Tools and Structures for the Application of Micro-Controller Technology to Small Hydro Automation

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Abstract

The past 10 years has seen significant advances in low-cost micro-processing devices, data communication and personal computing. The combined impact of these advances is challenging existing processing structures and development tools for plant automation. In the small hydro automation sector, cost-advantageous solutions involving distributed processing and real-time simulation are now available.

The first hydro station controllers were analog. During the 70's and 80's, analog controllers rapidly gave way to digital implementations based on Programmable Logic Controllers and Tailored Software Systems. The digital environment facilitated more complex control algorithms and brought SCADA (Supervisory Control and Data Acquisition) software within reach of most applications.

Around the 1990's, low-cost data buses began to replace point-to-point communication links, facilitating distributed computing solutions. Processing components themselves were becoming vastly more powerful, through computer-on-chip technology. Further, the processing power available in a standard desktop PC was surpassing the dreams of engineers a decade earlier.

Utilizing these technological advances, affordable distributed processing solutions for small hydro automation are now a commercial reality. The ability to reduce costs is due to the combination of more effective structures and the creation of low-cost development tools, such as:

- Off-line simulation in a standard PC with office tools
- Embedded simulators in distributed processors
- Integral data logging with standard PC office tools for data management
- Distributed processing verification using PC-based SCADA
- Real-time simulation in a standard office PC augmented with low-cost input-output boards

The successful application of this technology to the control and protection of a 2 MVA hydro generating unit is described. The design involved a set of micro-controllers covering control and sequencing, protection, human-computer interface, synchronization and water level measurement, all linked via data buses. Equipment development, factory-based system testing and on-site commissioning were optimized through the creation and use of these cost-effective tools. The tools and structures facilitated a modular solution with comprehensive functionality at an overall low cost.

1 Processing Structures

The first power stations were reasonably simple and small, with little or no automation. As the stations grew in size and complexity, more information on the plant status was required for the operator to make the necessary adjustments. Analog governors were introduced to provide speed regulation, with hard-wired protection relays, annunciation circuits and monitors to deal with fault conditions. Generally, there was no communication between the units [1].

Next, digital computers, offering increased functionality and versatility, began to replace many of the analog functions. These enabled more complex control algorithms to be implemented, for instance, multiple control modes covering start-up, shut-down, commissioning, power control and head level regulation. Two digital programming techniques evolved based on Programmable Logic Controllers, with software specific to that application, and on Tailored Software Systems, in which algorithms were pre-coded with a facility for parameter customization. Digital technology also facilitated the use of SCADA (Supervisory Control and Data Acquisition) to provide overall site control and monitoring. Initial SCADAs were hierarchical in nature, with point-to-point communication links with each of the unit controllers.

As communications technology advanced, these point-to-point communication links began to be superseded by data bus structures which offered significantly less wiring infrastructure. Data bus structures also facilitated distributed processing using modern low-cost micro-controllers. Single-chip micro-controllers are now commercially available equipped with on-board analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and serial and parallel communication ports.

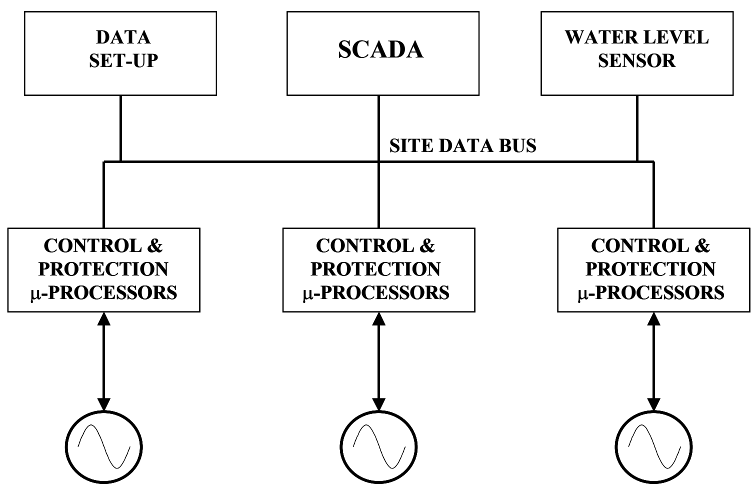

Figure 1.1: Distributed Processing Structure

With distributed processing structures (Figure 1.1), the site-based functions such as SCADA and water level measurement can be considered as peripheral functions attached to the site data bus. This structure also facilitates more efficient use of data set-up tools, and ably supports computational solutions based on tailored software systems. Data set-up itself becomes another peripheral function on the site data bus. These structures are further complimented by more powerful desktop PCs that are able to readily communicate on the data buses as well as hosting multiple peripheral functions such as Data Set-up and SCADA. Multiple communication buses are also widespread.

