An Application of IEEE 802.11 and 1490 to a Mobile Shopping Assistant

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Abstract - The constant product shuffle in the retail environment can make shopping and restocking a confusing process. To alleviate this problem, the team created a real time, interactive map display to guide customers and employees through the store. The device is cart-mountable and displays an easy to follow map that will indicate the exact location of any item entered by the user. Items can be entered by either typing them in one at a time or by importing a list of items via plugging in a USB flash drive or importing a user profile over the internet. The interface is an intuitive touch screen control that allows users of any age to easily become accustomed to the device. The device wirelessly accesses a database with location information for each item in the list currently entered into memory. Further information, such as price, nutrition facts, etc., can be accessed via the same connection if required by the user. This enables the customer or employee to quickly and efficiently go about his or her routine.

I. Introduction

This document outlines the definition and execution for the Shopping Kartographer senior capstone project. To fulfill project requirements, the team has set out to simplify the process of shopping and/or working in a retail establishment. The constant product shuffle in the retail environment can make shopping and restocking a bewildering process. The project is aimed at warehouse-style stores where the size and number of products can further complicate navigation. To solve this problem, the team created a real time, interactive map to guide customers and employees through the store. The goal was to build a cart-mountable system that will display an easy to read map that will indicate the exact location of any item entered by the user. Items can be entered by either typing them in one at a time or by importing a list from either a USB flash drive or an online user account. The interface is an intuitive touch screen control that will allow users of any age to easily become accustomed to the device. The device will wirelessly access a database with location information for each item in the list currently entered into memory. Further information, such as price, nutrition facts, etc., can be accessed via the same connection if required by the user. This would enable the customer or employee to quickly and efficiently go about his or her routine.

This report covers the team's goals, requirements, decisions, and results over the course of the project. The beginning sections will explain the team's problem formulation and the design requirements created to solve this problem. The following sections describe the process used to determine the optimal design solution and the timeline used to complete a prototype. Then, the report will detail all engineering decisions made to create a final design. Also, final hardware designs, software flow, and packaging will be discussed. From these designs, a cost analysis, reliability and safety analysis, and social/political/environmental impact will be created. At the end of the report, the team will discuss any conclusions reached and discuss the success of the project. Lastly, a user's manual for the prototype will be included.

As a past Sam's Club employee, team member Justin Kirkland witnessed firsthand the complex nature of a warehouse store. In such a store, there are multitudes of products that are often rotated throughout the building. This product movement can make shopping a complicated and confusing process. The team has decided that this is a need worthy of an engineering solution. In addition, team member Evan Freilich noticed a related problem while working in the retail business. Items at a store are stocked by employees. During this process, employees use a handheld tool to determine product placement. This tool can also be used to determine the number of any items currently in the store's stock. Though helpful, this tool is slow and outdated. This problem also requires a new solution.

II. Project Requirements

1) Create a bill of materials and order/sample all parts needed for the design.
2) Develop a complete, accurate, readable schematic of the design.
3) Complete a layout and etch a printed circuit board.
4) Populate and debug the design on a custom printed circuit board.
5) Package the finished product and demonstrate its functionality.
6) Provide a touchscreen user interface to browse product inventory and add items to shopping list.
7) Device will communicate wirelessly with any given node using the IEEE 802.11 b/g protocol at a distance up to 100 ft.
8) Power device with rechargeable batteries lasting a minimum of 2 hours.
9) Accurately display product information including price, location, and user generated shopping lists as requested by user on an LCD screen.
10) Device is able to be attached to, and detached from, a standard shopping cart within 30 seconds.

III. SYSTEM COMPONENTS

A. Power

The Shopping Kartographer will employs both 3.3V and 5V supplies. The wireless module in use requires a 3.3V supply which will have lower power consumption than comparable 5V devices. USB operation, however, requires a 5V supply. Also, all LCD/Touchscreen devices the team considered require 5V. All 5V devices accept 2.8V (or lower) as a high voltage so will be able to integrate with 3.3V circuitry. For this reason, the team selected a microcontroller powered by 3.3V that can accept 5V inputs. The team considered linear and switching voltage regulators to achieve these voltages. A practice board was created to determine current usage. At a current of 580 mA, the team decided to use a high efficiency linear regulator. Also, a 6-cell 7.4 V battery was used.

