Incorporation of Mobile Sensing with Conventional Instrumentation for Improved Credibility of Surveillance and Diagnosis in Nuclear Power Plant(原子力プラント監視診断の信頼向上を目的とした移動型計測と在来計装の統合利用)

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Abstract

1. Introduction

Discourse of immune system in the wide notion will make us admire the phenomena adhere in the behavior of living creatures. Self-diagnosis and recovery principle is desired for the artifacts, which articulate low-probability high-hazard technology such as satellite, space station and also nuclear power plant. In these types of plant, operator and maintenance personnel cannot face and observe the plant directly, freely and easily. Plant self-diagnosis and self-recovery can be implemented in two ways as (1) using intelligent material or (2) using moving agent. Recovery using moving agent even though require equipment like a robot as dynamic agent, this method seems more realistic to be implemented. To perform the self-diagnosis system based on moving a possible solution method is the incorporation of mobile sensing with conventional instrumentation for improved credibility of surveillance and diagnosis. This problem will be the theme of research

Realization of the whole project research is concerned with the methods as (a) robot navigation obstacle avoidance as autonomous as possible, (b) incorporation of conventional sensors and mobile sensors for surveillance and fault diagnosis. The research will be emphasized on the development of autonomous robot moving path planning technique avoiding the obstacles. Further, scheduling and fault diagnosis is also observed in a preliminary manner.

2. Inspection Scenario

Incorporation discussed before explains about collaboration between group of fixed sensors in the plant and group of mobile sensors, which manifested in the autonomous inspection duty. There are 2 strategy for autonomous inspection in the plant (a) pro-active mode inspection which inspects the critical part in the plant regularly whether symptom of faulty has already known or not, and (b) reactive mode which inspects the plant only if the fixed sensors in

the plant send a message when trouble occurs.

3. Issue of Sensor Movement and Suggested Method

Sensor movement concerns with path planning of sensor attached on the robot from initial point to destination point without colliding the obstacles. Two important requirements in the way to design a path planning are (a) shortest in distance function, (b) safety from colliding with obstacles. Safety requirement is very important for a low-probability high-hazard plant such as nuclear power plant because the occurrence of collision will harm both of the subject and structure to affect a dangerous situation.

In the research, a novel path planning or navigation strategy called Median Line Graph (MLG) has been developed. The MLG is derived from the visibility graph group in the navigation classification. Median line graph is a free-space bound process in finding collision free path planning. The concept of median line graph proposed here is based on (1) the fact of visibility sensing that human vision is limited by corner and (2) the optimum free space is determined at the centerline among bounded vertices of obstacles. From the principles described above we can calculate the sequence of local destination point to construct a skeleton of navigation route for moving object to make a path planning.

The MLG is not shorter than tangent line graph, but it is safer in the trajectory and faster in the algorithm. Utilization of the MLG is optimum in the 3D path planning of the expansion of subject point such as missile, satellite or plane.

Implementation of MLG requires the determination of 3D coordinate vertices of obstacles. To perform the 3D coordinate, then the x and y parameters should be determined utilizing vision sensor in 2D representation and distance in parameter z from vertex to camera should be determined by distance sensor such as laser pathfinder. But, this research observed the possibility of using single camera for both two functions as vision sensor and distance sensor.

Single camera in forward translation movement method for distance measurement compares two images between two positions in the robot movement. Thus, it allows us to utilize the techniques in image processing. Center among bounded vertices as local destination point is calculated by searching the vertices points of segmented image received from the camera utilizing hierarchical DBANN (Decision Based Artificial Neural Network). The accuracy of hierarchical DBANN is based on the emanating search based on (a) Euclidean distance to find the nearest vertices points from the center and (b) four sectors searching in "X" type direction.

4. Issue of Sensor Management and Suggested Method

Incorporation is a form of computation-based distributed operation of workgroups in which autonomous and spatial distributed entities or modules of computation interact by exchange of message vice versa to manage in harmony each resource of capabilities to reach the ultimate task. This research concerns with the development of management organization in emergency condition that includes and stratifies intelligent machines in functional aspects, not only point-to-point communication. Therefore a fast and precise decision making is required as constraints in the design. Concerning with the constraints above, the fast characteristic of authoritarian decision making to give a fast flow of instruction is employed. Besides, utilization of precise characteristic of hierarchical decision making is also required. Combination in the management organization guide us to the whole system building called Hybrid of Authoritarian and

Hierarchical Distributed Decision Making (HAHDDM), which can be break downed into (a) data fusion among sensors in the intelligent machine system in authoritarian relation, and (b) data fusion among intelligent machines in hierarchical distributed decision making.

Inspection for components is employed in surveillance of the normal operation condition. Optimization of surveillance is reached by making minimum value of bounded variables in each stepwise scheduling procedure to provide the minimum total distance to visit a set of location. Scheduling in the inspection program can be solved using Traveling Salesman Problem (TSP) approach. A certain constraint of variable can be determined to calculate the priority of visit in the scheduling. In the safety approach, the minimum variable constraints are failure probability and traveling distance. Ranking of priority is determined using simplification of AHP method approach. Simplification in here means that the AHP concept was used only for weight determination between the variables and then calculated the comparative value of components Comparative value each component showed the ranking of priority for components, while ranking priority of components.

