Technical University of Košice
Faculty of Electrical Engineering and Informatics

Modification of gl.inet board for communication with peripheral devices

Master's Thesis

2013 Peter Babič

Technical University of Košice
Faculty of Electrical Engineering and Informatics

Modification of gl.inet board for communication with peripheral devices

Master's Thesis

Study Programme:	Infoelectronics
Field of study:	5.2.13 Electronics
Department:	Department of Elecronics and Multimedia Communications (KEMT)
Supervisor:	doc. Ing. Vojtech Čierny, CSc.
Consultant(s):	Ing. Matej Biely, PhD.
	RNDr. Marián Čierny, DrSc.

Košice 2013 **Peter Babič**

Errata

Modification of gl.inet board for communication with peripheral devices

Peter Babič

Košice 2013

Ak je potrebné, autor na tomto mieste opraví chyby, ktoré našiel po vytlačení práce. Opravy sa uvádzajú takým písmom, akým je napísaná práca. Ak zistíme chyby až po vytlačení a zviazaní práce, napíšeme erráta na samostatný lístok, ktorý vložíme na toto miesto. Najlepšie je lístok prilepi

Forma:

Strana	Riadok	Chybne	Správne
12	6	publikácia	prezentácia
22	23	internet	intranet

Abstract

Text abstraktu v svetovom jazyku je potrebný pre integráciu do medzinárodných informačných systémov. Ak nie je možné cudzojazyčnú verziu abstraktu umiestniť na jednej strane so slovenským abstraktom, je potrebné umiestniť ju na samostatnú stranu (cudzojazyčný abstrakt nemožno deliť a uvádzať na dvoch strabách).

Keywords
Optimization, thesis, writing

Abstrakt

Abstrakt je povinnou súčasťou každej práce. Je výstižnou charakteristikou obsahu dokumentu. Nevyjadruje hodnotiace stanovisko autora. Má byť taký informatívny, ako to povoľuje podstata práce. Text abstraktu sa píše ako jeden odstavec. Abstrakt neobsahuje odkazy na samotný text práce. Mal by mať rozsah 250 až 500 slov. Pri štylizácii sa používajú celé vety, slovesá v činnom rode a tretej osobe. Používa sa odborná terminológia, menej zvyčajné termíny, skratky a symboly sa pri prvom výskyte v texte definujú.

Kľúčové slová
Optimalizácia, záverečná práca, písanie

Assign Thesis

Namiesto tejto strany vložte naskenované zadanie úlohy. Odporúčame skenovať s rozlíšením 200 až 300 dpi, čierno-bielo! V jednej vytlačenej ZP musí byť vložený originál zadávacieho listu!

Declaration

I hereby declare that this thesis is my own work and effort. Where other sources of information have been used, they have been acknowledged.

Košice, April 24, 2013 ....

Signature

Acknowledgement

I would like to express my sincere thanks to my supervisor Dr Vojtech Čierny, PhD, the main Supervisor. Special mention should go to Dr Matej Biely, CSc. for his constant, and constructive guidance throughout the study. To all other who gave a hand, I say thank you very much.

Preface

Predhovor (*Preface*) je povinnou náležitosťou záverečnej práce, pozri V predhovore autor uvedie základné charakteristiky svojej záverečnej práce a okolnosti jej vzniku. Vysvetlí dôvody, ktoré ho viedli k voľbe témy, cieľ a účel práce a stručne informuje o hlavných metódach, ktoré pri spracovaní záverečnej práce použil.

