Honeywell, Inc., Technology Center

Generic Neural Network Technology To Improve Complex Materials Manufacturing

By the early 1990s, the functions of complex materials such as composites, ceramics, and semiconductors had multiplied, and their importance to various manufacturing industries had escalated. Despite this expanded role, intelligent manufacturing of complex materials was based on techniques known to a handful of manufacturing engineers rather than on defined methods. To find more efficient and less expensive ways to produce quality products, Honeywell, Inc., wanted to add neural networks (that is, systems that can learn, infer, and model complex processes that lack explicit rules) to optimize the manufacturing processes of new complex materials.

Honeywell teamed with 3M, Sheldahl, and Hercules (now Alliant Techsystems) to examine specific processes to which neural networks might be applied. In 1992, Honeywell applied for and received $2.35 million in cost-shared funding from the Advanced Technology Program (ATP). Without the support of ATP, the other companies would have been unwilling to participate because of the project's high risk. By project conclusion in 1995, Honeywell had confirmed the value of neural networks as a new, advanced control technology. None of the partner companies has commercialized the technology resulting directly from the ATP-funded project because of high initial investment costs. Honeywell continues to explore neural network technology and has developed related products, such as its Profit Sensor software.

COMPOSITE PERFORMANCE SCORE
(based on a four star rating)
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Research and data for Status Report 91-01-0069 were collected during October - December 2001.

Neural Networks Too Costly for Complex Material Manufacturing

Neural networks are computing systems, modeled on the architecture of the human brain, that can learn and model complex processes even when relationships are not explicitly understood. A neural network consists of processing units (components that actually execute instructions) and direct connections between each unit. Each of these connections has a real-value weight associated with it. Through these weights, the network processes the impact of each variable and the real-time, nonlinear interactions of those variables on the final output. Thus, the neural network produces "recipes" of variables to achieve a particular output.

Honeywell predicted that the benefits of implementing neural networks would apply to a wide variety of U.S. industries. Industries that use complex materials, such as automotive, aerospace, pulp and paper processing, oil refining, and food and beverage manufacturing, could use cost-effective neural network technology to solve their unique production problems. Extending the use of neural networks to the production and application of new, complex materials, however, presented technical challenges. Classic use of neural network technology is designed for manufacturing processes that can utilize a single controller. This is the case, for example, for traditional metal and alloy processing techniques.

Properties of complex materials, such as viscosity, consistency, and porosity, are dependent on multiple variables that interact in nonlinear relationships and change in real time. Manufacturing control over these variables would require the gathering of a large amount of information from multiple sensors specific to each variable, as well as the advanced processing of the data. This effort would result in the need to build specific sensing and controlling (neural network) models for every variable in a complex materials manufacturing process, making classic techniques for complex materials costly for both consumers and developers of neural network technology.

High Technical Risk Threatens Use of Neural Networks

Honeywell believed that generic neural network technology could be used for multiple applications in the production of complex materials, thus eliminating the need to create specific models for each process.

Neural networks and complex materials processing were both emerging technologies, and the combination of these two in a single venture increased the risk of the project. Because of the high risk and the low probability of immediate payback, Honeywell had little incentive to pursue internal research and development (R&D) or to seek venture capitalist funding. These sources would hesitate to provide funding until they saw a proof-of-concept that overcame technical hurdles and demonstrated the ability of neural networks to reduce production costs and improve quality.

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Honeywell had another significant challenge to overcome. The company first needed to become familiar with various industrial settings, which would require its potential customers to open their production facilities to Honeywell's researchers. This step would introduce another major risk, since prospective customers would have to reveal their product and production process secrets to Honeywell's researchers without the assurance that Honeywell could ultimately assist the companies in improving their manufacturing processes. This risk was so great that, initially, potential customers were not willing to collaborate.

ATP Funding Enables Joint Venture

In order to examine specific processes to which neural networks might be applied, in 1992 Honeywell formed a joint venture that comprised 3M, a leader in the production and utilization of complex materials; Hercules (now Alliant Techsystems), a global supplier of advanced materials for aerospace; and Sheldahl, a producer of complex film and coating products. Honeywell also applied for and received $2.35 million in cost-shared funding from ATP. After defining three specific candidate manufacturing processes, Honeywell then worked to break down the acceptance barrier and to prove the value of neural networks for complex materials processing by developing generic sensor and control technology.

