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Effective Vital Sign Sensing Algorithm and System for Autonomous Survivor Detection in Rough-Terrain Autonomous Rescue Robots

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***Abstract*—The rescue robot becomes necessary for searching the survivors in the disaster area. Autonomous rescue robot is developed to increase the searching efficiency while the rescue robot's Tele-Operation is limited. The victim detecting system normally spots the victim with heat sensors. Thermophile array sensor is generally employed to read temperature in the fan-shape fashion. The statically equipped sensor on robot may not be enough for searching the victim in the rough terrain area. The panning sensor is developed to increase the scanning rate. The developed innovation of adaptive sensor module to vary its configuration is described in this paper. The victim searching and approaching also defined. The analyzing of the latest sensor module is investigated in the issue of panning speed, robot movement speed and the different phase of sensor angle. The combination of parameter variation is also investigated. The preliminary results show that the increasing of panning speed, and slowing down the robot movement increase the rate of scanning whereas the different phase in panning sensor provide the missing the area from the only one sensor module. The combination of frequency and phase increase the number of detection.**

KEYWORD - rescue robot, autonomous robot, sensor, victim detection

I. INTRODUCTION

GREAT DISASTER causes the severe damages to construction and lives. The Tohoku earthquake, the greatest japan earthquake occurs and destroys human lives for 15,889 peoples and numerous of injured [1]. These incidents also triggered Tsunami which chains the nuclear incident at Fukushima, in 2011.

Rescue robot is developed to be a tool for saving the victims. It is designed to have high ability in mobility, communication and victim identification. This is important for the human rescue units to realize a victim status, including several of vital signs, such as, heat, CO_2 gas, and sound for instance. Not only victim info but the physical environment is necessary for the safety of the human rescue units. A map to victim locations and warning information are useful evidence for human rescue units which can reduce the dangerous. The Tele-Operative robot was used in the real situation. In the 9/11 event, CRASAR from the Texas A&M university sent the Solem robot to search and rescue as the first time in WTC [2]. The Quince, measuring radiation robot, was sent to Fukushima nuclear incident [3]. Packbots from iRobot save many lives of EOD squad in Iraq war [4]. The Tele-Operative robot is remotely controlled by the experienced operator. The operator must have high skills to operate the special design robot in rough terrain and searching for the vital signals. From the consequent of limitation of expert operator, the autonomous robot is established to be a rescue assistant robot. The recruiting of the number of expert of Tele-Operation is difficult in real situation. The increasing of searching units to search and navigation is very necessary in time frame of 24 hours of life and death. The capabilities of autonomous robot which different from the Tele-Operative robot are self-navigation and autonomously victim identification. The Autonomous robot searches the victim based on the sensing system which designed to sense the multi modalities of vital signals [5].

The implemented autonomous robot has shown in Fig. 1. The robot is mainly divided into three parts, the mobile platform, manipulator, and sensing system.

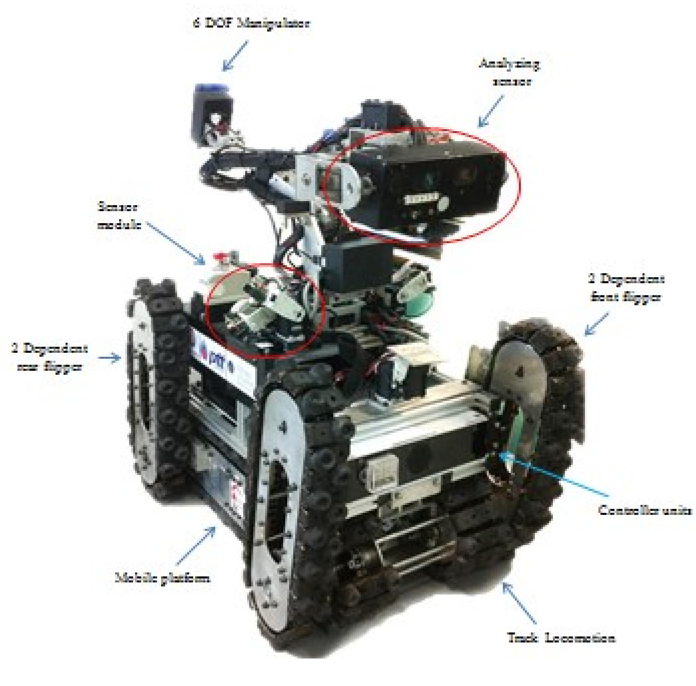

Fig. 1. Robot configuration

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II. Development of Autonomous Robot for Searching and Analyzing Victim Information

