Update: NBS Research Facility Addresses Problems In Set-Ups For Small Batch Manufacturing

By Philip Nanzetta
Center for Manufacturing Engineering,
National Bureau of Standards

Plans for the Automated Manufacturing Research Facility (AMRF) at the National Bureau of Standards (NBS) were described in detail by Robert Hocken in the April, 1982, issue of *Industrial Engineering* (see box on page 72). Now, two years later, there is a great deal to report about accomplishment of the first phase of these plans.

The AMRF is a research facility which is concentrating on the problems of manufacturing machined metal parts in small batch sizes. Attention is directed to issues of flexibility and adaptability to varying work set-ups.

The design features a modular, hierarchically structured control system and a wide variety of machining centers, robots, sensors and computing systems from many different vendors. These are linked by control and database structures which will utilize a system of standardized interfaces.

NBS is building the AMRF to serve as an engineering test-bed that researchers from NBS, universities, industry and other government agencies can use to study questions of standardization, measurement and quality control in the automated factory environment. There is already a high level of participation by universities and industry.

As of this writing, almost all of the major equipment for the AMRF is in place on the floor of the NBS Instrument Shop, and the first major integration stage within the facility has been publicly tested. Our work with the AMRF has already begun to clarify the technical issues which must be addressed by the next generation of standards for data formats and control interfaces in the automated factory.

Work on the AMRF is greatly strengthened by our interactions with the Navy Materiel Command and the Naval Air and Sea Systems Commands, which cosponsor the project and act as a "realism driver" for applications.

Units in place

The AMRF consists of five basic work stations: three machining, one cleaning and deburring, and one inspection. The automated material handling system is also treated as a work station within the control hierarchy. The machining centers and coordinate measuring machine are each tended by an industrial robot for parts loading and unloading as well as for tool or probe replacement. Figure 1 lists the details of equipment currently in place.

The computer architecture of the AMRF is highly distributed. The control modules run on a number of different computers, ranging from a VAX 11/780 to 8086- or 68000-based single board computers and multiple processor systems.

At present, the cell level of control, the material handling controller and the network manager run as modules on the Hierarchical Control System Emulator, written for NBS in Praxis by Bolt Beranek and Newman Inc. to run on a VAX, and subsequently augmented at NBS.

The data manager is built around the commercial version of RIM, which was originally developed for NASA, to which NBS has added a control oriented user front end. Appropriate database interfaces are provided at each of the control modules.

Fundamental approaches

It is more than just good fortune that the hierarchical control structure and modularization of the system, which allow easy testing of experimental units, also make it possible for the shop or factory to adopt the new technology in easy steps, upgrading one element at a time.