2 Development Tools

Today's development engineers use a very different toolbox compared to their predecessors. Tools which may have been expensive, unaffordable or inflexible, can now be realized for low-budget solutions:

1. Off-line simulation for algorithm development: Modern PCs with standard office software have been found to offer very powerful environments for dynamic system simulation. For instance, Microsoft Excel with its inherent Visual Basic for Applications (VBA) suite provides a versatile combination of a graphical human-computer interface with high-level language programming.

2. Embedded simulation: The power of modern micro-controllers enables plant simulations to be embedded within the application software to enable rapid development and verification of software algorithms within the target environment.

3. Data recording: Modern PCs are generally equipped with serial data ports and data communication software such as HyperTerminal™. Utilizing the serial data ports on modern micro-controllers, data can be readily sent to the PC as ASCII text, where it can be stored using such software, and subsequently processed using office tools.

4. SCADA for distributed processing diagnostics: Although SCADA systems were originally developed for operational monitoring and control, they offer a powerful tool for verifying distributed processing operation. SCADA systems can be implemented as software packages on a standard office PC with data bus communication via a standard PC serial port. Through exploiting the continual bus traffic monitoring capability of a bus peripheral with SCADA's inherent data recording facilities, SCADA systems can be extended to provide comprehensive event and data recording across a distributed processing structure, and thus aid system development and verification.

5. Hardware-in-the-Loop simulation for system verification: In addition to facilitating off-line simulation, the PC's internal clock can be used to effect real-time simulation. Combined with the use of commercially available PC I/O boards that offer direct communication with environments such as Excel/VBA, a complete real-time hardware-in-the-loop simulator can be realized at an extraordinary low cost. The human-computer interface can be further enhanced through the use of commercially available virtual instrumentation software.

3 Application to a 2 MVA Hydro Generating Unit

The successful application of these structures and tools to the automation of a 2 MVA Francis turbine hydro generating unit is described. The project involved the replacement of older protection and control equipments with a modern multi-functional micro-controller-based solution. The main components of the new system were (see Figure 3.1):

- Controller module – covering start/stop sequencing, wicket gate control, synchronization, fault detection and fault response
- Protection module – covering all required generator protections
- Local panel – with inter-bus communication capability
- Water level module
- SCADA – software installed on a standard PC
- Set-up guide – software installed on a standard PC
- Global (site) and local (unit) data buses

