PRINTSHOP: SERIAL PRINTER ENVIRONMENTS AND SECURITY

Research Proposal

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Introduction

1.1 Background

Serial printers are devices commonly used for instant reporting of system data for industrial control systems (ICS) and receipts for point-of-sale (POS) systems. These devices are connected to their host using Wi-Fi, bluetooth, ethernet, or USB; in some cases, serial RS232 is an option as well. The goal of this research is to assess what software and hardware protections are enabled, as well as, how configurable the serial printers are for further exploit research.

(a) Square POS (b) SurePOS

Figure 1.1: Comparison of common POS systems

Figure 1.1 shows us two similar looking point-of-sale systems, albeit one is much older looking. However, the operating system and required hardware is very different. Typically, unless you have the Square provided terminal, their software/client is installed onto an Android or iOS device and connected to a Square compatible card reader [1]. Whereas, the SurePoS, NCR, or other common EFTPoS system will run a proprietary OS based on Windows or Linux [2]. Furthermore, these PoS tend to require some form of printing receipts as record keeping for the business owner and customer. And these devices also vary in terms of processing capabilities and operating system.

For instance, a common thermal printer seen with PoS systems, integrated with fuel pumps, or other industrial control equipment, is the SNBC BTP-S80 thermal printer [3], [4]. There are multiple versions of the device with support for Bluetooth, USB only, or combination of USB/Serial/Ethernet. The bluetooth hardware is provided over an accessory 25-pin serial connection, with more I/O as a serial connection via RS232C connector and USB Type-B. It has driver support for various platforms: Android, iOS, Windows, Linux, and MacOS. The most interesting aspects are the processor, an Arm Cortex M4 clocked at 3.54MHz, and the operating system, a proprietary version of FreeRTOS. The system architecture is Armv7E-M with JTAG/SWD hardware debugging support [5], [6].

By default, the printer has enough headroom to process ESC/POS commands for printing paper and a webserver for debugging or general diagnostics. In theory, the uncompromised device could be flashed with modified firmware to act as a decoy and human-input-device (HID) against the host PoS. The viability of any vulnerabilities would likely be dependent upon supply chain attacks or physical bait-and-switch tactics [7].

1.2 Significance

According to the Federal Trade Commission (FTC), there were 37,932 reports of credit card fraud in 2012 and 87,451 reports in 2022. This marks an increase of credit card payment fraud by an estimated, 30.5%. By comparison, since 2020, there has been a 14.6% increase in credit card related fraud. Which does not include the millions of other fraud reports the FTC receives every year. In 2022 alone, there were around 5.1 million fraud, identity theft, and miscellaneous reports in total [8], [9]. The statistics for these reports stresses how crucial the security of payment systems are, both physical and online. And, the need to secure them grows every year.

Spyduino is [10] a working example of a programmable BadUSB device using an Arduino to mimic a Human Interface Device (HID). Arduinos are typically more accessible

and easily developed compared to an embedded device whose design is more single purpose. Especially if the goal is to not modify hardware or require hands-on access for exploitation. However, the research shows us that is it possible create HID clones from scratch if the hardware is compatible.

The Arduino used in their research is powered by an ATmega328P microcontroller with 32KB flash memory, 2KB SRAM, and 1KB EEPROM. Compared to the most likely target device of our proposed research, the SNBC BTP-S80, it features an ARM Cortex M4 microcontroller with 512KB flash memory, 96KB SRAM, 4KB of EEPROM. BadUSBs are a known and tested area of research. The novelty of this proposal comes from the assessment of the printer devices and showing whether one could be used maliciously within their environments (e.g., PoS systems, or ICS).

1.3 Research Goals and Objectives

This research primarily focuses on physical POS systems or terminals and their hardware (serial accessories), rather than online solutions. For instance, not mobile payment apps like Venmo, CashApp, Zelle, or Paypal [11]. There are many reasons, but the types of systems being targeted varies greatly in terms of the hardware and software supported, as well as, how the transactions are handled with the payment processor. Presumably, the host-to-guest communication will not differ greatly between other environments (e.g., ICS). If the printers have demonstrable weaknesses with an Ubuntu host, that will fulfill the testing requirements.

The goal of this research is to further establish academic works in regards to embedded printer devices testing and security. This area is loosely documented within academia and only mentioned vaguely in relation to statistical reports or applied research using entirely different environments. For instance, most researchers limit their analysis of the environment to smartphones and the corresponding payment app, or detection systems

for card skimmers [7]. Through this research we hope to apply gainful conclusions towards the development of an embedded environment for vulnerability assessment, penetration testing, and hardware-to-software interoperability against device hosts. Some examples of how the research could be applied in the future vary: BadUSB/BashBunny [12], JuiceShop [13], DVWA [14], or Webgoat [15]; no such work exists for embedded systems within the point-of-sale or serial printer context.

