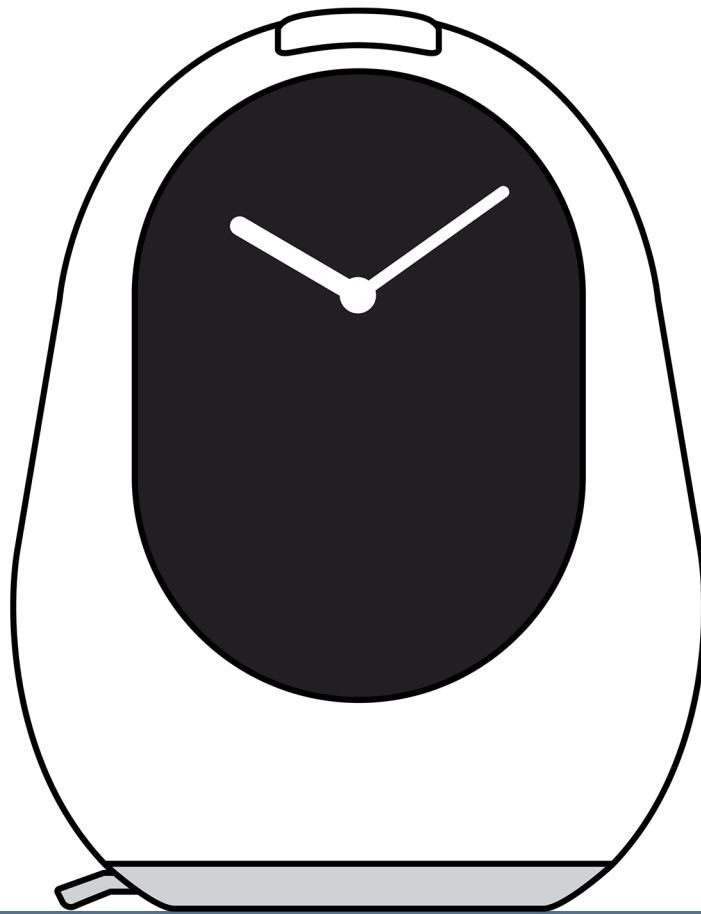


Improving Medication Sachet Identification in the Medido Medicine Clock



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Master Thesis

Integrated Product Design (Medisign)

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Executive Summary

Medication sachet identification plays an important role in the safe and reliable operation of the Medido Medicine Clock, an automated medication sachet dispenser used by more than 20000 clients in home-care and intramural settings. Accurate identification supports medicine roll validation, enables advanced dispensing functionality such as Advanced Roll Loading, and provides care organizations with confidence that the intended medication sachet is dispensed. However, barcode reading performance in deployed Medido model M302 devices has proven inconsistent due to optical conditions, variation in medication sachet layouts, contamination of the optical path, and hardware configuration.

This thesis investigated the factors limiting barcode reading performance and translated these findings into an integrated improvement concept for the existing M302 platform. An exploratory experimental research approach was used, combining controlled barcode performance testing with analysis of barcode scanner sensor output. The influence of medicine roll transport conditions, illumination, mirror contamination, scanner positioning, and scanner behavior was systematically investigated using both software and hardware modifications.

The research demonstrated that barcode reading performance is affected by multiple interacting factors. Scanning during motion, optical contamination of the mirror, scanner positioning tolerances, limited grayscale dynamic range, and specular reflections from medication sachet materials all reduce decoding reliability. In particular, stationary barcode reading and alternative illumination strategies substantially improved performance. The findings showed that barcode reading performance cannot be addressed through a single intervention, but requires a combined optical, mechanical, and firmware-based solution.

Based on these insights, a final design was developed that combines back-lighting through a revised Ultrasound Transmitter & Lighting PCBA, a Scan Engine LED Blocker, a Dust Cover, stationary barcode reading, and firmware-based reconstruction methods for incomplete scans.

Validation showed successful decode rates of 94% for top-positioned barcodes and 100% for bottom-positioned barcodes, resulting in an overall decode rate of 96%. The concept can be installed during refurbishment in approximately 15 minutes, at an estimated implementation cost of €25 per refurbished device. With a proposed development and validation trajectory of 6 to 9 months, the concept provides a feasible basis for improving medication sachet identification across refurbished M302 devices without replacing the installed fleet.

Lay Summary

The Medido Medicine Clock is a device that automatically dispenses medication sachets at scheduled times. To verify which medication sachet is being dispensed, the device reads a barcode printed on each sachet. In practice, however, barcode reading is not always reliable. Some barcodes are missed completely, while others cannot be read consistently because of lighting conditions, dust on the mirror inside the device, differences in sachet design, or variation between individual devices.

The goal of this project was to understand why barcode reading sometimes fails and to develop improvements that can be applied to existing Medido model M302 devices already in use.

A series of experiments was performed using Medido devices and medication sachets. Different lighting conditions, scanner positions, contamination scenarios, and software configurations were tested to determine their influence on barcode reading performance. Additional analysis of the barcode scanner itself provided insight into how the scanner sees and interprets barcodes.

The research showed that several factors contribute to barcode reading problems. Scanning a barcode while the sachet is moving makes reading more difficult, dust on the internal mirror can significantly reduce performance, and reflections from sachets can interfere with the scanner. The results also showed that performance can be improved considerably by changing the lighting conditions and by scanning the barcode while the sachet is stationary.

Based on these findings, a set of improvements was developed. These include a backlight that illuminates the sachet from behind, a component that blocks the original scanner LED, a cover that protects the mirror from dust, and software changes that allow the device to scan barcodes under more favorable conditions. When a full barcode cannot be read, additional software methods can use the remaining visible barcode information to support identification.

Testing of the final concept showed that 94% of top-positioned barcodes and 100% of bottom-positioned barcodes could be read, resulting in an overall reading performance of 96%. The proposed hardware can be installed during refurbishment of existing devices in approximately 15 minutes and is estimated to cost about €25 per refurbished device. This makes the concept suitable for gradual implementation on existing M302 devices, extending the useful life of the installed fleet and reducing the need for full device replacement.

Together, these improvements increase the reliability of medication sachet identification and support safer automated medication dispensing for clients, caregivers, care organizations, and Medido.

Glossary

Advanced Roll Loading

A Medido feature intended to automatically identify the loaded medicine roll and adjust dispensing based on the sachets present on the roll.

Backlighting

An illumination method in which light passes through the medication sachet from behind, making the printed barcode visible to the scanner without relying on direct scanner illumination.

Barcode Reconstruction

A software-based method for recovering barcode information when the scan engine cannot decode the full barcode, for example by using visible final characters, local brightness correction, or checksum-based correction.

Barcode Scan Engine

The hardware module within the barcode scanner responsible for capturing and decoding barcode information.

Barcode Symbolology

The encoding standard used by a barcode, such as Codabar, Code 128, or Interleaved 2 of 5.

CAPTURE Mode

A scan engine mode in which the scanner returns raw grayscale scan-line data instead of only returning a decoded barcode.

Checksum

A calculated control digit added to a barcode to detect reading errors or support limited reconstruction of incorrectly read barcode characters.

DECODE Mode

A scan engine mode in which the scanner attempts to interpret the barcode internally and returns the decoded barcode value to the Medido.

Dispense Moment

A scheduled date and time at which a medication sachet should be dispensed.

Dispense Process

The sequence of actions performed by the Medido to identify, transport, cut, and dispense a medication sachet.

Dust Cover

A component added above the mirror to prevent dust and transport roller debris from entering the optical path and degrading barcode reading performance.

Dynamic Range

The range between the darkest and brightest values captured by the barcode scan engine, used to assess barcode contrast in the sensor output.

Exposure Time

The duration for which the barcode scan engine collects light during a scan. Longer exposure can increase contrast, but may also affect decoding behavior.

Feature Flag

A software setting that allows a firmware function to be enabled or disabled remotely without installing a separate firmware version.

Filter Server

A system used by Medido for prepackagers to transfer medicine roll information to the Medido Schedule Service.

Firmware

Software embedded within electronic hardware that controls the operation of a device.

Medication Sachet

A sealed package containing medication intended for a specific administration moment.

Medication Sachet Identification

The process of determining which sachet is dispensed based on the read barcode.

Medicine Roll

A continuous strip of connected medication sachets arranged in chronological order.

Mirror Contamination

Dust, debris, or other material on the internal mirror that can obstruct or distort the barcode scanner's view of the sachet.

Optical Artifact

An unintended visual effect in the scan output, such as glare, reflection, overexposure, or dark spots, that can reduce barcode readability.

Optical Path

The route taken by light between the medication sachet, mirror, scanner, and any intermediate optical components.

Prepackager

An organization that packages medication into medicine rolls of connected sachets.

Refurbishment

The process in which returned Medido devices are inspected, cleaned, repaired, upgraded, tested, and prepared for redeployment.

Sachet Validation

The process of verifying that a dispensed medication sachet corresponds to the expected dispense moment or expected barcode information.

Scan Engine LED Blocker

A small component that blocks the barcode scan engine's integrated LED to prevent direct illumination from causing optical artifacts.

Schedule Service

The software system responsible for managing medication schedules, storing digital medicine roll information, and validating barcode information within the Medido ecosystem.

Sensor Frame

The structural component that contains a clear window for the barcode scanner, optical sensors, and associated mounting features.

Specular Reflection

A mirror-like reflection of light that can create glare and reduce barcode readability.

Stationary Scanning

A barcode reading method in which the medication sachet is temporarily stopped before the barcode is scanned, reducing motion-related reading errors.

Ultrasound Transmitter & Lighting PCBA

A printed circuit board assembly that combines the ultrasound transmitter with a backlight used to illuminate medication sachets during barcode scanning.

Abbreviations

ADD

Automated Dose Dispensing; a system that automatically packages medication into sachets based on administration time.

AIS

Apotheek Informatie Systeem; a pharmacy information system used to manage patient medication data.

ARL

Advanced Roll Loading; a Medido feature that automatically determines the correct medicine roll schedule during loading and can adjust dispensing schedules based on the sachets present on the roll.

CLSC

Closed-Loop Supply Chain; a supply chain that includes both product delivery and return flows for refurbishment or remanufacturing.

FDM

Fused Deposition Modeling; a 3D-printing process in which thermoplastic material is deposited layer by layer.

FFC

Flexible Flat Cable; a thin, flat cable used to connect compact electronic assemblies inside the Medido.

GDS

Geautomatiseerd Distributie Systeem; a system that automatically packages medication into sachets based on administration time.

GDPR

General Data Protection Regulation; European legislation governing data privacy and protection.

GPIO

General-Purpose Input/Output; a configurable electronic signal connection that can be used by a microcontroller or processor.

I25

Interleaved 2 of 5; a numeric one-dimensional barcode symbology supported by the barcode scanner firmware.

JTAG

Joint Test Action Group; a debugging and programming interface used on electronic circuit boards.

LED

Light-Emitting Diode; an electronic component that emits light when powered.

MDD

Multi-Dose Drug Dispensing; a medication packaging system in which multiple medications are packaged in a single sachet per Dispense Moment.

MDR

Medical Device Regulation; European legislation governing medical devices.

PCB

Printed Circuit Board; a board that mechanically supports and electrically connects electronic components.

PCBA

Printed Circuit Board Assembly; a printed circuit board with electronic components mounted on it.

PLA

Polylactic Acid; a thermoplastic material commonly used for FDM 3D printing.

PMR

Patient Medication Record; a digital record containing a patient's prescribed medications.

QR

Quick Response code; a two-dimensional barcode capable of storing information in a smaller footprint than traditional linear barcodes.

R&D

Research and Development; the department responsible for product development and technical innovation.

SE655

Zebra Technologies SE655 Decoded Linear Imaging Engine; the barcode scan engine used in the Medido M302.

USTL PCBA

Ultrasound Transmitter & Lighting Printed Circuit Board Assembly; a PCBA that combines the ultrasound transmitter with a backlight for barcode scanning.

USB

Universal Serial Bus; a standard interface used for communication and data transfer between electronic devices.

1D

One-dimensional barcode; a barcode consisting of parallel bars and spaces that encodes data in a single direction.

Abbreviations

2D

Two-dimensional barcode; a barcode that stores information in both horizontal and vertical directions.

M301 / M302 / M303

Different hardware generations of the Medido Medicine Clock with varying barcode scanning capabilities.

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1 Project Introduction

1.1 Context & Background

The Medido Medicine Clock is positioned by Evondos as a medical device under MDR Class I and functions as a medication dispenser. This device operates on mains power and contains internal rechargeable backup batteries. It is designed to dispense pre-packaged medication (on a roll) at pre-programmed times. At scheduled moments, the device alerts the client and, after the button is pressed (Figure 1), dispenses the medication sachet(s) and makes an incision for easy opening.

Figure 1

Medido in Action



Note. From *Medido being used by client* by Medido, 2025, (www.instagram.com/p/DK90cvGhdC5/).

The Medido is intended for clients requiring support in medication management and is used by over 20000 clients in home-care and institutional settings. Within the context of automated medication dispensing, opportunities exist to improve the accuracy and robustness of medication sachet identification. Reliable identification supports validation of the loaded medicine roll and increases confidence that the intended sachet is dispensed at the correct moment.

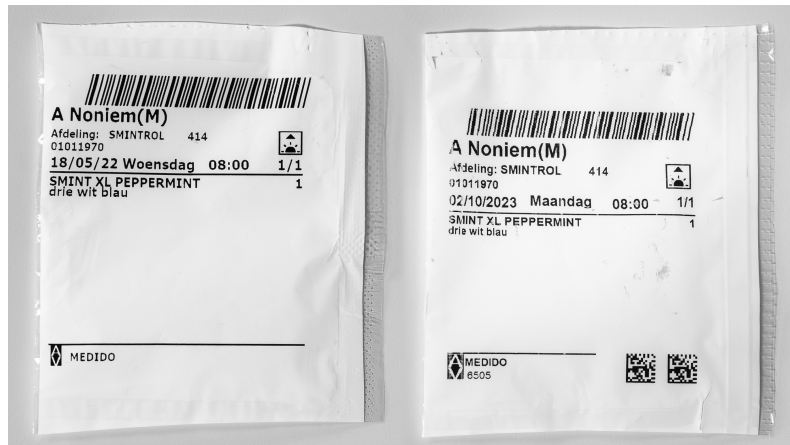
Improving medication sachet identification is also important from an organizational and commercial perspective. Care organizations are increasingly requesting more reliable verification, while tenders in several international markets include requirements related to the correct identification of the sachet. This creates a clear need for Evondos to improve the verification capabilities of the Medido to maintain its position in existing markets and support expansion into new countries.

