Feature Home *by Edward Cheung, Ph.D*

Edward Cheung's Automated Home

I have enjoyed electronics as a hobby since I was around 7 years old, and started 'automating' my room by stringing cable and installing switches to control my TV, desk lamp, ceiling fan and stereo from my bedside. Later, when I purchased my first home in 1991 I discovered X-10.

Initially, I just plugged in a few modules and control boxes, but after receiving many catalogs on the X-10 line, I found out about the TW523 X-10 Powerline Interface in '92. Things just took off from there.

One of my office collegues had an old PC Jr. that he was getting rid of, and I bought it for $40. The TW523 had some software on a disk, and I was totally floored when it ran on the Jr. (I called it the 'Junior'). I was soon thereafter writing my own programs in C to 'bit-bang' the TW523. The Jr was nice in that it had a cordless IR keyboard (allowing me to control it from across the room) and it had video out (which I piped around the house). Initially the program just displayed the house status and allowed the mapping of one X-10 address to another so I could control devices across house codes. I soon realized however that the power of a home automation system was limited by the type and amount of I/O (Input / Output) available. In other words, this home automation program could not react to other real world events such as the motion sensors, telephone or other devices that are part of the average home.

The First Control Center - A PC Jr.

First Control Center

That is when I purchased a parallel I/O port for the Jr, and built hardware to flash an infrared LED and interface to the phone line. With this modest addition, I could now control the entire Audio/Video system and get commands from touch tones on the phone line. One of the nicest features was that I programmed the system to mute the A/V system when there was an incoming call. My friends were amazed that little Jr. could do all that.

"A truly automated home is one where you don't even have to touch the switches because the home has anticipated your needs."

After reading all the home automation magazines and becoming active in the comp.home.automation newsgroup, I realized that there were even nicer systems out there and I started to design the next generation system. I liked the design of HCS II with its RS/EIA485 networked nodes. This is a 2-wire multidrop network, meaning that two wires connect all the components together. In addition, around that time the PIC processor from Microchip was making a big splash (I had been longing to get into programming microprocessors, and realized that this was a great opportunity). I decided to make these two items cornerstones of my new system. Having a purely serial interface is nice because this allows me to control the system with almost any computer. Every PC I own (including my palmtop) has a serial port. In addition, it allowed the program to

The Next Generation - 'Node O'

perhaps be run from non-PC computers such as my Mac.

The Next Generation

To be powerful, this system must be able to have sensing and control over almost the entire home. I recognized that I wanted to jump from merely remote-controlling the home to actual home automation. Product lines like X-10 serve only to allow control of your home from a convenient location. They do not actually fulfill the promise of automating the home. A truly automated home is one where you don't even have to touch the switches because the home has anticipated your needs. In order to be able to do this, the home control computer must have enough sensors and information about the home status so that it can tell what you may want next.

"I recognized that I wanted to jump from merely remote-controlling the home to actual home automation"

Of course what I have just described is the ideal. I may never get close to that, but the first requirement is a home control system that has a large amount of information at its disposal. The backbone of the system is the RS/EIA485 network using a simple protocol that is similar to HCSII's. I call this network simply 'the home automation network'. The main computer is the master node and talks to the other units that hang off to the side. They reply only when the master speaks to them directly. Note that the home automation network is not to be confused with the home computer network. The latter is the 10BaseT network installed in my home.

The First Node - Node 0

My first goal was to build one box that replaced the hodge-podge of hardware that I had on the Jr. It would all be accessible via a high level serial interface. Since it would be the home automation computer's interface to the rest of the network, I called it my 'Node 0'. In the end, these are the features of the resulting box:

- **X-10 Interface.** All critical timing handled by the Node 0 microprocessor.
- **Infra Red Interface.** The Sony protocol is built-in to facilitate hight-level commands.
- **LCD Panel.** The home automation computer can display a message on the front panel display.
- **RS/EIA485 Interface**. Future nodes connect to this port.

Node 0 was actually quite an achievement. The micro runs at the maximum 20Mhz and includes a mini real-time operating system to interleave four timing critical and two non-timing critical tasks. Very little processor free time exists on this node. Note that I was *not* able to include the phone interface to this node. It would have to be its own future node.