A. *Victim searching and approaching state*

The autonomous has a major task to search the signal of victim. While autonomous mobile platform performs the mobility task to move in the unknown terrain, the sensor and manipulator does the searching and approaching for acquisition the victim information. The autonomous robot has two states of victim inspection, primary scanning and analyzing victim information. An integrated system does the state starting with the primary searching follow by victim information analyzing. The state is shown in below diagram

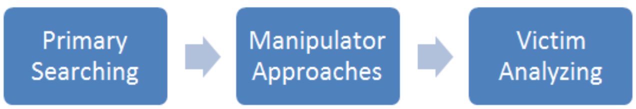

Diagram: victim searching & analyzing state

The primary searching has a responsibility to find out the primary information of the victims. Heat or temperature signal is general used as the primary signal because the high chance of detection. A heat sensor detects the victim by checking the read thermal with the setting threshold. If read temperature is higher than the threshold, the robot detected the primary victim signal. After the robot detected the primary victim signal, the robot sends the state logic to continue the analyzing state. Not only the logic state has been send but also the victim poses information. The pose information of the victims consisted of direction and displacement which collected from the sensor. In the analyzing state, an inverse kinematics is calculated by victim pose information and then the manipulator approaches the victim. Next, sensor system analyzed other vital sign of victim such as sound, gas, thermal, motion, and visibility clues.

B. *Milestone of autonomous robot in victim approaches*

The autonomous robot has been developed for several iterations. The position of the victim has a various position in the terrain in term of height. First iteration of autonomous is designed to be a static sensor. Even though the sensor has FOV around 40 degrees but this iteration cannot vary the direction and cause the less chance for detecting. Next iteration of sensor is the panned sensor. The thermophile array sensor is attached on the digital RC-servo motor, Dynamixel Ax-12 to make sensor tilting. From the previous version of sensor module which only has one phase of panning, the latest version of the robot adds another more sensor module and changes the direction of the sensor with dual phase, direct phase and inverse phase. Not only sensor modules are developed but also the manipulator. The previous development of manipulator can only analyze the victim with panning camera at the remote area from the victim position. The latest version of manipulation has more flexibility by add more degree of freedoms and this make a better approaching for the victim information analyzing.

The primary searching is applied as a local scanning in the real situation. The minimally direct searching is good for careful searching in the reachable workspace for robot manipulator to analyze the victim information. Otherwise the very large scene searching for instance the thermal camera can make complication in decision of choose interesting points.

C. *Robot configuration*

An autonomous robot is separated into two main parts. Firstly, the mobile platform is making to carry the searching module into the non-investigating area. The two dependent front flipper and two dependent rear flipper is used for climbing the rough terrain. The track locomotion is designed to increase the cling capability. These mobile has been widely used in Tele-Operative robot. The power source of driving system and electrical functions was used from the Lithium-Polymer batteries. The controller unit was also making in the platform part. This controller box consisted of micro controller unit, power regulator, motor driving, and computer. Next, the sensing system is designed to co-work between sensor module and manipulator. The sensor module is mentioned in this paper. The configuration of the sensor module and manipulation shown in the Fig. 1. Heat sensor is attached on digital RC-servo motor and the proximity sensor, IR displacement sensor is beside the heat sensor. This sensor module can generate the sufficient information to be as a primary searching sections. The heat signal is used for trigger logic state whereas the digital servo motor and the proximity sensor is generated information for calculation of victim pose estimation. The manipulator in the robot has 6 degrees of freedom, the first three joints mainly use for position moving and another three joint is used for alter the sensor direction at the end-effector. The first three joint is designed to be a two-links planar manipulator which has rotation base. The last three joint is designed to have two intersect axes and last joint to tilt the sensor head. The manipulation is setting to located in same path of the sensor axes to reduce the complication in inverse kinematics problems. The sensor head consisted of many sensors such as digital camera, thermophile array sensor, carbon dioxide gas sensor, microphone and speaker.