1.2 Problem Statement

In the Medido Medicine Clock, scanning of printed barcodes (see example sachets in [Figure 2](#)) forms one factor in the dispense process. If a barcode different from the expected value is detected, a warning is escalated to Medido support staff and, if necessary, the care team is contacted.

Figure 2

Example Medication Sachets



Following the 'Medication Under Own Management' principle, a barcode mismatch does not prevent dispensing, as clients and caregivers remain responsible for verifying that the correct medicine roll is loaded. Nevertheless, Evondos aims to improve medication sachet validation to reduce errors and increase reliability, as care organizations in the Netherlands and international markets increasingly demand more robust identification capabilities.

Furthermore, Evondos is working on a Medido feature called Advanced Roll Loading (ARL) which will automatically skip front and trailing sachets when loading the medicine roll and during regular dispensing. It will also be able to adjust the medicine roll schedule based on the first sachet, or in the case that sachets are physically missing on the roll. For ARL to work as intended, it is important to read as many barcodes as possible, as manual intervention from care staff might still be necessary if no barcode is read.

Barcode detection performance is inconsistent in practice due to variability in sachet layouts, print quality, optical conditions, and hardware-related factors. As a result, unverified sachets may still be dispensed without reliable validation. While the newest Medido model (M303) incorporates an improved barcode scanner, a major challenge remains in improving the performance of the installed M302 devices that form the primary installed base.

1.3 Research & Design Objectives

The primary objective of this project was to improve the accuracy and robustness of medication sachet identification within the Medido Medicine Clock.

From a research perspective, the project investigated factors influencing barcode scanning performance in existing Medido devices, with a particular focus on deployed M302 units. Areas of investigation included scanner configuration and positioning, barcode detection logic, medication sachet variability, and hardware-related factors such as optical contamination and environmental influences. Experimental testing was used to quantify current performance limitations and identify causes of inconsistent barcode detection.

From a design perspective, the objective was to translate these insights into improvements that could be implemented within the constraints of the existing hardware architecture. The project aimed to increase the percentage of correctly identified medication sachets, improve reliability under variable real-world conditions, and develop solutions that were technologically and economically feasible for large-scale deployment across the installed device base.

The design assignment was formulated as follows:

Improve
the barcode decoding performance in the Medido Medicine Clock
and create an implementation roadmap
to increase the percentage of correctly identified medication sachets
for clients, caregivers, and Medido
in homecare and intramural settings.

By focusing on improvements that could be realized within deployed devices, the project contributed to enhancing identification reliability in automated medication dispensing systems without requiring full device replacement.

1.4 Project Scope

This project focused on improving barcode-based medication sachet identification in the Medido Medicine Clock model M302. The scope was limited to the interaction between the medication sachet, transport mechanism, integrated barcode scanner, and associated identification logic, including firmware-level barcode detection and portal-side validation logic.

The project primarily addressed M302 devices currently deployed in the field. Although M301 devices use the same scanning hardware, they were not a primary focus due to their anticipated phase-out following the Dutch 2G network shutdown. The newer M303 devices were excluded from the scope because they already incorporated improved scanning hardware, although findings from this research might be applicable to future scanner variants.

From a technical perspective, the project investigated factors influencing barcode reading performance, including optical conditions, mechanical alignment, medication sachet variability, and contamination of optical components. The scope was limited to identification-related performance and excluded pharmaceutical packaging processes, barcode generation, and medication content.

The project was situated within home-care and intramural use contexts in the Netherlands, where devices operate under variable environmental conditions and user interactions. Design interventions were constrained to scalable and cost-effective solutions that could be implemented within the existing hardware architecture of deployed devices, without requiring complete device replacement or extensive dismantling.

Validation was limited to experimental testing and prototype evaluation under controlled conditions. Clinical validation, long-term field studies, regulatory certification, healthcare workflow optimization, medication adherence behavior, and broader backend system integration fell outside the scope of this project.

2 Medicine Roll & Medido Background Information

2.1 Introduction

Reliable medication sachet identification in the Medido Medicine Clock depends on the interaction between medication sachets, digital scheduling infrastructure, the medicine roll transport system, and barcode scanning performance. This chapter analyzes the current Medido system to identify the constraints, sources of variation, and technical factors that may impact barcode decoding reliability.

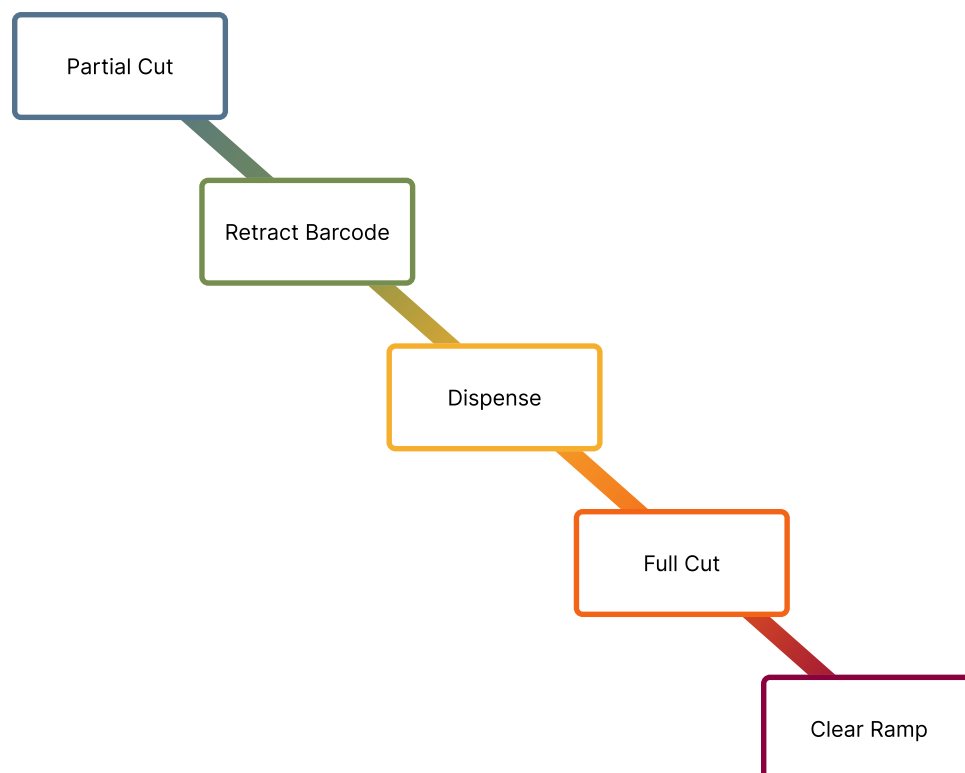
To establish this understanding, the chapter examines the Medido dispense process, medicine roll systems and sachet layout variability, the relevant hardware and barcode scanner integration, and the surrounding Medido ecosystem and data flow. Based on this analysis, a set of requirements was derived to guide the design phase of the project.

2.2 Medido Dispense Process

The Medido dispense process consists of several sub-processes being carried out per sachet, as outlined in [Figure 3](#):

Figure 3

Medido Dispense Process



2.2.1 Partial Cut

Before dispensing, the Medido advances the sachet, clamps and tensions it while verifying it remains correctly positioned under the clamp (using the ultrasound sensor, retrying with incremental adjustments if needed), then performs a controlled partial cut at the top for easier opening, after which the sachet is returned to its normal position with the top aligned at the cutting blade.

2.2.2 Retract Barcode

After the partial cut and before dispensing, the Medido checks whether the barcode is positioned beyond the barcode scanner, and if so, activates the scanner and retracts the sachet until the barcode is aligned for reading, then returns the sachet to the correct dispensing position.

2.2.3 Dispense / Detection Process

During the main dispense and detection process, the sachet is advanced past the optical and ultrasound sensors to locate the seam. If detected, the seam is aligned with the cutter blade; otherwise, detection is retried.

Barcode reading runs in parallel with sachet transport. Before movement starts, the process registers a barcode callback and activates the reader. When a barcode is detected, the callback briefly stops the reader, logs the barcode contents, type, and dimensions, and stores it in the roll manager. Its relative position is calculated from the current encoder position and the fixed offset between the scan window and cutter. The reader is then restarted to capture additional barcodes during transport.

The barcode reader is stopped when the detection process ends, regardless of whether it succeeds, fails, or is aborted. The process therefore does not reposition the sachet to search for a barcode, but records barcodes encountered as the sachet passes through the scan window.

2.2.4 Full Cut

Similar to the partial cut process, the sachet is clamped and tensioned, then fully cut, after which the clamp is retracted and the sachet typically falls down the exit ramp onto the tray.

2.2.5 Clear Ramp

To ensure any stuck sachet is released, the cutter performs another full stroke to push it down the exit ramp, after which the remaining sachets are slightly advanced to realign the top edge with the cutting blade for the next dispense.

2.3 Medicine Roll

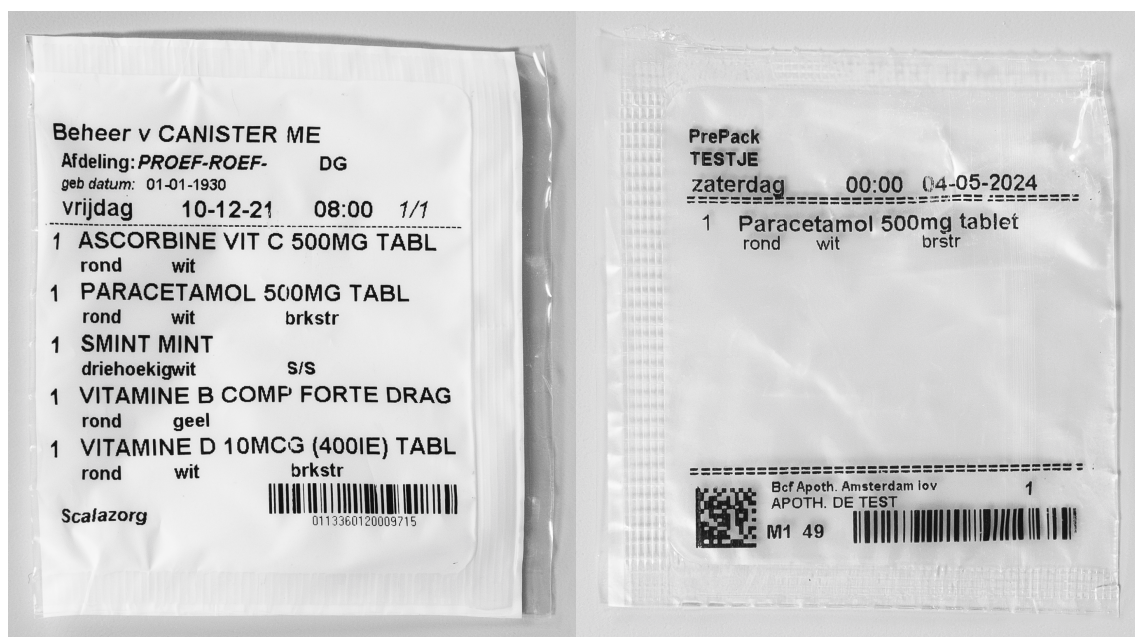
2.3.1 Definition

Medicine rolls, also referred to as Automated Distribution System (“Geautomatiseerd Distributie Systeem”, GDS) (KNMP, 2011), are a pharmaceutical repackaging format in which a patient’s oral solid medications are organized into individual sealed sachets according to their prescribed administration times. Each sachet typically contains all compatible tablets and capsules that the patient must take at a specific date and time and is labelled with identifying information such as the patient’s name, medication contents, dosage, and scheduled administration moment; see Figure 4.

More sachets may be required per medication moment due to medication incompatibility or the size and quantity of the medication. The sachets are connected sequentially in chronological order and supplied as a perforated roll (European Directorate for the Quality of Medicines & HealthCare, 2018; Sjöberg et al., 2011).

Figure 4

Medication Sachets with Different Layouts



2.3.2 Packaging Process

Medicine rolls are produced using automated dispensing machinery that integrates pharmaceutical handling, packaging, and labelling processes. These machines form a continuous web of flexible packaging film into individual sachets, dispense the prescribed medications, seal the sachets using heat sealing, and print patient-specific and dose-specific information onto the packaging surface. The sachets are perforated between each dose and wound into a roll for distribution.

2 Medicine Roll & Medido Background Information

Modern systems may incorporate barcode tracking and camera-based inspection systems to verify the identity and quantity of medications in each sachet (Sjöberg et al., 2011). However, the resulting sachets may differ between packaging systems and pharmacies in terms of packaging material, opacity, printed layout, barcode type, barcode dimensions, and barcode position. These differences directly influence how reliably the sachets can be identified by the Medido.

The medication inside the sachet also affects its physical shape. Differences in medication size and quantity, together with trapped air, folds, and wrinkles in the packaging film, can prevent the sachet from remaining flat during transport. This may change the distance and angle between the printed barcode and the barcode scanner and can cause medication to obstruct the barcode.

2.3.3 Post-production Medication Changes

Medication changes made after the medicine roll has been produced may require manual adjustments to individual sachets. A small incision is made in the sachet and medication is added or removed, after which the incision is taped shut and the updated information is written on the sachet by hand (Figure 5). These adjustments introduce additional physical and visual variation that may affect sachet transport or identification.

Figure 5

Medication Sachet Taped Shut with Blue Sticker After Change in Medication



2.4 Medication Sachet Layout

The Medido Medicine Clock is supplied with a configuration which is dependent on the type of medication sachet loaded. Each prepackager has a different layout varying in width (ranging slightly from 68 mm to 71 mm), length (60 mm to 87 mm), color (white or transparent), and machine-readable data (1D or 2D barcode, or none at all).