The Phone Node

The second node I built was the phone node. Using a PIC Processor again, I based it around the box I built for the Jr. This new unit has the following features:

- **DTMF Input.** It can decode the tones into a key.
- **DTMF Output.** It can generate the tone associated with a key.
- **Caller ID Input.** Using ITU Tech's module, it decodes the Caller-ID string during first incoming rings.
- **Voice Output.** The home automation computer sends a string to the unit, and the text to speech subunit speaks it into the amplified speaker or phone line.
- **Hook Status Detect**. Detects if the attached phone line has been taken off hook.
- **Line Seize.** Takes the attached phone line off hook to make a call with the DTMF output function.

With this set of features the Phone Node could detect incoming calls, know who was calling and even answer the phone by taking the line off hook and speaking into it. It could also place calls and take DTMF commands.

Sentry Node

This was a critical node that needed to be fault-tolerant. I did not want the home to be left unprotected because of a crash of the microprocessor. For this reason I built a simple discrete hardware circuit that trips the system when the system is armed and there is a zone violation. This discrete circuit is overriden by a watchdog that is 'pinged' regularly by the Sentry Node Microprocessor. As long as the Micro is alive and well, the hardware circuit does not intervene. However if the micro hangs, the discrete circuit takes over the sentry duties. With this handshaking in place I am free to implement some high level features in the Sentry Node Microprocessor. These are the features:

- Does not need the main home automation computer to perform sentry duties. If the home automation network goes down, protection is not affected.
- Reports the status of arm/disarm and status of zone sensors.
- Uses hardwire sensors to some windows, all doors, motion sensors on all levels, garage doors and glass break sensors.
- Opening one of the exterior doors results in a set number of 'ping' sounds by the hardware pinger. This way we can immediately tell that a door has been opened, and which door.
- Can selectively arm zones under main computer control.
- With the help of the home automation computer, door openings while dark will cause a nearby exterior light to turn on. In addition, motion inside the home while it is dark (no interior lights on and night time) will cause lights to come on for a few minutes.
- Has 'grace period' feature. This is where motion in the bedroom zones will disable protection in the downstairs zones for a set amount of time. In this manner, we can get up and temporarily roam around the home without disarming the system. If only two minutes of grace period are left, the Sentry Node starts pinging every time there is a motion sensor trip. After the grace period has expired and there is a motion sensor violation downstairs, the system goes into an alarm state.

The last two listed features make for a more livable intelligent home. Whether or not the alarm is armed, I can get up from my bed and go downstairs. When I get halfway down the stairs, the first downstairs motion sensor picks me up, and lights the way to where I go. After a

few minutes, the downstairs lights reset. I can also send an 'All Unit Off' to downstairs and the lights and sensor action resets.

Weather Node

The Weather Sensor pod is on the roof. I recognized early on that this node could be a hazard to the rest of the system. This hazard is lightning! The Weather Node actually contains two microprocessors. One is in the sensor pod on the roof, and the other is in the base unit that has the weather display and home automation network interface. They are connected together by a length of fiber optic cable for lightning strike isolation. Implementation of the latter is simple as the communication link is only one-way from the sensor pod. Normally, when two processors exchange data via a serial link, a driver is placed at the transmitter, and a receiver at the reception end. In the case of the fiber link, the transmitter is an LED, and the receiver a photodiode with a pull-up resistor.

The optical components are molded in special fiber friendly form, and the fiber is fastened to them. As far as wired connections to the sensor pod and how to protect them, there is only one pair supplying low voltage power to the pod. It would be very difficult to break this connection (possible with batteries, solar cells etc), but I decided that it was perhaps not worth it. My priority was protecting the home automation network and the main computer. The following weather parameters are collected:

- **Inside Temperature**
- **Inside Humidity**
- **Barometric Pressure**
- **Outside Temperature**
- **Outside Humidity**
- **Wind Speed**
- **Wind Direction**
- **Rainfall**

The node on the outside is inside the sensor pod on the roof, which was itself home-built from PVC tubing. The node on the inside (which has the home automation network interface) has a large one inch four-digit display to show the data from one of the selected parameters. In addition there is a sixteen character LCD display to show the name of the parameter (such as wind speed etc) and a button to allow the user to select which parameter to view. Due to the large bright display, the quantity is viewable across the room. The main control node graphs a 24 hour

The Weather Sensor Pod

history of all sampled parameters and derives two additional. They are the peak wind speed and the dew point. When the graphical history is recalled from any day, the mouse can position a cursor on the chart to recall the exact quantity of the parameter along with the corresponding time. Thus the height of a peak can be precisely determined. The system stores weather data for up to one year back.