B. Microcontroller

The Microchip PIC24FJ64GB108 was chosen for its market availability, memory capacity, and IO expandability. Some of the specific features include:

- 16-bit architecture
- 64K internal flash memory
- 16K RAM
- 64 I/O pines
- Internal 8MHz oscillator
- USB host support
- Internal PLL
- 4 UART – 3 SPI – 3 I2C
- 5 timers
- nanoWatt sleep modes
- 80 pin TQFP
- Free samples

C. LCD

Amulet Technologies has created a versatile LCD module with a built in touchscreen; The Amulet MK-480272C is a 4.3" full color screen with integrated touchscreen and proprietary Amulet operating system. The OS performs all low level functionality as well as some high level user interface tools such as buttons and sliders. Additionally, the MK-480272C has the ability to embed jpeg images into the interface. These modules can operate independently, but have a UART interface for microcontroller integration. The microcontroller plus wireless and USB capabilities will integrate directly with the LCD module's graphical controls. This device offers a user friendly user-interface, adequate hardware integration, and a suitable screen size.

D. Wireless Module

The team required a wireless device with a TCP/IP stack, on-board controller, wireless transceiver, UART communication capabilities, and a well documented data sheet. In short, the Connect One Nano Socket iWiFi met all these requirements. Specifically, this device contains a CPU that runs at 48 MHz, operates at 3.3V, and has a power save mode of 8 mA. The on-board 2dBi antenna facilitates strong signal quality and reliability. UART communication with the microcontroller facilitates queries easily being sent to a database. On-board HTTP protocols make sending SQL queries straightforward, and noTn-volatile on-chip memory allows for default network property storage. Helping simplify the process, an all-inclusive TCP/IP stack keeps connection and usage of network protocols to a few simple commands. All of these features come in one simple, small, and easily adaptable DIP package. Most importantly, extensive and detailed documentation makes device implementation seamless and straightforward.

IV. Hardware Design

The circuits for the Shopping Kartographer consist of three systems placed within two primary units: charging base unit and functional unit. Inside the charging base unit, AC wall power will be transformed, rectified, and then regulated to 12 V within the charging system. This voltage is made available on conductive posts by which each functional unit will be placed for charging its battery.

The functional unit consists of the battery management circuit and the functional circuit. The battery management circuit will take the 12V input and use it to charge the main battery for the portable modules. This circuit contains a Lithium-Ion battery management controller that regulates battery charging. Additionally, power is regulated to 5V before being output to the functional circuit. This circuit contains all the operating components including the microcontroller, LCD, and peripheral connections.

A. Battery Management Circuit

The battery management circuit utilizes diodes for circuit protection by preventing power from flowing backwards. Additionally, the circuit allows power to flow to the device and and charge the battery at the same time. One diode protects the circuit from reverse power input. A second diode works as a bypass of the battery circuit when plugged in. The voltage on the output of the third diode would be too high to drain power from the battery. This ensures that all current through the second resistor is actually going to the battery. Lastly, the third diode also stops current from the input going around the charging circuit and into the battery. This will also cause errors in current measurement from the second resistor. A high efficiency 5V regulator reduces the voltage so it can be used in the main board.

Within the battery management circuit, the BQ2057T circuit manages the battery charging process. The second resistor is used to detect the current into the battery. This resistor is .13 ? so very little power is lost. Charge is turned on and off using the P-Channel MOSFET. Again, very little power is lost at this stage. Finally, the power from the input is stored in the 7.4 V battery. The voltage on the battery is further monitored by the BAT input on the chip. Two scaling resistors are included that allows the battery to charge to its maximum capacity. The status of the circuit can be observed in the two LEDs on the bottom. These LEDs show when the circuit is charging the battery and when charging is complete. Two more resistors are used to disable temperature sensing since the battery in use does not have a built-in thermistor.