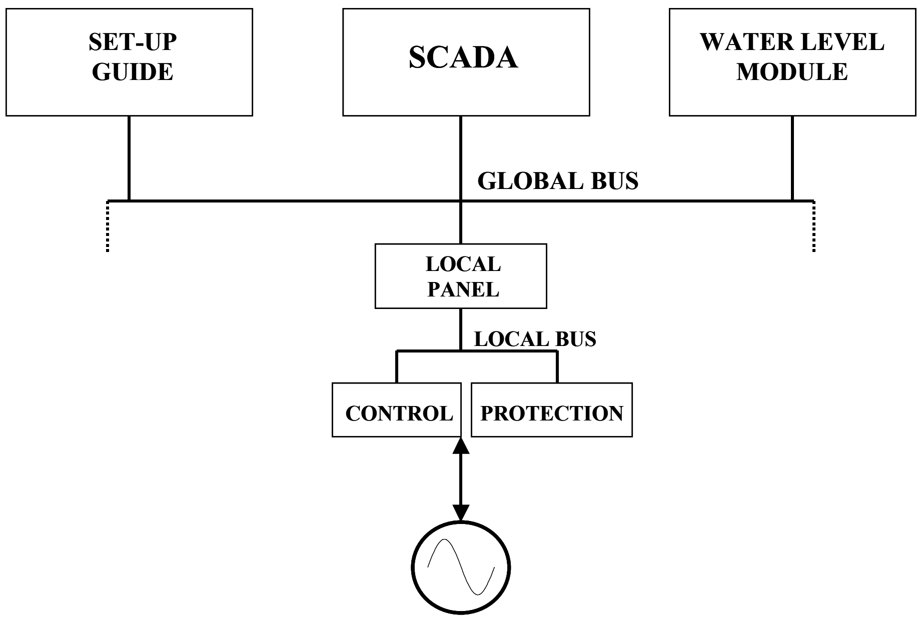

Figure 3.1: Equipment Structure for 2 MVA Hydro Generating Unit

The project required functional enhancements to existing equipments (e.g. SCADA, set-up guide, local panel), as well as the design and implementation of three new equipments:

- Multifunctional protection module containing all required generator protections
- Multimode controller module covering speed, power and wicket gate regulation in addition to various sequencing operations
- High-pressure hydraulic power unit (HPU) equipped with high-precision servo-valve

Rapid development and commissioning of these equipments in a cost-effective manner was achieved through the creation and use of new tools, which are described below.

3.1 Off-line Simulator Tools

The first tools employed were the Excel/VBA off-line simulators, which were used for algorithm development for both the protection and control modules.

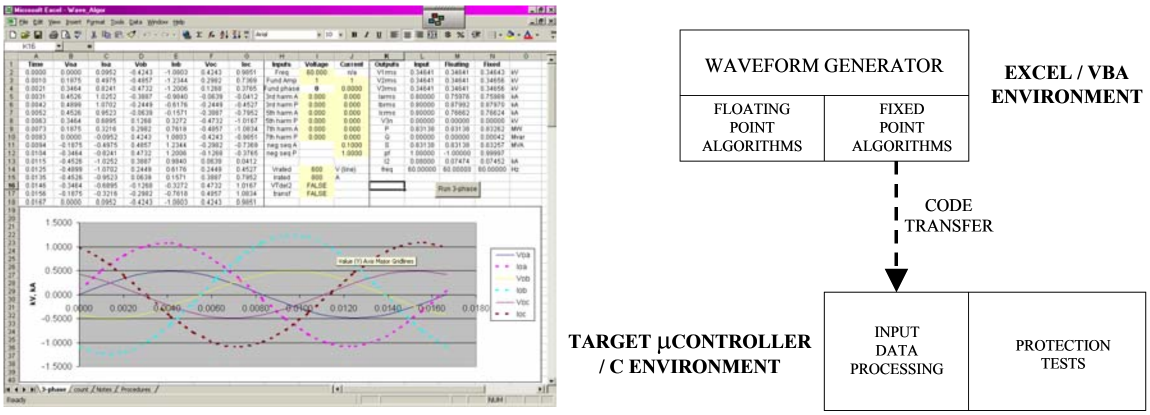

Figure 3.2: Power Measurement Tool (a) Interface and (b) Development Environment

For the protection module, it was desired to develop algorithms for the calculation every half-cycle (8.33ms) of [2]:

- RMS voltage and currents
- Power and energy (active and reactive)
- Negative sequence current
- Voltage third harmonic

Figure 3.2a shows the human-computer interface for the 'power measurement' tool that was implemented using Excel/VBA. Three-phase waveforms for the current and voltage were simulated, with options for:

- Voltage and current amplitudes
- Fundamental frequency
- Current phasing relative to voltage
- 3rd/5th/7th harmonics phase and amplitude for voltage and current
- Negative sequence current (magnitude and phase)
- Phase or line VT measurements
- Three-phase transformer between the voltage and current measurement points

Using the simulation, measurement algorithms were prepared and verified taking into account appropriate sampling and analog-to-digital conversion requirements. Algorithms were first prepared and verified using floating-point arithmetic, and then implemented in fixed-point arithmetic in order to achieve the required computational speed whilst maintaining accuracy. Following simulator verification, the algorithms were converted to 'C' and copied across to the target micro-controller environment (Figure 3.2b), for real-time verification using three-phase voltage and current sources.

A similar approach was followed for the off-line hydro-plant dynamic simulator [2]. The requirement was to design the control laws for a multi-rate multi-mode controller covering start-up, gate control, head regulation, power control, islanding control, shut-down and black start. In accordance with the appropriate IEEE standard [3], the starting point was to establish a dynamic simulation. Figure 3.3a shows the human-computer interface and Figure 3.3b contains an overview of the plant dynamic model. The model contained a 'single-machine-to-system' equivalent with provision for the system to range from an infinite bus to a small island.

