Session 1532

"Smart Pallet" Design using Optoelectronics and Programmable Microcontrollers

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Introduction:

The project goal was to design and implement a cost effective and autonomous product transport device capable of functioning in an automated assembly line manufacturing environment. All the information necessary for the automated assembly of a finished product accompanies the product through the manufacturing process. Specific assembly information is communicated from the device to each assembly workstation using a specialized wireless infrared system with a programmable microcontroller. This proof-of-concept project was one of several components in a Manufacturing Engineering Technology senior capstone course. The resulting device was given the name "Smart Pallet" by Dr. Wesley Baldwin who also presented the original concept for the project.

Background:

The operating environment for this project is a student constructed computer integrated manufacturing (CIM) laboratory. A 15 foot by 6 foot oval assembly line track is the central component in the CIM laboratory. Assembly workstations are positioned at several points around the outside perimeter of the assembly line track. In addition, GE Fanuc PLC's, Mitsubishi Movemaster robots, and IBM class personal computers.

When the services of a workstation are needed, stop pins in front of the assembly workstation are triggered halting the movement of the pallet. Another set of pins are then activated lifting the pallet off the assembly track. Next a transport arm extends under the pallet, the pallet is lowered onto the arm, then the arm and pallet are retracted to the workstation assembly position. When the workstation assembly process is complete, the sequence is reversed placing the smart pallet back on the assembly line track.

Historically students in the Manufacturing Engineering Technology (MET) capstone course are charged with enhancing, replacing and/or adding one or more major features in the CIM laboratory. Student activities can include everything from fabricating machine parts to bit level programming of microcontrollers. Students are assigned to project teams, inter-team and intra-team communications are stressed as absolutely critical for the success of the course project. Typically each student is required to maintain a chronological activity journal, and each team submits a detailed operational manual for their task. All class members participate in a formal project presentation to departmental faculty at the end of the term.

The following general project requirements were given to the students:

- Move all of the product assembly requirement instructions onto the physical pallet.
- Implement an inexpensive wireless communication system for the pallet and assembly workstation interface.
- Implement two workstations, a start/stop workstation and a product loading workstation.
- Report real time process status, errors and exceptions. Provide 'hooks' for future batch summary reporting.
- Changes made to the CIM laboratory must take into consideration future projects.

<u>The "smart pallet":</u>

The "smart pallet" has the approximate dimensions of 10" x 10" x 2" and is comprised of two main working sections mounted on a ¼ inch steel base. The working sections of the pallets were completely redesigned for this project. The "cup holder" section was machined from an aluminum block to hold one of three types of plastic cup. The "microcontroller" section was designed to hold and protect the microcontroller circuit board. Adjacent to the microcontroller section is a small mount point for the infrared emitter/detector circuit board.

Figure 1: Smart Pallet
- IR emitter/detector (top)
- microcontroller (middle)
- Cup holder (bottom)

The cup holder was manufactured within the department. It was designed to hold one of three types of plastic cups, round, square or rectangular. These three types of plastic cups are thought of as the base or frame of a general product upon which additional parts will be added. The cup holder section incorporates a cup type detector. The detector is designed to confirm the type of cup placed into the holder. Several design concepts were scrutinized for the detector function; proximity switches, contact switches, optical beam break switches.

The first design choice for the cup detector function was an infrared, distance measuring circuit. Each type (round, square or rectangular) of plastic cup is positioned at a different distance from the base of the aluminum holder. The microcontroller is capable of performing an infrared frequency sweep which can then be used to calculate the distance from the base of the cup holder to the bottom of a particular cup, hence confirming the type of cup placed in the holder. Regrettably the available infrared components were not sensitive enough to discriminate the small distance that was needed. A search yielded several suitable commercially available infrared products but these all proved to be beyond our budget limit.

The second design choice for the cup detector was relatively simple; a photoresistor paired with a 5mm white LED. This design proved to be much more effective than originally anticipated and well within our budget. A 3/8 inch hole was drilled in the center of the cup holder's base, and the photoresistor and LED were placed in this opening facing upward. The circuit for the two components was then incorporated with the other microcontroller circuitry. Microcontroller program code was created to recognize the different types of plastic cups based on the voltage level in the LED/photoresistor sub-circuit.

