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Hardware Chron:
A Hardware Implementation
Of the Cron Scheduling System Software

As a Partial Fulfillment of the Requirements for
EE 188 - Computer Architecture and Organization

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Table of Contents

Abstract	3	+--Algorithm and Process Flow	18
Acknowledgement	4	4--Read and Write for AT24C16 EEPROM	18
Introduction	5	+++Read and Write time from RTC Clock	19
Related Literature	7	+++The PC Interface	19
Scope and Limitation	10	+++General Outline of the Algorithm	20
Methodology	11	+++USB Implementation	21
+--Design of Scheduling Method	11	+--Method of Operation	23
+--Development Environment	12	+--Parts of the Device	23
+++Firmware	12	+--Parts of the Software	24
+++Software	13	+--Schedule Entry Designer	25
+++Hardware	14	+--Device Usage	26
+--Hardware Components	15	Results and Discussions	27
+++Microcontroller	15	+--Cost Summary	28
+++Real-time Clock	15	Conclusion and Recommendations	29
+++EEPROM	15		
+--Memory Organization	17		
Appendix A			
Simple design of the Scheduler Entry			30
Appendix B			
Example Partial Chron Entries			31
Appendix C			
A screen shot taken from a portion of the data sheet specification.			32
Appendix D			
A page taken from the DS1307 Real Time Clock IC Data Sheet			33
Appendix E			
A portion of the AT24C16's Data sheet Specification			34
Appendix F			
Device Addressing			35
Write Operations			35
Read Operations			36
Device Addressing Figures			37
Byte Write			37
Page Write			37
Current Address Read			38
Random Read			38
Sequential Read			38
Appendix G			
The Byte Level Read and Write Method in MikroC			39
Appendix H			
Real-time clock Memory Organization			39
Time Keeper Registers			40
Real-time Clock Device Addressing			41
Appendix J			
MikroC Code for Reading and Writing Time to DS1307			42

Abstract

This study focuses on the implementation of the famous Cron software for scheduling automation in UNIX and Linux systems to actual hardware implementation in scheduling on and off switching of actual hardware devices. The use of the Cron specification is the most unique characteristic of this research as it is the first time it is going to be used for hardware application for purposes of automation.

Acknowledgement

The Proponents of this project would like to thank the Heavenly Father for giving us the opportunity to work with this project and giving us the strength, time and knowledge to fulfill our duties. Much gratitude is also due to our instructor Sir Jabian, Marven for giving us time and chances in hopes of completing this project. Finally to our parents who helped fund the early development phase of this project and for always helping us in all matters that need may arise.

Also, our gratitude goes to the open source community at GitHub who have already made significant effort in establishing a few basic technologies that have been the corner stone of some of the components of our project. Special thanks to mikeobrien of Github for opensourcing his work on Hid Library for C# on Windows. Also special thanks to hanshuebner of Github for opensourcing his work in Hid Library for NodeJS. Thank you to everyone whose initial work and effort has been very instrumental to the completion of this project.

Introduction

Automation has always been a very important thing in a wide array of industries. Automation reduces labor cost, increases efficiency and increases overall revenue for certain companies. Depending on the type and cost of operation, automation systems will vary in performance and reliability.

Several automation systems are also implemented for security, safety, efficient energy usage and home use. Some of these may include closing doors during midnight, and opening them during the day, and some may even include opening valves in water stations at predetermined time, or turning on home lights at exactly 6PM in the evening and turning them off during the morning to save energy.

There are so many more applications for automation today and even though they vary, some of the most common of them involve some sort of scheduling. They are able to tell time and know when to turn on and off other devices, and thus come the inspiration for this project. In this project, a simple implementation of an automation system based on a predetermined schedule is designed and developed using the most common technologies such that not only will it be feasible for industrial application but also for home and personal use.

Much research has been done in order to determine the available technologies that can be used in order to efficiently design the device. However, a large portion of them are designed for highly industrialized purposes and the costs are certainly very prohibitive for regular home or personal use. That is why this project is undertaken to create a very feasible device and complementary software for automation.

The device will have a microcontroller, a real time clock and an electrically erasable and programmable read only memory. In order to increase the ease of use and simplicity of design the device will be powered using a regular USB socket for ease of use. USB Sockets are very widespread nowadays, almost every home that will have a computer will always have USB sockets.

Schedule entries will then be designed by the user using the associated software application which will also be developed. The desktop client software will also be responsible for writing these schedule information to the device memory in order for the devices to function without the aid of the computer once all data is stored in its own memory.

After the schedule entries are input to the device, it will then continually check for schedule entries and compare them with data from the real time clock and once a certain entry is scheduled to

run for the time, it will then turn off or on a certain device as specified. This will be done in one minute resolutions allowing the device to have schedules that are accurate to one minute.

Despite the fact device schedulers already exist, this research is undertaken using new methodologies for defining schedules. The unique use of the Cron syntax which is the defacto standard for scheduling in Linux is perhaps the most unique characteristic of this study. This allows us to put complex Cron statements that will allow complex schedule entries to be added with the minimal amount of coding required. Part of this project is modifying and improving the Cron syntax for hardware implementation.

In general this project is all about implementing the famous Cron Scheduling system for software applications in to hardware applications. And because this project is applied for hardware the system is named 'Chron' with an embedded letter 'h' between 'C' and 'r' indicating it is for hardware applications. The researchers believe that this has never been done before and it carries a large potential for automation systems of varying use cases.

Related Literature

Cron is the time-based job scheduler in Unix-like computer operating systems. Cron enables users to schedule jobs (commands or shell scripts) to run periodically at certain times or dates. It is commonly used to automate system maintenance or administration, though its general-purpose nature means that it can be used for other purposes, such as connecting to the Internet and downloading email.

The Cron standard is used as basis for scheduling data for this project. The widespread use and adaption of Cron in the software industry will increase the usage familiarity of our device for different applications. It is thus very new that the Cron standard is adapted for hardware scheduling as is the main focus of this project.

Universal Serial Bus (USB) is an industry standard developed in the mid-1990s that defines the cables, connectors and communications protocols used in a bus for connection, communication and power supply between computers and electronic devices.

USB was designed to standardize the connection of computer peripherals, such as keyboards, pointing devices, digital cameras, printers, portable media players, disk drives and network adapters to personal computers, both to communicate and to supply electric power. It has become commonplace on other devices, such as smart phones, PDAs and video game consoles. USB has effectively replaced a variety of earlier interfaces, such as serial and parallel ports, as well as separate power chargers for portable devices.

USB human interface device class (USB HID class) is a part of the USB specification for computer peripherals: it specifies a device class (a type of computer hardware) for human interface devices such as keyboards, mice, game controllers and alphanumeric display devices. This specification will be utilized by the project in order to facilitate low level interfacing with the PC and the device.

As of 2008, approximately 6 billion USB ports and interfaces were in the global marketplace, and about 2 billion were being sold each year. Given the widespread use and adaption of the USB standard, it will add improvement to our device if we use the USB as both the primary power source and interface bus with the PC.

I²C generically referred to as "two-wire interface is a multi-master serial single-ended computer bus invented by Philips that is used to attach low-speed peripherals to a motherboard, embedded system, cell phone, or other electronic device. Since the mid 1990s, several competitors (e.g., Siemens AG (later Infineon Technologies AG, now Intel mobile communications), NEC, Texas Instruments, STMicroelectronics (formerly SGS-Thomson), Motorola (later Freescale), Intersil, etc.) brought I²C products on the market, which are fully compatible with the NXP (formerly Philips's semiconductor division) I²C-system. The widespread use of the I²C interface allows for the project to be easily integrated with each subcomponent within it.

A microcontroller (sometimes abbreviated μ C, uC or MCU) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, implantable medical devices, remote controls, office machines, appliances, power tools, toys and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems.

PIC is a family of modified Harvard architecture microcontrollers made by Microchip Technology, derived from the PIC1650 originally developed by General Instrument's Microelectronics Division. The name PIC initially referred to "Peripheral Interface Controller". The PIC18F4550 is the Microcontroller to be used for the projects implementation of the device.

EEPROM is user-modifiable read-only memory (ROM) that can be erased and reprogrammed (written to) repeatedly through the application of higher than normal electrical voltage generated externally or internally in the case of modern EEPROMs. EPROM usually must be removed from the device for erasing and programming, whereas EEPROMs can be programmed and erased in-circuit. Originally, EEPROMs were limited to single byte operations which made them slower, but modern EEPROMs allow multi-byte page operations.

EEPROMs also have a limited life - that is, the number of times it could be reprogrammed was limited to tens or hundreds of thousands of times. That limitation has been extended to a million write operations in modern EEPROMs. In an EEPROM that is frequently reprogrammed while the computer is in use, the life of the EEPROM can be an important design consideration. It is for this reason that EEPROMs were used for configuration information, rather than random access memory. The Atmel AT24C16 IC is used for the implementation of the device.

A real-time clock (RTC) is a computer clock (most often in the form of an integrated circuit) that keeps track of the current time. Although the term often refers to the devices in personal computers, servers and embedded systems, RTCs are present in almost any electronic device which needs to keep accurate time. The DS1307 real time clock by Maxim is used for the implementation of the projects device.

Although keeping time can be done without an RTC, using one has benefits. Low power consumption, (important when running from alternate power); Frees the main system for time-critical tasks; and finally it is sometimes more accurate than other methods.

Scope and Limitation

However, due to time, and cost limitations, the project will be very limited in terms of scale and durability of design. The primary focus of the project will be on the firmware programming, software programming and hardware integration for a low cost and simple device used for scheduling and automation.

Due to time limitations only a prototype device and associated software applications will be developed, and the design for an actual device for consumer or industrial use is beyond the scope of the project. Due to the time taken towards software and firmware development, the researchers no longer have enough time to develop a suitable PCB for the circuit hence universal boards were used for quick development of the hardware.

The primary focus of this project is to demonstrate the feasibility of implementing the Cron scheduling mechanism for application of scheduling other hardware devices. And to demonstrate a prototype device that does this in the very basic level.