ATP support also allowed Honeywell to undertake the research needed to compete with overseas intelligent processing projects, including the European ESPRIT effort and intense R&D at Yokagawa in Japan and Siemens in Germany.

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Generic Neural Network Technology Promises Multiple Uses

Honeywell worked with the three companies to achieve better process understanding and control through the development and implementation of neural networks. The group hoped to gain general knowledge that would contribute to Honeywell's broader goal of developing

generic neural network technology for multiple applications in the complex materials industry. The companies focused on the precision film-coating process, the filament-winding process, and the continuous flexible circuit boards production process.

Precision Film-Coating Process

With 3M, Honeywell focused on optimizing 3M's precision film-coating process, important to photographic, magnetic, optical memory, adhesives, and paper products. In precision coating, the goal is to achieve consistency and uniformity in coating, with thickness as the quality index. A host of variables in this highly nonlinear and time-variant process, however, add to variance in the final product. To address this variance, Honeywell configured its NeuroCD (cross-directional) neural network controller to predict the required control action to minimize the variance in film thickness. This controller demonstrated robustness and achieved a reduction of variance in the thickness profile from five percent to three percent. In 1994, because of improved process understanding resulting from the ATP research, 3M implemented a new sensor technology that allows equipment to run more efficiently and the controller to reject a process disturbance within one minute, rather than the one hour it took the previous quality controller.

Filament-Winding Process

In its work with Hercules (now Alliant Techsystems), Honeywell concentrated on optimizing Hercules' filament-winding process for the manufacture of composite parts for defense aircraft and missile systems. Given high material costs for this type of manufacturing, it is essential to minimize scrap and defective parts. The filament-winding process, however, takes place in an uncontrolled production environment in which perturbations can create voids (air or gas bubble formations) that cause wrinkling, fiber reorientation, laminate microcracking, and delaminations that decrease tensile strength. Before the ATP project, Hercules experienced void volume fractions of seven percent. The ATP research team aimed to reduce that figure to between three and five percent. The team first developed an empirical model based on neural networks to predict the expected void volume fractions, given a set of input parameters. This model provided sophisticated process understanding, revealing unacceptable variation exhibited during resin impregnation. To remedy the problem, the team developed the manifold impregnation unit (MIU). The team then used a neural network model, hoping to identify problematic process conditions to control and optimize the system.

Honeywell developed a Neural Network Toolkit.

The MIU was enormously successful. It met the target void volume fraction of three to five percent and later received a patent. Alliant Techsystems did not incorporate this unit into filament-winding production, however, because of the significant costs associated with extensive alterations to its complex processes. Prohibitive costs and lack of sufficient process data also prevented further development of the first neural network model. Nevertheless, the model did provide important filament-winding-process knowledge by identifying areas that Alliant Techsystems could refine.

Continuous Flexible Circuit Boards

To improve complex materials processing at Sheldahl, Honeywell examined the production of continuous flexible circuit boards, Sheldahl's most profitable product. Sheldahl's process involved the physical vapor deposition of copper onto thin films via thermal evaporation from heater elements, called boats, which contain "puddles" of molten copper. Although the process functioned relatively well, a problem known as "spitting," which is the uncontrolled ejection of molten globules of copper onto the film, prevented uniform evaporation and deposition of metal onto the film. Honeywell first approached this problem by installing National Instrument's Labview. This neural network tool assists process understanding and enabled the research team to establish closed-loop process control. The research team also designed and applied a coating quality sensor (CQS), a neural network device that reliably detects puddle spitting and predicts the consequences of the process operator's actions, to determine what action inputs cause puddle spitting. In addition, Honeywell and Sheldahl closely observed the thermal and electrical characteristics of the entire system to improve process knowledge. Initial

experiments suggested that these improvements accelerated production line speed by 20 percent.