To simplify the programming of the microcontroller, each smart pallet was hardwired with a unique binary identification number. Four input lines to the microcontroller were dedicated to provide a pallet identification address from 1 to 15. Address zero was excluded as a valid address to avoid confusion with unmodified pallets during testing.

<u>The "Programming workstation":</u>

The programming workstation is the logical starting point for the assembly line process. This workstation consists of a microcontroller board in a protective housing, an infrared emitter/detector circuit board and a moderately powered personal computer. Physically this was the simplest workstation; however from the programming perspective, it is the most complex. Since the microcontroller does not have a direct human interface, a serially attached personal computer is used for this purpose. The operating premise at this point is that information about a "customer order" is obtained and downloaded to the programming workstation microcontroller. After the customer order information is obtained, the programming workstation attempts to locate an available smart pallet on the assembly line using infrared communications. When a free smart pallet is located, the programming workstation transmits the customer order information to the pallet. A slightly more powerful microcontroller is needed for the programming workstation when compared to the smart pallet due to the extensive human interface requirements. After a newly programmed smart pallet is released to the assembly line, the programming process starts over for the next customer order.

The programming workstation is also the logical end for the assembly process in this system. After the assembly process has been completed for particular smart pallet it will stop at the programming station. At this point it transmits several statistics and the overall status of the assembly process to the programming station for later reporting.

<u>The "Loading workstation":</u>

The loading workstation is the most physically complex in the system. This workstation's function is to load a specific number and combination of white and/or blue marbles into the plastic cup on the smart pallet based on instructions downloaded at the programming station. The workstation consists of a microcontroller board in a protective housing, an infrared emitter/detector circuit board, a 2 line by 16 character LCD panel and nine connections to solid-state relays that control pneumatic actuators. Additionally, switches were installed in a manual control box to facilitate testing of each pneumatic actuator in isolation.

The smart pallet communicating by means of the infrared emitter/detector circuit initiates a request for loading services. If the loading station is available, it acknowledges the request for service and deploys the pallet stop pin on the assembly line. Next the pallet lifting pins are activated, the transfer arm is extended, the pallet lifting pins are then deactivated and the smart pallet is moved to the assembly position. Once the smart pallet is in the assembly position, the microcontroller issues the appropriate commands to load the required quantity and type of marbles into the cup. When the marble loading is complete, the microcontroller issues the commands needed to return the loaded smart pallet back to the assembly line. Synchronizing the microcontroller commands with the mechanical devices at this workstation proved challenging.

The Microcontrollers:

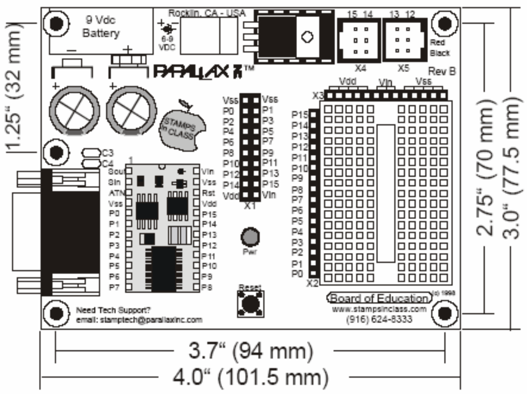

Figure 2: Board Of Education

The Parallax Board of Education[3] (BOE), Basic Stamp 2 (BS2) and Basic Stamp 2e (BS2e) were selected for this project. The cost, flexibility and availability were the primary considerations when selecting these products. The Board of Education revision B circuit board was used for all stations. The BOE has a small footprint, its voltage regulation system provides two options for power, a 9 volt battery used with the smart pallet and an AC transformer used with the programming and assembly workstations.

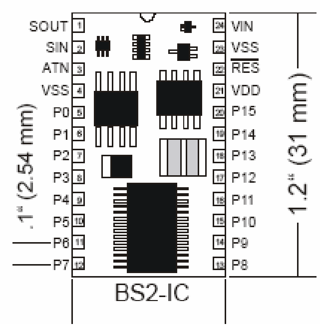

Figure 3: Basic Stamp 2

The plain Basic Stamp 2[6] microcontroller selected for the smart pallet executes approximately 4,000 instructions per second, and has a 2048 byte EEPROM, 26 bytes of usable RAM and 16 ports that can be dynamically configured for input or output functions under program control. Processing requirements for the prototype smart pallet were focused on communications, data storage and quality control functions. The plain BS2 microcontroller provided adequate performance and functionality for smart pallet. Future enhancements to the smart pallet will probably require a more powerful version of the BS2 microcontroller.