Methodology

Design of Scheduling Method

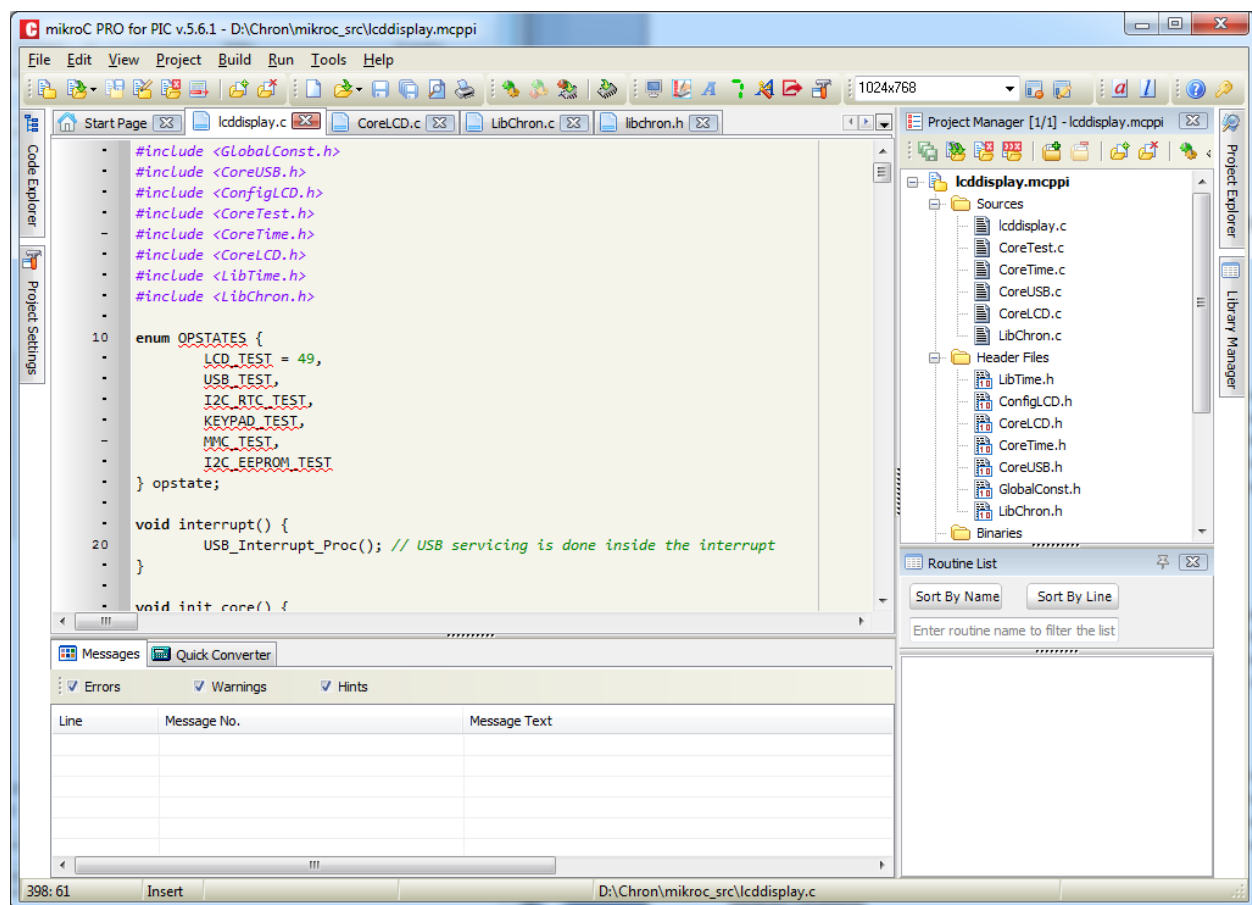
In order to automate processes, one must first establish a scheduling standard. The standard used for this project will be the existing standard used by the Cron Software. Only a fraction of the actual Cron specification will be taken in to account for this project due to inherent limitations when using only a microcontroller with limited memory and processing power. A 21 byte specification for a schedule entry is detailed on Appendix A.

The classifier can either be a NULL or a DASH. If it is a NULL the Lower Value will be considered as the defined unit for the schedule. If the lower limit is an ASTERISK, the software can evaluate it as being always valid. If the Lower Limit is a value then it can only become valid when the current time value is equal to the lower limit value. If the classifier is a DASH, then the entry will be evaluated considering the upper and lower limits. Refer to Appendix B for example Chron Entries and their explanations.

Development Environments

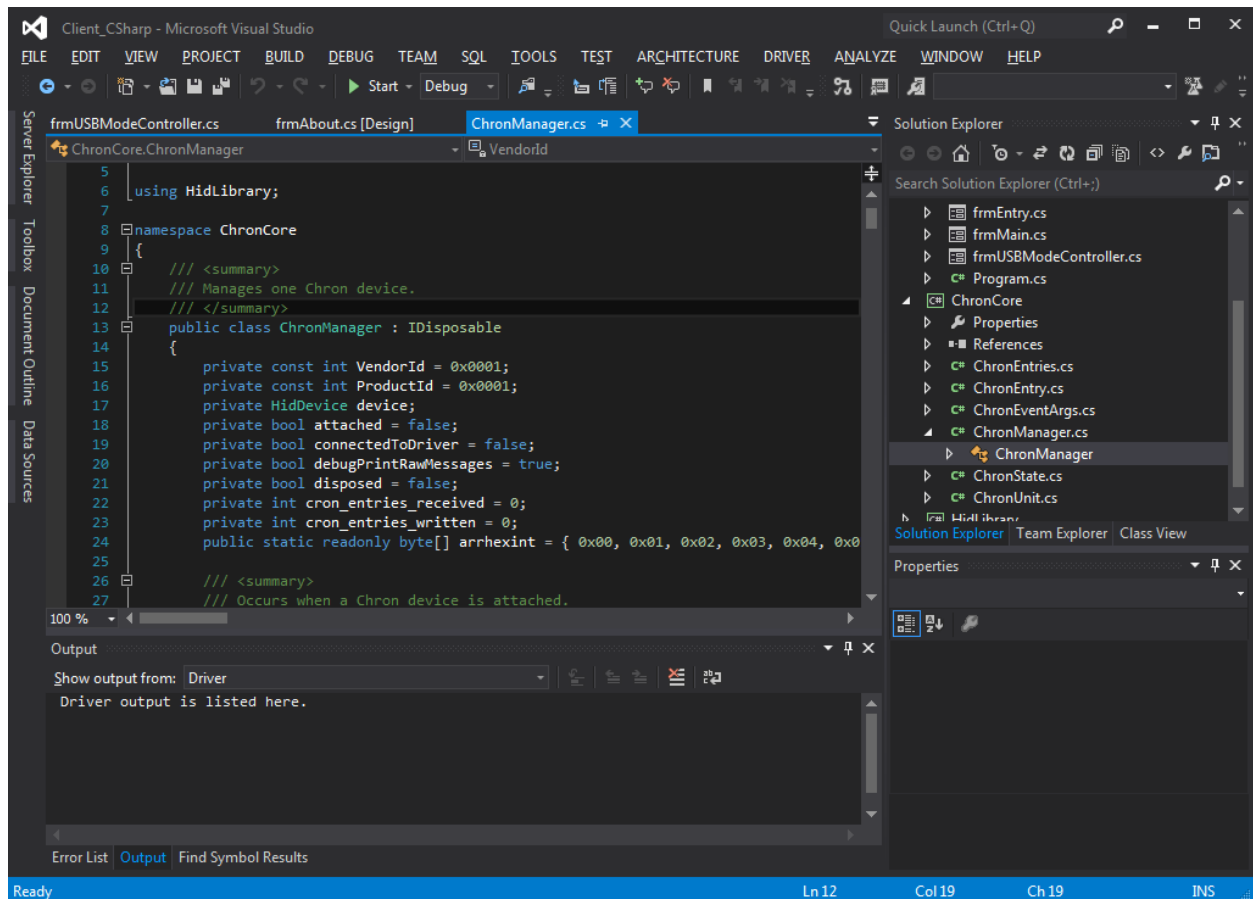
Firmware

Many development environments for the Firmware were considered for this project. However, for increased time to completion and simplicity of development the MikroC development environment for the PIC is utilized. Advantages for using MikroC are the well organized documentation and the wide array of Hardware and Software Libraries that can be easily utilized for use for the project. The extensive support of MikroC for PIC devices is perhaps the best strong point for choosing it as the major development platform for the Firmware.