Contents

List of Figures

List of Tables

Acronyms

ADC Analog-to-digital converter
AP Access Point
ASIC Application-specific integrated circuit
CPU Central processing unit
DAC Digital-to-analog converter
DDR Double data rate synchronous DRAM
DRAM Dynamic random-access memory
DSP Digital signal processor
EEPROM Electrically erasable programmable read-only memory
FPGA Field-programmable gate array
GPIO General-purpose input/output
HW Hardware
Hz Hertz, the SI unit of frequency
I^2S Integrated Interchip Sound
IC Integrated circuit
IEEE Institute of Electrical and Electronics Engineers
IP Internet Protocol
JTAG Joint test action group
LAN Local area network
LED Light emitting diode
LNA low-noise amplifier
LPCC Quad Flat No-leads
MHz Mega-hertz
MIPS Microprocessor without Interlocked Pipeline Stages
OS Operating system
PA Power amplifier
PCM Pulse code modulation
PDA Personal digital assistant
RAM Random-access memory
RF Radio frequency
ROM Read-Only memory
RTOS Real-time operating system
S/PDIF Sony-Philips Digital Interface Format

SDR Synchronous dynamic random access memory

SLIC Subscriber line interface circuit

SoC System-on-Chip

SPI Serial peripheral interface

SW Software

UART Universal asynchronous receiver/transmitter

USB Universal serial bus

VOIP Voice over IP

WAN Wide area network

WLAN Wireless local area network

List of Terms

Ethernet is a family of computer networking technologies for local area networks (LANs) and metropolitan area networks (MANs). it's standars is IEEE 802.3.

Firmware is "the combination of a hardware device, e.g. an integrated circuit, and computer instructions and data that reside as read only software on that device". As a result, firmware usually cannot be modified during normal operation of the device.

Flash (memory) is an electronic non-volatile computer storage medium that can be electrically erased and reprogrammed. Flash memory was developed from EEPROM (electrically erasable programmable read-only memory).

Linux is a Unix-like and mostly POSIX-compliant computer operating system assembled under the model of free and open-source software development and distribution.

Router is a networking device that forwards data packets between computer networks. A router is connected to two or more data lines from different networks.

System is a set of interacting or interdependent components forming an integrated whole, observing properties not obtainable with individual components.

Introduction

1 Embedded systems

An embedded system is some combination of computer Hardware (HW) and Software (SW), either fixed in capability or programmable, that is specifically designed for a particular function [3]. Industrial machines, automobiles, medical equipment, cameras, household appliances, airplanes, vending machines and toys (as well as the more obvious cellular phone and Personal digital assistant (PDA)) are among the myriad possible hosts of an embedded system. Embedded systems that are programmable are provided with programming interfaces, and embedded systems programming is a specialized occupation.

1.1 Processing units

The term embedded system is quite broad, so there is no surprise that the spectrum of used processing units is also wide. Since the general purpose microprocessors require external components, namely memories and peripherals, they tend to consume extra power and a board space. Since the design limitations of an embedded systems are most of the time low physical size, low power consumption and/or long uptime and ruggedness (more components mean more parts could fail), microprocessors are seldom used. However, most of the commonly used architectures and word lengths are covered. Due to aforementioned reasons, microcontrollers are favored over microprocessors.

1.2 System-on-chip

Today's state of chip integration allows production costs of a complex system on chip devices to be relatively low, thus making System-on-Chip (SoC) attractive choice for embedded systems. SoCs could be described as an Integrated circuit (IC) that integrates all components of a computer or other electronic system into a single chip. It may contain digital, analog, mixed-signal, and often radio-frequency functions - all on a single chip substrate [2]. SoCs are very common in the mobile electronics market because of their low power consumption.

A typical SoC consists of (specific block diagram can be seen on 2 − 1):

- a microcontroller, microprocessor or Digital signal processor (DSP) core(s)
- memory blocks including a selection of Read-Only memory (ROM), Random-access memory (RAM), Electrically erasable programmable read-only memory (EEPROM) and Flash

- timing sources including oscillators and phase-locked loops
- peripherals including counter-timers, real-time timers and power-on reset generators
- external interfaces, including industry standards such as Universal serial bus (USB), FireWire, Ethernet, Universal asynchronous receiver/transmitter (UART), Serial peripheral interface (SPI)
- analog interfaces including Analog-to-digital converters (ADCs) and Digital-to-analog converters (DACs)
- voltage regulators and power management circuits
- a bus connecting these blocks

SoCs can be implemented as an Application-specific integrated circuit (ASIC) or using a Field-programmable gate array (FPGA).

