proposed methods in sensor networks with large environment and more density and low number faulty sensor are very good.

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