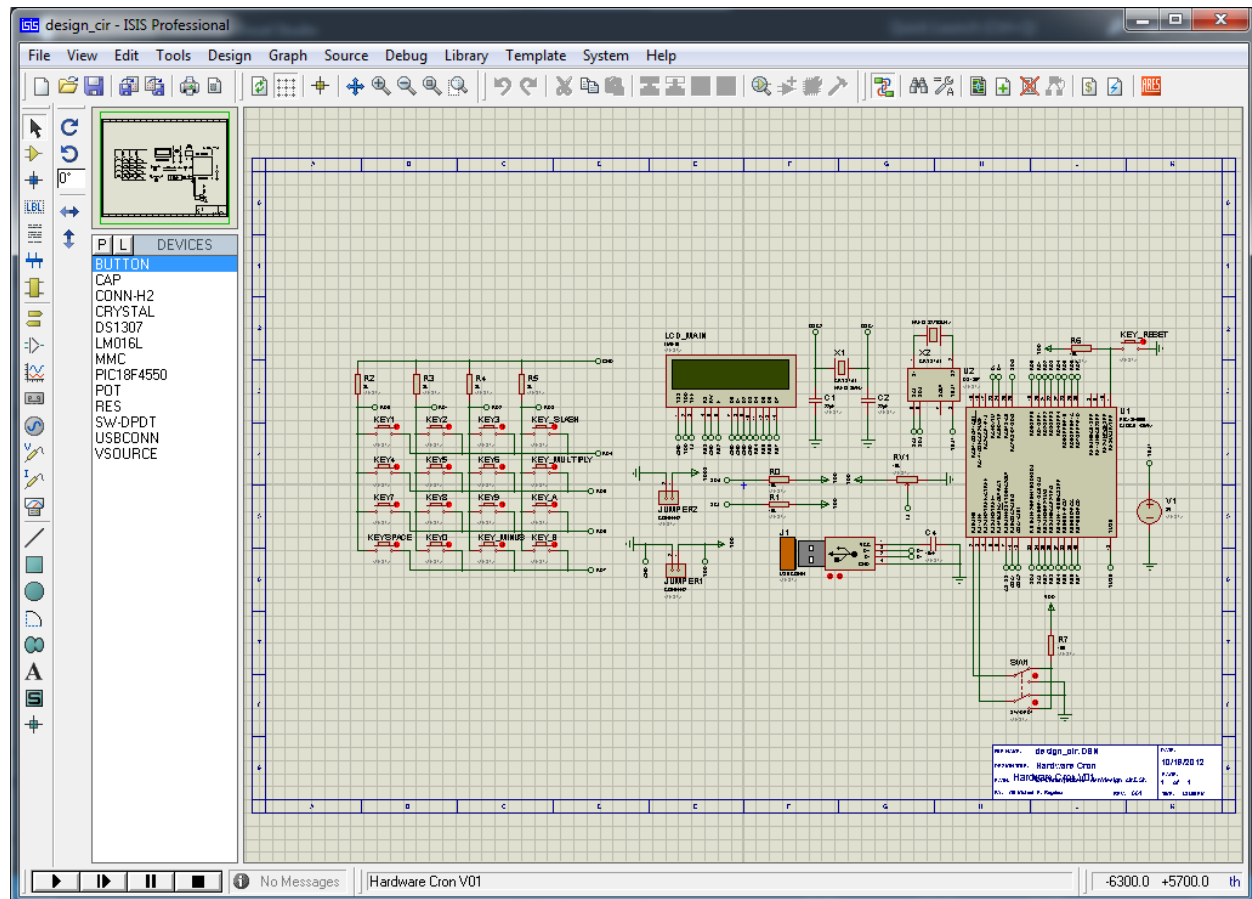
Software

In order to interface the device with the PC, suitable Software has to be developed to facilitate PIC and PC communications. The researchers decided to use Visual Studio C# for Windows as the Development Environment to support such purpose. Using the Visual Studio C# development environment will significantly increase development time and decrease debugging difficulty due to its fully featured debugging environment.



Hardware

In order to improve hardware development methods suitable simulation software for hardware components is utilized. The Proteus VSM suite is used for simulating the PIC and its associated hardware components. Also, the Proteus has support for simulating USB communications with the PC. However this only supported Proteus – Windows XP environment. So a Virtual Machine installation of Windows XP using Virtual Box was setup to facilitate this simulation.



Hardware Components

The ability to load schedule data from the user's computer to the device is very important for this project. Therefore one of the most important determining factors for the selection of components is the capability to interface with the computer. For this study, the USB interface was selected as the most common place and easiest to use interface that will add the benefit of simplicity of use for the product.

Microcontroller

The PIC18F4550 from Microchip was selected as the core Microcontroller for this project due to the fact that it has an internal USB Module that can be easily used to interface with the Personal Computer. Some very important details of the PIC18F4550 are listed on Appendix C.

Real-time Clock

The device has to be able to remember time regardless of its main power source present or not, and even if the Microcontroller is busy with other operations, it will not lag and fail to keep up with remembering time. In order to do this an external Integrated Circuit is used for remembering time. The real time clock DS1307 is used for this purpose. A portion of DS1307's data sheet is posted on Appendix D.

One of the major reasons for selecting this device was because of compatibility. It is very important that this device can be easily integrated with the main PIC18F4550 microcontroller. The interface type from IC to IC within the device must be feasible enough. This compatibility is provided by the I2C interface capability of the Real-time Clock and the PIC18F4550's own I2C controller module and because this, the main PIC can handle I2C connections, and the DS1307 can easily be interfaced with it.

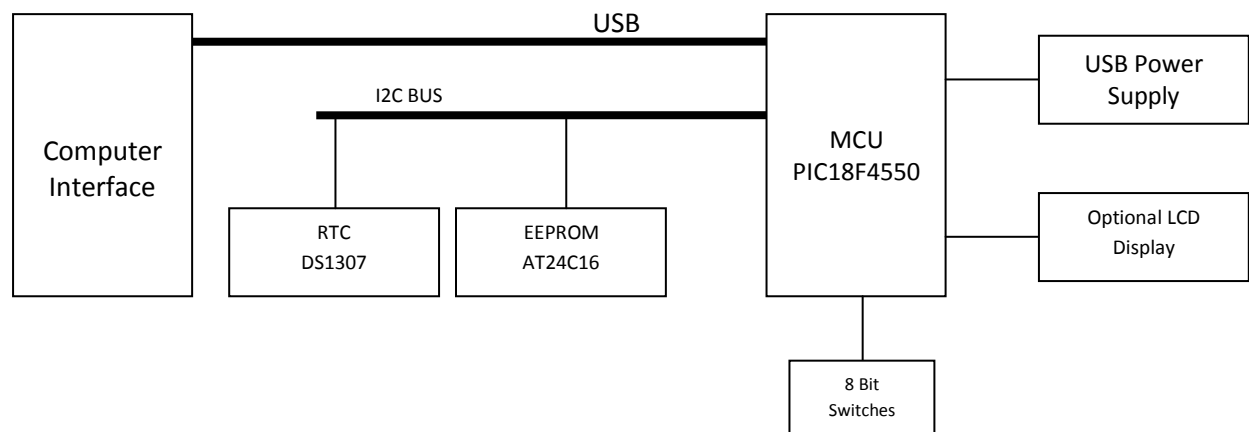
EEPROM

In order for the device to keep a significant number of schedules based on the initial schedule entry design, even if the device is turned off, the design must include the use of an EEPROM. The EEPROM will allow the device to remember schedule entries even if it was turned off for a short while. The PIC18F4550 has an EEPROM size of 256 bytes as detailed on the specification on Appendix C. However a simple calculation will tell us that 256 divided by 21 will only allow us to store 12 schedule entries.

If the device is capable of scheduling 8 switches, then there will almost likely be only 1 or 2 schedule entries for each switch. This is very limited and therefore not feasible. In order to improve the operation of the device, an external EEPROM of reasonable capacity must be selected for the purpose of storing schedule entries. The block diagram below shows the general overview of the device components.

The Atmel AT24C16 was selected for this purpose. It has 2048 bytes of storage capacity distributed in 8 internal pages. The added convenience is that the AT24C16 supports I2C communications and therefore it is easier to interface it with the PIC18F4550. A portion of AT24C16's data sheet is posted on Appendix F.

Block Diagram of the Hardware Components



Memory Organization

The following figure shows the AT24C16 memory organization.

Page 0	Page 1	Page 2	Page ...	Page 7
Byte 0	Byte 0	Byte 0	Byte 0	Byte 0
Byte 1	Byte 1	Byte 1	Byte 1	Byte 1
Byte 2	Byte 2	Byte 2	Byte 2	Byte 2
Byte 3	Byte 3	Byte 3	Byte 3	Byte 3
...
Byte 255	Byte 255	Byte 255	Byte 255	Byte 255

Now that the external memory IC was determined a simple Memory Structure is designed in order to handle the write and read of Schedule Entries to and from the AT24C16 EEPROM.

According to the data sheet the AT24C16 has a 3 byte page addressing which translates to 8 pages. Each page then contains an 8 bit address space for 256 separate addresses. Each address then finally contains 1 byte or 8 bits of data. With 8 pages, and 256 bytes per page, this translates to 2048 bytes of data. For a complete overview of AT24C16's device addressing scheme, refer to the first Page of Appendix F.

However, due to the complicated addressing scheme caused by the pages the researcher's decided to put only the number of 21 byte schedule entries that can fit in to a single page. Since there 256 bytes per page, then there can be 12 schedule entries per page. Finally, since there 8 pages, then the device can store 96 schedule entries in the EEPROM.

This simplifies the access and store mechanism considerable for the purpose of this research. Though it should be noted that this is not the most efficient way of doing this and dealing with storage efficiency for this matter is beyond the scope of the study.

Despite all these the device must still know how many schedule entries are written sequentially on itself. This is where the PIC18F4550's internal EEPROM is used. The first byte of the PIC's internal EEPROM is used for storing the number of entries stored on the External EEPROM. This way, the program can know ahead of time how many entries it has to read.

Abstraction Memory Organization for the Device (12 Entries are distributed to 256 Bytes)

Page 0	Page 1	Page 2	Page ...	Page 7
Entry 0	Entry 0	Entry 0	Entry 0	Entry 0
Entry 1	Entry 1	Entry 1	Entry 1	Entry 1
Entry 2	Entry 2	Entry 2	Entry 2	Entry 2
Entry 3	Entry 3	Entry 3	Entry 3	Entry 3
...
Entry 11	Entry 11	Entry 11	Entry 11	Entry 11

Among others, all the associated minor components that are required to run the major components are also acquired and an LCD Display is utilized in order to streamline the process of debugging the algorithms which are detailed on the next section. The LCD may be removed in order to produce a product of smaller size foot print and decrease power consumption.

Algorithm and Process Flow

Now that the important components are setup the algorithms that will make them work together in harmony are then established and coded in to MikroC, compile to a Hex File then loaded for testing. The details of the algorithms will be discussed in this section.

Read and Write for AT24C16 EEPROM

Using the memory organization as discussed from the previous section. A suitable write operation sequence is developed in order to allow the PIC18F4550 to write to the EEPROM and be able to store data. On Appendix F, the write operations are described by pages taken from the datasheet.

For the 16k version of the chip which is being used for this project, the algorithm will divide entries in to 8 pages. Then the algorithm will put only the amount of entries which can fit per page. Since each page can fit 256 bytes, then only 12 entries of 21 bytes are stored each page. Simple loops are used for this purpose.

However, for the actual writing, each byte is written individually on predetermined locations. This method is represented on Figure 8 of Appendix F. A compatible code is developed for this as presented on Appendix G.

