



PRINTSHOP: SERIAL PRINTER ENVIRONMENTS AND SECURITY

Research Proposal

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ABSTRACT

Securing supply chains for critical infrastructure and any production environment is a growing concern. Third-parties or nation state level attackers have been shown to target employees or infrastructure indirectly to gain access to their target's network. One of the devices being examined to aid this research is the SNBC BTP-S80, a USB/serial connected thermal printer. These devices are made with foreign software and hardware, and they are used off the shelf without any security review. In some instances, the devices implement an MPU/MCU and an FPGA for I/O processing, which creates a potential gap for data to be modified. The proposed research aims to assess these devices for any risks and demonstrate that they could be used as a part of supply chain attacks.

TABLE OF CONTENTS

| | |
|---|------------|
| Abstract | ii |
| Table of Contents | iii |
| List of Tables | v |
| List of Figures | vi |
| 1 Introduction | 1 |
| 1.1 Background | 1 |
| 1.2 Significance | 3 |
| 1.3 Research Goals and Objectives | 4 |
| 1.4 Research Questions | 4 |
| 2 Related Works | 6 |
| 2.1 RTOS: Software and Security | 6 |
| 2.2 PoS Attack Patterns | 6 |
| 2.3 BadUSB-like Devices | 8 |
| 2.4 Summary | 9 |
| 3 Proposed Research | 10 |
| 3.1 Methodology | 10 |
| 4 Research Design | 12 |

| | | |
|----------|--------------------------------------|-----------|
| 4.1 | Design Process | 12 |
| 4.2 | Data Collection Process | 14 |
| 4.3 | Hardware Assessment | 15 |
| 4.4 | Network Traffic Analysis | 17 |
| 4.5 | USB Communication Analysis | 18 |
| 4.6 | RTOS Modification | 19 |
| 5 | Timeline | 22 |
| 6 | Conclusion | 23 |
| | References | 24 |

LIST OF TABLES

| | | |
|-----------|---|----|
| Table 4.1 | SoC technical specs example using Stellaris LM3S2793 Microcontroller | 14 |
| Table 4.2 | Memory specs example using Infineon Technologies S25FL064P (<i>S25FL064P Series NOR Flash Datasheets – Mouser 2023</i>) | 15 |
| Table 4.3 | Example JTAG pin-out for the LM3S2793 | 16 |
| Table 5.1 | Research lifecycle | 22 |

LIST OF FIGURES

| | | |
|------------|--|----|
| Figure 1.1 | Comparison of common POS systems | 1 |
| Figure 3.1 | Research methodology diagram (Pefferers <i>et al.</i> 2007) | 10 |
| Figure 4.1 | Design process diagram | 12 |
| Figure 4.2 | JTAG pin out example for Texas Instruments LM3S2793 | 16 |
| Figure 4.3 | USB capture using WireShark | 19 |
| Figure 4.4 | Example w/ Ellisys USB Explorer 200 | 20 |
| Figure 4.5 | Example flashing device using Segger J-Flash (<i>J-Link Flash Down-load</i> 2023) | 21 |

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.



Figure 1.1: Comparison of common POS systems

Figure 1.1 shows us two similar looking point-of-sale systems. However, the operating system and required hardware used by both is 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 (Ondrus and Lyytinen 2011). Whereas, the SurePoS, NCR, or other common EFTPoS system will run a proprietary OS based on Windows or Linux (Ebimobowei *et al.* 2018). Furthermore, these PoS 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 (*SNBC BTP-S80 Thermal Printer - Black Cabinet (USB/Serial/Ethernet)* 2023; *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.* 2023). 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 (*Cortex-M4* 2023; *FreeRTOS - Market Leading RTOS (Real Time Operating System) for Embedded Systems with Internet of Things Extensions* 2023).

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 (Scaife, Peeters, *et al.* 2018).

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 (*Consumer Sentinel Network Data Book for January - December 2011 2023*; FortheSentinel 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 (*Consumer Sentinel Network Data Book for January - December 2011 2023*; FortheSentinel 2022). 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 (Karystinos *et al.* 2019) 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 (Griffiths and Kabir 2019; Patnaik Patnaikuni 2017). Especially if the goal is to not modify hardware or require hands-on access for exploitation. However, the research shows us that it is 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. This is relevant to the proposed research, because it shows that a device with similar hardware specifications was feasible; meaning, it is likely that our own research will be successful. 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 (Wang *et al.* 2016) since their environments typically do not use serial print devices. It is also likely that more research would be needed for emulating touch inputs for mobile environments versus the traditional keyboard attacks that will be implemented. 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 (Scaife, Peeters, *et al.* 2018).

Through this research we hope to identify supply chain risks using side channel attacks from auxiliary devices. Some examples of how the research could be applied in the future vary: BadUSB/BashBunny (Hak5 2023), JuiceShop (*OWASP Juice Shop — OWASP Foundation* 2023), DVWA (Wood 2023), or Webgoat (*OWASP WebGoat — OWASP Foundation* 2023). Works within the PoS system context or embedded systems discussing supply chain attacks through third-party hardware are limited.