1.3 Operating systems

An Operating system (OS) is a computer program that supports a computer's basic functions, and provides services to other programs (or applications) that run on the computer. The applications provide the functionality that the user of the computer wants or needs. The services provided by the operating system make writing the applications faster, simpler, and more maintainable.

Over time, a lot of *embedded* OSes suited for embedded systems were developed. An embedded OS is a type of OS that is embedded and specifically configured for a certain HW configuration. HW that uses embedded OS is designed to be lightweight and compact, forsaking many other functions found in non-embedded (i.e. desktop) computer systems in exchange for efficiency at resource usage [5]. This means that they are made to do specific tasks and do them efficiently. Notable embedded OSes currently in use by consumers include:

- **Symbian** - used in cell phones, mainly ones made by Nokia
- **Embedded Linux** - used in many other devices like printers, routers or smart TVs; Android $1-1$ is a subset of embedded Linux
- **BlackBerry OS** - for BlackBerry phones
- **iOS** - subset of Mac OS X, used in Apple's mobile devices Palm OS
- **Windows Mobile**

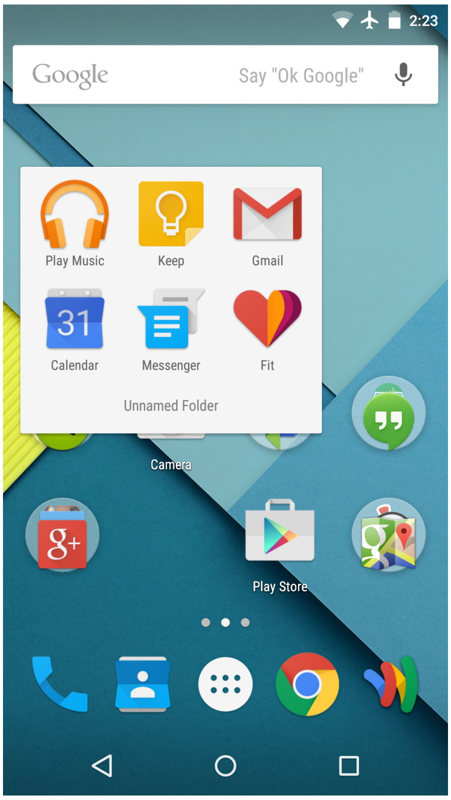

Figure 1 − 1 The Android 5 (Lollipop) screenshot - the most common operating system is among embedded ones

1.4 Real-time operating systems

A Real-time operating system (RTOS) is just a special purpose OS. The *real time* part of the name does not mean that the system responds quickly, it just means that there are rigid time requirements that must be met. If these time requirements are not met, the results can become inaccurate or unreliable[6]. Embedded systems frequently posses the real time requirement. There are two kinds of RTOS:

Hard Real Time - system delays are known or at least bounded. Said to be operating correctly if the system can return results within any time constraints.

Soft Real Time - critical tasks get priority over other tasks and will retain priority until the task is completed. This is another way of saying that real time tasks cannot be kept waiting indefinitely. Soft real time makes it easier to mix the system with other systems.

1.5 Embedded Linux

Linux itself is a kernel, but *Linux* in day to day terms rarely means so. Embedded Linux generally refers to a complete Linux distribution targeted at embedded devices. There is no Linux kernel specifically targeted at embedded devices, the same Linux kernel source code can be built for a wide range of devices, workstations, embedded systems, and desktops though it allows the configuration of a variety of optional features in the kernel itself. In the embedded development context, there can be an embedded Linux system which uses the Linux kernel and other software or an embedded Linux distribution which is a prepackaged set of applications meant for embedded systems and is accompanied by development tools to build the system[4].