Also the Random Read is utilized as discussed on the first Page of Appendix F, and a corresponding equivalent code for MikroC as continued on Appendix G. This shows the basic EEPROM read and write operations to be used for the Program.

A simple pseudo code follows detailing the reading of schedule entries.

```
total = get_total_number_of_entries_from_internal_eeprom;
entry[21];
entries_read = 0;
entry_per_page = 12;
bytes_per_entry = 21;
total_pages = 8;

for (page=0; page<total_pages; page++) {
    if (entries_read < total) {

        address_within_page = 0;

        // 12 entries per page
        for (entries=0; entries<entry_per_page; entries++) {

            // 21 bytes per entry
            for (entry_address=0; entry_address<bytes_per_entry; entry_address++) {
                entry[entry_address] = read_entry(page, address_within_page);
                address_within_page++;
            }

        }

    }

}
```

Reading and Writing time from the Real-time Clock

Same with the EEPROM, the PIC must now read and write time to the DS1307 Real-time Clock. On Appendix H and I are the Memory Organization and Device addressing schemes used by the IC. A compatible code is then described in Appendix J.

The PC Interface

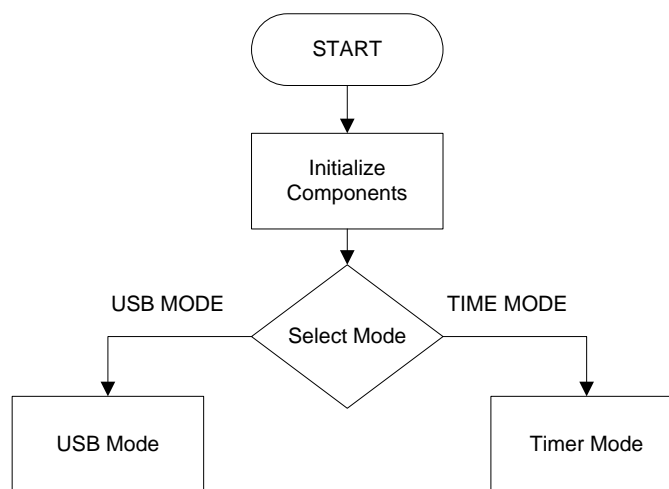
Though methods for USB Hid development with PIC18F4550 are well supported by the MikroC Development Environment, methods for establishing USB HID interfaces for the PC are widely varied depending on purpose and implementation. An open source HID Application Programming Interface created by a Github user *mikeobrien* is used for this purpose. The Hid Library he developed as an open source project will be used to interface the PC to the Device.

The decision for this move is also inspired by the use of the C# Development Platform for Window using Visual Studio 2012 as the development environment for the PC. Hence for this project the associated software components can only be run on the Windows PC. However, the use of NodeJS and the Node HID API is also recommended for Real-time Web Interfacing for NodeJS Supported platforms which include the MAC, PC and Linux.

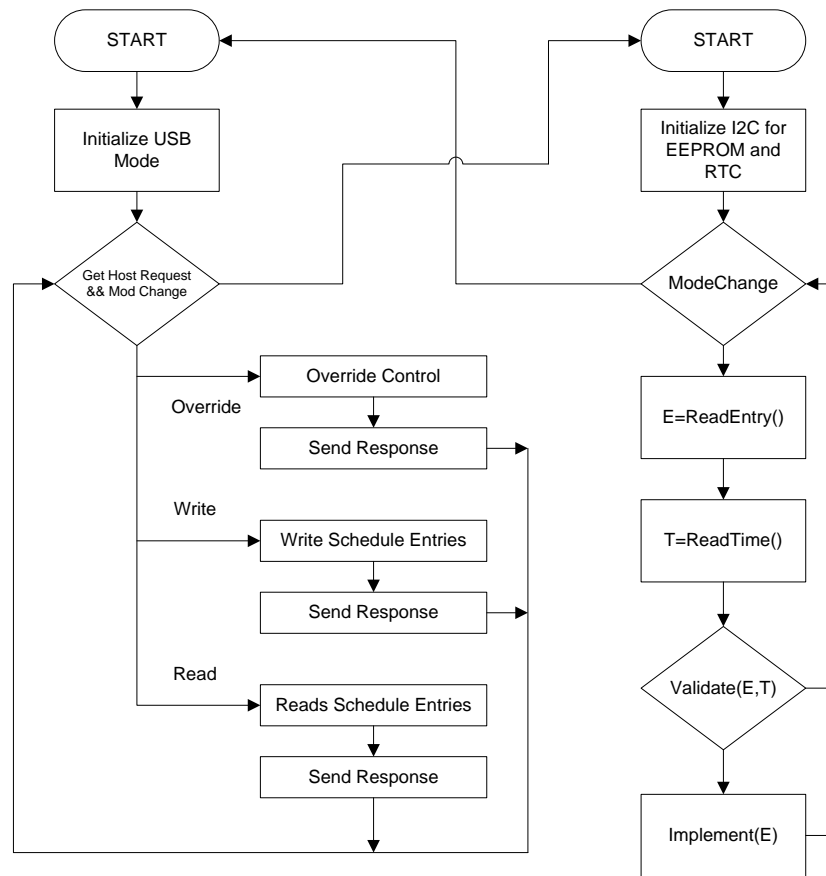
General Outline of the Algorithm

Now that the Core functionalities have already been described we will then discuss the general outline of the algorithm.

The user can use a toggle switch to choose between modes. The USB mode allows the device to connect to the computer. The timer mode will read the schedule entries in a loop and check each time if the schedule entry is valid for the current time. If it is valid, then it will implement this entry and switch on or off a certain device. Below is the flowchart for the startup sequence of the device.



Once the user has selected a mode, it will proceed to looping for requests and processing them along the way. Below is the flow chart for this sequence.



USB Implementation

In order to work with the PC interface the USB must be implemented in both the PC and the PIC. Though the USB module for the PIC is very well defined on the data sheet, USB interfacing with the PC is still quite a challenging task due to the fact that the PC is a much more complicated and proprietary system. In this study, the use of the USB human interface device class (USB HID class), a part of the USB specification for computer peripherals for human interface devices such as keyboards, mice, game controllers and alphanumeric display devices is used for interfacing this device to the PC.

Help and Support resources based from the MikroC was used in order to implement the USB HID specification on the firmware level. For the Host PC part, after research on the net, an open source project written by *mikeobrien*. His USB HidLibrary includes examples for use for other hardware which were then modified for use for this project.

A Software interface was designed to conduct the input of schedule entries and manual overrides for the device during testing and debugging. The picture below is a screen shot of the user interface created for this purpose.

The screenshot shows a window titled "Chron Scheduler Desktop Client". It has a menu bar with "File", "Tools", and "Help". Below the menu bar is a toolbar with icons for file operations. The main area contains a table with 13 rows of scheduled tasks. The table has columns for Device, ID, State, Minute, Hour, Day, Week Day, Month, and Year. The data is as follows:

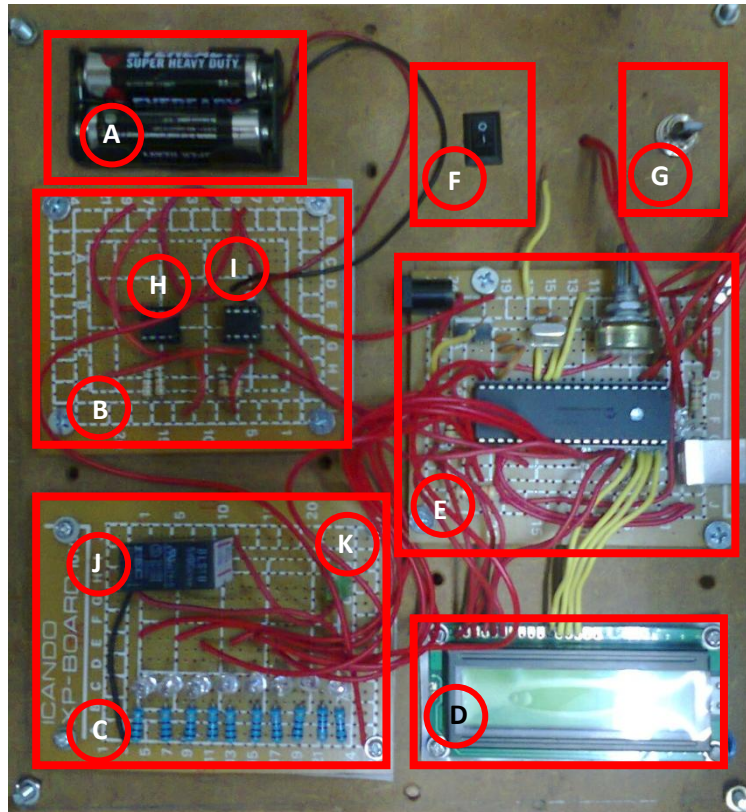
Device	ID	State	Minute	Hour	Day	Week Day	Month	Year
1	0	On	21	10	26	6	10	12
2	0	Off	22	10	26	6	10	12
3	1	On	21	10	26	6	10	12
4	1	Off	22	10	26	6	10	12
5	2	On	21	10	26	6	10	12
6	2	Off	22	10	26	6	10	12
7	3	On	21	10	26	6	10	12
8	3	Off	22	10	26	6	10	12
9	4	On	21	10	26	6	10	12
10	4	Off	22	10	26	6	10	12
11	5	On	21	10	26	6	10	12
12	5	Off	22	10	26	6	10	12
13	6	On	21	10	26	6	10	12

Below the table is a large empty rectangular area. At the bottom of the window, there is a status bar that says "Device not Found" on the left and "Nop ..." on the right.

Each of the eight available ports for device switching can individually be controlled by the user interface. The schedule entries will then be sent to the device when it is connected and the Write signal is started. The device can then be switched mode to run independently from the PC and it will begin looping all schedule entries and comparing them with the current time. If a certain switch in the port is slated for implementation for such time then it will be triggered.