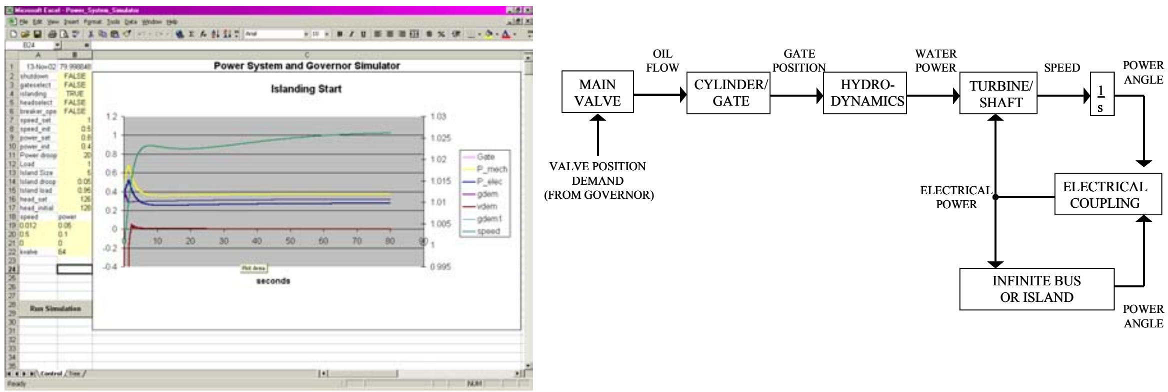

Figure 3.3: Off-line Hydro Simulator Tool (a) Interface and (b) Dynamic Model

3.2 Embedded Simulator Tool

Following development of the controls laws using the off-line simulator, both the control laws and the dynamic model were converted to 'C' and copied across to the target micro-controller environment (see Figure 3.4). With the plant simulation embedded within the controller software, this provided a facility for early closed-loop verification of the software algorithms within the target micro-controller.

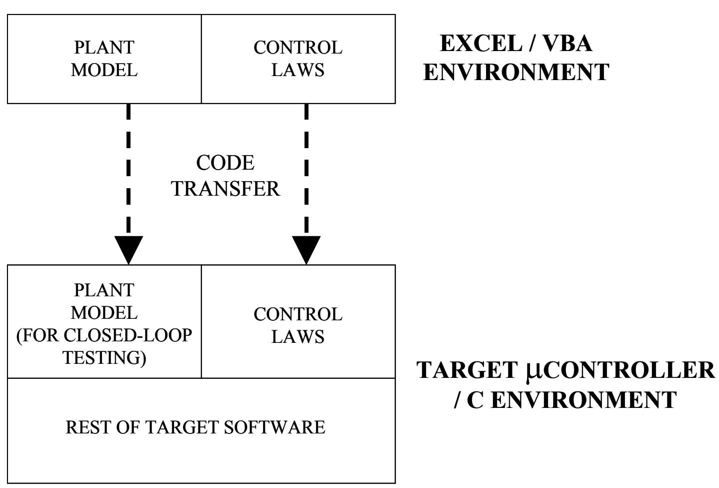

Figure 3.4: Off-line and Embedded Simulator Tool Environments

3.3 Data Recording Tool

Data logging has historically been performed using separate data recording equipment. However, an alternative lost-cost solution exploiting the technological advances was to:

- Use a serial communications port of the embedded micro-controller to output a stream of data in standard RS232 format
- Capture the RS232 data stream in a standard PC using HyperTerminal™ software, which is supplied with the Windows Operating System.
- Write an Excel/VBA macro to read, tabulate and plot the captured data.