1.4 Research Questions

The research questions that this proposal seeks to answer are as follows:

- Q1: Can the hardware be reflashed with a modified firmware image (e.g., FreeRTOS, ReconOS, VxWorks)?
- Q2: Does the base OS have bandwidth to support HID functionality?
- Q3: Besides HID cloning, what other threat areas are exposed (e.g., network stack, web management portal, memory protections)?

Each of these goals will be approached individually as prescribed by the methodology.

Related Works

2.1 RTOS: Software and Security

[16] introduces several embedded kernels and discusses their differences in regard to developing a secure mass storage device. For this research, we are primarily interested in RTOS-like kernels because of existing support for a sample device like the SNBC BTP-S80 printer. However, the paper criticizes such operating systems because their "real-time driven design is barely compatible with the overhead produced by security mechanisms." For many applications, there is a trade off with RTOS where performance is the main criteria and security is not a priority. [17] introduces several common RTOS and discusses their security issues. Notably, most RTOS are susceptible to code injection, cryptography inefficiency, unprotected shared memory, priority inversion, denial of service attacks, privilege escalation, and inter-process communication vulnerabilities. Depending on the MPU (microprocessor unit), the vendor has hardware protections like Intel SGX or Arm Trust Zone. These are all areas that can be used for pivoting onto the device, especially shared memory and privilege escalation. If the target device firmware is outdated (or, even libraries used by the firmware) and there are known CVEs that can be repeatedly exploited, persistence mechanisms are not a requirement to gain routine access.

2.2 PoS Attack Patterns

Section Outline:

- Card skimming (NFC + Magnetic)
- Terminal swapping
- Fake payment processor requests (e.g., venmo, cashapp)

- Memory scraping (i.e., virtualized PoS systems)
- EMV cloning

2.3 BadUSB-like Devices

BadUSB is a well-known and documented attack vector. One of the most popular hacker tools is built-on the concept [12]. However, there are some limitations:

- Precision of attacks is limited since scripts or effects are typically deployed blind. There is no knowledge of the user environment nor ability to interact with functional user interface mechanisms (e.g., a mouse clicking a button).
- Limited to the USB 2.0 standard. Meaning, no support for video adapters like HDMI, DisplayPort, or PowerDelivery like with USB 3.0.
- There are existing methods for limiting USB access from the host, such as GoodUSB [18].

GoodUSB supports the Linux USB stack, so another solution would be required for Windows systems or RTOS. This all depends on the environment of the connected host, the PoS system. It is entirely possible that the PoS could have software like Crowdstrike Falcon deployed, which would monitor system behavior and mass storage device access [19]. Although the experiment environment will not use such software, it is an important distinction to make.

In [20], they describe several attacks at each of the applicable layers to USB attacks: the human, application, transport, and physical layers. These attacks would typically require some human element for deployment, but that is not the focus of the research (e.g., social engineering versus hardware hacking). Whereas the physical layer could allow signal eavesdropping or injection. This could enable a modified printer to overvolt

the host (USBKiller [21]) to cause physical damage or perform other side-channel attacks [22]. Either of those methods would require investigating the device hardware to determine what level of control the bootloader or operating system has over power delivery.

2.4 Summary

As demonstrated by the previous works, vulnerability assessment of an embedded device is a well documented process. However, the extent that a serial thermal printer (e.g., Figure 1.1) can be maliciously expanded through a modified FreeRTOS image, while supporting original functionality, has not. And, given success in the assessment, it could suggest room for continual and improved research.

References

[1] J. Ondrus and K. Lyytinen, "Mobile Payments Market: Towards Another Clash of the Titans?" In *2011 10th International Conference on Mobile Business*, Jun. 2011, pp. 166–172. DOI: 10.1109/ICMB.2011.41. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/6047067?casa_token=jp6ioVlqPjQAAAAA:L69Yx3rjP2tvbnS5zWF8-eMm8sUNjXR586jm2QV6hLH8T2MyuueyIFCeMDqjhNWtUh-_2ERWgQ (visited on 10/23/2023).

[2] S. T. Ebimobowei, Z. Enebraye Peter, and Y. Pual, "THE ROLE OF SOFTWARE IN A CASHLESS ECONOMY (CASE STUDY NIGERIA)," *International Journal of Research -GRANTHAALAYAH*, vol. 6, no. 1, pp. 177–186, Jan. 31, 2018, ISSN: 2350-0530, 2394-3629. DOI: 10.29121/granthaalayah.v6.i1.2018.1607. [Online]. Available: https://www.granthaalayahpublication.org/journals/index.php/granthaalayah/article/view/IJRG17_A11_812 (visited on 10/23/2023).

[3] "SNBC BTP-S80 Thermal Printer - Black Cabinet (USB/Serial/Ethernet)," CRS Inc. (), [Online]. Available: https://www.crs-usa.com/products/snbc-btp-s80-thermal-printer-black-(usb-serial-ethernet) (visited on 10/23/2023).