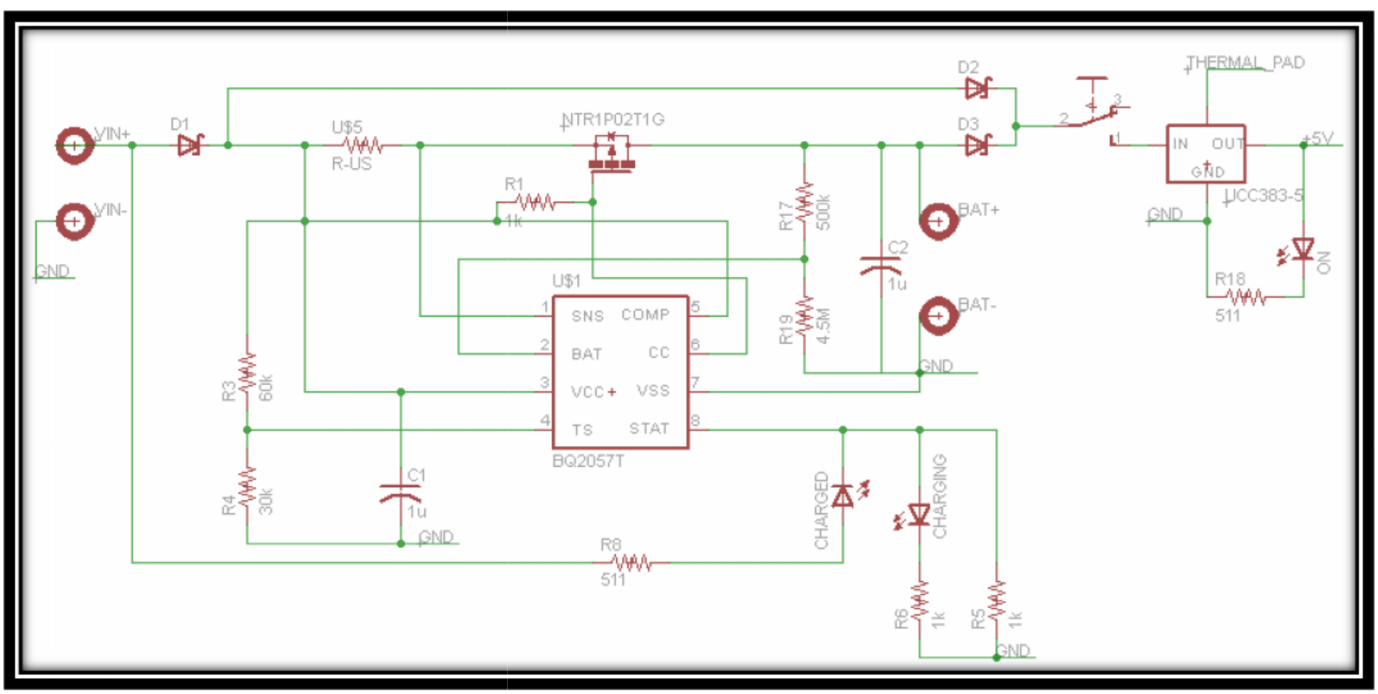

Figure 1: Battery Management Circuit

B. Functional Circuit

The functional circuit was developed using an iterative process with multiple versions and enhancements with each iteration. Four test LED's were included for output and four tactile buttons were included for input to aid in testing and debugging. I/O lines were added for the LCD touchscreen, wireless module, and USB interface. The LCD touchscreen and wireless module utilize a standard UART interface. The LCD touchscreen is a standalone component which contains its own controller to run the user interface. However, for the wireless module, Clear-To-Send and Request-To-Send signals have been connected to provide a more complete interface. This enables the 802.11 b/g communication to happen faster without interrupting a pre-existing operation.