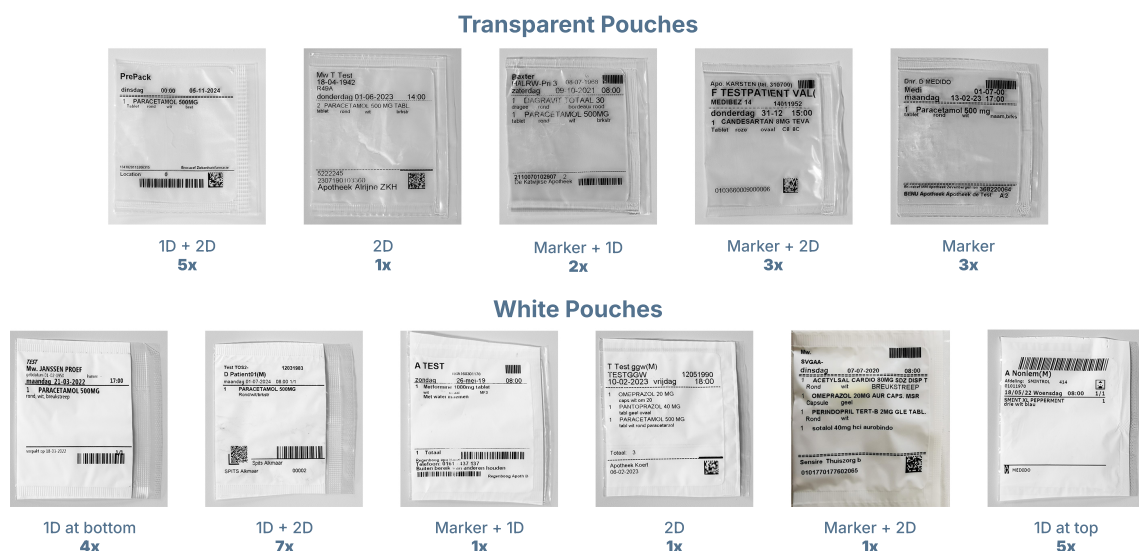
Although sachet layouts are determined by the prepackager, Evondos maintains working relationships with prepackers and can sometimes request or influence layout changes. For example, a prepackager recently added a barcode to a layout used by approximately 1300 clients, enabling sachet identification for this group. Evondos intends to strengthen these relationships in the future to better represent the interests of the Medido Medicine Clock in sachet layout decisions.

It is important that the configured layout matches the layout of the actual sachets inserted in the Medido, as incorrect settings can lead to dispense errors (e.g. sachets being cut at the wrong location) or trouble with reading the barcode if an incorrect barcode type is set. The configured barcode location also determines where the Medido attempts to read the barcode, further highlighting the need for accurate configuration management.

Figure 6 outlines the difference between supported Dutch sachet layouts. Appendix A explains the differences between sachet configurations and barcode types.

Figure 6

Different Sachet Layout Categories with Amount of Configurations per Type

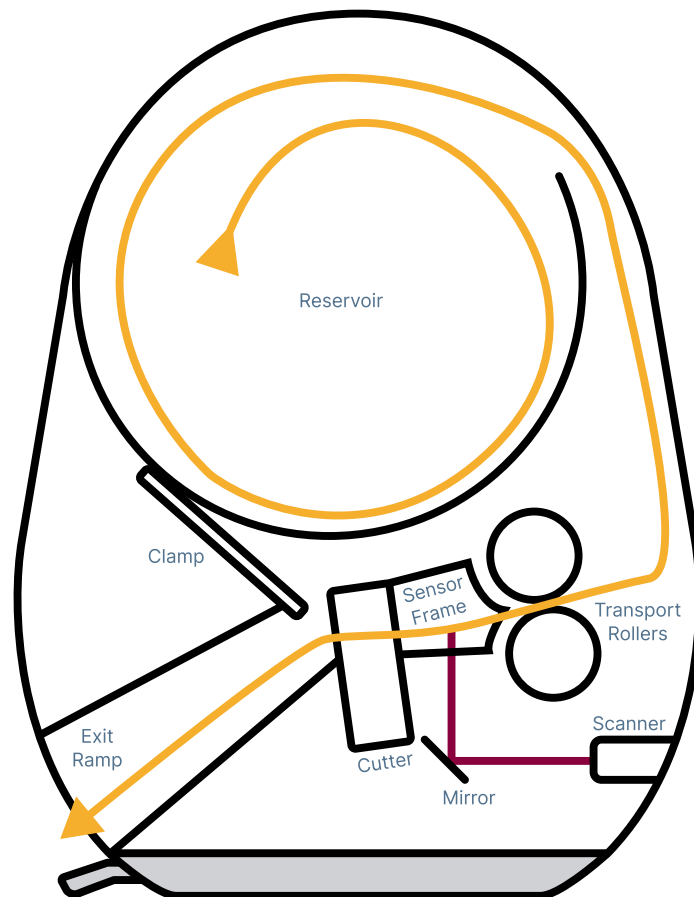


2.5 Medido Hardware

Figure 7 shows a schematic side view of the Medido, in which the medicine roll (yellow), transport rollers, barcode scanner (with the optical path in red), mirror, sensor frame with sensors, cutter and clamp are visible.

Figure 7

Schematic Drawing of the Medido Hardware



The start of the medicine roll is placed between the transport rollers, after which the lid is closed. The Medido automatically advances the first sachet past the barcode window and sensors in the sensor frame. After the sensors are the cutter and clamp, which moves diagonally down to clamp the sachet in place during tensioning and cutting.

The physical mounting of the barcode scanner within the Medido allows for significant variation in both the sideways positioning and rotational alignment of the scan area. As a result, the exact location and orientation of the projected scan line can differ between devices, potentially affecting barcode illumination, focus, and decoding performance.

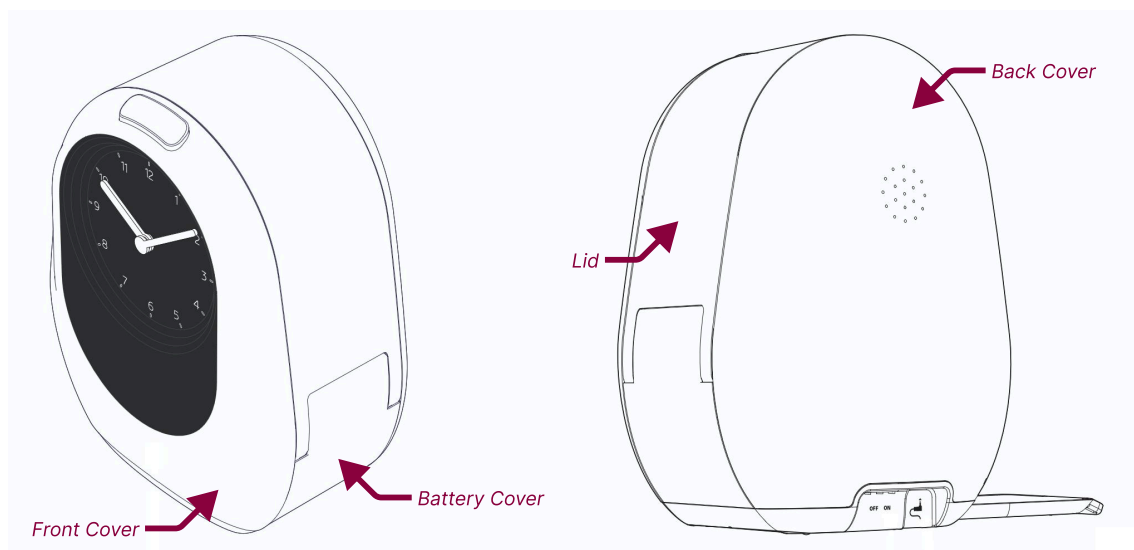
To access the barcode scan engine, the Battery Cover (Figure 8) can be removed by opening the Lid and sliding out the Battery Cover in a controlled sequence. This can be done without the use of tools. Removal of the barcode scan engine, mirror, sensor frame, and transport rollers requires separation of the Front Frame from the Back Frame, which involves loosening several T9 Torx screws inside the Medido.

Access to the main PCB is obtained by removing the Back Cover, which can be unclipped after loosening a T10 Torx screw. Similarly, the Front Cover, including the clock assembly, can be removed by unclipping it after loosening two T10 Torx screws.

The top of the sensor frame can be accessed by opening the Lid and unclipping the Reservoir Cover.

Figure 8

Global Medido Product Architecture



2.5.1 Barcode Scanner Integration

The barcode scanner used in the Medido M302 is the Zebra Technologies SE655 Decoded Linear Imaging Engine, a compact scan engine commonly integrated into industrial and retail barcode scanning systems.

Figure 9 shows the scan engine, with the circular sensor lens located on its right side and the rectangular illumination lens on its left side (the image is reversed due to the front view). The latter focuses the integrated illumination LED into a narrow rectangular slit of light used to illuminate the barcode during scanning.

Figure 9

SE655 Decoded Linear Imaging Engine



Note. From *SE655 Linear Imager Scanner* by Zebra, n.d., (<https://www.zebra.com/gb/en/products/spec-sheets/oem/oem-engines/se655.html>).

Performing a digital readout of the scan engine provides additional information regarding the internal firmware configuration, including the "revision" and "scankit" parameters. These parameters suggest that multiple firmware variants exist for different scanning applications and barcode configurations.

The scan engine used in the Medido is "SKIT_5.01 T12_Coupon_Coercion_03_I25_Aiming09_v3.1". Based on the naming convention, this firmware configuration appears to have been developed for coupon scanning applications and likely includes optimizations for reading Interleaved 2 of 5 (I25) barcodes. This indicates that scan engine behavior may partially depend on the installed firmware configuration and its intended use case.

The scan engine can operate in two different modes: DECODE and CAPTURE. In DECODE mode, the scanner continuously attempts to decode a barcode until a valid result is detected. Once successful, the decoded barcode is returned to the host system (the Medido) as a text string. This process operates at a rate of 50 scans per second.

In CAPTURE mode, a single scan image is captured and the raw grayscale data is returned to the host system. The output consists of 1500 grayscale values representing the captured scan line. In addition, diagnostic information such as the exposure time and the average black and white intensity levels is returned.

The exposure time is automatically determined by the scan engine, and cannot be locked or manually set to a certain value.

The Medido software operates the scan engine in DECODE mode while the medicine roll is moving. As a result, the barcode may shift position during the exposure time of the scan. This can lead to motion-induced distortion of the barcode image during decoding. The effect is especially relevant for slanted barcodes, where vertical movement of the sachet also introduces a horizontal displacement of the barcode within the scan image.

2.6 Literature Review of Remanufacturing of Medical Devices

Healthcare systems face increasing pressure to reduce environmental impact while maintaining patient safety, device performance, and regulatory compliance. Approximately 5% of global greenhouse gas emissions originate from the healthcare sector, with a substantial share resulting from supply-chain activities such as manufacturing and transportation (Das & Chandra, 2022; Or & Seppänen, 2024).

Within circular economy strategies, remanufacturing is often regarded as one of the most viable approaches for medical devices due to the strict quality, safety, and performance requirements imposed on healthcare technologies. Unlike lower-order circular strategies such as repair or reuse, remanufacturing aims to restore products through a structured industrial process involving collection, inspection, disassembly, cleaning, replacement or upgrading of components, reassembly, and validation to achieve performance comparable to newly manufactured products (Schulte et al., 2021). In addition to restoring functionality, remanufacturing can be used to implement technical upgrades that allow existing devices to meet evolving technological, operational, or clinical requirements (Asif et al., 2021).

A key challenge in medical technology is technological obsolescence: devices may remain physically functional while no longer satisfying contemporary performance expectations, compatibility requirements, or stakeholder demands. In such cases, upgrading deployed devices can offer an alternative to com-

plete replacement, potentially reducing material consumption, production impacts, and economic cost (Asif et al., 2021; Leemans et al., 2025). This is particularly relevant for medical devices with a large installed base, where replacing all deployed units may be impractical or economically undesirable.

The literature identifies several constraints that influence whether upgrading through remanufacturing is feasible. Product architecture plays a major role: devices must allow safe access to relevant components, support non-destructive disassembly, and use sufficiently durable materials and interfaces to survive multiple lifecycles (Gray & Charter, 2007; Kane et al., 2017). Modularity is repeatedly emphasized as an enabling factor, as it permits selective replacement or upgrading of subsystems without redesigning or discarding the complete device (Asif et al., 2021; Ijomah et al., 2006).

Beyond technical design, operational and business considerations influence remanufacturing feasibility. Product-service systems and closed-loop supply chains can facilitate the return, refurbishment, and redeployment of devices by maintaining control over product ownership, return timing, and device condition (Barquet et al., 2013; Benedettini, 2022). Such approaches are especially relevant in healthcare, where deployed devices often remain under long-term service arrangements.

Finally, regulatory and safety requirements strongly shape allowable remanufacturing practices. Medical devices operate under stringent hygiene, documentation, and quality expectations, and modifications require renewed validation and/or compliance assessment depending on the jurisdiction and device classification (Reinbold & Zaeh, 2025; Shukla et al., 2023). Consequently, upgrade-oriented remanufacturing in healthcare must balance technical improvement with safety assurance, regulatory acceptability, and operational feasibility.

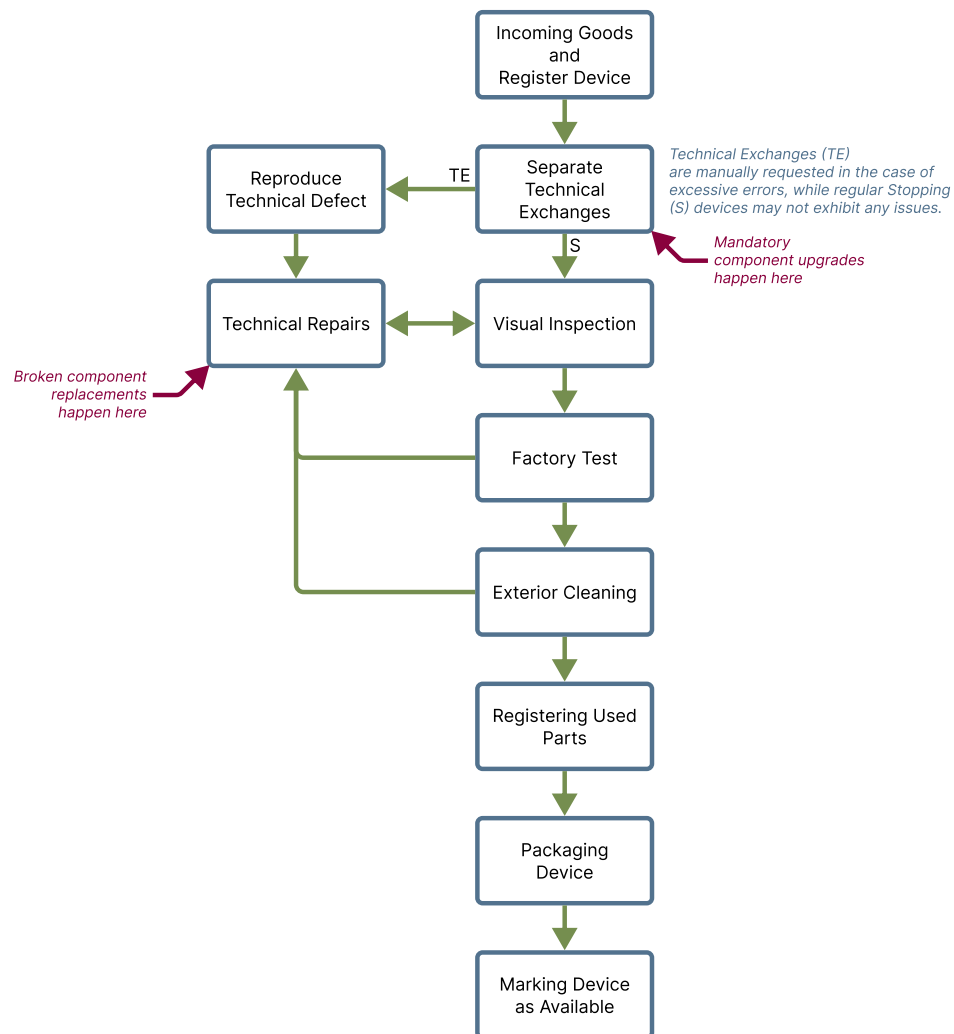
Within the context of the Medido Medicine Clock, these considerations are directly relevant. The project focuses on improving barcode identification performance in deployed M302 devices. Rather than developing an entirely new product platform, the assignment investigates how performance improvements can be realized within the constraints of existing hardware, firmware, and operational infrastructure. This positions the project within the broader context of upgrade-oriented remanufacturing and lifecycle extension of medical devices.