Being able to recall weather data that has been collected over the past 24 hours is a feature I really like. I can sometimes tell by the plots that a storm is coming (barometer drops), when the front is here (temp drops), when the rain has arrived (wind picks up and rain fall registers) and if the storm is passing to the north or south of us (the way the wind direction trends due to CCW circulation of wind around the low).

Future Nodes

No, these are not network nodes that can predict the future, but nodes that I plan to build next. They are:

• **Thermostat node.** Allows me to control the mode and set point of the two HVAC systems in my home. One decision is if and how to have slave temp sensors and how to communicate with them. I can use the home automation network, but a separate wiring network would provide fault tolerance in case the main network goes down.

• **Power monitor node.** Ideally I would know how much each circuit and outlet is consuming, but this would require a tremendous amount of hardware. I will settle for the ability to monitor the overall energy consumption of my home. The remaining decision is how to detect the consumption. I could use a current transformer at the main breaker panel, or an optical sensor to detect the movement of the utility's power meter outside my house. The latter is the preferred solution since that data will correlate closely with my power bill.

Other Components

In addition to the nodes that form the core of my home automation network, there are other components that I feel add to an intelligent home.

• **Motorized Window Treatments.** The window blinds in my two-story family room are remote controllable. This is done by two home-built motors and by combining the pull cords of eight blinds into two. It is an impressive sight to see them all open or close.

• **Voice Control.** Using HAL2000, an open 'flyswatter' PZM mike, and a mike preamp, I can control the system by voice with continuous speech. From across the room, commands can be received if spoken loudly. Since my home is very open and shell-like, I can control the system by voice from a large portion of the home.

• **Garden Irrigation System.** Irrigation is broken up into five zones that are controllable by the home control system. Because of the risks of a false trigger, the irrigation system sends an X-10 command when it turns a zone on. If the home control system sees this occurring without a valid reason, the system is shut off. This has not failed to detect a false turn-on to this date.

• **Whole-House Audio/Video System and CCTV Cameras**. Video sources are modulated onto unused TV channels so any TV in the home can access the VCRs, surveillance cameras and home automation computer screen by using their remote control. It really adds to a unified house to be able to change the channel to see the HA computer, and pick up a phone to control the system and see the immediate results. Before I go to sleep I usually look around the house for lights left on, these can then be turned off from my bedside.

• **Infra Red relay.** The Audio / Video system can be controlled by infra red remote from the Master Bedroom, First floor and Rec room via this system. I can thus watch a movie playing on one of the system VCRs and control it from the Master Bedroom.

• **No-Hum Fan Controller.** Allows X-10 control of a ceiling fan with none of the annoying hum that is associated with the X-10 fan controllers.

• **The Central Vacuum System.** A powerful system with no filter, weight and power constraints and that ejects the dust out of the house.

• **The Whole-House Blocker/X-10 firewall.** Isolates the home from outside X-10 traffic and couples the two phases.

• **Wristwatch Controller.** My watch that controls the Audio/Video system and sends X-10 commands from anywhere there is IR Relay coverage.

• **Home Wiring and Computer Network.** Access to the home computer network is available from many rooms in the home. I can share files with another PC, use a remote printer, and access the internet (via the modem and proxy server on the home automation PC) all with one 10Base-T connection to the hub in the wiring closet.

"There is also an incoming call screening system that has virtually stopped telemarketers from disturbing us."

• **Telephone System.** A commercial key system that allows me to talk to anyone in any room of the home without them having to lift a finger. No more shouting around the house to find others. There is also an incoming call screening system built in that has virtually stopped all telemarketers from disturbing us. This latter feature is one that my wife **really** likes.

• **PCS SceneMaster** (future addition). This item was won from the *Home Automator Magazine* contest for best web site and will be installed in the central location from where four main downstairs light sets are controlled. Due to the open, shell-like construction of the home, this will provide good coordination of lighting. In the future, when motion sensors turn the lights on, a dramatic path will be lit as they cascade on.

The HA Computer

The home automation computer display (see below). Custom software on the home automation computer written in C++ puts it all together. The interface is a GUI with sizeable, moveable and multiple windows. On the left in the image above is the home control window. Right clicking on a unit turns it off, and left clicking turns it on. Not shown are the other home levels because of lack of screen space. Having the screen be readable from any TV in the house placed a restriction on usable resolution. The top right window is the event window, and system messages scroll from the bottom. In the bottom right is the weather window showing the current environmental status. In the top right line the current house mode is shown. Modes set the overall behavior of the home control software. By having centrallized control, conditions observed by sensors can now trigger actions to make the home more livable. Here are some of the features:

• Motion sensors trigger lighting when needed (as described in the Sentry node section).