The PIC microcontroller has built in USB functionality. When placed in host mode, the microcontroller can access flash memory to read information. A CMOS switch is included to control power for USB. The microcontroller has the ability to turn on and off the USB port as needed. Since the controller uses 3.3 V and USB uses 5 V, the 3.3 V signal from the controller operates the switch. The switch is connected to 5V which will connect or disconnect power on the high speed USB 2.0 interface.

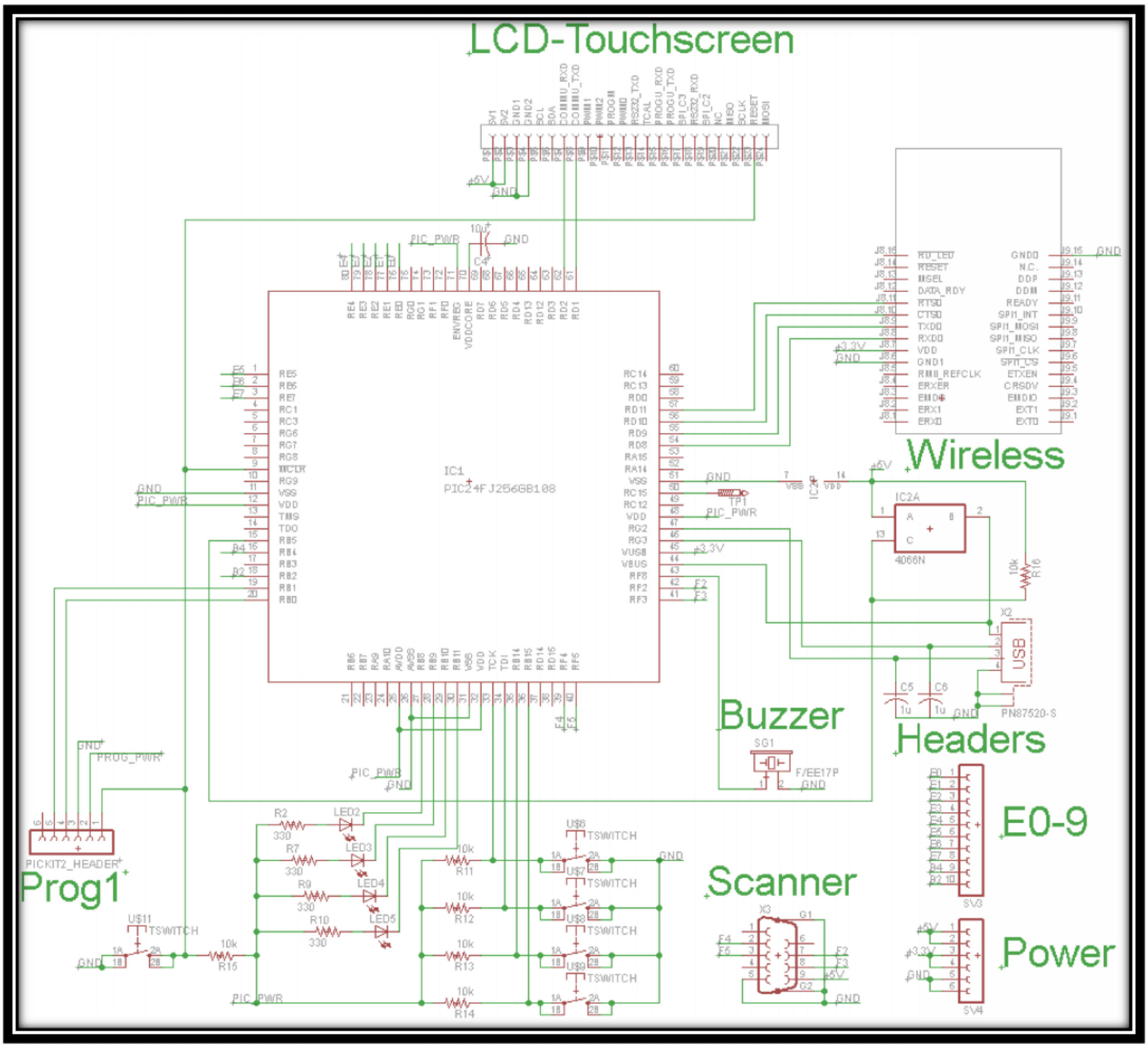

Figure 2: Functional Circuit

C. PCB Design

All circuits were combined into a single circuit board which was ordered through Advanced Circuits. The total area of the board was 58.7 in^2, which is just within the limit of 60 in^2. Placing everything on a single board saved the team $33. Once received, the boards were cut apart and individually fitted to the enclosures. All parts were then soldered in place as testing for those parts commenced. This meant that most of the central components such as the voltage regulators, microcontroller, and battery management were soldered quickly. Peripheral parts and headers were soldered once testing of central components was complete.

These are the two boards and their descriptions:

1) Power Board
   a. 100 mil traces
   b. Thermal pad for 12 V regulator
   c. 3.3 x 4.9 in
2) Main Board
   a. 8 x 4.9 in
   b. Battery Management Circuit
      i. 24 mil isolation
      ii. 24 mil traces
      iii. Ground plane
   c. Functional Circuit
      i. 24 mil isolation
      ii. 24 mil traces where possible
      iii. 12-16 mil traces near microcontroller
      iv. 0.5mm pitch between pins on microcontroller
      v. Ground plane

V. SOFTWARE DESIGN

A. Design Requirements

Between the microcontroller, wireless module, and the LCD, custom firmware is an essential. Without a single unifying language, a protocol had to be established to enable devices to communicate between each other.

In order to give the user a controlled interface, the Shopping Kartographer is coded as a state machine. The main software flow calls a succession of functions based on the user's choice. A custom communication protocol had to be established between each module and the PIC utilizing C language. Additionally, the WiFi module needed to be able to send PHP/SQL commands to the database. Without specializing the input from the database, parsing would have been close to impossible. The LCD had similar needs, where specific bytes are expected at certain instances within the program flow.