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)? Testing a version of the original firmware with additional libraries, or an alternative OS, allows us to see if supply chain attacks are a concern. Either by the manufacturer, supplier, or other party. Reflashing is not novel by itself, however, the device might have protections in place to prevent it.
- Q2: Does the hardware and firmware have enough resources to support HID functionality on-top of printing? In other words, can we maintain operation of standard printer command interpretation and side-channel input attacks without causing crashes or delays? The viability of the attack depends on it going unnoticed by operators or technicians.
- Q3: Besides HID cloning, what other threat areas are exposed (e.g., network stack, web management portal, memory protections)? Are there any identifiable or known exploits when accessing the configuration panel (e.g., HTTP/2)? These provide a non-invasive method for bootstrapping the device.

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

Related Works

2.1 RTOS: Software and Security

(Benadjila *et al.* 2018) 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. (Yu *et al.* n.d.) 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

Typically, when discussing attack patterns for PoS systems they are limited to card skimming, fake payment processor requests, or EMV cloning. In rarer cases, they might deliver malware to perform memory scraping within the PoS system or attempt swapping hardware while employees are distracted. None of these attacks include thermal printers at

any point during their attack chain or delivery.

Easily the most common and well known type of attack is card skimming. Attackers will place these devices directly on top of the existing equipment to skim, or gather, credit card information at the time of purchases. They can be incredibly difficult to identify because of the sleek and stealthy designs that fraudsters use. But there is plenty of research being presented on how to quickly detect these devices (Scaife, Peeters, *et al.* 2018; Scaife, Bowers, *et al.* 2019).

Without going into too much technical detail, card skimming attacks are accomplished by reading the signals emitted when swiping a magnetic card or by using an NFC reader in proximity to the payment terminal. When the customer goes to pay and uses their card, the nearby skimmer will record the transaction data being transferred. NFC skimmers, however, are not limited to being used near the terminals. Skimmer capabilities vary, and in some cases they have cameras as well or keypads for capturing PIN and zip code data.

In response to the susceptibility of magnetic cards, EMV cards were created. They are able to avoid the issues that magnetic cards and NFC share by using a chip to securely exchange transaction data with the payment terminal using secret authentication codes. The idea is that these codes cannot be tampered with or easily cloned. Despite these security advancements, EMV cards are susceptible to pre-play attacks targeting the "unpredictable number" (UN) algorithm used by ATMs (Bond *et al.* 2014).

Social engineers use payment processor mobile applications to directly target their victims instead of using elaborate and technical attacks against servers or user equipment (Beju and Făt 2023). The attackers simply send payment requests disguised as payments using their preferred platform. Unwittingly, the victim will accept the request thinking they were receiving money instead.

In some cases, the fraudster sends the victim money but requests a refund shortly after. As a result, the victim is either charged fees for processing the transactions or they have already spent the refunded money. These attacks are much simpler in-terms

of delivery compared to the others and the intended outcomes are different. There are instances where the user device is compromised by malware specifically for exfiltrating banking data or similar PCI, but further discourse is outside the scope of the proposed research (Darvish and Husain 2018).

Researchers at Stony Brook University (Hizver and Chiueh 2012), demonstrated a successful introspection-based memory scraping attack against nine commercial PoS applications. Within their environment, it is assumed that the given VM (i.e., Dom0) within the shared virtualization platform (i.e., Xen) is compromised and it has escaped the guest environment. Because the privileges associated with the first VM, it has read access to the others and can perform out-of-VM memory scraping. This exact attack is likely limited to the platform used for the experiment, Xen Hypervisor; attempting something similarly against VMWare, Virtualbox, or QEMU would require further experimentation due to architectural differences. Also, PCI-DSS and PA-DSS requirements were not an obstacle for this attack since the data is not stored to disk and it is read from memory instead.

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 (Hak5 2023). 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 (D. J. Tian *et al.* 2015).

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 (Backer 2021). Although the experiment environment will not use such software, it is an important distinction to make.

In (2018), 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 (*USB Kill Devices for Pentesting & Law-Enforcement* 2023)) to cause physical damage or perform other side-channel attacks (2003). 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.

Proposed Research

3.1 Methodology

For this research, the quantitative approach and case study research will be used (Babbie 2017; Creswell and Creswell 2017) to create a design artifact. The goal being to gather and examine, point-in-time, data from a serial printer device as a common sample representative of the affected population. By using quantitative survey research, it is possible to evaluate potential vulnerabilities for the attacks hypothesized, as well as, prototype a modified firmware image to use them against the host environment.