With the availability of consumer embedded devices, communities of users and developers were formed around theses devices: Replacement or enhancements of the Linux distribution shipped on the device has often been made possible thanks to availability of the source code and to the communities surrounding the devices. Due to the high number of devices, standardized build systems have appeared like OpenEmbedded, Buildroot, OpenWrt, and LTIB.

1.6 Kernel

The *kernel* is the essential center of a computer OS, the core that provides basic services for all other parts of the OS [1]. It has complete control over what happens in the system. A kernel can be contrasted with a *shell*, the outermost part of an OS that interacts with user commands. Kernel and shell are terms used more frequently in Unix or Unix-like operating systems than in IBM mainframe or Microsoft Windows systems.

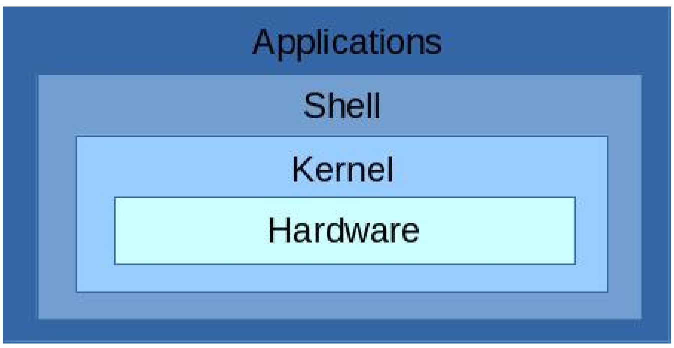

Figure 1 − 2 The simplified view on the Linux system structure

The simplified view on the Linux system structure can be seen on 1 − 2. It does not include device drivers, compilers, deamon, utilities, commands, library files and such, but should be enough for a demonstration.

1.7 OpenWRT

OpenWrt is an OS (in particular, an embedded OS) based on the Linux kernel, primarily used on embedded devices to route network traffic. The main components are the Linux kernel, util-linux, uClibc and BusyBox. All components have been optimized for size, to be small enough for fitting into the limited storage and memory available in home routers.

OpenWrt is configured using a command-line interface (ash shell), or a web interface (LuCI). There are about 3500 optional SW packages available for installation via the opkg package management system.

2 GL.inet board

GL.inet Smart Router is a remake of a common TP-Link router TL-WR703N. The board changes include, but are not limited to, increased RAM and Flash memory, custom firmware and what is the most important - 5 usable General-purpose input/output (GPIO) pins exposed to the 2cm pin header for utility. Whole thesis is revolving around taking advantage of this fact. The Central processing unit (CPU) frequency is 400 Mega-hertz (MHz) and it is suited for running Linux distributions for embedded devices, preferably OpenWrt or DD-Wrt. The board provides Local area network (LAN) and Wide area network (WAN) connection, as well as other interfaces defined in Institute of Electrical and Electronics Engineers (IEEE). The information about the board are summed up in the table $2-1$.

Table 2 − 1 The basic characteristics of the GL.inet board

Model	GL-iNet 6408A / 6416A
CPU	Atheros 9331, 400 MHz
RAM	DDR 64MB
ROM	Flash 8MB (6408A) / 16MB (6416A)
Interface	1 WAN, 1 LAN, 1 USB2.0, 1 Micro USB(Power), 5 GPIO
Wireless	IEEE802.11n/g/b, IEEE 802.3, IEEE 802.3u

2.1 Atheros 9331 Wi-fi System-on-Chip

The Atheros AR9331 is a highly integrated and cost effective IEEE 802.11n 1x1 2.4 GHertz, the SI unit of frequency (Hz) SoC for Wireless local area network (WLAN) Access Point (AP) and router platforms. The block diagram of the chip can be seen on figure $2-1$. Features of this SoC are following:

- Complete IEEE 802.11n 1x1 AP or router in a single chip
- Microprocessor without Interlocked Pipeline Stages (MIPS) 24K processor operating at up to 400 MHz
- External 16-bit Double data rate synchronous DRAM (DDR) or Synchronous dynamic random access memory (SDR) memory interface
- SPI NOR Flash memory support

- No external EEPROM needed
- 4 LAN ports and 1 WAN port IEEE802.3 Fast Ethernet switch with auto-crossover, auto polarity
- Fully integrated Radio frequency (RF) front-end including Power amplifier (PA) and low-noise amplifier (LNA)
- Optional external LNA/PA
- Switched antenna diversity
- High-speed UART for console support
- Integrated Interchip Sound (I^2S)/Sony-Philips Digital Interface Format (S/PDIF) audio interfaces
- Subscriber line interface circuit (SLIC) for Voice over IP (VOIP)/Pulse code modulation (PCM)
- USB 2.0 host/device mode support
- GPIO/Light emitting diode (LED) support
- Joint test action group (JTAG)-based processor debugging supported
- 25 MHz or 40 MHz reference clock input
- 148-pin, 12 mm x 12 mm dual-row Quad Flat No-leads (LPCC) package

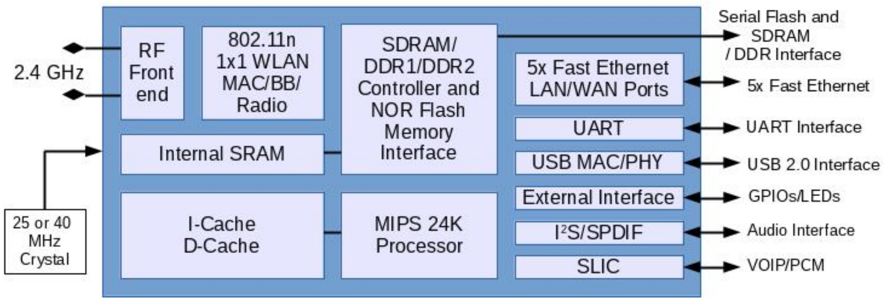

Figure 2 – 1 The block diagram of the Atheros AR9331 SoC used as a main processing unit on GL.inet board

2.2 From TL-WR703N to GL.inet

TP-Link TL-WR703N router is a popular choice among hacker community because of it's cheap price tag compared to processing power and usage of a full-grown Linux distribution. People have figured out how to upgrade RAM / Flash memories or to make use of not used GPIO / UART ports for their own needs. These solutions however were mostly crude and expensive to replicate. The GL.inet team saw an opportunity to grasp this public knowledge and rolled out their own improved board clone to the marked.

Whole printed circuit board of TL-WR703N was remade by the GL.inet team to expose the unused GPIO ports on the SoC, utilize two Ethernet port instead of one and utilize the USB 2.0 port. Memory chips were replaced by their higher capacity alternatives.