B. Functional Overview

The microcontroller oversees the total operation of the state machine. Protocols were established to ensure that data is sent back and forth between devices at expected times. The microcontroller's internal RAM was heavily utilized for data handling while the ROM was comprised mostly of code memory. The microcontroller contained several parsing functions and LCD page controls. All information received from a particular database query is split and parsed into usable data for the LCD. Though the LCD is capable of its own page changing, the majority of page changes are forced by the microcontroller for greater control.

The LCD is used mainly as a communication medium between the user and the device. All user interaction takes place on the touch screen, which converts commands into microcontroller processing data. The LCD has an adequate RAM variable storage buffer. It has 255 byte wide string registers capable of storing null terminated strings necessary for dynamic item data. Displaying item data requires the LCD to constantly be updated. Each screen change that uses a string requires these variables to be cleared and repopulated according to the user's request.

The iWiFi module's transfers data between the microcontroller and database over the 802.11b/g protocol. As item's are changed in the database, the wireless data will deliver a real-time snapshot of inventory without so much as a system restart.

A MySQL database was hosted on an Ubuntu Linux server. Apache was also installed to enable web page hosting for front end and query purposes. Test data was easily uploaded to the database using this web front end. In a professional setting, the customer would provide the database to interface with the wireless module. The front end was coded in PHP, which seamlessly integrated user queries with an easy to use interface. As an added bonus, the WiFi module used PHP queries for information retrieval, making the database not only multifaceted, but incredibly flexible.