Each step of the process shown in Figure 3.1, is described as follows:

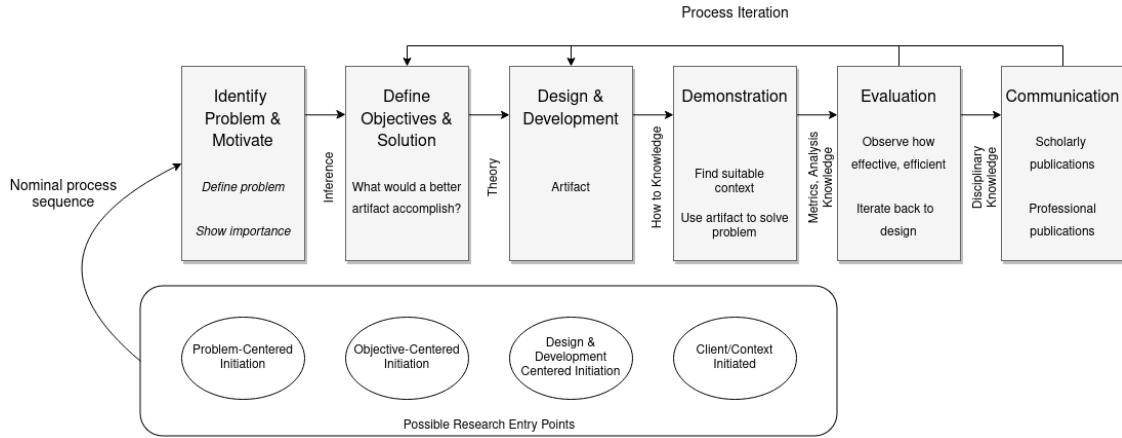


Figure 3.1: Research methodology diagram (Peppers *et al.* 2007)

- **Problem Identification:** A research gap exists when identifying the risks that off-the-shelf hardware exposes to host environments (i.e., PoS systems, HMI, ICS). Auxiliary devices, like serial printers, are black box pieces of equipment with questionable supply chain and development life cycles.
- **Objectives and Solutions:** This research aims to thoroughly examine such a device and demonstrate that it can be used as a part of a hypothetical supply

chain attack. Using the information gathered, a modified firmware image with HID cloning will be created. This solution should prove that such an attack is a viable method and there are existing issues with sourcing third-party hardware.

- **Research Design:** The research design process begins by tearing down the target device and identifying components. That information is then used to recover the firmware for analysis, as well as, analyze the network and USB communications with a host. After reviewing, a modified firmware image will be created and then flashed to the device. All information is documented and collected. Refer to Section 4.1 for further detail about the exact process.
- **Demonstration:** Using the artifact, the researcher will demonstrate that scripted HID attacks against the host are possible. Should the host filter devices using restricted vendor IDs, this attack will still work irregardless of the host operating system. It is also important that original functionality is maintained with the modified firmware.
- **Evaluation:** Whether or not the research has been successful depends on several factors: firmware recovery, firmware modification (using recovered firmware or third-party), attack development, and sustaining the original ESC/POS print functions. Assuming each step has been completed, the final demonstration should be able to show working print operations and scripted attacks against the host. These attacks should also work irrespective of target environment.
- **Communication:** The research will present the identified gaps and issues to the embedded security field. By demonstrating the research and artifacts, the researchers hope to greater increase the scrutiny for auxiliary, third-party hardware and the associated risks. In addition, the artifacts could potentially be used for future research into embedded security and exploit development.

Research Design

4.1 Design Process

The design process is divided into two parts, information collection and exploitation. Beginning with teardown of the equipment, identification of components, and then analysis of the firmware, networking, and lastly, the USB communications between the host and device. Using the information gathered within the first stage, modifications will be made to the firmware installed on the serial printer. Each step of the process shown in Figure 4.1, is described as follows:

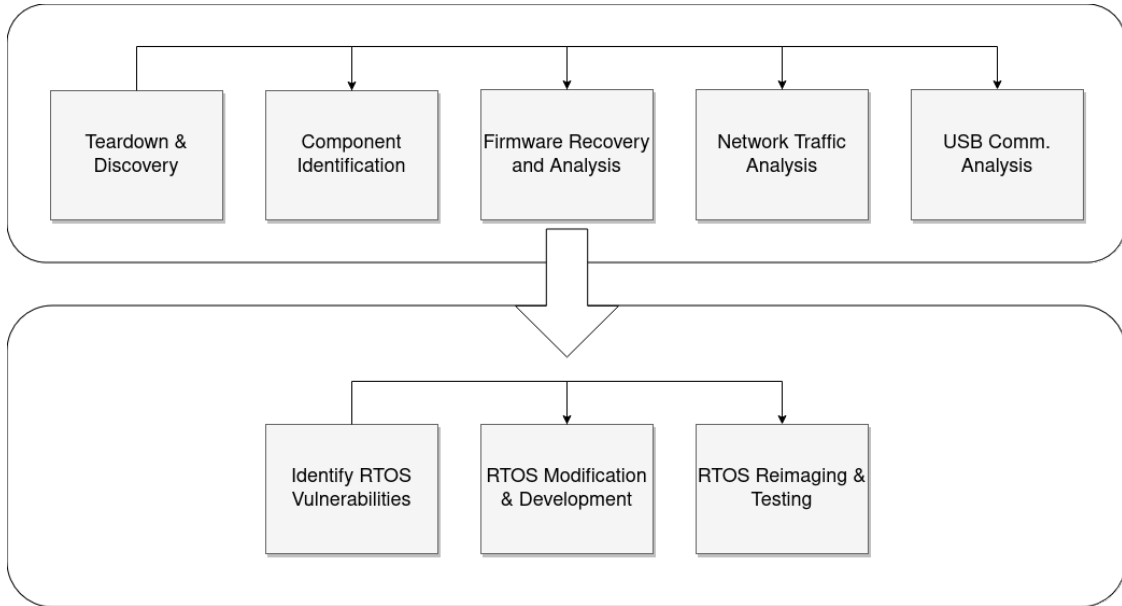


Figure 4.1: Design process diagram

- **Teardown and Discovery:** The device is disassembled and documented at each step. Pictures are taken of each component, part numbers are identified, and technical datasheets are collected.
- **Component Identification:** Using information from the prior step, component

function is identified and any information needed to interface with the component is documented.

- **Firmware Recovery and Analysis:** Using the technical datasheets, firmware is recovered and analyzed in a disassembler (e.g., Ghidra). Libraries used by the operating system and their opensource repositories are documented. Using the opensource information, potential vulnerabilities are identified within the firmware.
- **Network Traffic Analysis:** Any network traffic created during use is captured and analysed using software tools (e.g., WireShark). In conjunction with prior firmware analysis and identification of operating system libraries, communications are reviewed for potential vulnerabilities. This is a potential area for remote code execution (RCE) if the management software is poorly implemented.
- **USB Communication Analysis:** Communications between the host and device are captured for future development of human-interface-device (HID) cloning. The information is needed for accurately cloning identifiers assuming hosts restrict devices using vendor IDs.
- **Identify RTOS Vulnerabilities:** Should analyses identify any exploitable vulnerabilities, further research is conducted to discover any public releases or proof of concepts (PoCs).
- **RTOS Modification and Development:** Opensource RTOS firmware is modified to allow HID cloning while maintaining original print functionality. The attack vector is crucial step towards proving viability of supply chain attacks using the print devices.
- **RTOS Reimaging and Testing:** Firmware is built and reimaged/reflashed onto the target device. Testing includes the verification of ESC/POS commands interpreter operation and HID attack vector.

4.2 Data Collection Process

The data collection process begins with gathering technical specifications from device manufacturers. Typically, these contain information about the capabilities of the intended device functions. For a printer, this could contain information ranging from hardware specifications (e.g., CPU, architecture, memory) to things like printed pages per minute. This information forms the baseline for the device survey. Afterwards, further specifications will be gathered for components as each device is disassembled and examined.

The next step in the data collection process would be identifying the SoC. In the event that there is no beforehand knowledge, the SoC can be identified by comparing gathered datasheets during the components discovery. This is easily accomplished using an online service like FindChips (*Findchips: Electronic Part Search* 2023). The expected type and format for SoCs is described by Figure 4.1.

The process for gathering flash/memory chip specifications is similar; identify serial number and manufacturer, then find the component datasheet. Gathering the pin layouts and format is useful for later stages, should manual flash recovery be needed. The expected format for memory chips can be seen at Figure 4.2.

| Specifications | |
|---------------------------|---|
| Architecture | 32-bit ARM |
| Platform | ARM Cortex-M3 |
| Frequency | 80-MHz, 100DMIPS performance |
| Memory | 128KB single-cycle Flash memory 64KB single-cycle SRAM |
| Firmware | Internal ROM loaded with StellarisWare |
| Advanced Comm. Interfaces | UART, SSI, I2C, I2S, CAN |
| Debug Interfaces | JTAG, SWD |
| Package format | 100-pin LQFP 108-ball pin BGA |

Table 4.1: SoC technical specs example using Stellaris LM3S2793 Microcontroller

The final report will contain each of these tables for the device and their identified core components. Operating system features and protections will be loosely summarized for the device, and there is no set reporting format or requirements. The identified information will aid the final step of the process, creating a design artifact.

| Specifications | |
|-------------------------------|---|
| Single power supply operation | 2.7 to 3.6V |
| Software Features | SPI Bus Compatible Serial Interface |
| Memory architecture | Uniform 64KB sectors 256 byte page size |
| Programming | Page programming (up to 256 bytes) Operations are page-by-page basis Accelerated mode via 9V W#/ACC pin Quad page programming |
| Erase commands | Bulk erase function Sector erase for 64KB sectors Sub-sector erase for 4KB and 8KB sectors |
| Protections | W#/ACC pin used with Status Register Bits to protect specified memory regions and configure parts as read-only One time programmable area for permanent and secure identification |
| Package format | 16-pin SO 8-contact WSON 24-ball BGA, 5x5 pin config 24 ball BGA, 6x6 pin config |

Table 4.2: Memory specs example using Infineon Technologies S25FL064P (*S25FL064P Series NOR Flash Datasheets – Mouser* 2023)

4.3 Hardware Assessment

NIST SP 800-115 (“NIST SP 800-115” 2020) provides general guidelines for performing information security testing and assessment, however, there is little information regarding hardware reverse engineering and firmware analysis. Their guidelines are aimed more towards single/multi-tasking operating systems like Windows or Unix-like, those where network logging and listener agents is feasible. For the targeted devices in this research

proposal, a different approach is needed that evaluates hardware protections of the SoC and flash memory.