Fault diagnosis using Bayesian network showed that fault components could be estimated using feedback searching by employing the error messages coming from a bank of conventional sensors in the plant. Chain rule derived from Bayes rule shows the relation among series of components. Probability of each components related with the other components in the network system can be calculated using Bayesian Network program. If component get a fault, then the fault propagation can change the initial component probability. Fault diagnosis of the components can be employed utilizing bottom-up reasoning, which will search from effects to causes. Component fault estimation is ranked based on probability each component. To assure the fault components in the research, a mobile agent should be moved to the components location recommended by Bayesian Network. A fit sensor related with the faulty component characteristic should attach the mobile agent. The collaboration between fixed sensors and mobile sensors is managed by multiple sensors incorporation.

5. Experimental Evaluation

Camera calibration experiments showed that lens distortion was 2 pixels or less. This amount of error is no need compensation, because the valid change of pixel in the observation is determined for 4 pixels and more.

In the laboratory experiment, MLG was articulated for robot manipulator movement avoiding obstacle utilizing single camera for vertex coordinate determination employed in the both as vision sensor and distance measurement sensor. Accuracy of the distance estimation between camera and vertex of obstacle was related with (a) focus length of lens, (b) S_x coefficient, and (c) the angle position of camera facing the object. In focal length of 30 cm, $S_x = 1$, the error of estimation is in the range of 0 % - 9.7 %. Error of estimation can be suppressed by S_x coefficient and to make the direction of lens perpendicular with object.

Image processing for vertices localization in color reflection, segmentation, smoothing sing median filter, and hierarchical DBANN could determine the coordinate of vertices successfully. Center point of circle determination with possibility variation if center of attention was (a) obstacle, (b) free space and if the free space is bounded by (a) single vertex, (b) double vertices, (c) multiple vertices was successfully done. Robot trajectory in the 7 experiments with variation of starting points and destination points in the graphics of trajectory showed that MLG could work successfully to avoid the obstacle.

Simulation of the scheduling was conducted in LabView. In the research, DURESS system was employed for case study. Two variables concerned in the research are failure probability and traveling distance. Failure probability is calculated from fault tree analysis of cause-consequence of DURESS components, while the traveling distance is calculated based on Euclidean distance among components of DURESS. In the calculation, it showed that the highest priority to visit based on both the variable constraints is component flow sensor FA1. The surveillance based on determined scheduling should be completed with the capability of robot obstacle avoidance to assure the movement can avoid the obstacles. Further, the sensor variation based on the characteristic of components can be attached to the robot in the way to make a component inspection in incorporation constellation.

Component VA fault was simulated in the fault scenario for DURESS. Error massage would appear in FA, FA1, FA2, FR1, FR2. Using bottom-up searching the cause of fault propagation can be estimated. Because of the top of error message came from FA, then, the fault component can be estimated coming from PA or/and VA. Ranking of failure probability calculated using Bayesian Net can be determined the priority of fault diagnosis. Then, mobile robot was moved equipped with laser vibration sensor to the pump PA, and CCD camera to the valve VA location for diagnose and fault localization.

6. Conclusions

Conclusion of the research are (a) single camera in translation movement was shown to be capable of measuring the distance from robot to nearest vertex, (b) MLG in algorithm is proven short, safe and fast, (c) MLG in experiment can move successfully avoiding the obstacle, (c) MLG in experiment can move successfully avoiding the obstacle, (d) incorporation of conventional sensors and moving sensor is articulated in the simulation of surveillance scheduling based on 2 variables, (d) incorporation of conventional sensors and moving sensor has been validated in the simulation of fault diagnosis using Bayesian Network.

論文審査結果の要旨

原子力発電所の異常監視と診断は運転安全性を確保する上で重要な技術であり、その実現を目指し様々な開発がなされているが、未だ多くの解決すべき課題が残されている。特に近年、安全に関する要請の高まりから、従来にもまして信頼性の高い監視・診断技術の開発が期待されており、そのためのブレークスルー技術が必要な現状にある。

本論文は、この要請に応えることを目的として、移動型計測系と在来型計装の統合という新しい着眼に基づく監視診断の基盤技術開発を行ったたもので全編６章よりなる。

第１章は序論である。

第２章では、移動型計測システム導入に際しての問題設定の理論的枠組みを論じている。固定計装と移動計測とを統合利用する際に、相対的位置関係や経路途中の障害の多寡によって実行の難易度は異なることを考慮して、自律移動の可能性を評価する方式を提唱した。

第３章では、移動計測系の具備すべき要件を明らかにし、それに基づいて移動効率化と障害物回避性能とを兼ね備えたMLG(Median Line Graph)法と呼ぶ経路探索技法を提唱している。さらに画像情報だけを利用して簡便に対象物との距離を推定する方式も提案した。

第４章では、多数の異種センサー情報を統合利用するための考察を述べている。状況に応じた逐次移動計測の計画の動的立案のために、配慮すべき諸要件の優先付け(prioritization)、ならびにそれに基づいた移動計測位置及びセンサー属性選択、そして異常事象診断を実行するための意思決定支援方策として、ベイジアンネットワーク(Bayesian Network)をベースとした具体的技法を提案した。この方式によって、自律的移動計測と人間による大局的意思決定を状況に応じて併用することが可能になり、監視診断の性能を大幅に向上させることができた。

第５章では、手法の有効性に関する実験的検証結果を述べている。小型の加熱水供給システムを対象として、レール上を移動できるロボットアームが障害物を回避しながら目的点に移動する際の距離計測ならびに目的点到達の空間的精度が評価され、要求される位置精度と衝突回避能力が十分実現されていることが確認された。また移動計測の逐次利用によって、異常事象が的確に同定できることも確認されている。これらの知見は原子力発電所等において移動計測系を実装する際の有力な技術基盤を与えるものであり、重要な成果といえる。

よって、本論文は博士（工学）の学位論文として合格と認める。