C. Communication Protocol

Two separate custom protocols were developed to interface the different modules. For the LCD, state machine flow was controlled by user input. Unless the LCD let the microcontroller know that there was a change, no processing would be able to take place. Therefore, on a button press that invokes a state change, a specific byte is transmitted. For example, initially, the UI could go either to the administrative console, or the user list. If the administrative console is selected, the LCD sends an 'A' to the PIC. The controller then expects either a 0x00 to indicate that the user is inputting a username and password, or a 0x01 for validation. All operation is designed to take the user step-by-step through the process of accomplishing a task, whether that be adding an item to the virtual shopping list, or connecting to a specific SSID with the WiFi module.

In order to minimize the amount of data sent back and forth over the internet, a specialized interface was established between the WiFi module and the database. A PHP page (get.php) was written with specific parameters for the different kinds of queries that the Kartographer would be carrying out. On the high level, there were seven different commands that could be carried out on this particular file. For example, the query "[server]\ get.php?item_name=[item name]" would retrieve all item names matching the name of [item name]. Each of these commands could be handed a different parameter (like [item name]), that would acquire and pass back different types of information.

The information retrieved from the database had to be split into different pieces in order to be displayed for the user. To facilitate this process, specific tokens were used to delimit the queries. The '@' symbol, for example, indicated the beginning of the data stream. The WiFi module included extra information before and after each query. In order to minimize the work done by the parsing functions, it was easier to isolate the particular data being received than to try to sort through each piece individually. A semicolon (';') was used to indicate the end of the data stream. Each particular query could have had one or more tuples. These were separated by an open bracket ('{') symbol. Other times, there were separate columns retrieved within a single tuple. Column separators were question marks ('?').

VI. Application of IEEE Standards

A. IEEE 802.11[1]

The need for centralized, easily accessible data in the grocery store environment lead to the need for a pre-established, widespread solution for communication between electronics devices. As a wired system was not feasible for this project, the clearest choice for such an implementation is the IEEE 802.11 standard. This standard's simplicity of use was the primary selling point for the Kartographer project. Though there were other potential alternatives, the widespread acceptance of WiFi has allowed for it to be easily established in any business. If a business were lacking in the possession of an 802.11 network, the simplicity and low cost of implementation makes the Kartographer a very portable product.

Integration of the above mentioned Nano Socket iWiFi module facilitated rapid prototyping, inclusion, and deployment of the Kartographer prototype with the 802.11 standard. Due to the iWiFi's modular design, the team avoided the costly research and development required to create this sub-system and instead focused on its use. The DIP pin layout allowed for simple through-hole mounting and an almost "plug-and-play" end-user functionality.

With the ease-of-use provided by the iWiFi module, most of the work involving the use of the 802.11 standard was in software. Querying and connecting to local WiFi networks was as simple as giving the module a command to do so. Seamless integration of WEP or WPA encryption allowed for these to be used to protect the private data of the end-user. A PHP interface kept data transfer light-weight. Text-based queries were formulated based on customer input and submitted to a listening Apache server. Resulting data was then transmitted back, read in from the iWiFi module, and parsed into the user interface. In this way, the Kartographer could be prototyped and tested using a local ad-hoc network or a true centralized WiFi network.

B. IEEE 1490[2]

The team designed and implemented a hardware and software system that was carefully governed by the principles of project management. Initially the team went through the Scope Management where we defined the processes to complete the project successfully. Once the scope was defined and these processes were in place we used "One Page Project Manager" tracking tool to help us manage time and cost. Every week "one page project manager" was submitted to faculty including a summary and forecast of the project milestones. Communicating this to faculty on a weekly basis kept them up to date on project progress.

Applicable Knowledge Areas from IEEE Standard 1490:

1) Integration Management
2) Scope Management
3) Time Management
4) Cost Management
5) Quality Management
6) Communication Management
7) Risk Management

VII. Conclusion

The Shopping Kartographer demonstrates the successful integration of a microcontroller with its peripherals, including communication with an external database over the IEEE 802.11 protocol. Project management throughout the project adhered to the IEEE 1490 standard with an emphasis in integration and time management.

Acknowledgment

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References

[1] *IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements*, 802.11, 1999.

[2] *A Guide to the Project Management Body of Knowledge*, 1490, 2003.