Analysis of device components, once disassembled, requires using a hardware debugger tool with the correct interface. The majority of the targeted devices are expected to use joint test action group (JTAG) or single wire debugging (SWD). By referring to the manufacturer datasheet for a given SoC, it is possible to identify the pin layout for serial debugging access.

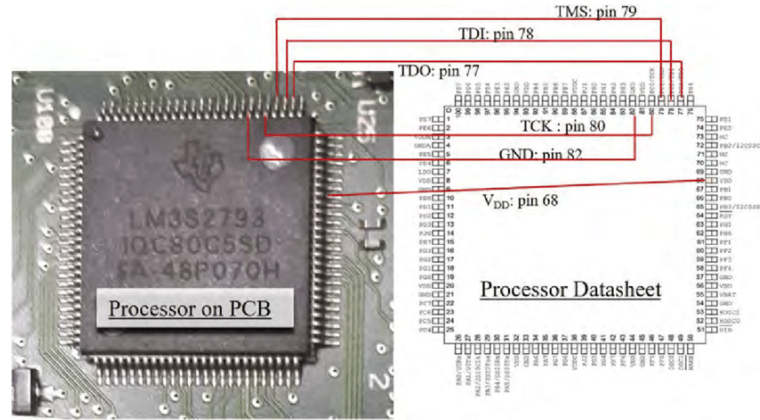


Figure 4.2: JTAG pin out example for Texas Instruments LM3S2793

Figure 4.2 is an example showing what the physical SoC looks like on a PCB compared to the pin layout described in the datasheet. The dot in the top left of the SoC denotes the beginning of the pin layout. Counting in a counter-clockwise method indicates the pin number and the associated functions. For instance, to access the JTAG debug interface on the LM3S2793:

| Function | Pin # | Function | Pin # |
|----------|-------|-----------------|-------|
| TDO | 77 | TDI | 78 |
| TMS | 79 | TCK | 80 |
| GND | 82 | V _{DD} | 68 |

Table 4.3: Example JTAG pin-out for the LM3S2793

Using this information, a device like the JTAGULATOR (*JTAGulator* 2023) can be connected and enumerate or verify pin layouts as described. Ball joint SoCs require a

different process and are much harder to debug if there is no visible header available on the board. Once an interface is connected, if debugger access is not disabled, the researcher can interact with the bootloader to further investigate enabled protections and recover flash storage.

If the JTAG is disabled, the researcher will then attempt to recover flash manually using a device like the Segger J-Link (*SEGGER J-Link Debug Probes* 2023). The Segger has pre-defined and existing support for working with flash memory and flash breakpoints, whereas using OpenOCD with the JTAGULATOR would require time crafting custom configurations. Assuming there are no access protections to the flash memory, the researcher can begin performing firmware analysis to identify the operating system or potential vulnerabilities. Documenting the size and address range of memory regions is a key part of the process.

4.4 Network Traffic Analysis

Capturing and understanding the traffic between the serial printer and the host helps to identify incorrect implementations or misconfigurations. This information can then be analyzed to further identify any misuses of authentication methods, cookies, or input validation. All of which are potential areas an attacker could use to leverage unprivileged access.

For example, the Treck TCP/IP networking library, before version 6.0.1.68, had multiple input validation and out-of-bounds read vulnerabilities that allowed attackers unauthenticated remote access (*NVD - CVE-2020-25066* 2024; *NVD - CVE-2020-27336* 2024; *NVD - CVE-2020-27338* 2024; *NVD - CVE-2020-27337* 2024). Following that example, one of the goals of this research is to identify vulnerabilities within the serial printer firmware or networking libraries that could be used to gain unauthenticated access. This is not the only method that will be used to gain access for in-memory modification or

reflashing, but it is relevant to identifying supply chain risks and the indirect methods that attackers could use to compromise equipment. Preliminary research into serial devices, and the target of this proposal, identified that the printer uses WebNet v1.0.0 (*RT-Thread-packages/Webnet* 2024). This library is an independent package developed by RT-Thread to support basic HTTP functionality.