2.7 Medido Refurbishment Process

Figure 10 outlines the Medido refurbishment process for regular stopped devices (i.e. the client will no longer use the device) and Technical Exchanges (the device was exchanged due to excessive errors).

Figure 10

Medido Refurbishment Process



Mandatory component upgrades due to a design change (for example as the result of this thesis) happen before the distinction between Stopping devices and Technical Exchanges, as either option will lead to the component needing to be exchanged.

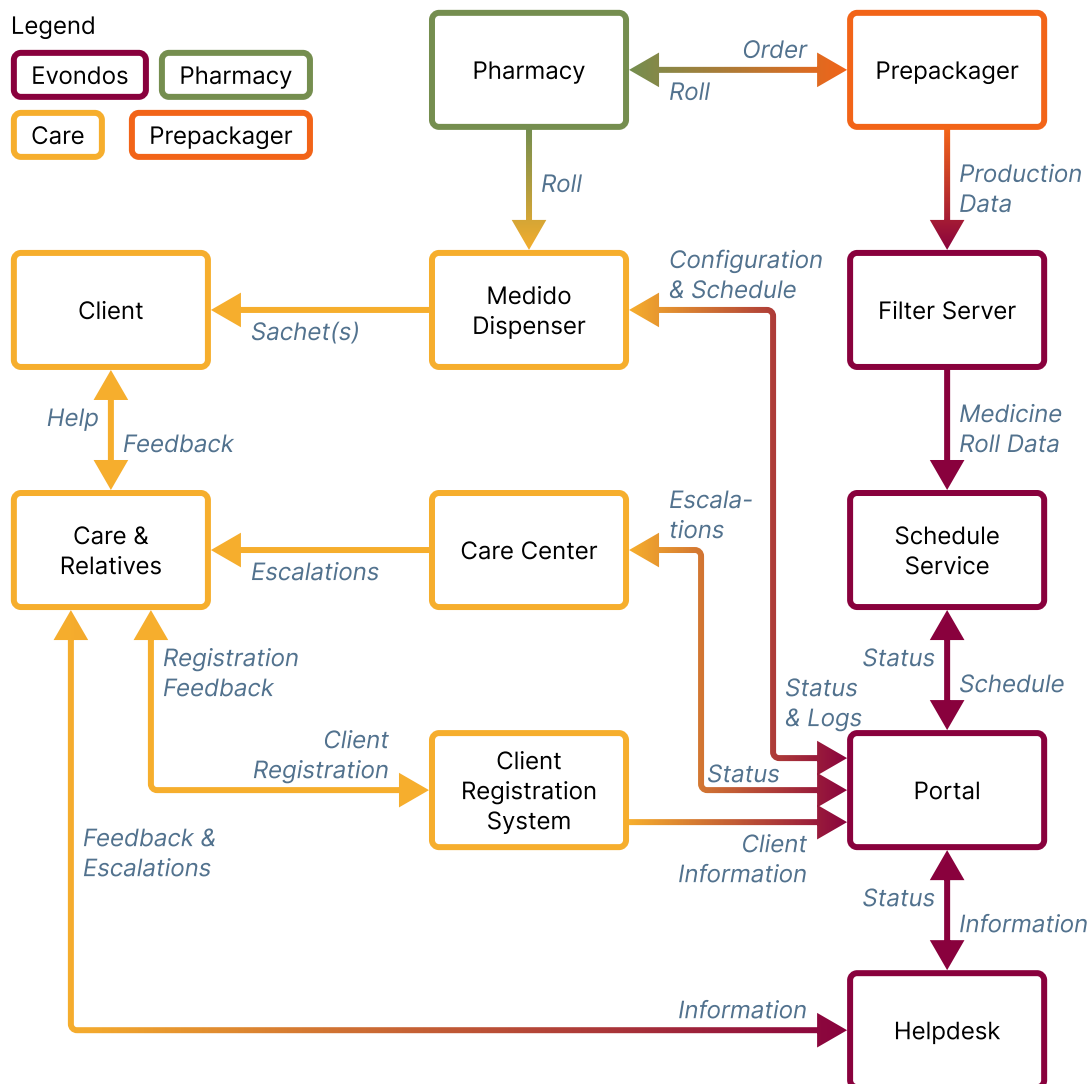
Broken components are replaced in the Technical Repairs step, either due to a Reproduced Technical Defect, Visual Inspection of the device, or a component defect noticed during the Factory Test of Exterior Cleaning.

2.8 Medido Ecosystem & Data Flow

The Medido Medicine Clock works together with multiple supporting services to maintain a dispensing schedule, monitor dispenses, and enable the detection and escalation of errors when necessary. Figure 11 outlines the exchange in data between actors and systems in the Medido ecosystem.

Figure 11

Medido Ecosystem & Data Flow



2.8.1 Portal

The Medido Portal functions as the central interface for managing the Medido system. It connects directly to the device and is used to maintain client information and configure dispenser settings. Through the Portal, staff can issue commands to the Medido, as well as access device logs and detailed records of dispensing events.

Historically, dispensing schedules were manually created and maintained by Medido's Customer Support department. This responsibility has since been transferred to the Schedule Service, which now centrally manages all scheduling functionality.

2.8.2 Schedule Service

The Schedule Service is responsible for the management and visualization of dispensing schedules. It provides a calendar-based overview of both past and upcoming dispensing events, including their corresponding statuses.

Dispensing schedules are structured around digital representations of medicine rolls, which correspond to the physical rolls inserted into the Medido. Each digital roll contains entries for individual medication sachets, specifying the scheduled dispensing date and time, as well as the expected barcode when such information is available from the prepackager.

During dispensing, scanned barcodes are transmitted back to the Schedule Service and the Portal. These are validated against expected values, and discrepancies result in warnings to Medido staff.

For the majority of clients (over 93%), dispensing schedules are automatically provided by prepackaging partners following the production of medicine rolls, through the use of a Filter Server. For the remaining clients, schedules are generated within the Schedule Service itself based on rules set by Medido's Pharma Support department. In these cases, new digital schedules are created automatically when a medicine roll is depleted, but barcode data is unavailable in this scenario.

2.8.3 Filter Server

Prepackaging partners may use a Filter Server, which can be implemented either as a physical system or as a digital integration within their infrastructure. The Filter Server processes production data related to medicine rolls and links this information to the corresponding client within the Schedule Service.

This integration eliminates the need for manual schedule creation and ensures that updates to medicine roll data are automatically reflected in the system. As a result, dispensing schedules remain accurate and up to date with minimal manual intervention.

2.9 Requirements

Based on the background information, a list of requirements was extracted.

The design shall:

- **R1.1 Functional compatibility**
Support successful decoding (a decode 95+% of the time) of all barcode types and supported sachet configurations used within the Medido ecosystem, including variations in sachet dimensions, material transparency, barcode location, and barcode symbology.
- **R1.2 Robustness to operational variation**
Maintain barcode decoding performance under realistic variations in sachet positioning during transport and manufacturing tolerances in scanner mounting position and rotational alignment between devices.
- **R1.3 Hardware integration compatibility**
Fit within the existing Medido hardware architecture, remain compatible with the mirror-based optical path and Zebra Technologies SE655 scan engine, and not interfere with existing dispensing components or mechanisms.
- **R1.4 Optical performance compatibility**
Provide optical conditions compatible with SE655 operation, including adequate barcode contrast under automatic exposure behavior, without introducing optical artefacts that reduce decoding performance.
- **R1.5 Operational compatibility**
Support continuous operation throughout the dispense cycle without manual intervention and remain compatible with existing digital schedule validation processes.
- **R1.6 Retrofit compatibility**
Support implementation on existing Medido devices during refurbishment without requiring modifications to the main housing structure or major subsystem redesign.
- **R1.7 Minimal installation impact**
Minimize the disassembly time of existing components that must be removed, modified, or replaced during installation.
- **R1.8 Existing tooling compatibility**
Support installation using tools and equipment already available within existing Medido assembly and refurbishment processes.
- **R1.9 Installation repeatability**
Support consistent installation across devices without requiring device-specific calibration, alignment procedures, or specialist training.

- **R1.10 Serviceability**

Maintain accessibility of added components for inspection, cleaning, maintenance, and replacement during normal servicing activities.

2.10 Conclusion

This chapter provided the background information required to understand medication sachet identification within the Medido Medicine Clock. Analysis of the dispense process showed that barcode reading is part of a larger sequence of mechanical, optical, and software-controlled operations. The timing and positioning of barcode scanning are closely linked to the transport mechanism and overall dispense process.

The chapter further demonstrated that substantial variation exists in medication sachets used within the Medido ecosystem. Differences in sachet dimensions, materials, barcode types, barcode locations, and printing quality introduce variability that cannot be controlled by Medido and must therefore be accommodated by the identification system.

Analysis of the Medido hardware showed that barcode reading performance depends on the interaction between the SE655 scan engine, the mirror-based optical path, illumination conditions, and the mechanical positioning of the scanner. In addition, the refurbishment process revealed that any proposed solution must be compatible with existing M302 devices and practical to implement during refurbishment activities without changes in required tools.

Finally, examination of the Medido ecosystem demonstrated that barcode information is not only used for sachet identification, but also supports error handling, communication between multiple systems and stakeholders, and schedule validation in the future through Advanced Roll Loading. Together, these findings established the technical, operational, and organizational constraints in which improvements to medication sachet identification must be developed. Based on these findings, a set of requirements was formulated to guide the design phase.

2 Medicine Roll & Medido Background Information

New chapter on the next page. ►

3 Barcode Scanner Performance Research

3.1 Introduction

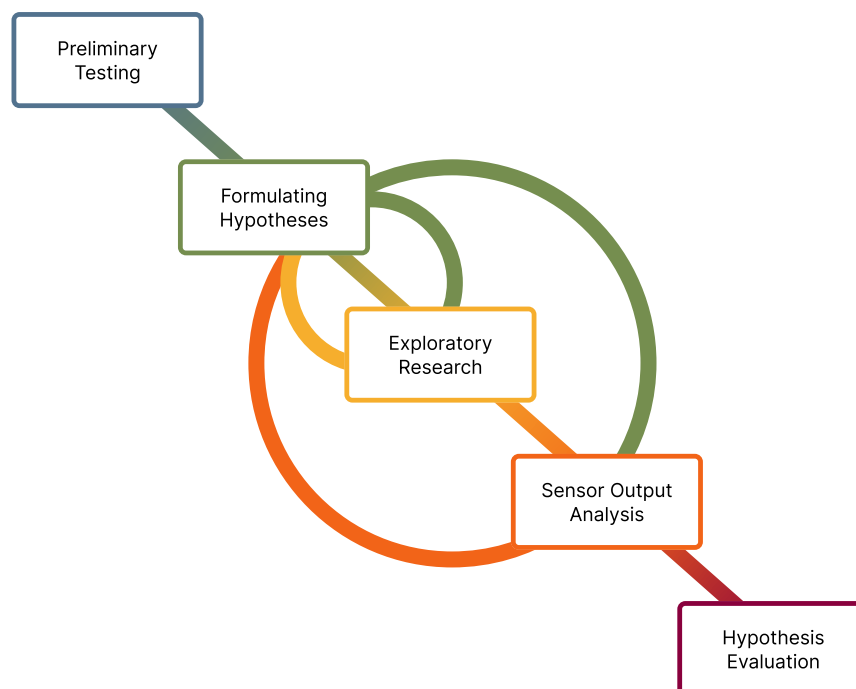
This chapter presents an exploratory investigation into the factors influencing barcode reading performance in the Medido Medicine Clock (see [Figure 12](#)). Preliminary testing and troubleshooting activities revealed substantial variability in barcode decoding behavior between devices and operating conditions. Based on these observations, a set of hypotheses was formulated concerning the influence of transport conditions, illumination, contamination, optical configuration, and scanner behavior on barcode reading reliability.

These hypotheses were investigated through an iterative experimental process consisting of two complementary phases. First, an exploratory testing phase examined the effects of different scanning positions, lighting conditions, and contamination scenarios. Barcode reading performance under these conditions was quantified using custom Python scripts. Second, a sensor output analysis phase employed the scan engine's CAPTURE mode to qualitatively assess optical phenomena visible in the scan data, including contrast limitations, reflections, and exposure behavior.

The outcomes of this investigation were used to assess the validity of the hypotheses, deepen understanding of the barcode scanning system, and derive requirements that informed the subsequent design phase.

Figure 12

Barcode Scanner Research Workflow



3.1.1 Preliminary Testing

Preliminary testing was conducted to explore the barcode scanning behavior of the Medido Medicine Clock and to identify potential factors affecting barcode decoding performance. Initial observations revealed substantial variability between devices, inconsistent performance under different lighting conditions, and sensitivity to changes in scanning configuration. These findings indicated that barcode reading performance was likely influenced by a combination of transport, optical, and environmental factors, which formed the basis for the formulation of the hypotheses investigated in this chapter.

3.1.2 Hypotheses

H1: Barcode reading performance is negatively affected by scanning during motion.

Preliminary testing showed improved reading performance when barcode scans were performed while the sachet was stationary.

H2: Using diffuse illumination improves barcode decoding reliability compared with illumination from the scanner LED.

Initial observations suggested that alternative lighting conditions influenced barcode reading performance.

H3: Contamination of the mirror negatively impacts barcode detection accuracy.