The control structure of the AMRF is based on a hierarchy of

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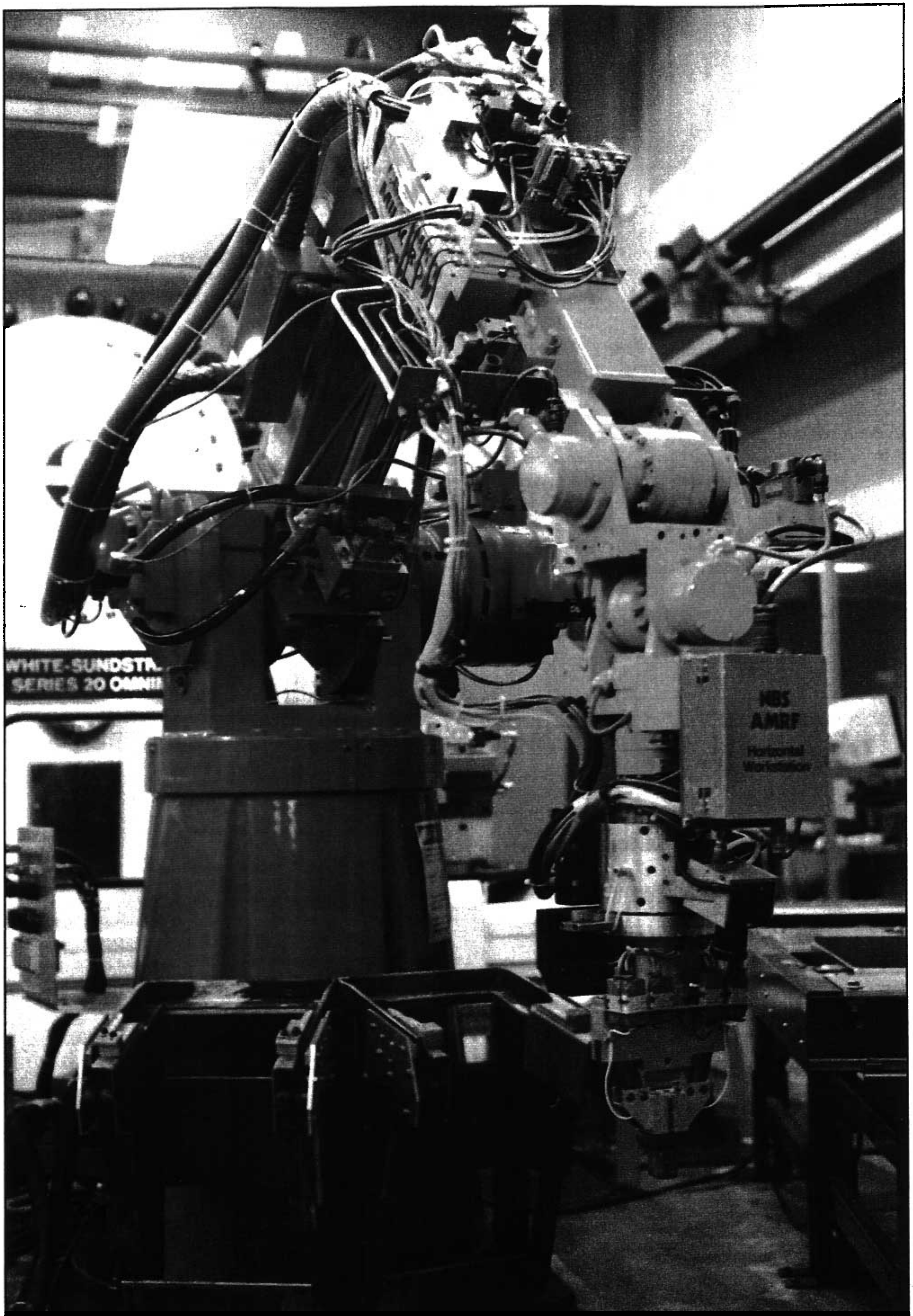

The extensive end-of-arm devices developed by the NBS were added to a commercial robot. These devices include a three-dimensional system and a gripper which has a servo-controlled grip opening and grip force.

control modules, each receiving commands from above and returning status to the level above, and each with independent access to the database.

Each control module is designed to handle all decisions which are within the span of its knowledge but not within the span of any lower level. Complex global tasks in the AMRF are broken down level by level into successively more detailed and particular tasks.

In the AMRF, the control modules are being designed with particular attention to specifying the input and output interfaces. In this way, a control module can be replaced by an upgraded version which has exactly the same interfaces without causing unexpected results elsewhere in the system. This modular approach makes it possible to construct a system step by step, and to upgrade it as new capabilities become available, much as one is able to do with a modular stereo system.

Machining accuracy is important in the factory of the future. A technique developed at NBS makes it possible to improve the accuracy of the CNC machine tool, which already has high repeatability.

This accuracy enhancement is based upon preparation of an "error map" of the machine tool using laser interferometery. The error map is then used in a software correction via the machine's controller.

For robots, greatly enhanced accuracy can be obtained by use of a high level controller which can utilize input from sensors to make fine adjustments in the robot's position or trajectory. It will be more economical in the long run to measure and then adjust for the robot being .020 in. out of position than it will be to build in an inherent repeatability greater than .020 in.

Since, in actual practice, the robot's working environment itself will also be non-repeatable, the use of sensory information is the only way to extend the range of suitable applications of robots.

First integration stage

The first integration stage of the AMRF was publicly tested for one week during November, 1983. Over 600 visitors witnessed the test runs, which, on the whole, were extremely successful. Refinements based on the test run have been incorporated into the system as described here.