Knowing that information, all network traffic between the serial printer and host will be captured using WireShark. This will be useful later during firmware analysis because the library is open source and it will provide the researcher with realtime data produced by the library to compare when reviewing the firmware disassembly. During analysis of the network traffic, any URL or call to an API with references to AUTH, CGI, or ASP functions will be documented and tested for input validation (*WSTG - Latest — OWASP Foundation* 2024). The HPP vulnerability that affected Apple Cups, a common printing system for UNIX systems, is an example: `hxxp://127.0.0.1:631/admin/?kerberos=onmouseover=alert(1)&kerberos`. By modifying the kerberos parameter, it allowed attackers to trigger a cross-site scripting vulnerability.

4.5 USB Communication Analysis

Recording the data transmitted between the host and the printer or target HID provides necessary information for RTOS modification. In order to maintain the appearance of the serial device and cloned HID, device descriptors and vendor IDs are needed (Karystinos *et al.* 2019; *SoK: "Plug & Pray" Today – Understanding USB Insecurity in Versions 1 Through C — IEEE Conference Publication — IEEE Xplore* 2023). The information will then be used to modify firmware and/or bootloader configuration to allow setting the new IDs needed for the HID cloning attacks. Masking vendor IDs and descriptors is not absolutely necessary when emulating a HID, but it helps bypass whitelists which limit what devices can connect.

Communication between the host, printer, and target HID will be recorded using WireShark and an Ellisys USB Explorer 200. WireShark is a software based solution and it natively provides support for USB protocol logging and analysis (*CaptureSetup/USB - Wireshark Wiki* 2024). The Ellisys USB Explorer, however, is a hardware and software solution that allows only USB 2.0 analysis. Since both the printer and HID use the USB 2.0 protocol, the explorer is appropriate. Currently, there is no preference for using either tool because of a certain feature or other reason. In the event that data cannot be logged correctly, the other tool will be used.

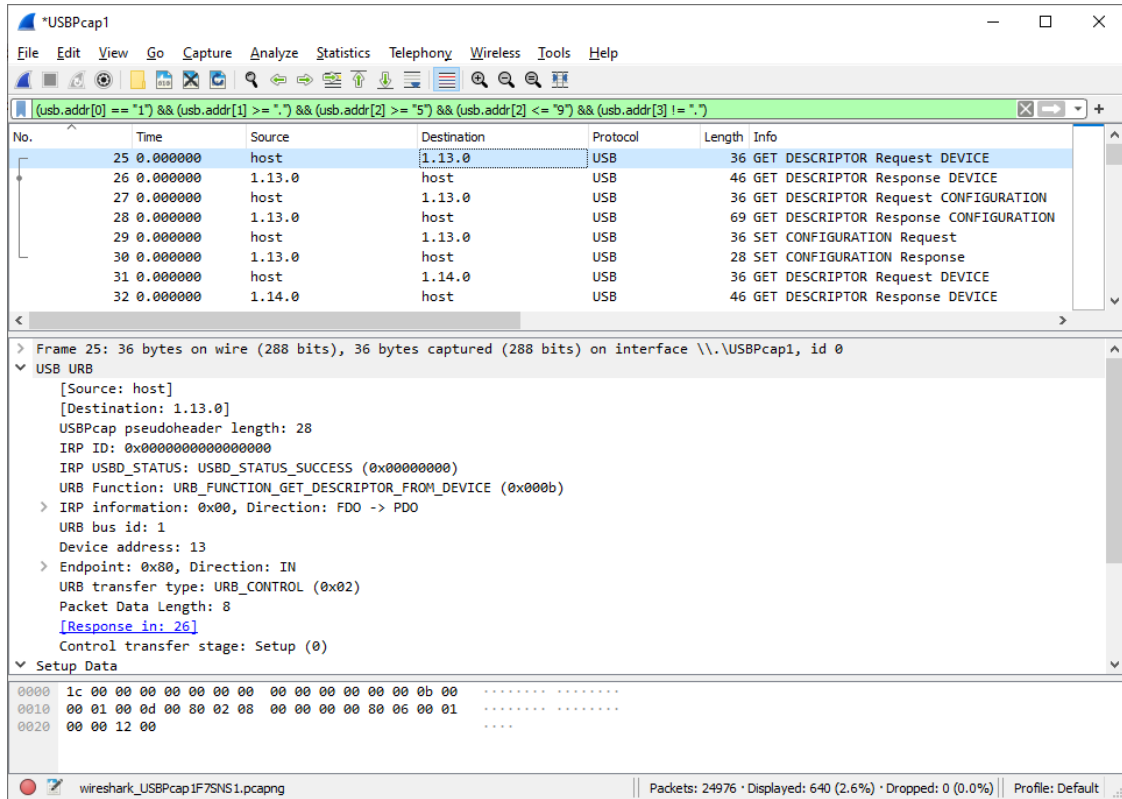


Figure 4.3: USB capture using WireShark

4.6 RTOS Modification

Using the information collected through prior analyses, the firmware will be modified using one of two methods. Either through in-memory exploitation identified through the