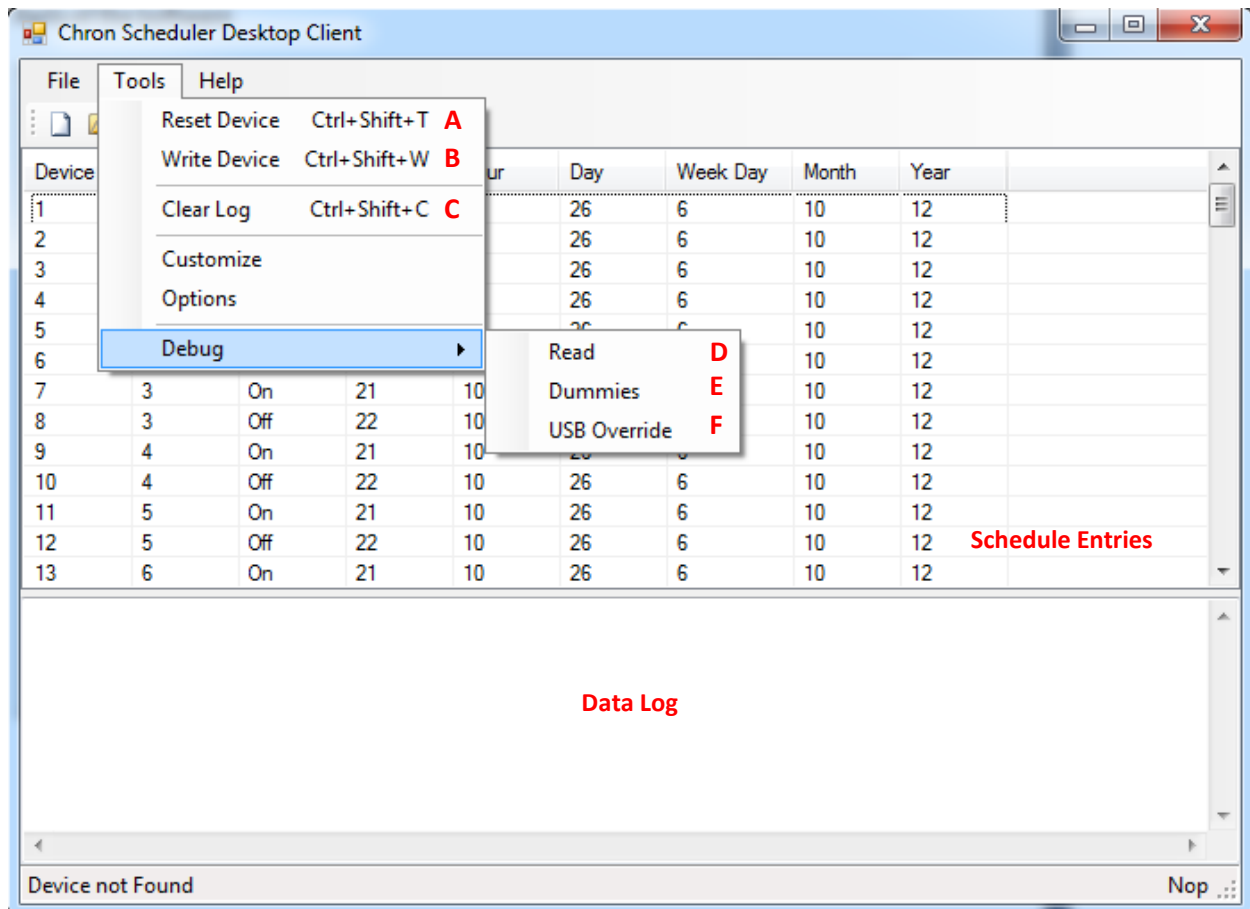
Method of Operation

Parts of the Device



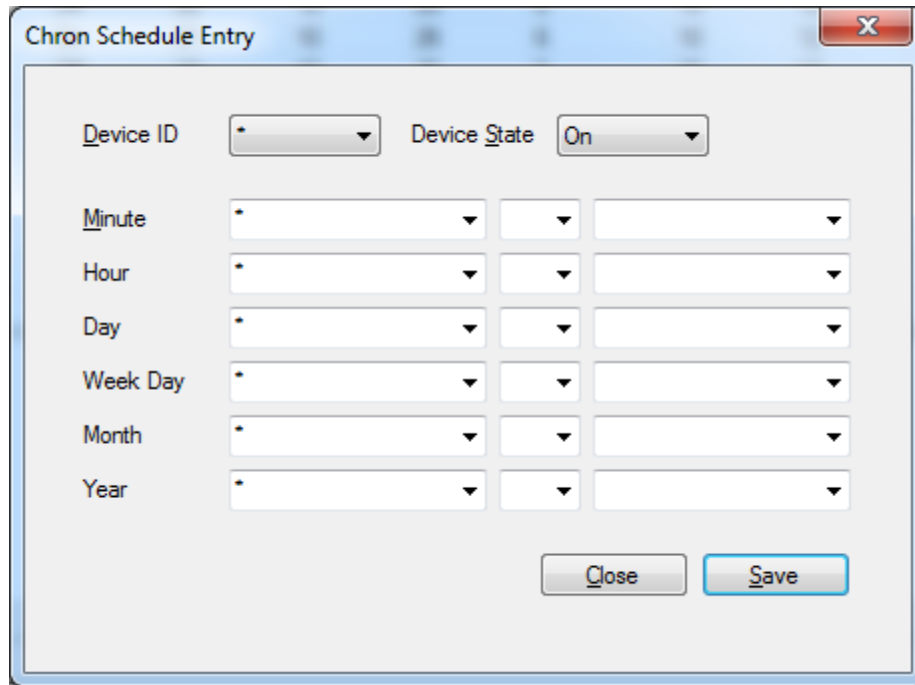
- A. The 3V AA battery series which provides power to the DS1307 Real-time Clock when the primary USB power source is out.
- B. The EEPROM and RTC module.
- C. The switching and monitoring Module. The eight LED Devices represent one switching device. Only the first LED which is Device 0, has a 5V DC 220V AC relay.
- D. LCD Display module. Can be removed on the final product. Useful for debugging the device during development phase.
- E. The Main Board. Contains the PIC and the USB port which feeds power and interfaces to the PC.
- F. Power switch. The O symbol is open and the 'I' symbol is closed.
- G. The toggle switch for mode switching. Toggles between USB and time Modes.
- H. The Atmel 119 24C16 EEPROM.
- I. DS1307 Real-time Clock.

Parts of the Software



- A. Allows the user to reset the device. It will sync PC time and device time. It will also set the number of entries to 0. It should be noted that since the number of entries are recorded on the PIC18F4550's EEPROM in the first byte, this operation only 0's the first byte of the PIC18F4550's internal EEPROM.
- B. Once you are done putting in the schedule entries, you can then choose this option to write the schedule entries to the device EEPROM.
- C. Clears the Data log.
- D. Reads all EEPROM entries regardless of how many entries were written before. Useful for debugging.
- E. Writes 95 schedule entries which can be readily written to the device itself. This is for testing the maximum number of entries to be written.
- F. Allows for controlling the individual switches in real-time.

Schedule Entry Designer



The image shows a Windows-style dialog box titled "Chron Schedule Entry". It contains the following fields:

- Device ID:** A dropdown menu with an asterisk (*) selected.
- Device State:** A dropdown menu with "On" selected.
- Minute:** Three dropdown menus, each with an asterisk (*) selected.
- Hour:** Three dropdown menus, each with an asterisk (*) selected.
- Day:** Three dropdown menus, each with an asterisk (*) selected.
- Week Day:** Three dropdown menus, each with an asterisk (*) selected.
- Month:** Three dropdown menus, each with an asterisk (*) selected.
- Year:** Three dropdown menus, each with an asterisk (*) selected.

At the bottom right, there are two buttons: "Close" and "Save".

- The asterisk ('*') will indicate an 'all' directive. Refer to the Appendix on the discussion of Cron scheduling for in-depth review on the matter.
- Device state allows you to turn on or off a certain device on the specified time.
- Device ID allows you to choose which device are turned on or off at the specified time. There are 8 devices available for control on this version of the hardware.

Device Usage

1. Prepare a copy of the Hardware Chron Desktop Client Software for Windows.
2. Open the program and start designing your preferred schedule. You may save and open predefined schedule as desired.
3. Make sure the device is in the off state.
4. Make sure to set the device toggle switch to USB mode.
5. Connect it to the USB port of your PC.
6. Turn the device on. It should begin initializing the device for USB connectivity.
7. Wait for the software's status bar to say connected before proceeding.
8. On the software, go to Tools Menu and click Write. It will begin writing the schedule entries to your device. Make sure not to remove the device from the USB port while the schedule entries are being written.
9. After the schedule entries have been written. Turn off the device.
10. Toggle the device switch to 'Time Mode'.
11. Turn on the device.
12. This will start the device as time mode and will be independent of the USB interface with the PC. It only requires USB connectivity to get clean 5V power from the PC.
13. Once a schedule entry is slated for activation the Device will automatically implement the required state for a certain switch.

Results and Discussions

The device has been successfully developed in a prototype stage. All firmware and software components were also completed. However it should be noted that the Cron specification for the device was heavily modified. Also, not all of Cron's features are applicable to the device due to its inherent limitations. To end, the device is working properly and has limitless potential for use on different applications.

Cost Summary

Model	Description	Price	Items Acquired	Sub Total	Items Required	Sub Total
PIC18F4550	Flash32K 2KRAM EEPROM USB DIP40	470.00	4	1880.00	1	470.00
DS1307	64 x 8, Serial, I ² C Real-Time Clock DIP8	45.00	4	180.00	1	45.00
8.000MHz	crystal	20.00	2	40.00	1	20.00
32.768KHZ	32.768KHZ crystal	20.00	2	40.00	1	20.00
22pf	cap 22pf	0.50	4	2.00	2	1.00
TX2-5V	NAIS 5V DPDT	33.50	10	335.00	0	0.00
USB type B	USB type B	16.50	2	33.00	1	16.50
24C16	16K bit Serial EEPROM DIP8	42.00	2	84.00	1	42.00
Capacitor 103 / 0.01uf	Ceramic Cap 103 / 0.01uf	0.50	10	5.00	2	1.00
100nF (104)	100nF/104 Ceramic Cap.	0.50	10	5.00	2	1.00
1WT Resistor	resistor 1wt	1.00	20	20.00	20	20.00
2x16 LCD	lcd w/backlight 2x16 (new)	350.00	2	700.00	1	350.00
Assembly	PCB, Etching and other Manufacturing Services per Device	500.00	0	0.00	1	500.00
	Total Cost of Development			3324.00		
	Total Cost of Product					1486.50
	Total Cost of Product w/o LCD					1136.50

It should be obvious by now that significant cost reduction is made from actual device and associated software development is done and more especially when the final product is made without the LCD.