Visible dust and debris accumulation in the optical path were observed during device inspection and troubleshooting.

H4: Small variations in scanner alignment and positioning reduce barcode decoding consistency between otherwise identical devices.

Substantial performance differences were observed in the field between nominally identical devices under similar conditions.

H5: The barcode scanner under-utilizes the available grayscale dynamic range, limiting barcode contrast.

CAPTURE mode sensor output indicated relatively low contrast between black and white barcode regions.

H6: Increasing barcode scanner exposure time improves barcode contrast and barcode decoding reliability.

Preliminary experiments suggested that longer exposure times increased contrast in the captured scan data.

H7: Specular reflections from black barcode regions can be interpreted as white space by the barcode scanner, leading to decoding errors.

Optical artifacts resembling localized reflections were observed in barcode scan output during exploratory testing.

3.2 Methods

3.2.1 Exploratory Research

Two Medido M302 units (D1 and D2) were used for controlled testing. Both devices were modified by removing the back cover to access the USB port for serial readout, and the battery cover to visually inspect the barcode scanning process (Figure 13).

In every test, the same medicine roll with 62 white sachets (the print of the first sachet was worn off over time and disregarded in the data) and one trailing sachet was used to ensure variability in performance could not be attributed to the medicine roll used.

Figure 13

Medido with Back and Battery Cover Removed



A serial connection was established using Tera Term to capture device logs during testing.

Experiment ER1 - Baseline Performance

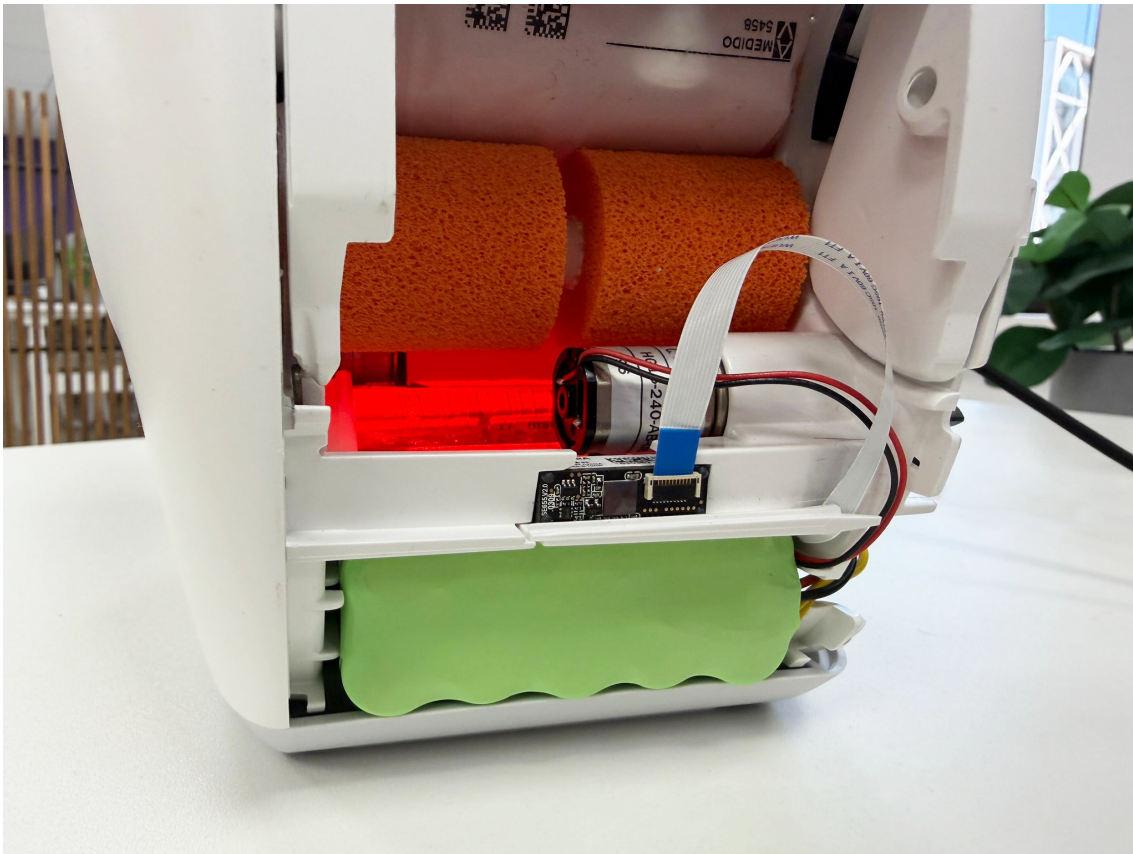
Investigates **H4**: *Small variations in scanner alignment and positioning reduce barcode decoding consistency between otherwise identical devices.*

Each device was tested five times with the same medicine roll using the default firmware, in which the barcode scanner operates *while* the medicine roll is transported through the device (Figure 14). See Confidential Annex Appendix A Section A.1 for the code.

To evaluate the influence of ambient light, the battery cover was reinstalled in two of the five trials for each unit, partially shielding the scanner.

Figure 14

Barcode Scanner in Action



Experiment ER2 - Controlled Scanning Position

Investigates **H1**: *Barcode reading performance is negatively affected by scanning during motion.*

To investigate barcode detection as a function of position, a custom test script was developed that directly controls the transport motor and barcode scanner. See Confidential Annex Appendix A Section A.2 and Section A.3 for the code.

The sachet length was configured at 80 mm, with a distance of the top of the sachet to the barcode of 10 mm. The length of valid barcodes was set at 11 characters, and a maximum of 64 sachets was configured (or until the end barcode is read which has an extra prefixed '9').

The script transports the sachet to 2 mm above the expected start of the barcode, and attempts 10 consecutive reads with one motor step (1 mm) in between. As barcodes on the test sachets are 6 mm tall, this results in a 2 mm buffer before and after the barcode to account for small shifts.

The script allows configuration of:

- Sachet length
- Barcode position on the sachet
- Barcode length in characters
- Maximum number of sachets
- Scanner timeout (maximum read duration)
- Number of read retries per sachet

For each motor step (approximately 1 mm), the script records whether a barcode is successfully read. Based on the known barcode format (numeric only), the script validates detected values and flags incorrect readings.

To determine barcode position, the center is calculated by averaging the motor positions of the first and last successful detections. The transport system then advances to the expected position of the next barcode based on this barcode center and the known sachet length.

Experiment ER3 - Light Configuration

Investigates **H2**: Using diffuse illumination improves barcode decoding reliability compared with illumination from the scanner LED.

To investigate lighting effects, multiple configurations were tested:

- Partially shielded (battery cover installed)
- Fully enclosed (all covers installed)
- Increased ambient light (external LED panel, see Figure 15)

Figure 15

Setup with Added Ambient Light



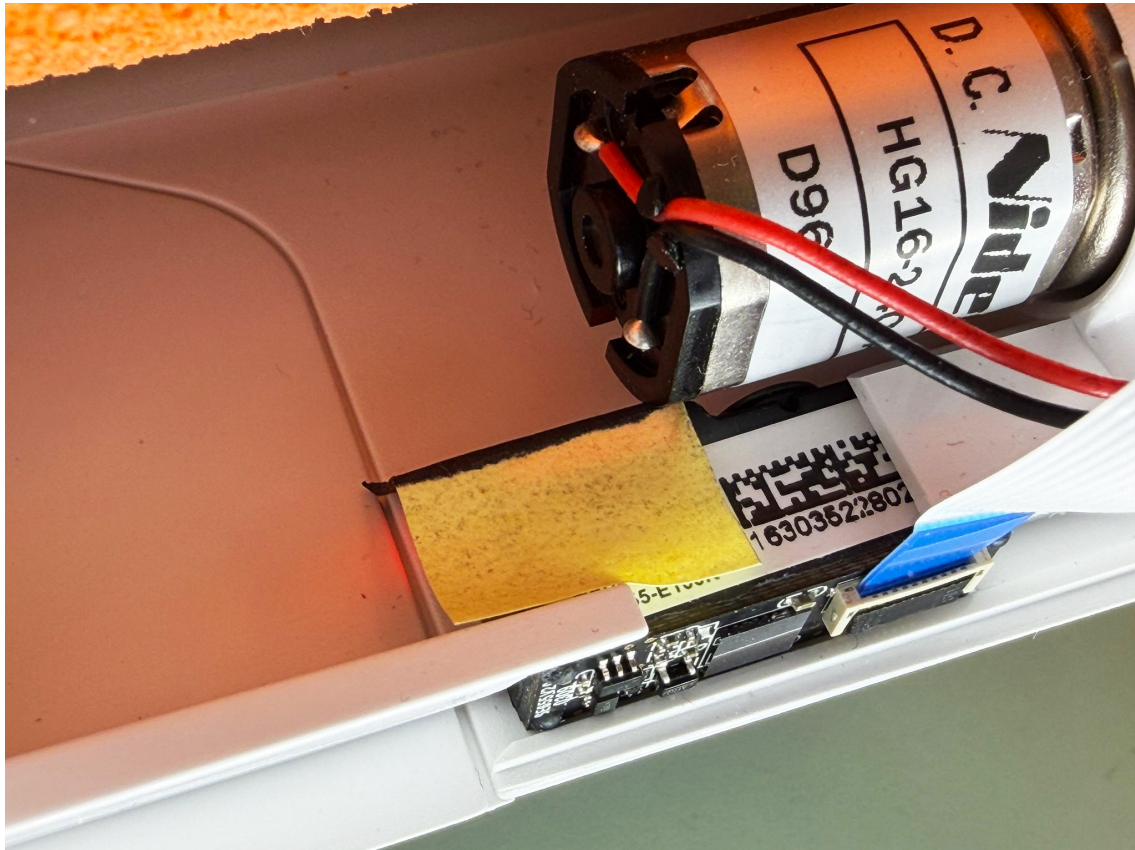
Experiment ER4 - Scanner LED Isolation

Investigates **H2**: Using diffuse illumination improves barcode decoding reliability compared with illumination from the scanner LED.

To isolate the influence of the internal scanner LED, the LED was physically blocked while maintaining external illumination (Figure 16).

Figure 16

Barcode Scanner with LED Blocked



Experiment ER5 - Mirror Contamination

Investigates **H3**: Contamination of the mirror negatively impacts barcode detection accuracy.

The effect of contamination was assessed through repeated testing with varying levels of dust and debris on the mirror, followed by cleaning using compressed air.

3.2.2 Sensor Output Analysis

A series of experiments was conducted using the scan engine's CAPTURE mode, which returns 1500 grayscale values representing the captured scan line. This made it possible to directly analyze the optical output of the scanner and to experiment with different optical configurations, barcode types, and test patterns. These experiments provided additional insight into the operating principles and behavior of the scan engine under varying conditions.

Experiment S01 - Baseline Performance

*Investigates **H5**: The barcode scanner under-utilizes the available grayscale dynamic range, limiting barcode contrast.*

CAPTURE mode sensor output was recorded for representative white and clear sachets containing Codabar and Code 128 barcodes under normal operating conditions. The grayscale scan data were analyzed to assess contrast and dynamic range utilization.

Experiment S02 - Diffusing Scanner LED

*Investigates **H6**: Increasing barcode scanner exposure time improves barcode contrast and barcode decoding reliability.*

A semitransparent 3D printed PLA diffuser was placed in front of the scan engine LED, after which CAPTURE mode output was recorded and compared with the baseline configuration.

Experiment S03 - Testing Various Sachets

*Investigates **H7**: Specular reflections from black barcode regions can be interpreted as white space by the barcode scanner, leading to decoding errors.*

CAPTURE mode output from multiple sachet types and experimental lighting configurations was qualitatively examined for optical artifacts, including reflections and local overexposure.

3.3 Results

3.3.1 Exploratory Research

In total, 23 tests were carried out in varying configurations of the back cover, battery cover, external ambient lighting through an LED panel, and the built-in scan engine LED. See [Confidential Annex Appendix B Section B.1](#) for the exact results. See [Confidential Annex Appendix B Section B.2](#) for the corresponding tables and graphs.

Experiment ER1 - Baseline Performance

Substantial variation in performance was observed between two similar devices with a clean mirror. The same medicine roll was dispensed five times per test.

Experiment ER2 - Controlled Scanning Position

In preliminary testing (only one test was done per device) with the step-based test script where the barcode was stationary during reading, performance improved significantly over reading while the sachet moved past the barcode scanner.

Experiment ER3 - Light Configuration

With both the back and battery covers installed, performance decreased. Introducing external ambient light resulted in a substantial improvement. When all covers were installed, performance decreased compared to baseline.

Experiment ER4 - Scanner LED Isolation

Blocking the scanner LED while maintaining ambient light resulted in near-perfect performance.

Experiment ER5 - Mirror Contamination

Contamination of the mirror resulted in both failed reads and incorrect character recognition (e.g., detection of '.' or ':' instead of numeric values). In some cases, valid barcode positions were detected but barcodes were not correctly interpreted.

Gaps between successful reads were observed, leading to inaccuracies in calculated barcode positions as the calculated center of the barcode was used to transport to the next sachet. Over multiple sachets, these errors accumulated, eventually causing the system to lose track of barcode locations entirely.

Cleaning the mirror with compressed air consistently restored performance.

3.3.2 Sensor Output Analysis

Experiment S01 - Baseline Performance

Relatively low contrast between the black and white intensity values was observed (Figure 17). The measured white intensity values did not exceed 114 on an 8-bit grayscale scale with a maximum value of 255. A similar result was achieved with clear sachets. This indicates that only approximately 45% of the available dynamic range of the scan engine is utilized under normal operating conditions.

Figure 17

Low Contrast in Baseline Tests

scan #15, type 0 "unknown", code "unknown", exposure 127 μ s, decode 0 ms, black 3/255, white 48/255



scan #16, type 0 "unknown", code "unknown", exposure 129 μ s, decode 0 ms, black 8/255, white 99/255



scan #17, type 0 "unknown", code "unknown", exposure 127 μ s, decode 0 ms, black 6/255, white 80/255



Experiment S02 - Diffusing Scanner LED

The modified setup resulted in a higher dynamic range utilization (75% instead of 45%, see scans in Figure 18). The reduced illumination intensity caused the scan engine to automatically increase the exposure time.