III. Sensor Module Analyzing

A. *Dual phase panning for heat detection*

The robot is designed to have primary searching. The sensor module which consisted of heat sensor, digital RC-servo motor and proximity sensor has a sequence to move for scanning the victim signals. The sensor module was shown in figure 2. The motor alter the angle of the heat sensor and pan like a bird wing. While the sensor is panning, the mobile platform also moves along the terrain. The simulated victim is attached on the wall

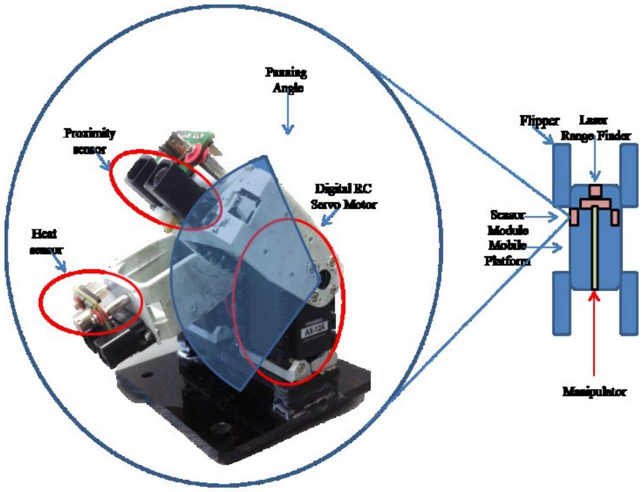

Fig. 2. The Integrated sensor module

The equation to explain the detect level of sensor was described in this section. In this simulation, the robot simulate in the environment that have a flat ground and plain wall. The diagram shows the sensor detection shown in Fig. 3.

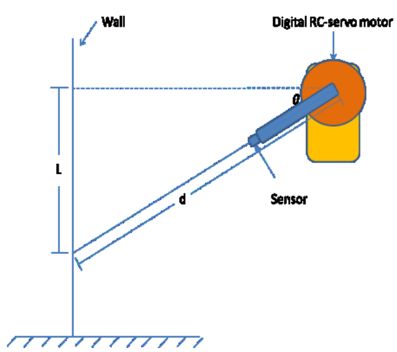

Fig. 3. sensor detection diagram

The robot sensor module set to have a distance from the wall around 40 centimeters in the principle axes and height from the ground is 40 centimeters. The equations 1-3 describe the scanning point on the wall.

$$h = d_{wall} \cdot \tan(\sin(\theta_{sr})) + d_{offset} \qquad (1)$$

Where

$$\theta_{sr} = A \cdot \sin(2\pi f t + \phi) \qquad (2)$$

And

$$s = \frac{v}{t} \qquad (3)$$

Before start detailed description, the notation of the equation is clarified first.

h : height is the distance from the ground to the sensor points position on the wall.

d_{wall} : the distance from the head of the sensor perpendicular to the wall.

d_{offset} : the distance from the ground to the axes of digital RC-Servo motor.

θ_{sr} : the angle of the sensor direction on the digital RC-Servo motor.

A : the maximum the panning angle in the positive and negative direction.

f : the frequency of sensor panning

∅ : the phase of the sensor panning

s : the distance of the robot movement

v : the speed of robot movement

The simulation has been set to three variations. Firstly, the frequency of the sensor panning is investigated in three levels which are normal, half and double frequency. The first investigation is designed to see the frequency of the sensor detection. Next, the detection of the sensor is explored in the term of the change of the robot speed. Lastly, the sensor has been added to increase the rate of detection and the added sensor module has a different phase of panning angles. The Fig. 4.a) showed the sensor detection with the different panning frequency. The x-axes show the time and the y-axes show the sensor angle. The Fig. 4.b) showed the sensor detection with different speed of robot movement, forward movement. The plot shown the relationship between the distance that robot has been moved and the height of sensor detection along the distance with the time equalization. A different height changed due to the different phase panning shown in Fig. 4.c).