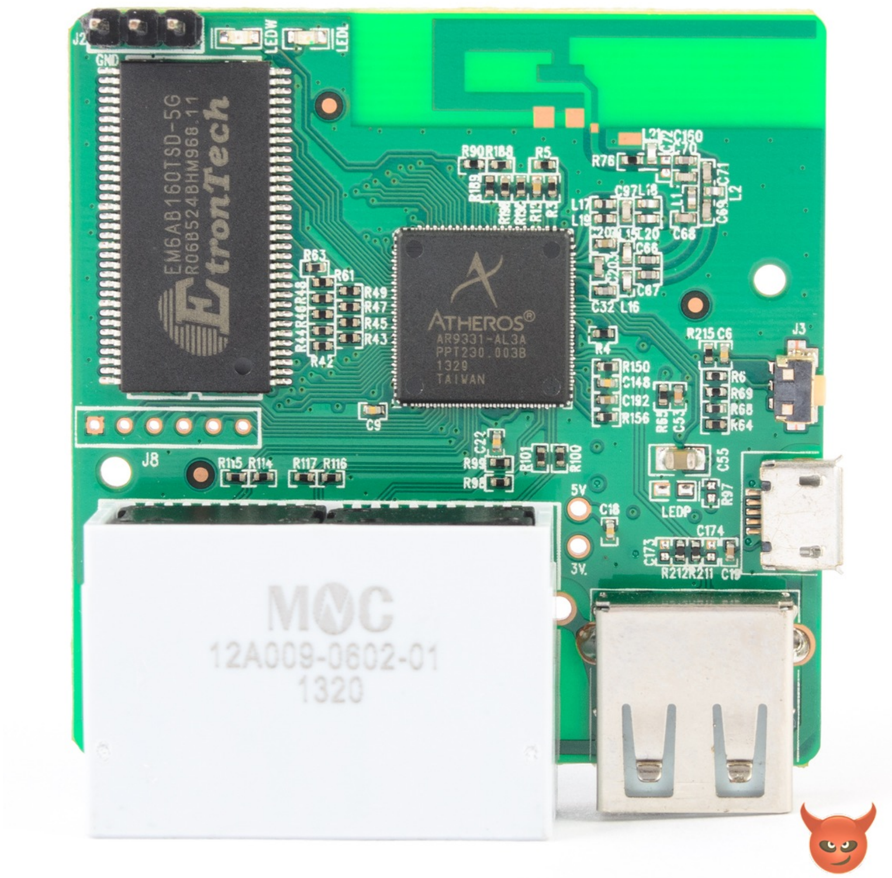

Figure 2 – 2 The front side of the GL.inet board exposing the main Atheros SoC, RAM and interfaces

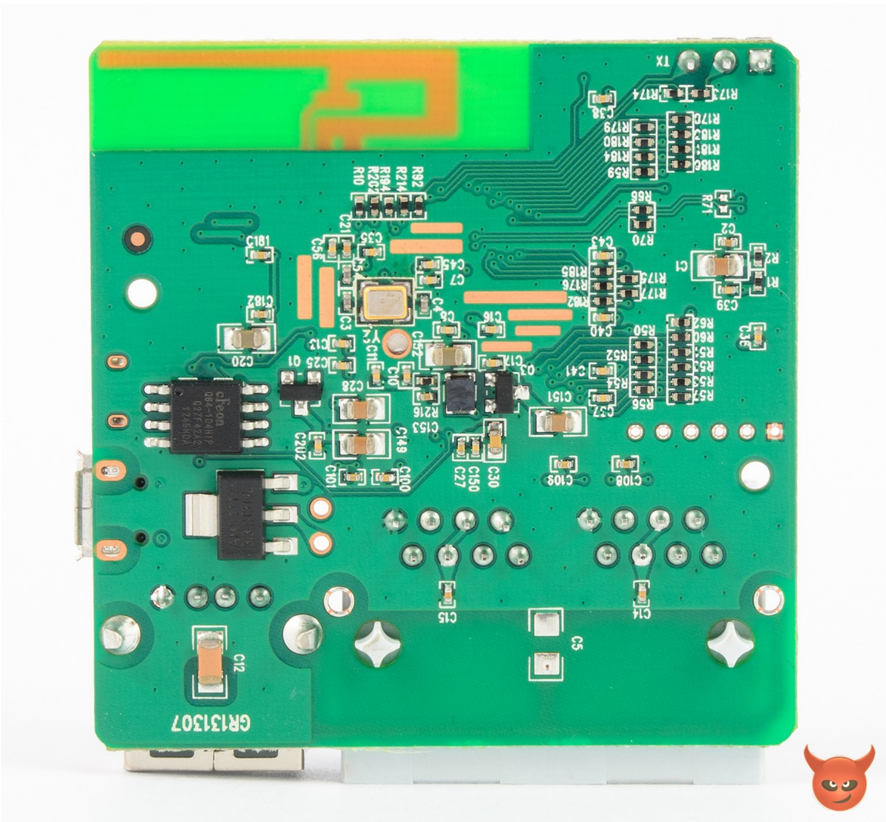

Figure 2 – 3 The back side of the GL.inet board exposing the Flash memory and a main voltage regulator