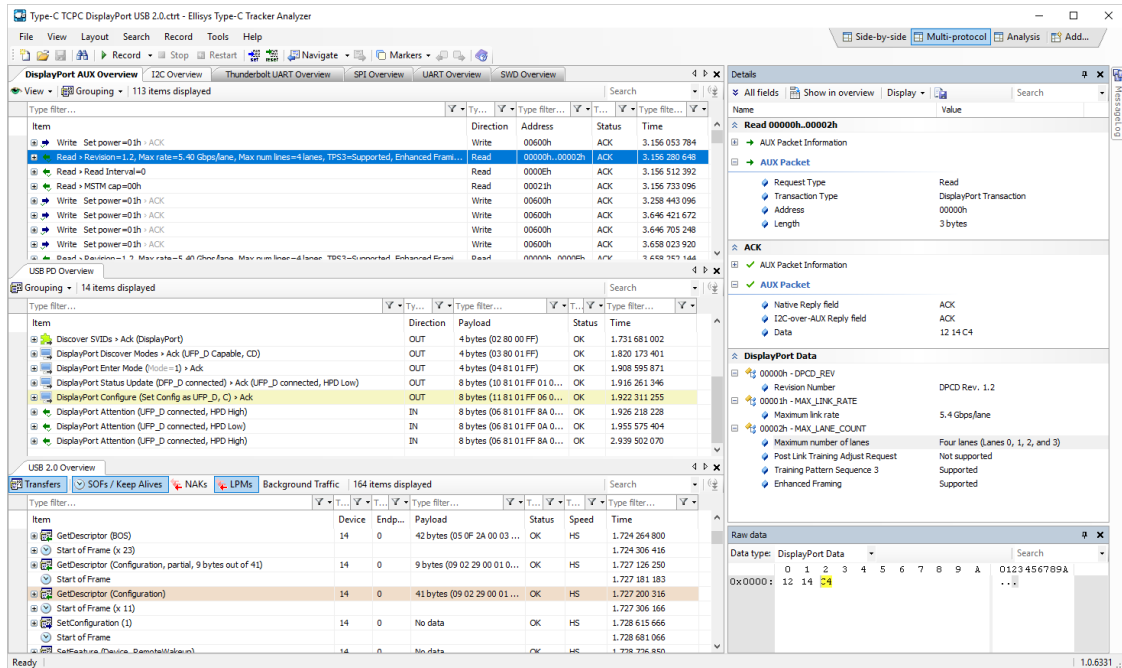


Figure 4.4: Example w/ Ellisys USB Explorer 200

network and firmware analysis stages or by reflashing firmware manually. Following the Treck vulnerability example, any in-memory modifications would begin through unauthenticated remote code access using a method similar to the heap-based buffer overflow within the HTTP server component. This would allow an attacker to push a payload into memory via the same HTTP server. Depending on the type of payload, the same method used to write into memory could then be used again to trigger the payload. Such a method would require that the payload overwrote a function that is used and exposed by the HTTP server (e.g., CGI/ASP).

Modification and reflashing of the firmware (RT-Thread) is made easier since it is open source. The print interpreter library (ESC/POS) and HTTP server library (WebNet) are also open source. If there are no identifiable vulnerabilities within the WebNet HTTP server component to enable RCE, rebuilding the firmware is a reliable method and it still fits within the supply chain attack context. Reflashing firmware also assumes that hardware write protections for the flash are not enabled.