Two machining work stations, the horizontal and the turning, now run under control of individual work station controllers. Each machine tool is tended by a robot, which moves part blanks and finished parts between a material handling interface and the workpiece holding devices. The robot also handles partially finished parts, placing them in the workpiece holding devices so that different surfaces can be machined.

NBS-developed high-level machine tool controllers "sit on top of" the manufacturers' controllers to give the necessary interfaces for control, sensor and data flow purposes.

Work station programs, parts programs and robot handling programs are obtained as required by each control level by request to the database.

Blanks are brought to the work stations and finished parts are removed by a robot cart managed by a material handling system.

A cell controller performs order entry, rudimentary scheduling, coordination of work stations and management of inventory.

Communication among the units of the AMRF is handled by a temporary low speed network, using the basic protocols which will later be implemented on a high speed network.

In the horizontal work station, a sophisticated realtime control system (RCS) developed at NBS provides high-level robot control. RCS makes it possible for the robot to react to input from an unlimited variety of sensors, and this in turn opens the door for a practical approach to offline programing. Currently the horizontal work station uses an NBS-developed structured light vision system in conjunction with the RCS to handle part blanks brought into the work station only loosely positioned on a tray.

The vision system examines each part, compares it with a model of the part in its internal database and determines whether it is the part called for by the work station controller. RCS then uses the vision system to position the robot gripper to pick up the part, even though its position is not precisely known in advance. In handling parts, RCS—through a gripper controller—sets the desired gripper opening and grip force.

Fixturing is handled by a special combination of hydraulic vise jaws and linear actuators controlled by a fixture controller which receives its commands from the work station controller.

In the turning work station, an NBS-developed gripper is used to place part blanks and semi-finished

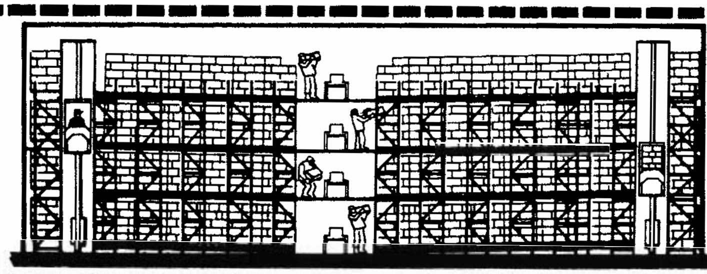

Figure 1: AMRF Shop Floor Equipment

Horizontal Workstation (Level II Operation)	
Machine Tool	White Sundstrand Series 20 Omnimil, CNC Horizontal Spindle Machining Center
Robot	Cincinnati Milacron T3 Robot
Grippers	NBS developed, force and position servoing
Special Sensors	NBS developed vision
Turning Workstation (Level I Operation)	
Machine Tool	Hardinge Superslant, CNC Turning Center
Robot	Bendix electric, fixed gantry mounted
Grippers	NBS developed, force and position servoing
Vertical Workstation	
Machine Tool	Monarch VMC 75, CNC Vertical Spindle Machining Center
Robot	(in procurement)
Inspection Workstation	
Machine Tool	Bendix Horizontal Arm CNC Coordinate Measuring Machine
Robot	American Robot, gantry mounted active 7th axis
Cleaning and Deburring Workstation	
Robots	Unimation Puma 760 Unimation Unimate 2000B *

* Scheduled but not delivered

parts in the collet of the turning center. The gripper has an active (7th) axis of motion normal to its fingers which it uses for linear insertion of parts into the collet. It has servo-controlled grip opening and grip force.

Each of the work stations in the AMRF is being developed in levels. Level I operation means that the major pieces of equipment are present in the work station, a basic work station controller is present, there is a material handling interface and the work station operates as a unit.

Level II operation means that there is a flexible work station controller, flexible robot controller and initial sensors and that the database and cell links are fully functional. Level III operation means operation with significant sensory interactive control.

Upgrading workstations

During the next year, the horizontal work station will be brought up to Level III and the turning work station will be brought to Level II. The vertical and inspection work stations will be brought to Level I.

An automated buffer storage system served by a multi-cart transport system will be implemented.

A high-speed network will be installed, serving the AMRF and related software development systems.

The capabilities of controllers at all levels of the hierarchy will be enriched. The cell controller, material handling controller, network man-

A Brief Overview Of AMRF's History . . .