The data logging tool was used for both in-factory development and on-site control law tuning (see Figure 3.5). It is interesting to note that during commissioning, a single lap-top PC was used for:

- Downloading the controller software
- Capturing and processing of logged data
- Module parameter set up
- SCADA operation and verification

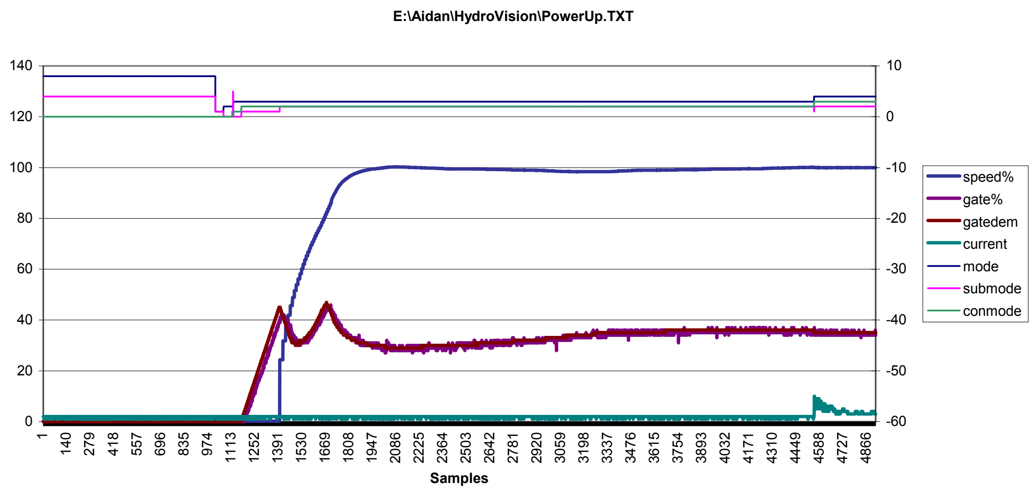

Figure 3.5: Data Logging Tool Example

3.4 SCADA for Distributed Processing Diagnostics

The SCADA software resides on a standard office PC. As with most SCADA systems, its original purpose was for commands and for recording of operational data including event logging. The SCADA system connects to the global (site) bus via a standard serial port of the PC, and communicates over the bus by listening to all bus traffic and seeking to recognize commands directed to it.

The combination of inherent data recording with continual listening to global bus traffic enabled the SCADA to offer system-wide diagnostics. This capability was further enhanced through the significant transfer of data between the global and local buses, which included individual module diagnostic codes. By intelligent specification of data recording criteria combined with standard database query tools, a low-cost effective system-wide diagnostics tool was enabled.

3.5 Real-time Simulation Tool

Although hardware-in-the-loop simulators have been well established for controller development, these are frequently expensive and often require specialist computational environments. A very low cost solution adopted in this instance was to (see Figure 3.6):

- Augment the off-line Excel/VBA simulation to include the full set of controller I/O channels (analog and Boolean)
- Purchase off-the-shelf I/O boards, which when plugged into a standard PC allowed access directly into the Excel/VBA software environment.
- Use the PC's internal clock to trigger repetitive operation of the model equations to enable real-time computation

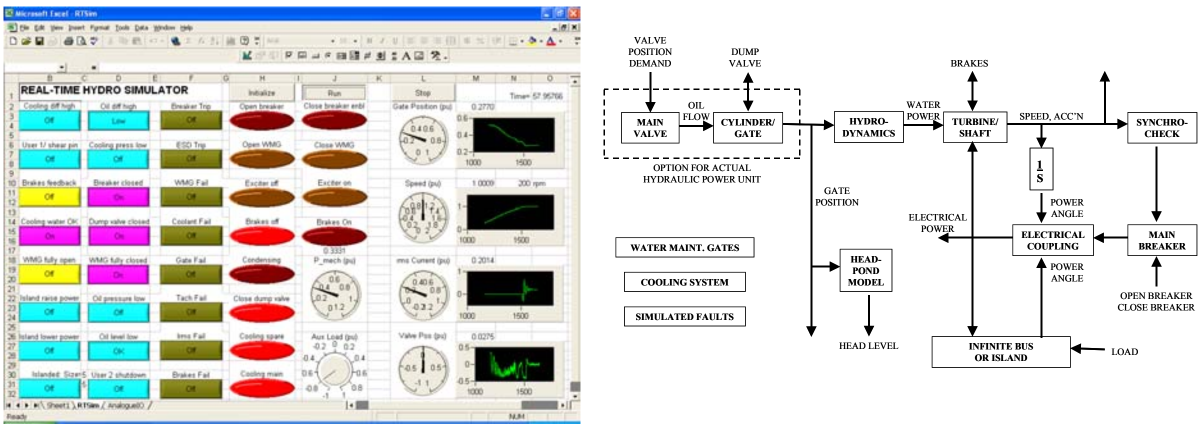

Figure 3.6: Real-time Hydro Simulator Tool (a) Interface and (b) Dynamic Model

Three further features contributed to the versatility of the real-time simulation:

- Virtual instrumentation software was purchased and used to enhance the human-computer interface – thus simulated pushbuttons, knobs, dials, LEDs and trace recorders augmented the usual Excel interface.
- A number of plant faults were programmed into the simulator to aid testing of the fault detection and response software.
- The simulator could be run in two modes – either the HPU could be included in the simulation, or the actual HPU could be part of the hardware-in-the-loop test environment.

This enabled cost-effective factory-based hardware-in-the-loop testing of a complete system comprising controller module, protection module, local panel, SCADA, set-up guide, water level module, hydraulic power unit, with global and local data bus connections.

4 Conclusions

New control system structures and development tools are being facilitated by technological advancements such as:

- Low-cost versatile embedded micro-controllers
- Low-cost communication data highways
- Low-cost personal computing software and hardware

The new structures are based on distributed computing, with processing elements linked via data communication buses. Development tools that may have been expensive or unaffordable in the past, can now be realized for low-budget solutions.

This technology was successfully applied to the control and protection of a 2 MVA hydro generating unit. The design involved a set of micro-controllers covering control and sequencing, protection, human-computer interface, synchronization and water level measurement, linked via site and unit data buses. Equipment development, factory-based system testing and on-site commissioning were optimized through the creation of cost-effective tools covering:

- Off-line simulation in a standard PC with office tools
- Embedded simulators in distributed processors
- Integral data logging with standard PC office tools for data management
- Distributed processing verification using PC-based SCADA
- Real-time simulation in a standard office PC augmented with low-cost input-output boards

The tools and structures facilitated a modular solution with comprehensive functionality at an overall low cost.

5 References

[1] Y Grandmaitre, “Low Cost, Operator Friendly Controls for Small Hydro – Fact or Fiction?”, Presented at HydroVision 2000, North Carolina, August 2000.

[2] A Foss, Y Grandmaitre, J Morton, W Kemp, “Lowering the Cost of Small Hydro Protection and Control through Tailored Algorithms and Simulations Optimized for Low-cost Microcomputers”, Presented at WaterPower 2003, Buffalo, July 2003.

[3] ANSI/IEEE Std 125-1988, IEEE Recommended Practice for Preparation of Equipment Specifications for Speed-Governing of Hydraulic Turbines Intended to Drive Electric Generators.

Authors

Aidan Foss P.Eng. is the Principal Engineer of ANF Energy Solutions. A graduate in mathematics from Cambridge University with a doctorate in turbine control from Imperial College, Aidan specialized in computer control and simulation and was Vice-Chairman of the United Kingdom Simulation Council. Through the National Grid Company, he focused on power applications, including auditing and modeling of generator control systems. Currently based in Ottawa, Aidan provides technical consultancy services covering power systems, power measurement, power-plant automation and simulation.

Yves Grandmaitre, CSP, V.P. Sales and Marketing at Powerbase Automation Systems Inc., has been active in selling and interfacing with industrial controls for over fifteen years. His experiences have spanned the pulp and paper industry, petrochemical, waste water and many more. Yves practices a hands-on approach to selling and has been involved in many installations and commissioning of control systems. He has also traveled extensively and written articles promoting the benefits of an embedded application specific controller approach for small hydro sites.

William (Bill) Kemp, V.P. of Engineering, has over 20 years experience in the development of high performance embedded control systems, focusing on scalable hardware and software solutions to the on and off grid power generation industry. Also experienced in PV and wind technology, Bill is the principal system architect of the Powerbase Platform. He has traveled extensively promoting to industry the effectiveness of the Powerbase platform as an ideal solution for the small hydro protection and control market.

Dale van Spengen is the Chief Technology Officer at Powerbase Automation Systems, Inc. For over 12 years, Dale has been involved in the design, testing, and commissioning of electronic control systems for the commercial and industrial markets using embedded micro-controllers, and communications subsystems. Dale's involvement in projects, from concept to commissioning, has cultivated an in-depth understanding and approach to turning ideas into real-world applications.

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