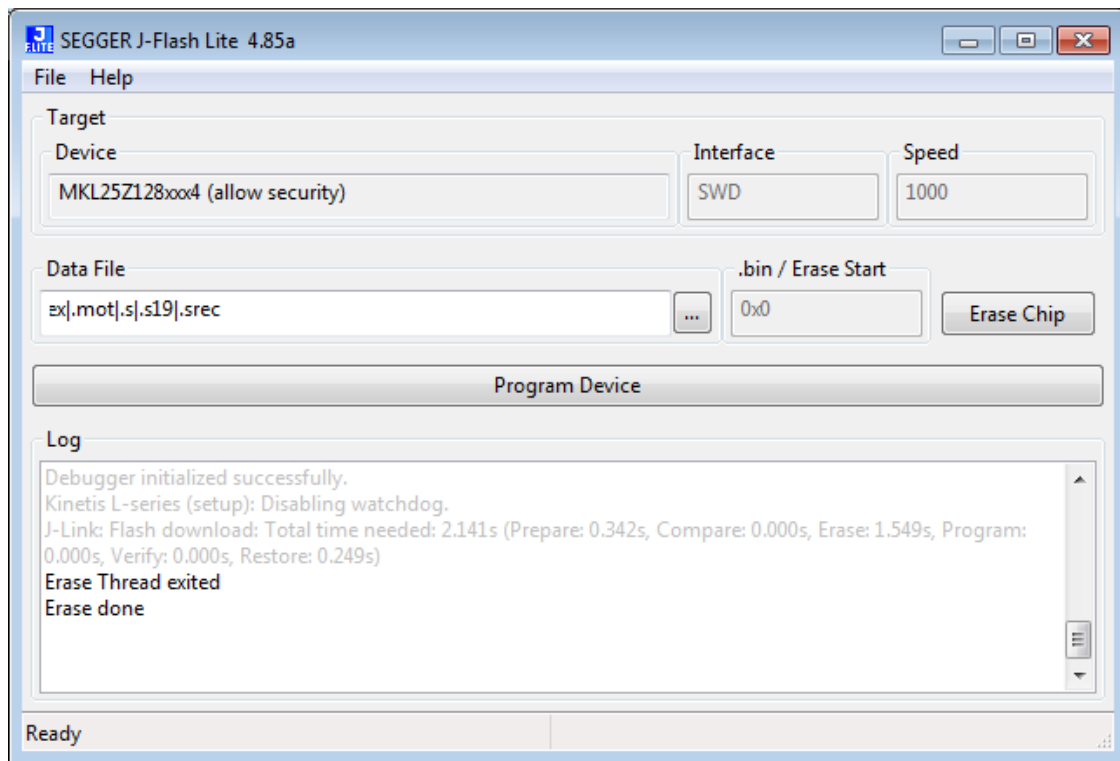


Figure 4.5: Example flashing device using Segger J-Flash (*J-Link Flash Download* 2023)

Timeline

The timeline for the research proposal is divided into several parts: review, disassembly, identification, analysis, firmware modification, testing, and writing. The dates provided are rough estimates and will vary as the project progresses. Each part of the research process is described as follows (refer to Table 5.1):

| Task | Duration | Start Date | End Date |
|--|----------|------------|-----------|
| Review | 7 days | 24 Mar 25 | 30 Mar 25 |
| Review proposal comments/feedback | 2 days | 24 Mar 25 | 25 Mar 25 |
| Amend any changes | 3 days | 26 Mar 25 | 28 Mar 25 |
| Prepare work environment | 2 days | 29 Mar 25 | 30 Mar 25 |
| Disassembly | 7 days | 31 Mar 25 | 06 Apr 25 |
| Disassemble printer | 2 days | 31 Mar 25 | 01 Apr 25 |
| Document interior/exterior of device | 5 days | 02 Apr 25 | 06 Apr 25 |
| Identification | 7 days | 07 Apr 25 | 13 Apr 25 |
| Identify device components | 3 days | 07 Apr 25 | 09 Apr 25 |
| Attempt hardware debug | 1 days | 10 Apr 25 | 10 Apr 25 |
| Identify software/hardware protections | 2 days | 11 Apr 25 | 12 Apr 25 |
| Document | 1 days | 13 Apr 25 | 13 Apr 25 |
| Analysis | 76 days | 14 Apr 25 | 29 Jun 25 |
| Capture network/USB traffic | 7 days | 14 Apr 25 | 20 Apr 25 |
| Analyze network/USB traffic | 31 days | 21 Apr 25 | 21 May 25 |
| Analyze recovered firmware | 31 days | 22 May 25 | 22 Jun 25 |
| Document previous tasks | 7 days | 23 Jun 25 | 29 Jun 25 |
| Firmware Modification | 62 days | 30 Jun 25 | 31 Aug 25 |
| Modify existing firmware | 31 days | 30 Jun 25 | 31 Jul 25 |
| Modify third-party firmware | 31 days | 01 Aug 25 | 31 Aug 25 |
| Testing | 60 days | 01 Sep 25 | 31 Oct 25 |
| Setup testing environment | 7 days | 01 Sep 25 | 07 Sep 25 |
| Reflash device w/ modified firmware | 14 days | 08 Sep 25 | 21 Sep 25 |
| Test print operations | 7 days | 22 Sep 25 | 28 Sep 25 |
| Test HID attacks | 7 days | 29 Sep 25 | 05 Oct 25 |
| Make changes and retest | 25 days | 06 Oct 25 | 31 Oct 25 |
| Extra | 30 days | 01 Nov 25 | 30 Nov 25 |
| Writing | 62 days | 01 Dec 25 | 31 Jan 25 |

Table 5.1: Research lifecycle

Conclusion

Securing supply chains for critical infrastructure and any production environment is a growing concern. Third-parties or nation state level attackers have been shown to target employees or infrastructure indirectly to gain access to their target's network. One of the devices being examined to aid this research is the SNBC BTP-S80, a USB/serial connected thermal printer. These devices are made with foreign software and hardware, and they are used off the shelf without any security review. In some instances, the devices implement an MPU/MCU and an FPGA for I/O processing, which creates a potential gap for data to be modified.

Data will be collected by assessing a serial printer and its components, firmware, network stack library, featured capabilities (e.g., intended operations like ESC/POS commands to printed paper over serial), and security protections. Using that information the firmware will be modified in-memory or by reflashing to implement HID cloning for scripted attacks. By demonstrating that the original functionality can be maintained in addition to the attack channel, the research will present a viable supply chain attack that could be used against vendors. The proposed research aims to assess a serial printer for such risks and demonstrate that they could be used as a part of a viable supply chain attack.

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