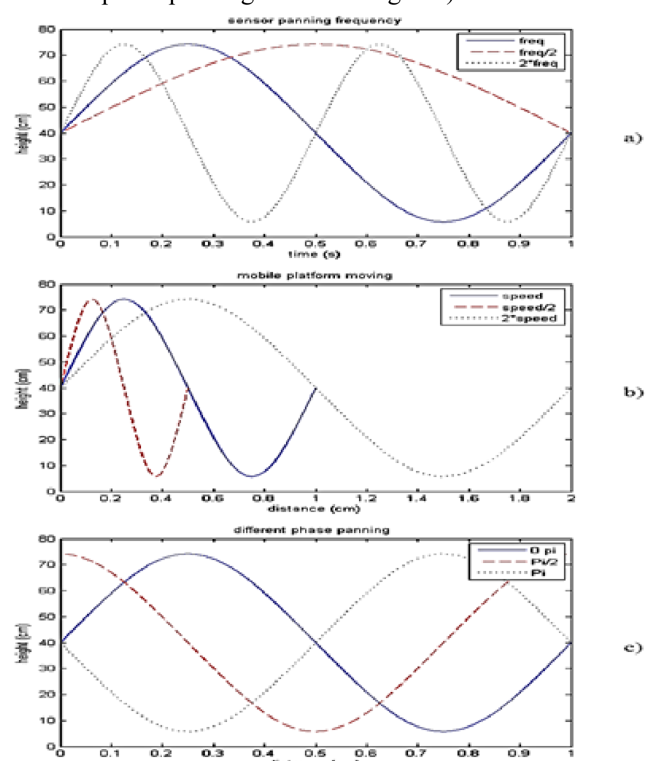

Fig. 4. the results from varying the interest parameter, a.) Sensor panning with different frequency, b.) Sensor detection with different robot speed, and c.) Sensor detection with altered phase panning angle.

IV. VICTIM POSES ESTIMATION

After the primary searching detected victim signal, the controller sent the collected data which necessary for victim position calculation. The victim pose estimation is based on two type of the information from the sensor module. The proximity sensor provides the distance from the heat sensor probe to the detected point. The Proximity sensor in this experiment is the Sharp GP2Y0A02YK0F which range from 20-150 cm. due to this sensor is the analog device so the mean filter applied to the read value to enhance the results. Another sensor is which actually actuator is also is the encoder from the digital RC-servo motor that provide the angle of sensor panning. The digital RC-servo motor is the Robotis Ax-12 form Dynamixel. The sensor detection range, L measures from horizontal line from the center of RC-Servo motor to the detected point on the wall. This distance defines in equation 4

$$L = d \cdot \sin(\theta) \tag{4}$$

Where d is the measured distance from the proximity sensor and θ is the sensor angle. The 3D position of the victim was calculated and sent this information to approaching state. After the information was sent to high level control, the manipulation approach to the target point by inverse kinematics calculation.

V. EXTRACTING VICTIM INFORMATION

At the nearest of approaching point, the sensor head analyzes the victim information in many modalities555. The topic of examination consisted of hazard sign, heat, QR code, motion, sound, carbon dioxide. These analyzed data is useful for the rescue unit to plan the strategy. Each of the victim signal must been analyzed and sent through the rescue[6]. Hazard sign is detected by using the camera and analyzed by the SIFT algorithms, scale-invariant feature transformation. This algorithm extracted the features in the image and clustered into the data based model by linear least-square estimation. Temperature of the victims is delivered by the heat sensor, TPA81, which is thermophile array sensor. The normal temperature of human is around 37 Celsius. The body temperature can express the body condition. If the temperature is lower or higher than 35 - 39 Celsius, the human or victims is in not good condition. The QR code is trendy used described in term of 2D resolution. Camera also searching the QR code by using the Z-Bar code reader from open GNU. The movement of the victim is also important information that index us the living of the victim. The movement is autonomously detected by using the subtraction image. The sum of different in the two images shows a quantity of movement. The sounds are also necessary to communicate between the rescue unit and victims. Sound localization can be used for searching the sound source which may be the sound of the victims [7]. The concept of sound localization is similar to our human ear. The different time of sound that occur in the first microphone and second microphone is used for direction calculation of sound source. The last information is the carbon-dioxide gas concentration. Human normally breathe provide a CO_2 gas concentration around 40,000 ppm[8].The COZIR CO_2 GC-0006 meter is used for CO_2 analyzing. The greater CO_2 gas than normal concentration means the victim is in the excited state, where as the lower means the body has a low metabolism or low activity. Not only the signal of the victim is important but also the environment information such as the map of the unknown terrain, hazard signs and vision clues in 2D or 3D. 2d map is generated from laser range finder with SLAM algorithms [9-11], while the 3D can be generated by the depth camera, Kinect[12, 13]. The danger signs in the area represent the dangerous in area. This is helpful for the rescue unit to avoid or plan in that area.