Conclusion and Recommendations

The researches have demonstrated that indeed it is feasible to implement the Cron specification in scheduling hardware devices. However, the cost of the project has indeed also increased with complexity. It is therefore recommended that optimization be made in order to increase capacity and lower cost of the device.

The EEPROM memory allocation can be improved by setting up better memory allocation strategies. Because the researchers only took care of completing the project within time allotted, there was no optimization made in the memory allocation of the system.

Also, the Read and Write algorithms can be improved after optimizing the memory allocations strategy. Developments to use Page Write and Read operation can be implemented in order to increase the speed of reading and writing. This was not included in this project due to the added complexity that may arise if this optimization path was taken. Relevant data for implementing this would be available on the EEPROMs data sheet as posted on the Appendix.

Improved schedule entry and parsing can be implemented in order to reduce read times and increase the number of schedules read per minute. And in fact the resolution can be increased to seconds depending on the speed of the microcontroller used.

The LCD display can also be removed to save space as it is only helpful during the debugging phase. Also, in this device, only one switch has a relay attached to it. A separate module of Relay Arrays can be used and a specialized connection system can be implemented to connect the Relay Array with the device can be developed.

On the software side, the HID driver can be implemented in to multiplatform applications using the Multi Paltform GNU Hid Library. Also, the device can be interfaced to the Internet using the NodeJS HID library.

This project, all relevant data, source code and design files has been opensourced by its researchers and is posted for public reference and use at <https://github.com/bangonkali/Chron> in hopes of improving this project for actual use and application.

Appendix A

Simple design of the Scheduler Entry

Byte	Name	Description
0	Enable	This will be 0 when disable and 1 when enabled.
1	DeviceID	Device that will be turned on or off
2	DeviceState	On or Off
3	MinutesLower	The lower limit for the minute
4	MinutesClassifier	Classifier for the range of the minute
5	MinutesUpper	The upper limit for the minute
6	HourLower	The lower limit for the hour
7	HourClassifier	Classifier for the range of the hour
8	HourUpper	The upper limit for the hour
9	MonthDayLower	The lower limit for the day of month
10	MonthDayClassifier	Classifier for the range of the day of month
11	MonthDayUpper	The upper limit for the day of month
12	WeekdayLower	The lower limit for the weekday
13	WeekdayClassifier	Classifier for the range of the weekday
14	WeekdayUpper	The upper limit for the weekday
15	MonthLower	The lower limit for the month
16	MonthClassifier	Classifier for the range of the month
17	MonthUpper	The upper limit for the month
18	YearLower	The lower limit for the year
19	YearClassifier	Classifier for the range of the year
20	YearUpper	The upper limit for the year

Appendix B

Example Partial Chron Entries

MM	HH	MD	WD	MO	YY	Description
*	6	*	*	*	*	Activate every 6:00 AM every day.
30	7	*	*	*	*	Activate every 7:30 AM every day.
15	12	*	2-6	*	*	Activate every 12:15 PM every Monday to Friday.
*	24	1	*	1-3	12-13	Activate every 12:00 AM every first day of the Month only during January, February, and March for Year 2012 to 2013.
*	20	1-15	4	*	12	Activate every 8:00 PM, only from 1 st to 15 th day of the month were it is Wednesday and the year is 2012.

Appendix C

A screen shot taken from a portion of the data sheet specification.

PIC18F2455/2550/4455/4550

TABLE 1-1: DEVICE FEATURES

Features	PIC18F2455	PIC18F2550	PIC18F4455	PIC18F4550
Operating Frequency	DC – 48 MHz	DC – 48 MHz	DC – 48 MHz	DC – 48 MHz
Program Memory (Bytes)	24576	32768	24576	32768
Program Memory (Instructions)	12288	16384	12288	16384
Data Memory (Bytes)	2048	2048	2048	2048
Data EEPROM Memory (Bytes)	256	256	256	256
Interrupt Sources	19	19	20	20
I/O Ports	Ports A, B, C, (E)	Ports A, B, C, (E)	Ports A, B, C, D, E	Ports A, B, C, D, E
Timers	4	4	4	4
Capture/Compare/PWM Modules	2	2	1	1
Enhanced Capture/ Compare/PWM Modules	0	0	1	1
Serial Communications	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART	MSSP, Enhanced USART
Universal Serial Bus (USB) Module	1	1	1	1
Streaming Parallel Port (SPP)	No	No	Yes	Yes
10-Bit Analog-to-Digital Module	10 Input Channels	10 Input Channels	13 Input Channels	13 Input Channels
Comparators	2	2	2	2
Resets (and Delays)	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT	POR, BOR, RESET Instruction, Stack Full, Stack Underflow (PWRT, OST), MCLR (optional), WDT
Programmable Low-Voltage Detect	Yes	Yes	Yes	Yes
Programmable Brown-out Reset	Yes	Yes	Yes	Yes
Instruction Set	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled
Packages	28-Pin PDIP 28-Pin SOIC	28-Pin PDIP 28-Pin SOIC	40-Pin PDIP 44-Pin QFN 44-Pin TQFP	40-Pin PDIP 44-Pin QFN 44-Pin TQFP

Appendix D

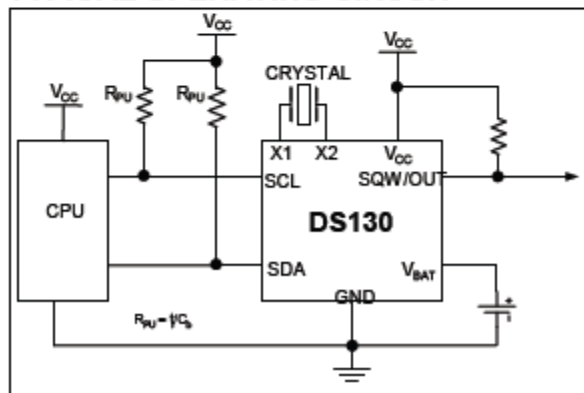
A page taken from the DS1307 Real Time Clock IC Data Sheet

DS1307 64 x 8, Serial, I²C Real-Time Clock

GENERAL DESCRIPTION

The DS1307 serial real-time clock (RTC) is a low-power, full binary-coded decimal (BCD) clock/calendar plus 56 bytes of NV SRAM. Address and data are transferred serially through an I²C, bidirectional bus. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with AM/PM indicator. The DS1307 has a built-in power-sense circuit that detects power failures and automatically switches to the backup supply. Timekeeping operation continues while the part operates from the backup supply.

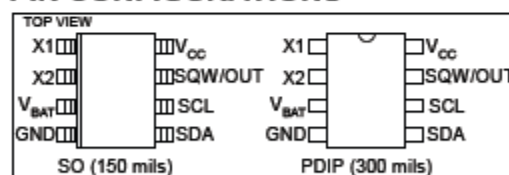
TYPICAL OPERATING CIRCUIT



FEATURES

- Real-Time Clock (RTC) Counts Seconds, Minutes, Hours, Date of the Month, Month, Day of the week, and Year with Leap-Year Compensation Valid Up to 2100
- 56-Byte, Battery-Backed, General-Purpose RAM with Unlimited Writes
- I²C Serial Interface
- Programmable Square-Wave Output Signal
- Automatic Power-Fail Detect and Switch Circuitry
- Consumes Less than 500nA in Battery-Backup Mode with Oscillator Running
- Optional Industrial Temperature Range: -40°C to +85°C
- Available in 8-Pin Plastic DIP or SO
- Underwriters Laboratories (UL) Recognized

PIN CONFIGURATIONS



Appendix E

A portion of the AT24C16's Data sheet Specification

Features

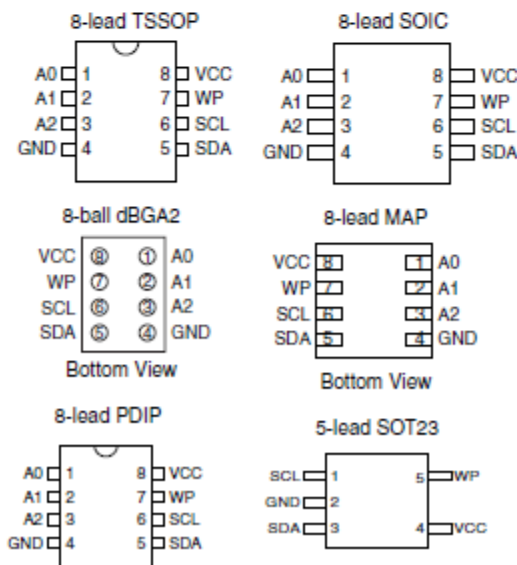
- Low-voltage and Standard-voltage Operation
 - 2.7 ($V_{CC} = 2.7V$ to 5.5V)
 - 1.8 ($V_{CC} = 1.8V$ to 5.5V)
- Internally Organized 128 x 8 (1K), 256 x 8 (2K), 512 x 8 (4K), 1024 x 8 (8K) or 2048 x 8 (16K)
- Two-wire Serial Interface
- Schmitt Trigger, Filtered Inputs for Noise Suppression
- Bidirectional Data Transfer Protocol
- 100 kHz (1.8V) and 400 kHz (2.7V, 5V) Compatibility
- Write Protect Pin for Hardware Data Protection
- 8-byte Page (1K, 2K), 16-byte Page (4K, 8K, 16K) Write Modes
- Partial Page Writes Allowed
- Self-timed Write Cycle (5 ms max)
- High-reliability
 - Endurance: 1 Million Write Cycles
 - Data Retention: 100 Years
- Automotive Grade and Lead-free/Halogen-free Devices Available
- 8-lead PDIP, 8-lead JEDEC SOIC, 8-lead MAP, 5-lead SOT23, 8-lead TSSOP and 8-ball dBG2 Packages
- Die Sales: Wafer Form, Waffle Pack and Bumped Wafers

Description

The AT24C01A/02/04/08A/16A provides 1024/2048/4096/8192/16384 bits of serial electrically erasable and programmable read-only memory (EEPROM) organized as 128/256/512/1024/2048 words of 8 bits each. The device is optimized for use in many industrial and commercial applications where low-power and low-voltage operation are essential. The AT24C01A/02/04/08A/16A is available in space-saving 8-lead PDIP, 8-lead JEDEC SOIC, 8-lead MAP, 5-lead SOT23 (AT24C01A/AT24C02/AT24C04), 8-lead TSSOP, and 8-ball dBG2 packages and is accessed via a Two-wire serial interface. In addition, the entire family is available in 2.7V (2.7V to 5.5V) and 1.8V (1.8V to 5.5V) versions.

