Exploring Multi-Objective Optimization to Enhance Sensor Integration Technology for Course Instruction and Laboratory Development

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Abstract

Multiple sensor integration is fundamental to various engineering applications such as robotic control and machining automation. In most cases, sensor integration is the major component for artificial intelligence applications and multi-objective optimization is crucial to achieve the best performance. Consequently, more critical sensing information has to be focused, detected, extracted and optimized which will be included into high level sensing and recognition systems. For a series of related course instruction and laboratory development at electrical engineering, mechanical engineering, chemical engineering, civil and environment engineering, it is important to address, emphasize and implement multi-objective optimization technology. The objective of this research is to investigate some feasible instances for multiple sensor integration based on primary needs of engineering education. A sensing structure will be constructed by integrating multiple sensor information. By virtue of actual modeling on electrical, mechanical, biomedical and environmental systems, sensor integration problems can be transformed into multi-objective optimization functions, where mathematical models should be designed and employed. On the other hand, various multi-objective optimization methodologies could be developed for certain applications, thus assessment of optimization approach is necessary. For the purpose of engineering education, especially for laboratory development, it is natural to select performance index that could give rise to maximal performance with a minimal cost, considering various penalty terms and constraint terms. Some research on optimization issues in terms of electrical and mechanical systems will be conducted to improve engineering education.

Introduction

A human being recognizes external environment via several types of sensing information: vision, sound, touch, smell and taste. By integrating and compromising all these sensing information, a more reliable and multilateral object recognition can be achieved. Most current sensing systems use a single sensor technology as the source of information since all types of sensors tend to be ineffective beyond certain operation condition. Advanced sensor technology tends to incorporate different sensor types which are employed to take into consideration the actual subject from different aspects of insights. There are three basic categories for sensor integration. That is, complimentary sensors, competitive sensors and cooperative sensors. Complimentary sensors do not depend on each other directly but can be merged to generate a more complete picture of environment. Complimentary integration is easily implemented since no information conflicting and overlapping has been present. Tactile sensors and visual sensors can be integrated under this category. Competitive sensors each provide equivalent information about the environment. For instance, ultrasonic image and 3D stereoscopic image might contain similar information, which is redundant in a typical condition. Cooperative sensors work together to derive information that neither sensor could provide exclusively. An example of cooperative sensing would be using two video cameras in stereo for 3D vision. Sensor integration has a plenty of potential applications. Robotic integration of smart sensor is a typical example, where visual feedback and haptic feedback are collaborated via various sensors, such as CCD array, ultrasound array, acoustic wave, vibration, pressure sensors, etc.

On the other hand, automation of machining operations is usually conducted under a condition that different types of sensors, transducers, actuators, signal processing schemes and control strategies are extensively integrated in order to be robust against harsh and complicated machining environment, unavoidable presence of chips, fluids, noise and vibration, so that rapid, precise, convenient and direct measurement can be conducted. Machine parameters can be autonomously tuned on-line in a real time to substantially increase machine tool performance in terms of part tolerances, surface finish and operation cycle time. This gives rise to the increased productivity, improved part quality, reduced cost and relaxed machine design constraints. These sensing and actuation technologies should be emphasized in several engineering courses, e.g., signals and linear systems, dynamic control systems, machining and mechatronics. Fully instrumented laboratories (e.g. control laboratory and micromachining laboratory) are capable of providing training and research opportunity for education purposes. Both graduate and undergraduate students can become acquainted to optimization and sensor integration technology upon taking lecture and lab courses. Global optimization is widely conducted for sensor integration problems by minimizing cost and maximizing performance. A number of optimization approaches can be selected, namely, dynamic programming, genetic algorithm, fuzzy logic, neural network, simulated annealing, linear programming, and so on. Lots of applications have been conducted which can be used as examples for class instructions. In one example, partitioning large-scale problems into sub-problems increases the search efficiency, which can be solved using parallel processed genetic algorithm. This method is effective to avoid some local optima for optimization of large-scale machine system with a general hierarchical structure which is possible for diversifying computational loads. For a complex mechanical assembly, genetic algorithm can be employed on a population of sets, resulting in a posteriori decision on tradeoff issues between various objectives. In a configuration design optimization method, decrease in performance is linear while complexity increases exponentially. Genetic algorithm method helps to escape these local minima and provides better points distribution from local optima. For a speed reducer application, an entropy-based metric can be used in analysis of multi-objective evolutionary algorithms, which is to produce and maintain diversity among different desired solution points in order to compare on a quantitative basis. The metric can be used to capture and compare the capability of different population-based multi-objective optimization algorithms in generating well-distributed solution sets. Then population reaches its maturity in terms of distribution qualities of solution points and then entropy remains almost constant subsequently. Entropy of each generation of observed solutions is computed throughout optimization process. Control methodology of sensor integration can also be conducted in some other ways which are closely related to course instructions and laboratory experiments [1-11].