• Nightfall triggers prechosen lighting.

• When the alarm is armed, and it is night, random lighting events are fired off to make the house look lived in.

• When the alarm is armed, and it is near bed time, and the garage door is

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The Home Automation Computer's Display

Equipment List
Edward Cheung's Automated Home

Main Automation Closet
- 200Mhz Pentium Wintel unit
- HAL2000 Voice Command software
- Home control software (home built)
- Radio Shack PZM Microphone
- Tandy microphone preamp
- CP290 X-10 Controller
- Cordless Mouse
- Tripp-Lite 420VA UPS
- Security System (home built)
- Z-World Microcontroller (for security system)
- Node 0 unit (home built)
- Phone and voice node (home built)

Wiring Closet
- BBS telephone unit (phone hub)
- 8 port 10Base-T hub (computer hub)
- Radio Shack Video Distribution box (TV hub)
- Type 66 punchdown blocks with integral RJ11 jacks
- ACT CP303 whole-house blocker and coupler

Audio Video Center
- Sony 32" XBR TV
- Sony Hi-Fi VCR
- Sony standard VCR
- Sony CD player
- Sony Cassette player
- Sony Surround Sound receiver
- Technics tower speakers
- Radio Shack satellite speakers
- Floor mount woofer w/200W amp (home built)
- Radio Shack video distribution unit

Misc. Equipment
- Approximately 70 X-10 receivers
- Approximately 10 X-10 table top transmitters
- PCS Scenemaster (handles four loads)
- Weather node (home built)
- Five key telephones and 7 standard phones
- Integrated fax and answering machine
- Rabbit video distribution unit (for IR relay only)
- Front door video camera
- Baby room camera
- Child room camera
- TV for master bedroom, rec room and master bath
- Casio CMD-40B learning remote watch
- Vacu-Maid central vac system
- Dual window motor units (home built)
- Five solenoid water valves with power supply
- Fan motor speed control (home built)

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left open, the X-10 beeper is sounded to remind the user to close it.
- Faxes with the event log (includes X-10 traffic, calls received, motion sensor events, and weather summary) can be sent to a programmable number at a programmable time.
- X-10 commands are 'remapped' to others, allowing macros where one button push triggers other events such as IR commands, or spoken words. This allows the setting of 'scenes'.
- Upon sunrise, an 'All Lights Off' is sent to all house codes.
- Motion detected outside the home causes a light to turn on (if it is at night) and a chime to sound inside the house.
- Commands to a certain house code are combined pair-wise so that the entire house can be addressed. This allows controllers with a limited number of buttons (mini controllers, wrist watch, telephones) to control the whole house.
- Messages can be sent to my pager by the home control system.
- High level of phone access. The system can be controlled by any touch tone phone in the world. The caller can control any device and can arm and disarm the system as well as control the automatic fax setup. The text-to-speech subunit gives voice prompts for help.

Future Plans & Projects

I still haven't achieved my goal of not having to push buttons. We still use control buttons when we go to bed at night. I haven't yet found a signal based on available sensors that the home automation system can use that will allow it to detect that scenario.

There are many more features available with the current setup, but have not been implemented in software:
- The key telephones have speakers that can be used for paging. The Phone node could make a call to the phone system and announce a message around the house by injecting the text to speech output into the paging speakers of the system phones. Information such as Caller-ID could be announced over the phones.
- Sufficient rainfall could inhibit irrigation.
- More extensive use of voice control.
- Control of the HVAC system based on weather conditions.
- Incoming call automatically shuts off the central vacuum or mutes the TV or Audio system. This has been difficult to implement as there are now numerous phone system extensions inside.
- One enhancement that I have been thinking about is control of the system by web. I have started learning Java to see if this type of control is feasible. One alternative is using a CP290 control program such as Xpress which has a web server built into it.

Conclusion

I hope you will also visit my web site. It has won several awards for its home automation content, and contains more information on the components that I have described here. By hand-building the system I have not only saved some money, and made the trip educational, but I have also built a system that can easily be extended and changed. To go to my web site, go to http://automated.home.ml.org

About the author

The author graduated with a Ph.D. in Electrical Engineering from Yale in 1991, and currently works for the Hubble Space Telescope (HST) Project at the NASA Goddard Space Flight Center in Greenbelt, MD. Most recently he test flew some instruments destined for HST on STS-95, which was Senator John Glenn's return to space flight. He can be reached at edward.b.cheung.1@gsfc.nasa.gov.