Figure 18

Extended Exposure Time Resulting in Higher Dynamic Range

scan #23, type 2 "Codabar", code "27734589415", exposure 504 μ s, decode 266 ms, black 23/255, white 111/255



scan #24, type 2 "Codabar", code "27734589415", exposure 510 μ s, decode 374 ms, black 20/255, white 101/255



Experiment S03 - Testing Various Sachets

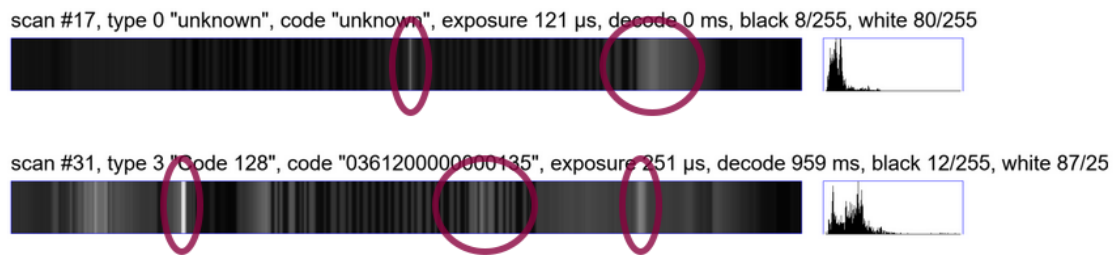
Strong reflections were observed in the scan output (Figure 19). These reflections negatively affected the effective dynamic range of the scan, as the reflected light intensity was significantly brighter than the normal white regions of the barcode image.

The reflections were visible both in the white background surrounding the barcode and on the black barcode bars themselves. In some cases, black bars

reflected sufficient light to appear similar to white regions in the captured scan data, which can severely disrupt or completely prevent correct barcode decoding. These reflections were less pronounced (but still visible) in setups where a diffuse filter was placed in front of the illumination LED.

Figure 19

Visible Reflections in Sensor Output



3.4 Discussion

Based on the results of the research, the seven hypotheses were evaluated (Table 1). See Appendix B for substantiation of the evaluation.

Table 1

Evaluation of Hypotheses

Hypothesis	True / False	Informing Experiments
H1: Barcode reading performance is negatively affected by scanning during motion.	True	ER2 - Controlled Scanning Position
H2: Using diffuse illumination improves barcode decoding reliability compared with illumination from the scanner LED.	True	ER3 - Light Configuration & ER4 - Scanner LED Isolation
H3: Contamination of the mirror negatively impacts barcode detection accuracy.	True	ER5 - Mirror Contamination
H4: Small variations in scanner alignment and positioning reduce barcode decoding consistency between otherwise identical devices.	True	ER1 - Baseline Performance
H5: The barcode scanner under-utilizes the available grayscale dynamic range, limiting barcode contrast.	True	SO1 - Baseline Performance
H6: Increasing barcode scanner exposure time improves barcode contrast and barcode decoding reliability.	True	SO2 - Diffusing Scanner LED
H7: Specular reflections from black barcode regions can be interpreted as white space by the barcode scanner, leading to decoding errors.	True	SO3 - Testing Various Sachets

3.5 Requirements

Based on the findings, a second list of requirements was extracted.

The design shall:

- **R2.1 Contamination robustness**
Prevent dust and debris from entering, accumulating within, or obstructing the optical path, and remain operational after realistic minor contamination during normal device use.
- **R2.2 Optical performance**
Provide illumination and optical conditions that minimize reflections, overexposure, and optical artefacts, while maintaining sufficient grayscale contrast, dynamic range, and barcode feature distinguishability for reliable decoding.
- **R2.3 Robustness to mechanical variation**
Reduce sensitivity to realistic variations in scan engine position, mirror position, rotational alignment, and assembly tolerances, maintaining intended scan line placement and repeatable scan output across equivalent Medido units.
- **R2.4 Barcode decoding performance**
Improve barcode decoding performance relative to the current moving, internally illuminated baseline configuration, including operation under both white and transparent sachet conditions.
- **R2.5 Stationary scanning capability**
Enable barcode scanning while the sachet is stationary.

3.6 Conclusion

This chapter investigated the factors influencing barcode reading performance in the Medido Medicine Clock through a combination of exploratory testing and sensor output analysis. The research demonstrated that barcode decoding reliability is affected by multiple interacting factors rather than a single root cause.

The exploratory experiments showed that transport conditions, illumination, contamination of optical components, and scanner positioning all influence barcode reading performance. In particular, scanning while the sachet is moving was found to reduce reliability, while ambient illumination and scanner configuration significantly affected decoding success. Furthermore, contamination of the optical path, especially the mirror, proved to substantially degrade performance.

Analysis of the scan engine sensor output provided additional insight into the underlying optical mechanisms responsible for these observations. The results showed that reflections from medication sachets can reduce barcode contrast and create localized overexposure, while the scanner's automatic exposure behavior limits the available grayscale dynamic range. These effects help explain the variability observed between sachet types, lighting conditions, and individual devices.

Together, the findings demonstrate that improving barcode reading performance requires a combination of optical, mechanical, and software interventions. The research established the key factors that limit identification performance in the current Medido M302 platform and translated these insights into a set of requirements for the subsequent design phase. These requirements form the foundation for the development and evaluation of concepts aimed at improving medication sachet identification within the constraints of the existing system.

4 Design & Engineering

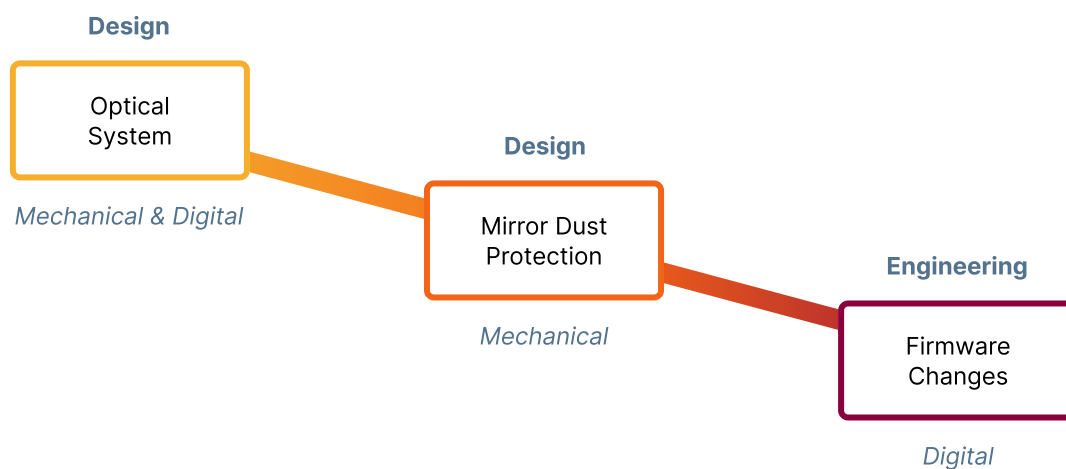
4.1 Introduction

This chapter presents the design and engineering phase of the project, translating the research findings into concrete solutions for improving barcode reading performance in the Medido Medicine Clock.

Based on the findings in [Section 3.4](#), three main design directions emerged, spanning from mechanical to digital (see [Figure 20](#)).

Figure 20

Design Directions



[Section 4.2](#) presents the proposed evolution of the optical system design, focused on improved illumination and reducing the impact of variability on barcode decoding performance.

[Section 4.3](#) discusses the proposed solution to maintain a clean mirror to reduce the impact of contamination.

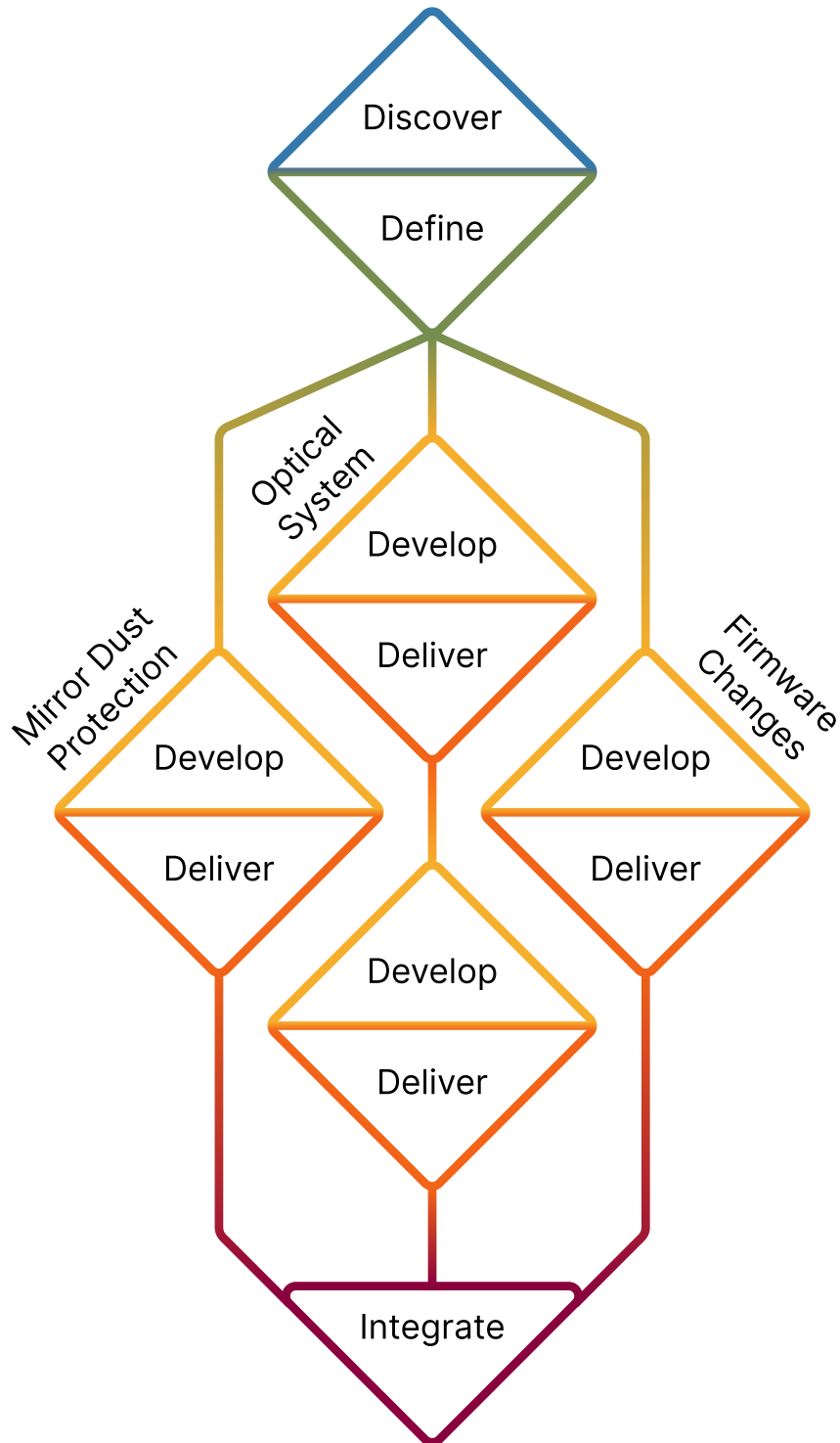
Several firmware changes are explored in [Section 4.4](#) in conjunction with the improved optical system, some of which can be implemented independently of hardware modifications and are therefore applicable across all three Medido Medicine Clock models.

The chapter concludes with the integration of the proposed solutions into the existing system architecture.

The design process of this project is outlined in [Figure 21](#).

Figure 21

Design Process



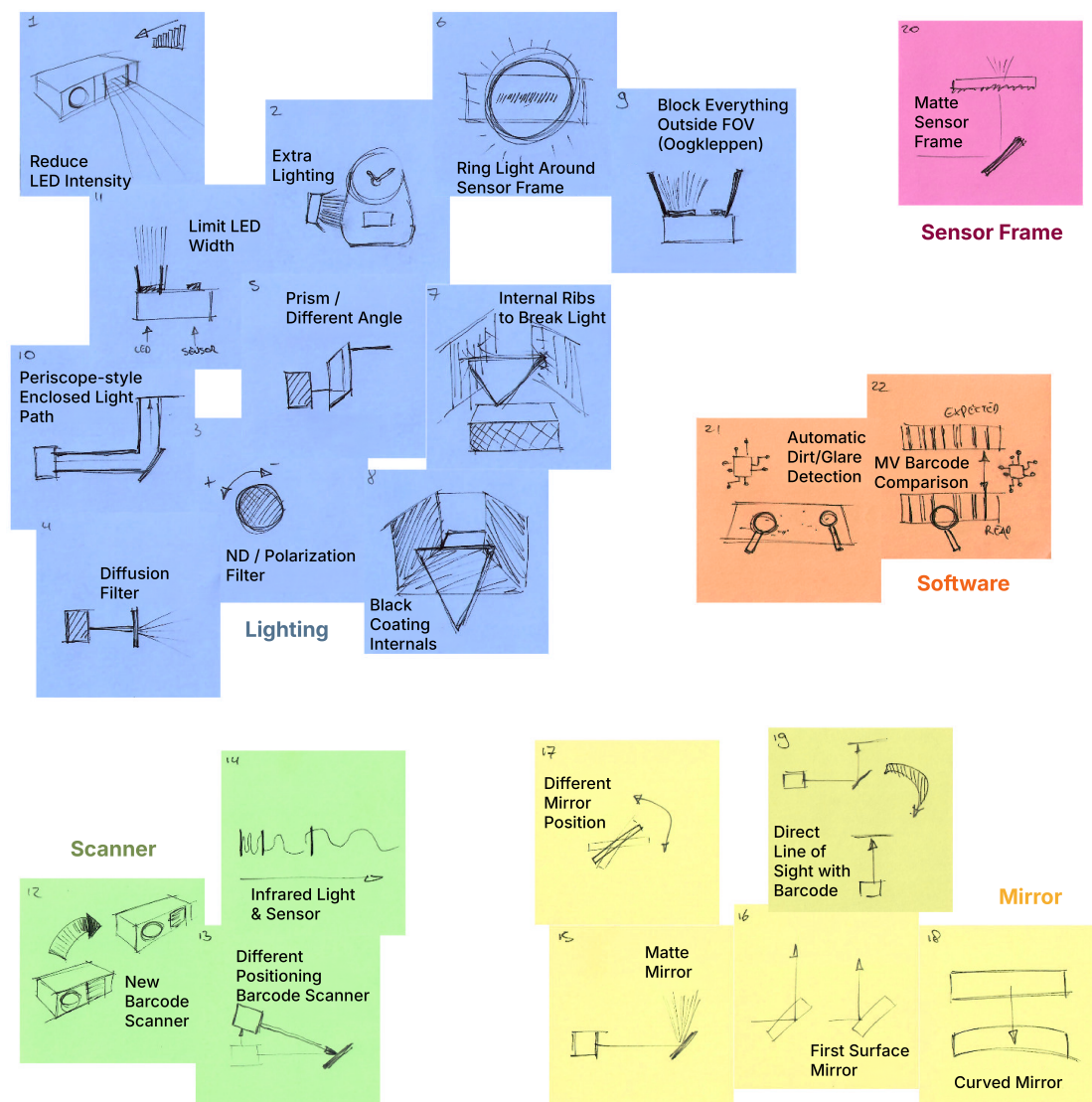
4.2 Optical System

4.2.1 Ideation

A brainstorming session was done to reduce glare in the optical system (due to the scanner LED) and to remove the impact of variability in positioning of the barcode scanner and sachet. This session yielded 22 concepts; see [Figure 22](#).