Sensor Integration and Potential Robotic Control Applications

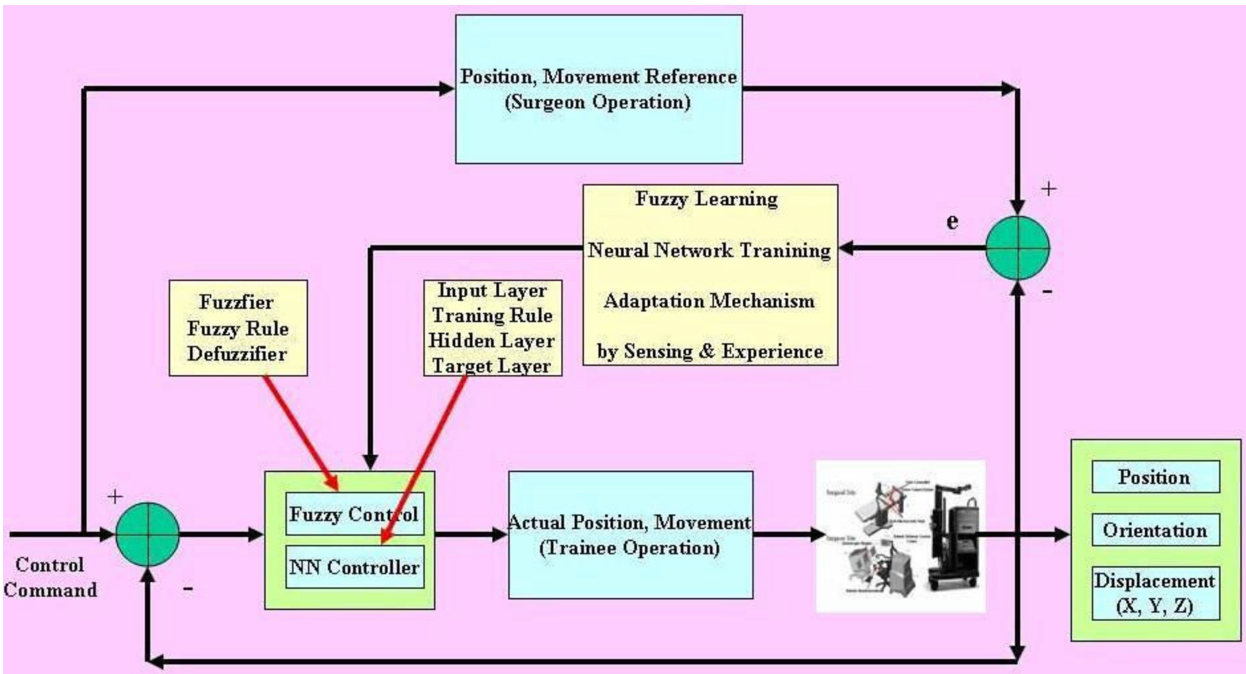

Fig. 1 Optimization in Robotic Integration of Smart Sensors

Multiple sensor integration is essential for various engineering problems where the artificial intelligence based optimization is one of the key issues. One typical example is robot operation and robotic control. The benefits of sensor integration can be illustrated by the fact comparable to that of human senses. If one can provide a robot with an eye, a hand, a mouth, a nose and an ear, especially with a mind via intelligent control technology, then robot can implement any actions that human beings do. Integrating multi-sensor information resembles the sensing structure of human beings which conceive senses of vision, touch, sound, smell and taste, from which actions are determined by sensing integration. Sophisticating sensing information has to be focused, detected and extracted, which will be promoted to high level recognition systems. Intelligent visual detection system generally can be used in robotic control applications. One advantage is that robots might be able to detect some information that human beings can not perceive directly, such as ultrasonic sensor, infrared sensor, microwave sensor, etc. Each control system consists of sensors in which sensing data are fused to provide performance improvements and capabilities for tracking and surveillance. In sensor integration, data from individual sensors are usually transformed to a common reference system for merging. Most sensor integration applications require high resolution data, solid data fusion architectures and optimized control algorithms. Typical data fusion algorithms include classical inference, Bayesian inference, Boolean algebra, artificial neural networks and fuzzy logic in order to detect and track those acquired data. For classroom education purposes, some sensor integration schemes can be proposed to build the standard architecture for information fusion, such as adaptive sensor integration. Its goal is to construct a system with standard sensory information to maximize interoperability among different sensor fusion systems, where a human-machine interface is needed at the same time. So far it is impossible to design a solid sensor integration strategy that covers all sensing information under any possible circumstances due to diversified circumstances. In most cases, the sensory fusion system must be capable of reacting to unforeseen situations and unexpected requirements quickly and dynamically. It is reasonable to enclose a certain adaptive controller within its integration architecture so as to achieve the optimized performance based on available information. Modeling, optimization and control of sensor integration and data fusion processes will lead to an effective, complete and prompt usage of available sensing information.