Table 1. Pin Configuration

Pin Name	Function
A0 - A2	Address Inputs
SDA	Serial Data
SCL	Serial Clock Input
WP	Write Protect
NC	No Connect
GND	Ground
VCC	Power Supply



Two-wire Serial EEPROM

1K (128 x 8)

2K (256 x 8)

4K (512 x 8)

8K (1024 x 8)

16K (2048 x 8)

AT24C01A
AT24C02
AT24C04
AT24C08A
AT24C16A

0180V-SEEPR-8/05

Appendix F

Device Addressing Scheme for AT24C16

Device Addressing

The 1K, 2K, 4K, 8K and 16K EEPROM devices all require an 8-bit device address word following a start condition to enable the chip for a read or write operation (refer to Figure 7).

The device address word consists of a mandatory one, zero sequence for the first four most significant bits as shown. This is common to all the EEPROM devices.

The next 3 bits are the A2, A1 and A0 device address bits for the 1K/2K EEPROM. These 3 bits must compare to their corresponding hard-wired input pins.

The 4K EEPROM only uses the A2 and A1 device address bits with the third bit being a memory page address bit. The two device address bits must compare to their corresponding hard-wired input pins. The A0 pin is no connect.

The 8K EEPROM only uses the A2 device address bit with the next 2 bits being for memory page addressing. The A2 bit must compare to its corresponding hard-wired input pin. The A1 and A0 pins are no connect.

The 16K does not use any device address bits but instead the 3 bits are used for memory page addressing. These page addressing bits on the 4K, 8K and 16K devices should be considered the most significant bits of the data word address which follows. The A0, A1 and A2 pins are no connect.

The eighth bit of the device address is the read/write operation select bit. A read operation is initiated if this bit is high and a write operation is initiated if this bit is low.

Upon a compare of the device address, the EEPROM will output a zero. If a compare is not made, the chip will return to a standby state.

Write Operations

BYTE WRITE: A write operation requires an 8-bit data word address following the device address word and acknowledgment. Upon receipt of this address, the EEPROM will again respond with a zero and then clock in the first 8-bit data word. Following receipt of the 8-bit data word, the EEPROM will output a zero and the addressing device, such as a microcontroller, must terminate the write sequence with a stop condition. At this time the EEPROM enters an internally timed write cycle, t_{WR} , to the nonvolatile memory. All inputs are disabled during this write cycle and the EEPROM will not respond until the write is complete (see Figure 8 on page 11).

PAGE WRITE: The 1K/2K EEPROM is capable of an 8-byte page write, and the 4K, 8K and 16K devices are capable of 16-byte page writes.

A page write is initiated the same as a byte write, but the microcontroller does not send a stop condition after the first data word is clocked in. Instead, after the EEPROM acknowledges receipt of the first data word, the microcontroller can transmit up to seven (1K/2K) or fifteen (4K, 8K, 16K) more data words. The EEPROM will respond with a zero after each data word received. The microcontroller must terminate the page write sequence with a stop condition (see Figure 9 on page 11).

The data word address lower three (1K/2K) or four (4K, 8K, 16K) bits are internally incremented following the receipt of each data word. The higher data word address bits are not incremented, retaining the memory page row location. When the word address, internally generated, reaches the page boundary, the following byte is placed at the beginning of the same page. If more than eight (1K/2K) or sixteen (4K, 8K, 16K) data words are transmitted to the EEPROM, the data word address will "roll over" and previous data will be overwritten.

Read Operations

ACKNOWLEDGE POLLING: Once the internally timed write cycle has started and the EEPROM inputs are disabled, acknowledge polling can be initiated. This involves sending a start condition followed by the device address word. The read/write bit is representative of the operation desired. Only if the internal write cycle has completed will the EEPROM respond with a zero allowing the read or write sequence to continue.

Read operations are initiated the same way as write operations with the exception that the read/write select bit in the device address word is set to one. There are three read operations: current address read, random address read and sequential read.

CURRENT ADDRESS READ: The internal data word address counter maintains the last address accessed during the last read or write operation, incremented by one. This address stays valid between operations as long as the chip power is maintained. The address "roll over" during read is from the last byte of the last memory page to the first byte of the first page. The address "roll over" during write is from the last byte of the current page to the first byte of the same page.

Once the device address with the read/write select bit set to one is clocked in and acknowledged by the EEPROM, the current address data word is serially clocked out. The microcontroller does not respond with an input zero but does generate a following stop condition (see Figure 10 on page 12).

RANDOM READ: A random read requires a "dummy" byte write sequence to load in the data word address. Once the device address word and data word address are clocked in and acknowledged by the EEPROM, the microcontroller must generate another start condition. The microcontroller now initiates a current address read by sending a device address with the read/write select bit high. The EEPROM acknowledges the device address and serially clocks out the data word. The microcontroller does not respond with a zero but does generate a following stop condition (see Figure 11 on page 12).

SEQUENTIAL READ: Sequential reads are initiated by either a current address read or a random address read. After the microcontroller receives a data word, it responds with an acknowledge. As long as the EEPROM receives an acknowledge, it will continue to increment the data word address and serially clock out sequential data words. When the memory address limit is reached, the data word address will "roll over" and the sequential read will continue. The sequential read operation is terminated when the microcontroller does not respond with a zero but does generate a following stop condition (see Figure 12 on page 12).

Figure 7. Device Address

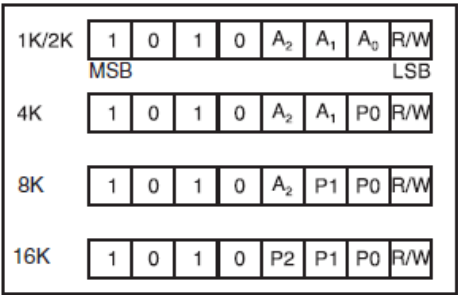


Figure 8. Byte Write

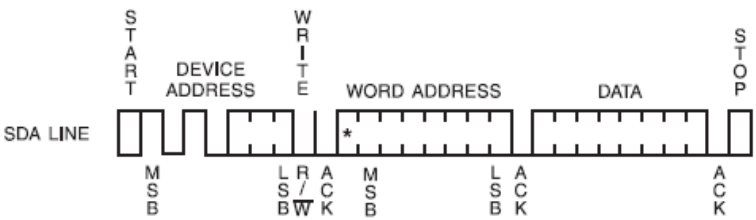
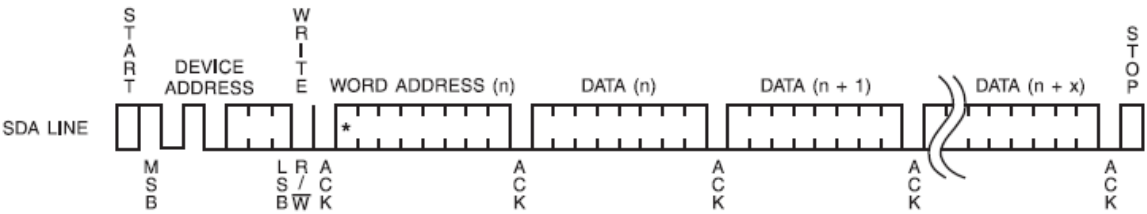


Figure 9. Page Write



(* = DON'T CARE bit for 1K)

Figure 10. Current Address Read

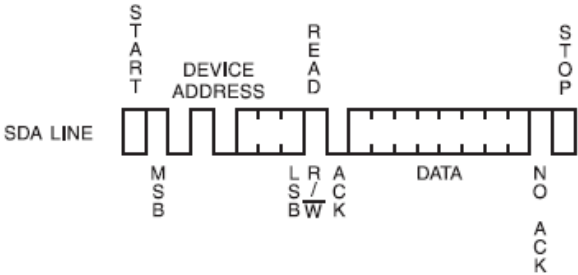
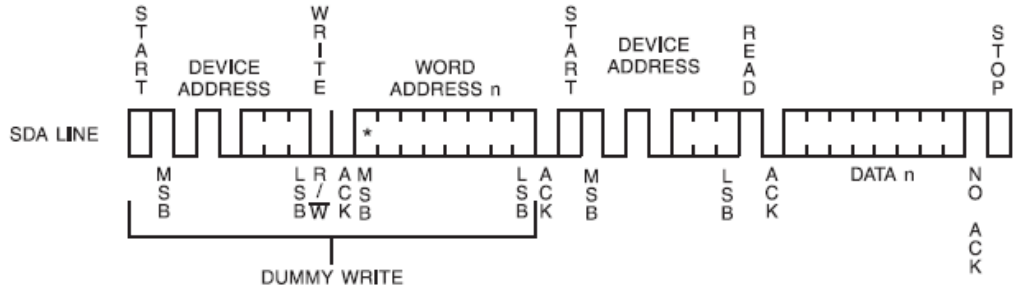
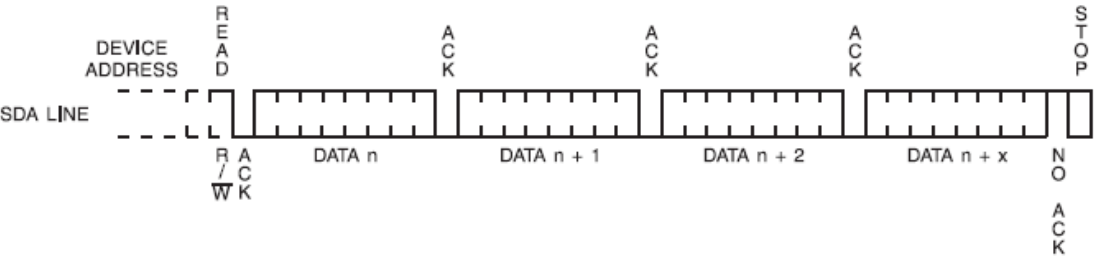