VI. PANNING SENSOR INSPECTION

An autonomous robot has many methods for searching and detection the victim signals. The proposed method for scanning the victim uses the dual phase panning sensor with TPA81 sensor for heat detection. There are three parameters to investigate in this sensor module configuration, which included panning frequency, speed of the robot movement, and the combination of dual phase panning. The inspection for the detecting performance is designed in the simulation. The testing scenario is a robot straight movement along the wall with a generated victim. The simulated victim on the wall was shown in the figure 5.

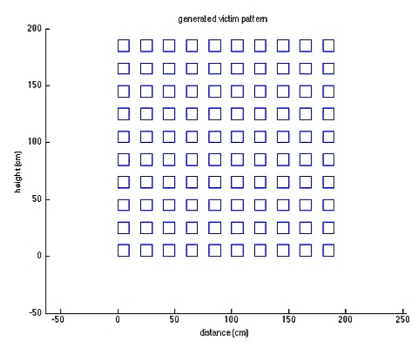

Fig. 5.Generated victim pattern

An above plot depicts the wall that attached the victim in the different position. The 10x10 cm^2 target is set to have a pattern like in the figure 5. The X-axis in the plot is the robot movement distance whereas the Y-axis is the height of the wall. Each victim has a gap between each other to distribute the chance of detection.

Three tasks for inspection are designed for each parameter. Firstly, the sensor panning frequency testing the result from alteration speed variation. Three frequencies are consisted of normal frequency, half of normal frequency, and double of normal frequency. The number of hit target is used to index the capability of detection. However the preliminary result show that the number of hit target of each frequency has a quite same value due to the redundant detection in same victim block. The number of hit block is proposed to clarify the rate detection. The number of hit block count only number of detected block neglected the redundant detect in the same block. The speed of robot movement has equalization speed. Secondly, the robot movement speed is being investigated. The speed of robot is separated into three levels, which are normal speed, half of normal speed, and double of normal speed. The number of hit block is used to explain the detection rate. Nevertheless, the different speed of movement makes the different distance of in same period of time, so the number of hit block per movement range is introduced as detection rate index in this testing. Lastly, the dual combination of phase panning is investigated. There are three levels of phase angle, which are zero phase angles, half pi phase angles, and pi phase angles. The combination of panning frequency is also investigated with the equal phase. Two sensor modules set the different phase angles with the same robot speed. The dual phase combination consisted of zero-half pi phase angles, half pi-pi phase angles, and zero-pi phase angle. The number of hit block was used as index, but this value has to check the redundancy detection from each module. To avoid the redundant detects in the same block, the proposed index has idea from Venn diagram. The number of hit block in dual phase combination is calculated from the number of hit block form sensor I plus number of hit block from sensor II then minus with the intersection part of sensor I/II.

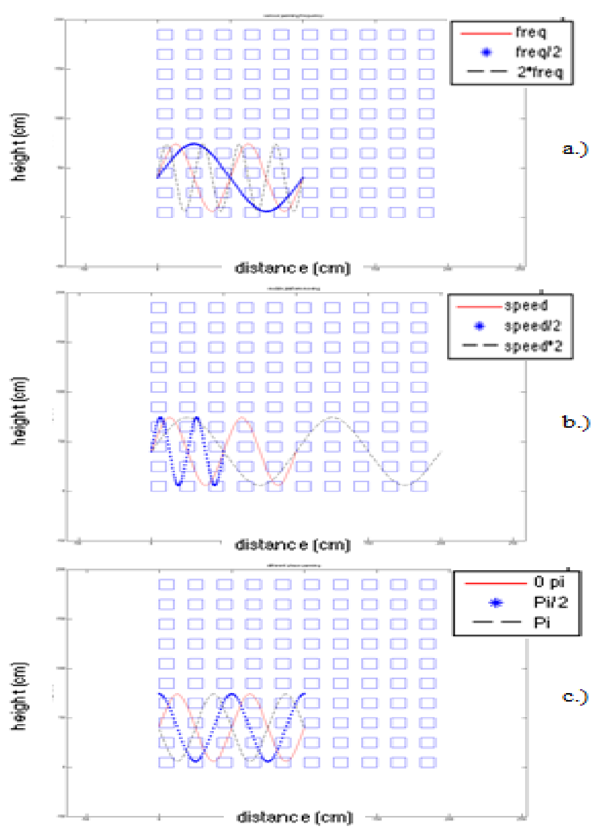

Fig. 6.Panning sensor result,
a.) sensor panning frequency testing,
b.) robot movement speed testing,
c.) dual combination of phase panning