Modeling and Multi-Objective Optimization

Any satisfactory and fully functional sensor integration can not be achieved without effective modeling and multi-objective optimization of dynamic systems, especially for those large-scale systems. Being the initial stage, modeling should be conducted accurately in terms of intrinsic physical mechanisms out of various mechanical, electrical, automotive, robotic, environmental systems. Usually complex dynamic systems can be modeled as ordinary differential equation, partial differential equation, stochastic differential equation, nonlinear equation, piecewise function, switching function and lookup table. Modeling can be conducted in a time domain or frequency domain. Two direct artificial intelligence approaches for decision making are the macro modeling of human intelligence and micro modeling of human intelligence. Macro approach is knowledge-based systems where the human brain is treated as a black box. The human reasoning process is modeled through cognitive analysis of the decision-making tasks as described by some experts. In micro approach the human brain is treated as a white box, and the human reasoning process is modeled through observation of neural connections in the brain. A systematic parametric identification procedure must be conducted until simulation results coincide with those from experiments. Modeling and control engineering education should include some experimental exercises following theories behind the classroom instruction. From these exercises, modeling, analysis and design can be conducted in a sequence. Some knowledge background information regarding real world engineering problems should be discovered and developed along with the modeling process of sensor integration for engineering education.

The next important stage is to conduct overall performance optimization. It is appropriate to use overall performance/overall cost ratio as an actual performance index reflecting the degree of satisfaction for sensor integration problem. Sensor integration problem is in fact multi-objective, multi-disciplinary, multi-lifecycle and reliability-based optimization, where those constraints involved from complex problems should be evaluated at the same time. All sensor integration sustainable systems will benefit from a large overall performance/overall cost ratio over life durations. Some factors act as constraint terms that can affect the determination of final optimal solution. For example, each sensor has its own effective dynamic range which depends on temperature, humanity, pressure, etc, must be taken into account for consideration of constraint terms. On the other hand, weighting functions for different objective terms of performance index should be selected empirically and adaptively. Trial and error method may be used at first followed by optimized approach considering all uncertainty encountered. The collaborative optimization framework of sensory integration should be robust to various ambient conditions while its effectiveness is usually offset by extra computational expense. Sometimes intelligent control based optimization is presented for multidisciplinary robust design of sensory integration. Artificial intelligence is a discipline which combines neural networks, fuzzy control, genetic algorithm as well as some logic functions. The field of artificial intelligence is valuable in the control hierarchy of multiple sensor integration.

Impact on Course Instruction and Laboratory Development

The knowledge background of sensor integration is closely associated with engineering lecture course instructions of signals and linear systems, dynamic control and mechatronics as well as laboratory courses of control systems, signal and image processing, and so on. The traditional approach of data fusion in a multi-sensor environment is the exploitation of the complementary nature of information across the entire possibilities of decision choices from a series of sensors. The function of integration process is to combine various binary decisions from individual sensors to derive a robust multi-choice decision. The novel system on-chip integration has enabled solid micro-optic-electro-mechanical system technology to be integrated into one solid system. A versatile human-machine interface on communication devices is feasible for sensor integration. For instance, on a basis of visual information exclusively, visual perception, image processing and visual feedback control should be combined together. Robotic control research involves the synergistic usage of other sensing information. One satisfactory real time sensor integration technology is crucial to intelligent control of robotic systems and human-computer interface design. With a particular focus on multiple sensor integration, some portions of fuzzy control and neural networks should be emphasized. Complete instrumented facilities in any engineering laboratory should also be used to emphasize primary sensing principles and control principles. Both undergraduate and graduate students could benefit from these enhanced course instructions and laboratory experiments, coupled with some additional research activities. These techniques provide a valuable experience to confront with real world problems for future career of students which also gives rise to better learning opportunities. Optimization methods are important to dynamic control systems and sensor integration course instruction.

Conclusions

The multi-sensor integration is essential for various engineering application problems, such as robot operation and manipulation as well as cooperative interaction of multiple robots. Modeling, control and intelligent automation through enriched approaches at different levels should be investigated and implemented. This problem is multi-objective, multi-disciplinary issue, while optimization should be conducted in terms of a ratio of overall performance over overall cost accompanying with some real world constraints. Course instructions and laboratory exercises are two best ways to convey these technologies to educations of engineering students, where a plenty of processes are involved. The educational systems should also incorporate flexible tutoring techniques and adapt to instructional sequence. In this article, sensory integration is introduced at first, where the corresponding modeling and control technologies are discussed. In order to solve complex multi-objective and multi-disciplinary problems, various multi-objective optimization techniques are proposed for the potential multi-sensor integration application. Particularly, those modeling, control and optimization methodologies are accessible to implement for classroom instructions and laboratory exercises have been developed. Eventually, typical engineering applications are discussed, such as robotic integration of smart sensors. The effort is focused on addressing, analyzing and solving some of the difficulties in applying optimization technologies to creating, disseminating and archiving of multiple sensor integration on both engineering and science education.

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