Figure 11. Random Read



(* = DON'T CARE bit for 1K)

Figure 12. Sequential Read



Appendix G

The Byte Level Write Method in MikroC

```
unsigned char I2C_Read_Byte_From_EEPROM(unsigned char page_write, unsigned
char page_read, unsigned char address) {
    unsigned char x;
    I2C1_Init(100000);
    I2C1_Start();           // issue I2C start signal
    I2C1_Wr(page_write);    // send byte via I2C (device address + W)
    I2C1_Wr(address);      // send byte (data address)
    I2C1_Repeated_Start(); // issue I2C signal repeated start
    I2C1_Wr(page_read);    // send byte (device address + R)
    x = I2C1_Rd(0);        // Read the data (NO acknowledge)
    I2C1_Stop();           // issue I2C stop signal
    return x;
    Delay_ms(20);
}
```

The Byte Level Read Method in MikroC

```
void I2C_Write_Byte_To_EEPROM(unsigned char page_write, unsigned char
address, unsigned char byte2write) {
    I2C1_Init(100000);    // initialize I2C communication
    I2C1_Start();         // issue I2C start signal
    I2C1_Wr(page_write);  // send byte via I2C (device address + W)
    I2C1_Wr(address);     // send byte (address of EEPROM location)
    I2C1_Wr(byte2write);  // send data (data to be written)
    I2C1_Stop();          // issue I2C stop signal
    Delay_ms(20);
}
```


Appendix H

Real-time clock Memory Organization

CLOCK AND CALENDAR

The time and calendar information is obtained by reading the appropriate register bytes. Table 2 shows the RTC registers. The time and calendar are set or initialized by writing the appropriate register bytes. The contents of the time and calendar registers are in the BCD format. The day-of-week register increments at midnight. Values that correspond to the day of week are user-defined but must be sequential (i.e., if 1 equals Sunday, then 2 equals Monday, and so on.) Illogical time and date entries result in undefined operation. Bit 7 of Register 0 is the clock halt (CH) bit. When this bit is set to 1, the oscillator is disabled. When cleared to 0, the oscillator is enabled. On first application of power to the device the time and date registers are typically reset to 01/01/00 01 00:00:00 (MM/DD/YY DOW HH:MM:SS). The CH bit in the seconds register will be set to a 1. The clock can be halted whenever the timekeeping functions are not required, which minimizes current (I_{BATDR}).

The DS1307 can be run in either 12-hour or 24-hour mode. Bit 6 of the hours register is defined as the 12-hour or 24-hour mode-select bit. When high, the 12-hour mode is selected. In the 12-hour mode, bit 5 is the AM/PM bit with logic high being PM. In the 24-hour mode, bit 5 is the second 10-hour bit (20 to 23 hours). The hours value must be re-entered whenever the 12/24-hour mode bit is changed.

When reading or writing the time and date registers, secondary (user) buffers are used to prevent errors when the internal registers update. When reading the time and date registers, the user buffers are synchronized to the internal registers on any I²C START. The time information is read from these secondary registers while the clock continues to run. This eliminates the need to re-read the registers in case the internal registers update during a read. The divider chain is reset whenever the seconds register is written. Write transfers occur on the I²C acknowledge from the DS1307. Once the divider chain is reset, to avoid rollover issues, the remaining time and date registers must be written within one second.

Table 2. Timekeeper Registers

ADDRESS	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0	FUNCTION	RANGE
00h	CH	10 Seconds			Seconds				Seconds	00–59
01h	0	10 Minutes			Minutes				Minutes	00–59
02h	0	12	10 Hour	10 Hour	Hours				Hours	1–12 +AM/PM 00–23
		24	PM/ AM							
03h	0	0	0	0	0	DAY			Day	01–07
04h	0	0	10 Date		Date				Date	01–31
05h	0	0	0	10 Month	Month				Month	01–12
06h	10 Year				Year				Year	00–99
07h	OUT	0	0	SQWE	0	0	RS1	RS0	Control	—
08h–3Fh									RAM 56 x 8	00h–FFh

0 = Always reads back as 0.

Appendix I

Real-time Clock Device Addressing

The DS1307 can operate in the following two modes:

1. **Slave Receiver Mode (Write Mode):** Serial data and clock are received through SDA and SCL. After each byte is received an acknowledge bit is transmitted. START and STOP conditions are recognized as the beginning and end of a serial transfer. Hardware performs address recognition after reception of the slave address and direction bit (see Figure 4). The slave address byte is the first byte received after the master generates the START condition. The slave address byte contains the 7-bit DS1307 address, which is 1101000, followed by the direction bit (R/ \bar{w}), which for a write is 0. After receiving and decoding the slave address byte, the DS1307 outputs an acknowledge on SDA. After the DS1307 acknowledges the slave address + write bit, the master transmits a word address to the DS1307. This sets the register pointer on the DS1307, with the DS1307 acknowledging the transfer. The master can then transmit zero or more bytes of data with the DS1307 acknowledging each byte received. The register pointer automatically increments after each data byte are written. The master will generate a STOP condition to terminate the data write.
2. **Slave Transmitter Mode (Read Mode):** The first byte is received and handled as in the slave receiver mode. However, in this mode, the direction bit will indicate that the transfer direction is reversed. The DS1307 transmits serial data on SDA while the serial clock is input on SCL. START and STOP conditions are recognized as the beginning and end of a serial transfer (see Figure 5). The slave address byte is the first byte received after the START condition is generated by the master. The slave address byte contains the 7-bit DS1307 address, which is 1101000, followed by the direction bit (R/ \bar{w}), which is 1 for a read. After receiving and decoding the slave address the DS1307 outputs an acknowledge on SDA. The DS1307 then begins to transmit data starting with the register address pointed to by the register pointer. If the register pointer is not written to before the initiation of a read mode the first address that is read is the last one stored in the register pointer. The register pointer automatically increments after each byte are read. The DS1307 must receive a Not Acknowledge to end a read.

Figure 4. Data Write—Slave Receiver Mode

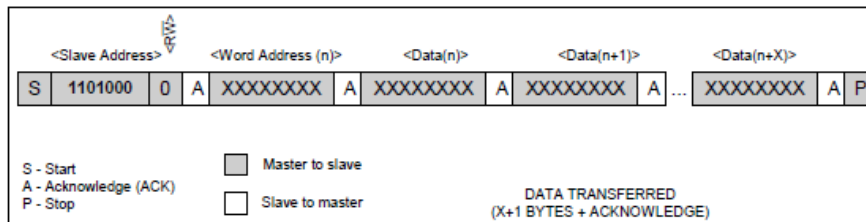
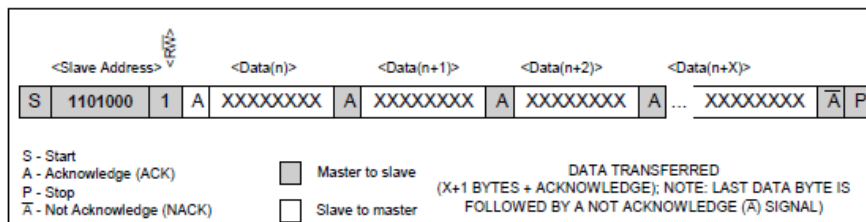


Figure 5. Data Read—Slave Transmitter Mode



Appendix J

MikroC Code for Reading and Writing Time to DS1307

Reading Time

```
void Read_Time(unsigned char *sec, unsigned char *min, unsigned char *hr, unsigned char *week_day,
unsigned char *day, unsigned char *mn, unsigned char *year) {
    I2C1_Start();
    I2C1_Wr(DEVICEID_DS1307);
    I2C1_Wr(0);
    I2C1_Repeated_Start();
    I2C1_Wr(0xD1);
    *sec = I2C1_Rd(1);
    *min = I2C1_Rd(1);
    *hr = I2C1_Rd(1);
    *week_day = I2C1_Rd(1);
    *day = I2C1_Rd(1);
    *mn = I2C1_Rd(1);
    *year = I2C1_Rd(0);
    I2C1_Stop();
}
```

Writing Time

```
void Write_Time(unsigned char sec, unsigned char min, unsigned char hours, unsigned char day,
unsigned char dayofweek, unsigned char month, unsigned char year) {
    I2C1_Start();    // issue start signal
    I2C1_Wr(DEVICEID_DS1307);    // address DS1307 which is 0xD0
    I2C1_Wr(0);    // start from word at address (REG0)
    I2C1_Wr(0x80 + sec);    // write $80 to REG0. (pause counter + 0 sec)
    I2C1_Wr(min);    // write 0 to minutes word to (REG1)
    I2C1_Wr(hours);    // write 17 to hours word (24-hours mode)(REG2)

    I2C1_Wr(dayofweek);    // write 5 - Tuesday (REG3)
    I2C1_Wr(day);    // write 18 to date word (REG4)
    I2C1_Wr(month);    // write 10 (Oct) to month word (REG5)
    I2C1_Wr(year);    // write 12 to year word (REG6)
    I2C1_Stop();    // issue stop signal

    I2C1_Start();    // issue start signal
    I2C1_Wr(DEVICEID_DS1307);    // address DS1307 which is 0xD0
    I2C1_Wr(0);    // start from word at address 0
    I2C1_Wr(0);    // write 0 to REG0 (enable counting + 0 sec)
    I2C1_Stop();    // issue stop signal
}
```