[4] "SNBC New Beiyang-Intelligent Micro-Super, Smart Express Cabinet, Barcode Label Printer, Ticket Printer_Electronics_Receipt/Log Printer, Barcode/Label Printer, Special Scanning Products, Mixed Print Scanning Products, Smart Express Cabinet, Smart Micro-Super_New Beiyang specializes in the development, production, sales and service of intelligent print identification and system integration products. It provides leading products and complete, one-stop application solutions for various industries around the world. It is the only core design in the industry in the country through independent innovation. Manufacturing technology and forming a large-scale production enterprise." (), [Online]. Available: https://www.snbc.com.cn/ (visited on 10/23/2023).

[5] "Cortex-M4." (), [Online]. Available: https://developer.arm.com/Processors/Cortex-M4 (visited on 10/23/2023).

[6] "FreeRTOS - Market leading RTOS (Real Time Operating System) for embedded systems with Internet of Things extensions," FreeRTOS. (), [Online]. Available: https://www.freertos.org/index.html (visited on 10/23/2023).

[7] N. Scaife, C. Peeters, and P. Traynor, "Fear the Reaper: Characterization and Fast Detection of Card Skimmers," presented at the 27th USENIX Security Symposium (USENIX Security 18), 2018, pp. 1–14, ISBN: 978-1-939133-04-5. [Online]. Available:

https://www.usenix.org/conference/usenixsecurity18/presentation/scaife (visited on 10/23/2023).

[8] "Consumer Sentinel Network Data Book for January - December 2011," Federal Trade Commission. (Oct. 22, 2023), [Online]. Available: https://www.ftc.gov/reports/consumer-sentinel-network-data-book-january-december-2011 (visited on 10/23/2023).

[9] C. FortheSentinel, "Consumer Sentinel Network Data Book 2022," 2022.

[10] E. Karystinos, A. Andreatos, and C. Douligeris, "Spyduino: Arduino as a HID Exploiting the BadUSB Vulnerability," in *2019 15th International Conference on Distributed Computing in Sensor Systems (DCOSS)*, May 2019, pp. 279–283. DOI: 10.1109/DCOSS.2019.00066.

[11] Y. Wang, C. Hahn, and K. Sutrave, "Mobile payment security, threats, and challenges," in *2016 Second International Conference on Mobile and Secure Services (MobiSecServ)*, Feb. 2016, pp. 1–5. DOI: 10.1109/MOBISECSERV.2016.7440226.

[12] Hak5. "Bash Bunny," Hak5. (), [Online]. Available: https://shop.hak5.org/products/bash-bunny (visited on 10/23/2023).

[13] "OWASP Juice Shop — OWASP Foundation." (), [Online]. Available: https://owasp.org/www-project-juice-shop/ (visited on 10/23/2023).

[14] R. Wood, *DAMN VULNERABLE WEB APPLICATION*, Oct. 22, 2023. [Online]. Available: https://github.com/digininja/DVWA (visited on 10/23/2023).

[15] "OWASP WebGoat — OWASP Foundation." (), [Online]. Available: https://owasp.org/www-project-webgoat/ (visited on 10/23/2023).

[16] R. Benadjila, M. Renard, P. Trebuchet, P. Thierry, and A. Michelizza, "Wookey : Usb devices strike back," 2018. [Online]. Available: https://api.semanticscholar.org/CorpusID:199552896.

[17] W. D. Yu, D. Baheti, and J. Wai, "Real-Time Operating System Security,"

[18] D. J. Tian, A. Bates, and K. Butler, "Defending Against Malicious USB Firmware with GoodUSB," in *Proceedings of the 31st Annual Computer Security Applications Conference*, ser. ACSAC '15, New York, NY, USA: Association for Computing Machinery, Dec. 7, 2015, pp. 261–270, ISBN: 978-1-4503-3682-6. DOI: 10.1145/2818000.2818040. [Online]. Available: https://doi.org/10.1145/2818000.2818040 (visited on 10/24/2023).

[19] J. Backer, "Sdn-controlled isolation orchestration to support end-user autonomy," Ph.D. dissertation, WORCESTER POLYTECHNIC INSTITUTE, 2021.

[20] J. Tian, N. Scaife, D. Kumar, M. Bailey, A. Bates, and K. Butler, "SoK: "Plug & Pray" Today – Understanding USB Insecurity in Versions 1 Through C," in *2018 IEEE Symposium on Security and Privacy (SP)*, May 2018, pp. 1032–1047. DOI: 10.1109/SP.2018.00037. [Online]. Available: https://ieeexplore.ieee.org/document/8418652 (visited on 11/05/2023).

[21] "USB Kill devices for pentesting & law-enforcement," USBKill. (), [Online]. Available: https://usbkill.com/ (visited on 11/05/2023).

[22] K. Sridhar, S. Prasad, L. Punitha, and S. Karunakaran, "EMI issues of universal serial bus and solutions," in *8th International Conference on Electromagnetic Interference and Compatibility*, Dec. 2003, pp. 97–100. DOI: 10.1109/ICEMIC.2003.237887. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/1287775 (visited on 11/05/2023).