The more powerful Basic Stamp 2e[6] was required for the programming workstation. The BS2e retains all the functionality of the plain BS2 but provides seven additional 2048 byte slots or banks of EEPROM space for program and data storage. The BS2e can only execute in one 2048 byte slot at a time, but the BS2e microcontroller can dynamically jump to and begin executing a program in any slot after initially starting in slot zero. Switching between the EEPROM slots on the BS2e is similar to calling a subprogram in other languages systems. Due to the extensive use of program literals in the human interface, the code on the programming workstation quickly exhausted the single 2048 byte EEPROM space of the plain BS2. The functions of the programming workstation were divided into five sub-functions. Each sub-function was then loaded into a separate BS2e program slot. Using the BS2e program slots provided adequate space for each sub-function and leaves three slots available for future expansion.

The relatively diverse processing requirements for the loading workstation were satisfied by a plain BS2 microcontroller. The primary requirements for this workstation included IR communications with the smart pallet and interfacing to the mechanical devices attached to the workstation. The human interface at this workstation used a 2 by 16 character LCD panel to display processing status messages. This display only type interface kept the EEPROM space requirements within the 2048 byte limit of the plain BS2 microcontroller. Microcontroller speed was not an issue at this workstation, due primarily to the response time of the mechanical devices it controlled. The microcontroller command execution speed is extremely fast when compared to the response time of the attached mechanical devices.

The Infrared Emitter/Detector:

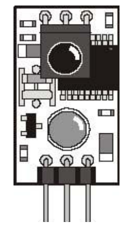

Figure 4a: IR Buddy

The IR emitter/detector is a small (1” by ½”) three-pin board that communicates serially with the Basic Stamp. This device is marketed by Parallax, Inc. under the trade name IR Buddy[1]. The IR Buddy employs the Phillips RC-5 protocol to transmit and receive IR signals. The RC-5 protocol is commonly used with consumer electronics. The IR Buddy requires only one bi-directional serial I/O connection to the BS2 or BS2e microcontrollers. Despite the fact that the smart pallet was moving relative to the assembly workstations, the IR Buddy proved to be very reliable in maintaining bi-directional communications with the workstations.

Figure 4b: IR Buddy

This project uses the buffered “8-byte data packet” operating mode of the IR Buddy. Data is transferred in structured 8-byte packets. The first byte of the packet is for identification. Bytes two through seven are for commands and assembly instruction codes. Byte eight in the packet is a parity byte used to verify the accuracy of the packet transmission. Simply put, the IR Buddy circuitry handles the low level processing required for the synchronization and buffering of infrared signals to and from the IR Buddy device. The use of a less powerful central microcontroller was made possible in large part by off loading the majority of the low level infrared communication tasks to the IR Buddy sub-processor.

The Cup Type Detector Sub-System:

The cup type detection sub-system was implemented for quality control purposes. The actual type of cup loaded onto then smart pallet is compared to the type of cup requested at the programming workstation. A 5mm white LED, photoresistor and an 8-bit analog to digital converter (ADC0831) combined with microcontroller program code make-up the cup detection sub-system. The cup detection sub-system has two functional modes; teach mode and normal operating mode. A small slide switch on the smart pallet is used to toggle between the functional modes. The smart pallet must successfully complete the teach mode processing before it can be placed into operating mode.

In the teach mode, a cup is placed in the cup holder. The white LED is activated, the voltage level across the photoresistor is input to the analog to digital converter and the resulting digital output value is stored in RAM. Three measurements using different cups of the same type are taken and the average value is computed. This process is repeated for each type cup for a total of nine measurements. The average digital values representing each type of cup are written to upper memory locations in the EEPROM.

An LED on the smart pallet is programmed to assist the operator while taking measurements. The LED begins to flash slowly indicating to the operator that a measurement is about to be taken and that a cup should be placed in the cup holder. The LED is steady on while a measurement is being taken, the LED is then turned off when the measurement is complete. The operator removes the cup and prepares to repeat the measurement cycle for the remaining cups. After all the cup types have been processed, a unique value is written to an upper memory location that acts as a completion flag for the teach mode processing. At the end of the teach mode processing four values have been written to EEPROM upper memory locations, three values representing the different cup types and one value representing the teach mode processing completion flag.