Figure 22

Optical System Brainstorming Result

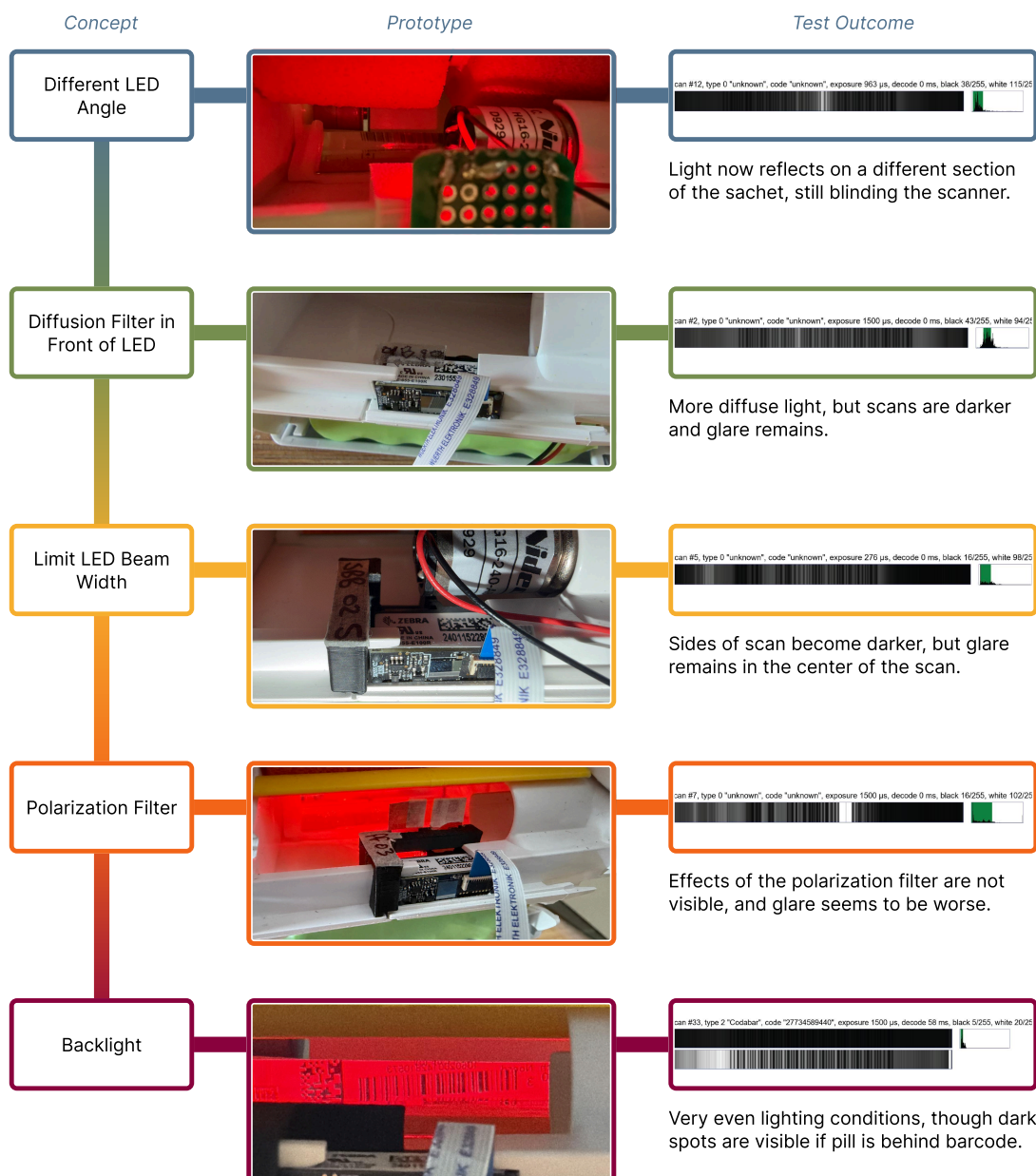


4.2.2 Selection & Rapid Prototyping

Initially, three concepts were explored and prototyped based on design intuition and technical judgment. A preliminary Weighted Objectives procedure was used to support their selection and reduce the influence of subjective judgment (see [Appendix C](#)). As these concepts did not produce satisfactory results, two additional concepts that emerged during the first prototyping cycle were subsequently explored (see [Figure 23](#)). The complete design and evaluation process is documented in [Appendix D](#).

Figure 23

Optical System Prototyping Process



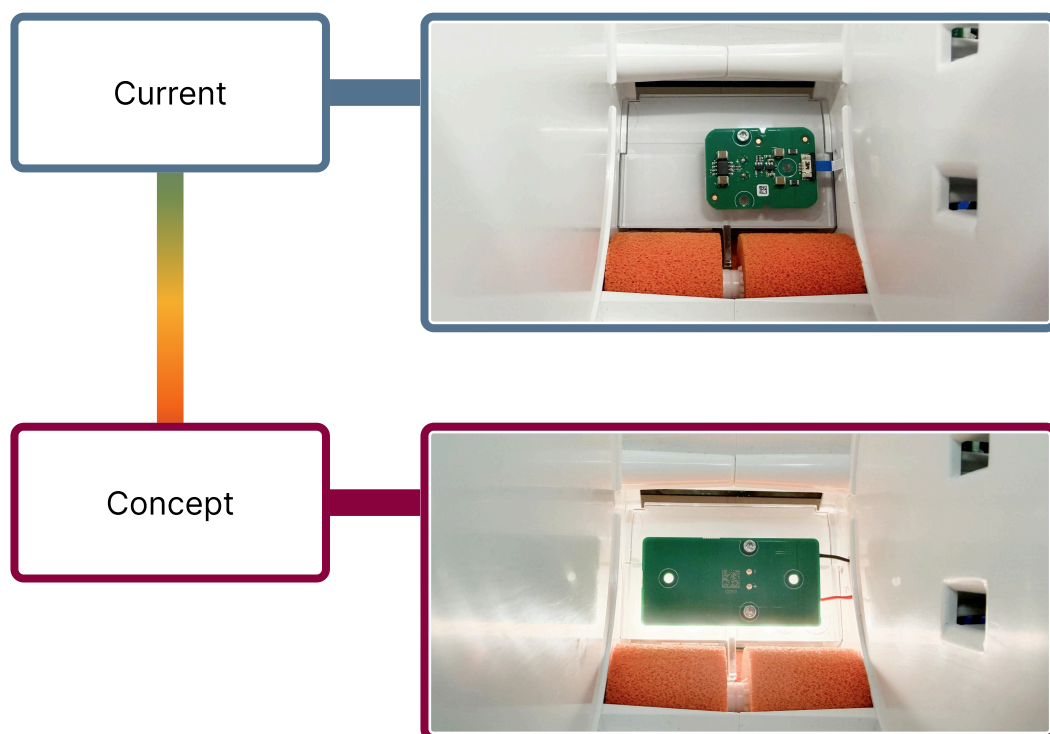
4.2.3 Final Concept

The final concept uses a backlighting approach, completely disabling the LED integrated in the barcode scan engine.

To illuminate sachets from the back, a revised version of the Medido M303 *Ultrasound Transmitter & Lighting PCBA* (USTL PCBA, in the M303 used in conjunction with a different barcode scan engine) is used, which is installed in place of the old *Ultrasound Transmitter PCBA* (see [Figure 24](#)).

Figure 24

Before and After of Medido M303 Ultrasound Transmitter & Lighting PCBA



This PCBA is installed on the top of the sensor frame, allowing the light to pass through the white sticker on the transparent frame (see side view in [Figure 25](#)). This sticker aids in diffusing the light, which passes through the sachet.

Figure 25

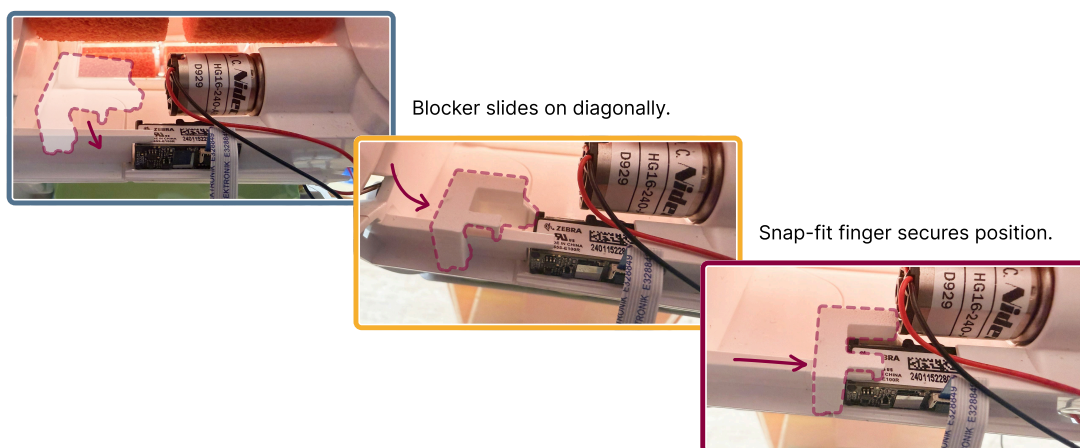
Effect of Medido M303 Ultrasound Transmitter & Lighting PCBA



As the scan engine LED was identified as the primary source of optical artifacts, it is blocked by a new component called the Scan Engine LED Blocker. The component slides over the LED and is secured by an integrated snap-fit finger (Figure 26).

Figure 26

Scan Engine LED Blocker Installation



4.2.4 Materials, Production & Cost

Revised Ultrasound Transmitter & Lighting PCBA

As the M302 motherboard has a 6 pin output for the ultrasound circuitry while the USTL PCBA has an 8 pin input, a revised USTL PCBA with a 6 pin input will have to be made for the M302, that triggers both the lighting and the ultrasound transmitter at the same time. This would not affect the detection process of the Medido as the lighting does not influence the ultrasound readings, and the ultrasound does not affect the barcode reading.

Based on quotations of the current PCB and development and prototype costs, the new USTL PCBA is estimated to cost €15 per unit.

Scan Engine LED Blocker

Although the Scan Engine LED Blocker could be manufactured from injection-molded PC, the component is concealed within the device and can therefore be produced from PLA using conventional FDM 3D printing. As only a relatively small production volume is required, injection molding is estimated to cost approximately €3.50 per part¹. These costs are largely driven by the off-axis mold movement and the fine details of the snap-fit finger.

Quotations from external 3D-printing suppliers ranged from €0.70 to €2.20 per part. In-house production was therefore identified as the most cost-effective option, with an estimated combined material and labor cost of approximately €0.18 per part. The planned production quantity includes a 12% surplus to account for failed prints, rejected parts, and spare stock.

Producing a limited spare stock reduces the need for stringent mechanical quality control, as parts that do not fit can be rejected during the refurbishment process. Since material and energy costs are substantially lower than labor costs, it is more efficient to produce a small surplus of parts than to perform extensive dimensional inspection on every part.

¹This estimate was aided by ChatGPT 5.5-Medium.

4.3 Mirror Dust Protection

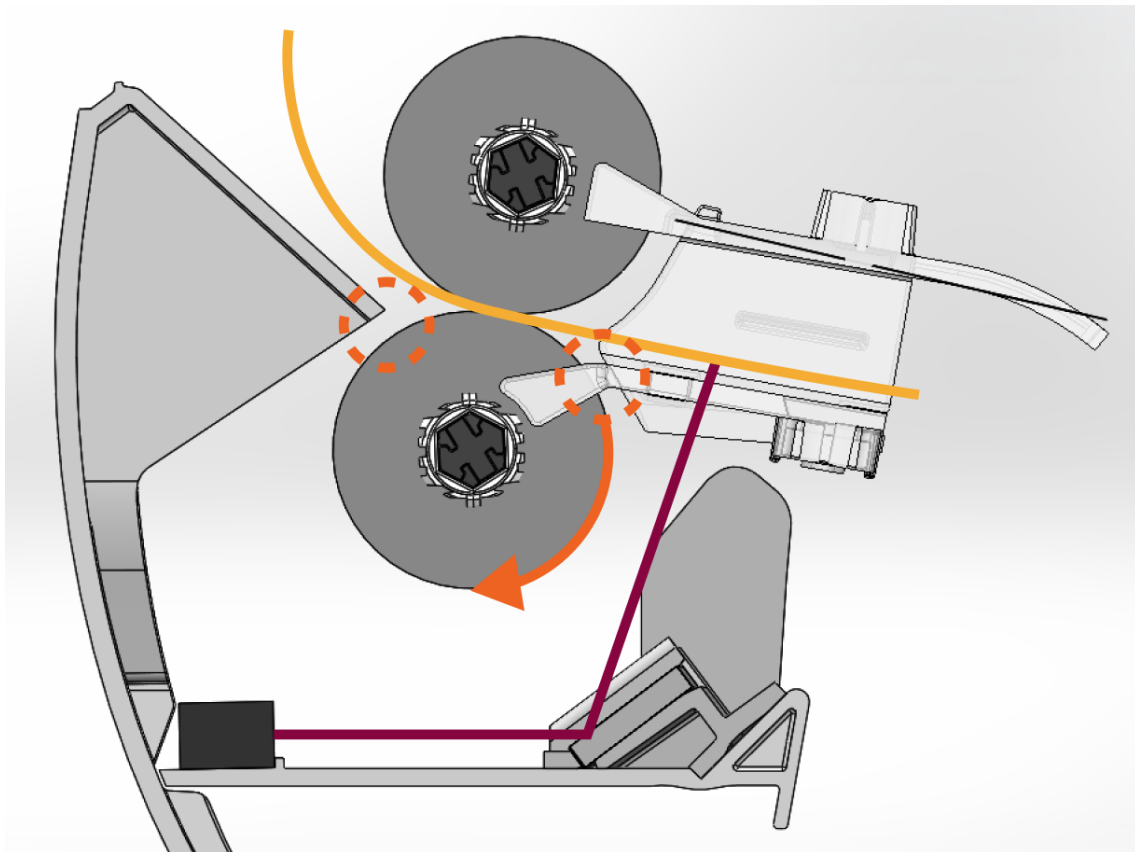
4.3.1 Dust Source

As the medicine roll (Figure 27, yellow) is transported through the transport rollers, dust can pass through the gap between the transport roller and the sensor frame (right circle). Particles entering through this gap may fall directly onto the mirror located beneath it. Additionally, if fragments of the foam transport roller detach, they can also be deposited onto the mirror as the lower roller rotates clockwise (as indicated by the arrow).