Honeywell Develops Toolkit to Transfer Technology

As a result of its work with the three companies, Honeywell developed a package of software tools as a means to transfer technology to its partners and to incorporate the concepts gained for continued improvement of control approaches for complex materials.

This Neural Network Toolkit also provided an internal resource for Honeywell's continued development of advanced neural network technology. Although the toolkit design was based on the specific problems of 3M, Alliant Techsystems, and Sheldahl, it is generic in its outlook. The toolkit extracts common procedures and practices from various processes to support visualization, modeling, and control strategies. Its visualization tool supports the analysis of process variables, facilitates identification of key relationship trends, and aids in selecting variables for control. The modeling tool provides a user-friendly mechanism for designing, training, and testing neural network models. The toolkit also provides graphic depictions of the three control strategies provided for each of Honeywell's partner companies. By 2001, Honeywell had distributed the toolkit to only the three companies.

ATP Project Defines Worth of Neurocontrol

The four joint-venture participants continue to make use of the ATP-funded developments. For example, the project has allowed Honeywell to explore the previously untapped complex materials market. The company's industrial division continues to develop neural network control strategies, including a parametized neurocontroller for its total downtime controller Total Plant product line and an adaptive cross-direction controller for application to the paper-processing industry.

3M's film-coating process is less variable as a result of the NeuroCD controller. Alliant Techsystems benefits from advanced process understanding,and Sheldahl has improved its production of flexible circuit boards with Lab-view's and CQS's ability to detect and predict outcomes based on hypothetical actions.

The results of Honeywell's research have confirmed that neural network-based approaches to control are useful for complex manufacturing.

Support from ATP at the initial stage of development was critical for both Honeywell's development of neural networks and to cultivate industry curiosity concerning the new technology. Honeywell has encountered acceptance barriers from potential users, however, who are unable to justify the investment in generic neural networks technology when their current processes are functioning adequately.

Conclusion

The results of Honeywell's research have confirmed that neural network-based approaches to process control are useful for complex manufacturing. Currently available neural network technology provides a worthwhile method for process data exploration and empirical process modeling. Honeywell recognizes that developing neural networks that are sufficiently generic and therefore worthy of initial capital investment remains a challenge. Honeywell has continued to explore neural network technology and has developed related products, such as its Profit Sensor software. Because neural networks offer a high-tech, advanced control approach, a great deal of technical research will need to precede any significant business development. The work of the ATP project and resulting technical literature, such as Honeywell's paper, "Neural Networks in Control Systems: A Review," will help guide that development.

PROJECT HIGHLIGHTS
Honeywell Inc., Technology Center

Project Title: Generic Neural Network Technology to Improve Complex Materials Manufacturing (Neural Network Control and Sensors for Complex Materials)

Project: To develop generic sensor and control technology based on neural networks for application to complex materials processing.

Duration: 7/1/1992-6/30/1995
ATP Number: 91-01-0069

Funding (in thousands):

ATP Final Cost	$ 2,138	49%
Participant Final Cost	2,225	51%
Total	$ 4,363	

Accomplishments: This ATP project generated advanced process understanding for neural network controls and sensors for complex materials and established the groundwork for Honeywell's continued development of neural networks.

Alliant Techsystems received the following patent as a result of technology related to the ATP project:

- "Apparatus for fiber impregnation" (No. 5,766,357: filed September 19, 1996; granted June 16, 1998)

Honeywell published the following paper as a result of the ATP project:

- Neural Networks in Control System: A Review

Commercialization Status: By 2001, none of the partner companies had commercialized technology resulting directly from the ATP project. However, Honeywell has continued to explore neural network technology and has developed related products, such as its Profit Sensor software.

Outlook: Honeywell engineers have continued to develop neural networks and have received several patents in this area that build on the work that was completed during the ATP project. Honeywell still notes a persistent acceptance barrier by the industry because of high initial investment costs, but expects that both incremental improvements and innovation breakthroughs will eventually bring advanced neural network technology to complex materials processing, thereby revolutionizing this industry.

Composite Performance Score: *

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Subcontractors:
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Sheldahl
Hercules (now Alliant Techsystems)

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