The National Bureau of Standards began carrying out its five-year program of building a special research facility to examine problems in process measurement and standards for automated manufacturing, particularly as these applied to the small and medium-sized machine shop that manufactures a wide part mix.

The set-up of the AMRF and proposed research efforts were detailed in an article in the April, 1982, issue of *Industrial Engineering* written by Robert J. Hocken in his capacity as chief of the automated production technology division of the National Bureau of Standards Center for Manufacturing Engineering.

Instead of doing much actual production, researchers were proposing to be looking for solutions to problems such as:

☐ The lack of standardization in hardware and software interfaces among the wide variety of machines that might be found in such a shop.

☐ The lack of a standard system for part descriptions among various automated design and manufacturing systems.

☐ The lack of an appropriately integrated sensor system and safety system for an automated shop (for example, a useful, flexible vision system for inspection). A variety of technical gaps in the creation of standardized data structures to describe fixturing, part handling and general problems in part routing.

The AMRF proposed to use about one-third of the main shop floor for production (approximately 4,350 sq ft). Another 5,000 sq ft off the main shop floor was planned for the parts inspection station. Maintenance, inventory, computer control, CAD and other support facilities were expected to use another 10,000 sq ft in other locations in the building.

The AMRF set up some specific research programs. Among these were better sensor systems and more intelligent control systems and a vision system capable of sensing in real-time the position and orientation of objects.

The AMRF was also working to refine the concept of hierarchical control of robots to improve the integration of force, touch and vision information with the robots' actions and reduce the processing time.

Safety systems for both the fixed robot manipulators and the robot cart system were also targeted for development.

The AMRF was also proposing to develop automatic tool set stations that would work with a wide variety of possible machine tools by investigating types of flexible fixturing systems for holding the workpieces.

One of the key projects proposed in the program was the extension of the hierarchical control system. The AMRF planned to incorporate recently developed data transfer standards for the exchange of grapics and design data between CAD/CAM systems.

ager and database manager will be implemented on stand-alone computer systems.

Enhanced computer-aided process planning and offline preparation systems for NC, robot and work station programs will be developed and tested.

Next generation of standards

The problems of interconnecting controllers and CNC equipment of various manufacturers is such that virtually every FMS is provided to the end user by a single vendor who solves the interface problems for his particular system.

The AMRF is constructed of controllers and CNC equipment of many vendors, so that we can confront all of the interface problems that need to be addressed in development of technical standards for the future.

During the past several years, NBS has provided technical support for the ASME B89 committee developing a standard to specify coordinate measuring machines. That work has led to adoption of an interim standard B89.1.12. Because of our work in the AMRF, NBS will be in a position to support similar efforts on standards for specifying robots.

The first integration state of the AMRF involves over 30 interfaces for command-status and data flow. The electrical interfaces are generally standard, such as RS-232C or RS-442. The information interfaces, however, are just in the developmental stages. Each of these has the potential to lead to a worthwhile standard.

Technology transfer

NBS and the Navy, cosponsors of the AMRF, are particularly interested in making available and assisting in the implementation of technology which might come out of research on the AMRF, both now during the building of the facility and later as it is used as a research test bed.

In the turning work station, an NBS-developed gripper is used to place part blanks and semi-finished parts in the collet of the turning center.

Industrial research associateships have proven to be a highly effective tool for bringing together industrial applications and NBS technical research. Under this program, a research project of mutual interest is defined by NBS and an industrial firm. An employee of the firm is sent to work at NBS for a period of typically six months to a year. Salary is paid by the firm and general laboratory space and equipment are provided by NBS.

There is such a high level of industry interest in the work of the AMRF that a series of one-day industry briefings has been organized by the Center for Manufacturing Engineering; briefings are being scheduled once every two months.

For further information on the research association program and the industry briefings, contact the author in writing through the Center for Manufacturing Engineering, NBS, Washington, DC 20234.

Philip Nanzetta is technical assistant to the director, Center for Manufacturing Engineering, where he has project management responsibilities in the AMRF. He served as dean of the faculty and vice president for academic affairs at Stockton State College in New Jersey. Nanzetta has been a faculty member at Case Western Reserve University and the University of Florida. He received his PhD in mathematics from the University of Illinois in 1966.