The figure 6 shown the simulation results and the table 1 shown the result from each testing

a.)

Testing	**Parameters**	**Number of Hit Block**	**Number of Hit block per range**
Panning Freq.	Freq.	9	0.09
	Freq/2	6	0.06
	Freq*2	15	0.15
Robot Speed Movement Testing	Spd.	9	0.09
	Spd/2	9	0.18
	Spd*2	9	0.045

b.)

Testing	**Dual Parameters Combination**	**Number of Hit Block**
Dual Frequency Combination	**Freq., Freq./2**	13
	Freq./2, Freq.*2	17
	Freq., Freq.*2	22
Single Phase	**0**	9
	π/2	7
	π	9
Dual Phase Combination	**0 , π/2**	15
	π/2, π	15
	0, π	17

Table 1. the result from parameter variation in different testing,
a.) result of changing parameter variation,
b.) result of dual parameters combination

The result from speed panning frequency show that the high frequency has a highest number of hit blocks and the combination of two frequencies between normal frequency and double frequency has highest number of hit blocks. Next, the outcome of robot speed differences effect to the number of hit blocks. The highest number of hit block per movement distance was affected by lowest speed. Lastly, changing of single phase scanning has a similar result, while the dual combination of phase provides increasing of number of hit blocks.

DEMONSTRATION

Victim detection in flat terrain is satisfied. The robot has been moved in the maze like arena and found the victim which is hot water bag. After heat signal is detected by the sensor module, the manipulator moved the analyzing sensor into the same level of the victim and analyzed the victim info. Not only the flat terrain is tested by the robot, the rough terrain, isosceles triangle and right angle with 15 slope degrees. The robot can move in difficult area and can detect the hot water bag in the arena. The dual phase panning of sensor can detected even though the robot is sidle in roll and pitch. Figure 7 showed autonomous robot implementation in the simulated arena.

Fig. 7. Robot implementation in simulated rough terrain

CONCLUSION

The design of the robot to have primary searching and approaching state was described in this paper. The development of the sensor module increase the rate of searching that improves the rate of detection in minimally direct searching. Sensor detection point was shown in the equation 1-3. Three parameters sensor-robot is investigated. First parameter is speed in angle alteration of the sensor. The faster speed results the increase rate of scanning. In the Fig. 4.a) the fastest provide us 2 cycles of whereas the half speed provides us only half cycle. The next parameter is the speed of the robot movement. When the mobile platform is moving, the sensor module is moving along the mobile platform. The sensor detection is effected by the velocity of the mobile platform also. The velocity increasing of the robot effects scanning point in one area. The higher speed deliver the less scanning point in one unit area whereas the slower speed provide us the higher scanning points in area. At the same amount of time, the robot can go further along the terrain but robot can go with different distances. It would be better to set the robot to have a slow movement or better increase the panning speed. The different in the scanning point per area was shown in fig 4.b). Lastly, we add another sensor module beside together but let each module have the different phase of sensor angle. The inverse phase of angle sensor increases the scanning point from different position. The dual-frequency sensor module improves the rate of detection. The combination of phase angle is also improve the number of hit blocks. In contrast between the increasing speed of sensor panning or slow the robot and increase another sensor with the different phase angle is the limitation of the hardware. We know from the results that the increasing of panning speed and slow the robot movement can increase the scanning rate but the hardware limitation restricted us from varying the parameter values. For example, the Robotis AX12 provide us just only 59 rpm. Another thing which has to be concern is the sampling rate of the data. The I2C bus speed is 100 Kbits/s in normal mode and in one thermophile array which consisted of 8 arrays. These sensors also consume time to read the values which make the gap in sampling interval.

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