3 Analytical considerations

4 Main part of Thesis

5 Conclusion

Táto časť záverečnej práce je povinná. Autor uvedie zhodnotenie riešenia. Uvedie výhody, nevýhody riešenia, použitie výsledkov, ďalšie možnosti a pod., prípadne načrtne iný spôsob riešenia úloh, resp. uvedie, prečo postupoval uvedeným spôsobom.

References

[1] D.P. Bovet and M. Cesati. *Understanding the Linux Kernel*. O'Reilly Media, 2005. ISBN: 9780596554910.

[2] M.J. Flynn and W. Luk. *Computer System Design: System-on-Chip*. Wiley, 2011. ISBN: 9781118009918.

[3] J.G. Ganssle and S.R. Ball. *Embedded Systems*. Computer languages, systems & structures. Elsevier/Newnes, 2008. ISBN: 9780750686259.

[4] C. Hallinan. *Embedded Linux Primer: A Practical Real-World Approach*. Prentice Hall Open Source Software Development Series. Pearson Education, 2010. ISBN: 9780137061105.

[5] A. Holt and C.Y. Huang. *Embedded Operating Systems: A Practical Approach*. Undergraduate Topics in Computer Science. Springer London, 2014. ISBN: 9781447166030.

[6] Jean J. Labrosse. *MicroC/OS-II: The Real Time Kernel*. Meets requirements for safety-critical systems. Taylor & Francis, 2002. ISBN: 9781578201037.

Appendices

Appendix A Prílohy

Appendix B Bibliografické odkazy

Appendix C Vytvorenie zoznamu skratiek a symbolov

Appendix D

Appendix A

Prílohy (Appendices)

Táto časť záverečnej práce je povinná a obsahuje zoznam všetkých príloh vrátane elektronických nosičov. Názvy príloh v zozname musia byť zhodné s názvami uvedenými na príslušných prílohách. Tlačené prílohy majú na prvej strane identifikačné údaje – informácie zhodné s titulnou stranou záverečnej práce doplnené o názov príslušnej prílohy. Identifikačné údaje sú aj na priložených diskoch alebo disketách. Ak je médií viac, sú označené aj číselne v tvare I/N, kde I je poradové číslo a N je celkový počet daných médií. Zoznam príloh má nasledujúci tvar:

Appendix A CD médium – záverečná práca v elektronickej podobe, prílohy v elektronickej podobe.

Appendix B Používateľská príručka

Appendix C Systémová príručka

Prílohová časť je samostatnou časťou kvalifikačnej práce. Každá príloha začína na novej strane a je označená samostatným písmenom (Appendix A, Appendix B, ...). Číslovanie strán príloh nadväzuje na číslovanie strán v hlavnom texte. Pri každej prílohe sa má uviesť prameň, z ktorého sme príslušný materiál získali.

Appendix B

Bibliografické odkazy

Táto časť záverečnej práce je povinná. V zozname použitej literatúry sa uvádzajú odkazy podľa normy STN ISO 690–2 (01 0197) (Informácie a dokumentácia. Bibliografické citácie. Časť 2: Elektronické dokumenty alebo ich časti, dátum vydania 1. 12. 2001, ICS: 01.140.20). Odkazy sa môžu týkať knižných, časopiseckých a iných zdrojov informácií (zborníky z konferencií, patentové dokumenty, normy, odporúčania, kvalifikačné práce, osobná korešpondencia a rukopisy, odkazy cez sprostredkujúci zdroj, elektronické publikácie), ktoré boli v záverečnej práci použité.

Existujú dva hlavné spôsoby citovania v texte.

- Citovanie podľa mena a dátumu.
- Citovanie podľa odkazového čísla.