In the normal operating mode, when an unconfirmed type of cup is placed in the cup holder a voltage measurement is taken. If the measured value is within the tolerance band of one of the cup values previously stored in the EEPROM upper memory, the type of cup in the holder can be confirmed. The type of cup confirmed to be in the holder is now compared to the type cup required for the customer order as entered at the programming workstation. If the correct type of cup has been placed in the cup holder, the smart pallet continues normal processing. Otherwise, a red LED will begin to flash indicating an error and the smart pallet will reject any further processing until the error is corrected.

<u>Observations and benefits:</u>

The smart pallet device developed for this project successfully demonstrates that process control and product assembly information can be imbedded with the product in an automated manufacturing environment. A constant connection to a centralized real-time computer is not required to direct the manufacturing process with the smart pallet system. Further, the smart pallet can independently respond to many error and exception conditions.

Success was also realized from the cost perspective. The total cost of the electronic components for the smart pallet was less than $150.00. Most of the electronic components can easily be recycled reducing the cost of future projects.

Using a smart pallet system does not preclude an interface to a central computer. It does present an alternative to utilize a batch mode interface rather than a time critical real-time computer interface. Consider the following example scenario. Information about multiple customer orders can be assembled into a batch on a central computer system and downloaded as a group to the programming workstation. After the information download is complete, the connection to the central computer can be closed. Then the programming workstation can begin (or continue) to transfer information to smart pallets for independent processing. When the programming workstation approaches the end of its list of unsatisfied customer orders, it can open a connection to the central computer system and request additional customer order information. The batch communication cycle between the central computer system and the programming workstation could range from hours to days or more depending on the type product, business and capacity of the programming workstation.

An early design concern was the ability of the IR Buddy device to establish and maintain a dependable bi-directional communications link while the smart pallet was in motion on the assembly line, fortunately the IR Buddy device proved to be very robust. The most complex aspect of using the IR Buddy device was developing the microcontroller code to coordinate the transfer data between the smart pallet and the workstations. The data transfer procedure is based on the 8-byte data packet mode of the IR Buddy, and as the name implies 8-bytes of data are transferred as a single function. Two data bytes are used for communication control and one to six data bytes are used for the transfer assembly information. The specific details of the microcontroller code are beyond the scope of this paper, but can be accessed on the ITMFG473 cap-stone course web site[2].

The educational benefit of the smart pallet project extended beyond the typical capstone course; consider the following two points:

1) When the smart pallet project began the IR Buddy device had just recently been introduced by Parallax. The only documentation on the IR Buddy was from the vendor and then only illustrated the basic functions of the device. A literature search for other IR Buddy applications failed to produce any useful results. The failed search served as a source of both frustration and motivation for the students. The motivation came when the students realized that the failed literature search implied that they were probably developing a truly new type of processing system using the IR Buddy device.
2) Developing the teach mode procedure for the cup type detector sub-system was a new process for the students. Running the teach procedure was just like many other calibration routines which the students had done many times before. This project required the students to create a calibration routine for an electronic circuit and a process of their own design.

The Future:

The results of this project have made it clear that more complex workstations and smart pallets can be added to the CIM laboratory assembly line. Multicolor cups will be an added option; a microcontroller based polychromatic sensor system is being design for this workstation. The loading station will be upgraded with more complex mechanical systems which will allow additional types of objects to be loaded.

Bluetooth may replace the IR Buddy as the communication method for the smart pallet system. Remote monitoring and control of the CIM laboratory assembly line via the Web may complement or replace the existing on-site control systems. The best enhancement ideas will probably come from the next group of cap-stone course students.

Bibliographic Information:

1. *IR Buddy Demo Kit*, Parallax Inc., Rocklin California, November 2002, Document #28016
2. http://web.bsu.edu/itmfg473
3. *Board of Education Revision B*, Parallax Inc., Rocklin California
4. http://www.parallaxinc.com and http://www.stampsinclass.com
5. Groover, M. P., Automation Production Systems, and Computer-Integrated Manufacturing, Second Edition, Prentice Hall, Upper Saddle River, NJ, 2001
6. *BASIC Stamp ® Programming Manual*, Parallax Inc., Rocklin California, Version 2.0c

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