Preferovanou metódou citovania v texte vysokoškolskej a kvalifikačnej práce je podľa normy ISO 7144 citovanie podľa mena a dátumu . V tomto prípade sa zoznam použitej literatúry upraví tak, že za meno sa pridá rok vydania. Na uľahčenie vyhľadávania citácií sa zoznam vytvára v abecednom poradí autorov.

Príklad: ...podľa je táto metóda dostatočne rozpracovaná na to, aby mohla byť všeobecne používaná v ...

Druhý spôsob uvedenia odkazu na použitú literatúru je uvedenie len čísla tohto zdroja v hranatých zátvorkách bez mena autora (autorov) najčastejšie na konci príslušnej vety alebo odstavca.

Príklad: ...podľa [13] je táto metóda dostatočne rozpracovaná na to, aby mohla byť všeobecne používaná v ...ako je uvedené v [14].

Citácie sú spojené s bibliografickým odkazom poradovým číslom v tvare indexu alebo čísla v hranatých zátvorkách. Odkazy v zozname na konci práce budú usporiadané podľa týchto poradových čísel. Viacero citácií toho istého diela bude mať rovnaké číslo. Odporúča sa usporiadať jednotlivé položky v poradí citovania alebo podľa abecedy.

Rôzne spôsoby odkazov je možné dosiahnuť zmenou voľby v balíku `natbib`:

```
% Citovanie podla mena autora a roku
\usepackage[]{natbib}\citestyle{chicago}
% Možnosť rôznych štýlov citácií. Príklady sú uvedené
% v preambule súboru natbib.sty.
% Napr. štýly chicago, egs, pass, anngeo, nlinproc produkujú
% odkaz v tvare (Jones, 1961; Baker, 1952). V prípade, keď
% neuvedieme štýl citácie (vynecháme \citestyle{}) v "options"
% balíka natbib zapíšeme voľbu "colon".
```

Keď zapneme voľbu `numbers`, prepneme sa do režimu citovania podľa odkazového čísla.

```
% Metoda ciselnych citacii
\usepackage[numbers]{natbib}
```

Pri zápise odkazov sa používajú nasledujúce pravidlá:

Pri využívaní informácií z elektronických dokumentov treba dodržiavať tieto zásady:

- upredností̌ujeme autorizované súbory solídnych služieb a systémov,
- zaznamenáme dostatok informácií o súbore tak, aby ho bolo opäť možné vyhľadať,
- urobíme si kópiu použitého prameňa v elektronickej alebo papierovej forme,
- za verifikovateľnosť informácií zodpovedá autor, ktorý sa na ne odvoláva.

Pre zápis elektronických dokumentov platia tie isté pravidlá, ako pre zápis „klasických“. Navyše treba uviesť tieto údaje:

- druh nosiča [online], [CD-ROM], [disketa], [magnetická páska]
- dátum citovania (len pre online dokumenty)
- dostupnosť (len pre online dokumenty)

Poradie prvkov odkazu je nasledovné: Autor. Názov. In Názov primárneho zdroja: Podnázov. [Druh nosiča]. Editor. Vydanie alebo verzia. Miesto vydania : Vydavateľ, dátum vydania. [Dátum citovania]. Poznámky. Dostupnosť. ISBN alebo ISSN.

Appendix C

Vytvorenie zoznamu skratiek a symbolov

Ak sú v práci skratky a symboly, vytvára sa *Zoznam skratiek a symbolov* (a ich dešifrovanie). V prostredí LaTeXu sa takýto zoznam ľahko vytvorí pomocou balíka `nomencl`. Postup je nasledovný:

Curriculum vitae

Táto časť je nepovinná. Autor tu môže uviesť svoje biografické údaje, údaje o záujmoch, účasti na projektoch, účasti na súťažiach, získané ocenenia, zahraničné pobyty na praxi, domácu prax, publikácie a pod.