The left circle in Figure 27 indicates a gap between the transport roller and the battery cover. Although this area is exposed, it does not pose a risk to the mirror, as particles entering through this gap do not reach the mirror surface.

Figure 27

Schematic Side View of Mirror and Dust Source (Circled)



4.3.2 Ideation & Rapid Prototyping

Using the existing Medido Medicine Clock SolidWorks assembly as a reference, a Dust Cover design was developed based on the geometry of the little space that was still available (see [Figure 28](#)). Several iterations were made with improved clearances, facilitating easier snap-fit attachment to the sensor frame. The final iteration incorporated a central reinforcement rib designed to fit between the two sides of the lower transport roller, thereby increasing structural rigidity.

Figure 28

Dust Cover Prototyping



4.3.3 Materials, Production & Cost

The Dust Cover is also suitable for production in PLA using conventional FDM 3D printing, as the central reinforcement rib can be printed without support material. However, because the component is considerably taller than the Scan Engine LED Blocker, its print time is substantially longer. Its larger footprint also limits the build plate capacity. At a production rate of three batches per week, manufacturing the required quantity would take approximately 67 weeks. Including material consumption and operator labor, the estimated production cost is €0.81 per part.

Alternatively, the relatively simple geometry of the component makes it suitable for injection molding in a conventional straight-pull mold ([Figure 29](#)). With an estimated lead time of 12–16 weeks, this production method would be approximately five times faster than in-house 3D printing. The estimated cost is approximately €1.80 per part². Injection molding would, however, require minor modifications to the geometry, including the implementation of a uniform wall thickness and a draft angle of 1° to facilitate reliable mold filling and part ejection.

Despite the longer production time, in-house 3D printing remains the more cost-effective option. As the Dust Cover can be introduced gradually during future refurbishment cycles, temporary shortages are not considered critical.

²This estimate was aided by ChatGPT 5.5-Medium.

Production can therefore proceed at a lower rate without delaying the initial implementation of the proposed design changes.

Figure 29

Impression of Injection Molded Dust Cover

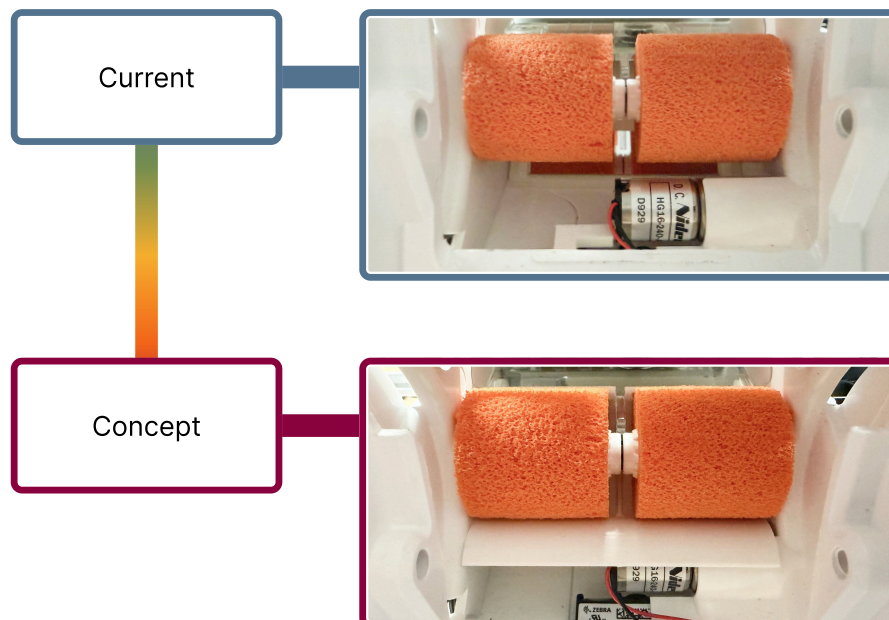


Note. Image created in ChatGPT 5.5 based on screenshot from SolidWorks.

Figure 30 illustrates the difference between the baseline configuration and the assembly with the Dust Cover installed. In the top image, the mirror is visible behind the orange transport rollers. With the Dust Cover installed (bottom), the mirror is no longer accessible from the top, thereby preventing dust and fragments from the transport roller from being deposited onto its surface.

Figure 30

Before and After of Dust Cover Installation

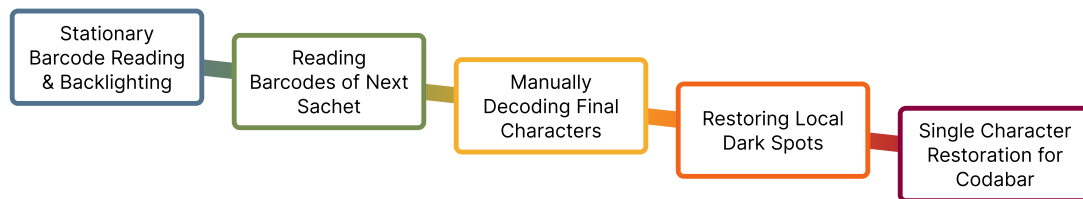


4.4 Firmware Changes

The proposed redesign also requires several firmware adaptations (Figure 31), some of which can be implemented separately from the hardware changes, meaning they can be tested and implemented quicker.

Figure 31

Proposed Firmware Changes

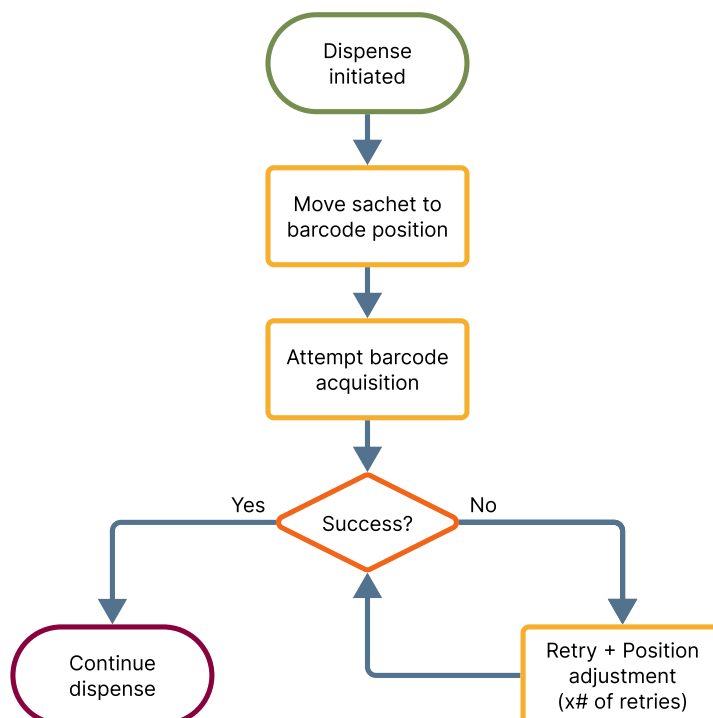


4.4.1 Stationary Barcode Reading & Backlighting

Rather than continuously transporting the sachet past an active scanner, the barcode is positioned directly in front of the scanner and held stationary during decoding. If the barcode is not successfully detected, multiple retries can be performed, optionally including small positional adjustments to improve alignment. The adapted dispensing sequence is shown in Figure 32.

Figure 32

Stationary Barcode Reading Flow Chart



During the dispense process (Section 2.2), the ultrasound sensor is already enabled. With the introduction of the adjusted USTL PCBA, this means the backlight should already automatically turn on while the barcode decode is attempted.

4.4.2 Reading Barcodes of Next Sachet

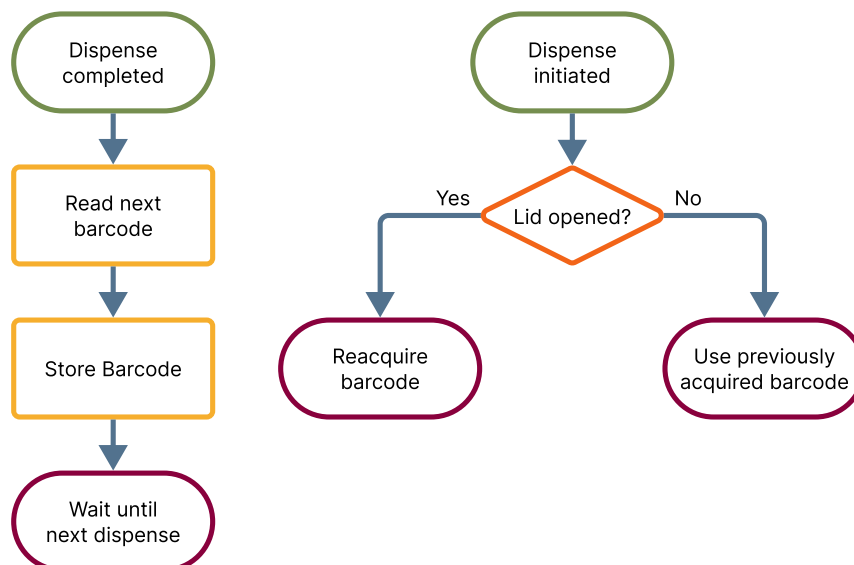
To reduce processing time, the barcode of the next sachet can be read immediately after dispensing and stored in memory. If the lid remains closed and the sachet position is unchanged, the stored result can be reused during the next dispense cycle (Figure 33).

If the lid is opened, the sachet may have moved or been replaced, requiring the barcode to be reacquired during the next dispense cycle. The resulting delay is negligible within the overall process.

With ARL, the first sachet can already be validated during loading, eliminating the need for barcode acquisition during the first dispense cycle.

Figure 33

Reading Barcodes of Next Sachet Flow Chart



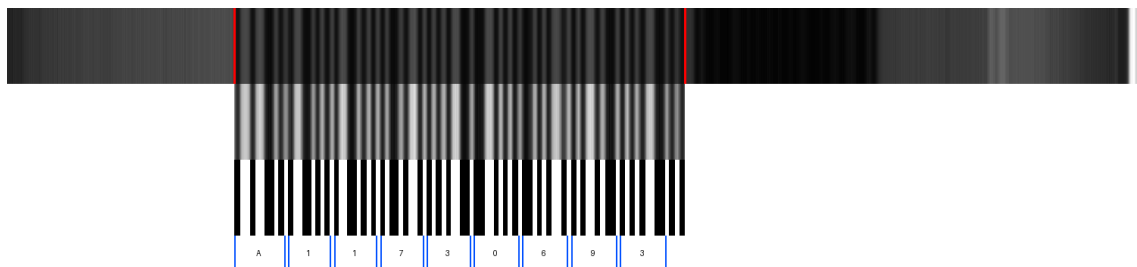
4.4.3 Manually Decoding Final Characters

For sachets with top-positioned barcodes, medication may obstruct the back-light. When the scan engine cannot decode the full barcode, its sensor data can instead be processed by the Medido main PCBA.

If the final barcode characters remain visible, they can provide sufficient information to verify the expected sachet. A proof-of-concept algorithm was developed to reconstruct this section of the barcode (Figure 34; the left side corresponds to the barcode end).

Figure 34

Final Character Decoding Proof-of-Concept with Dark Spot



Note. From top to bottom: 1) Original scan, 2) Contrast corrected scan, 3) Binarized scan, 4) Decoded characters

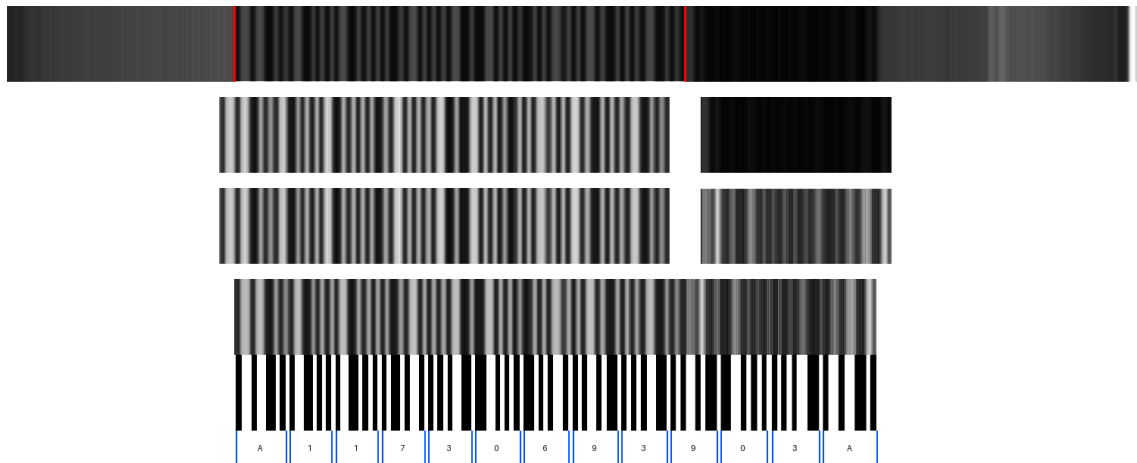
In many cases however, enough detail remains visible in dark areas to reconstruct the whole barcode (see Section 4.4.4), which is preferred from a safety standpoint over only using the final characters.

4.4.4 Restoring Local Dark Spots

In [Figure 35](#), medication obstructs the backlight on the right side of the barcode, creating a dark region. In many cases, sufficient detail remains to reconstruct this area through local brightness correction, making the full barcode visible and decodable in the case that the final characters are not decodable in the original scan.

Figure 35

Dark Spot Reconstruction Proof-of-Concept



Note. From top to bottom: 1) Original scan, 2) Contrast corrected scan with dark spot isolated, 3) Dark spot corrected, 4) Combined scan, 5) Binarized scan, 6) Decoded characters

4.4.5 Single Character Restoration for Codabar Barcodes

If a decoded Codabar barcode differs from the expected barcode by one character, the incorrect character can be replaced and the Codabar checksum recalculated. A valid checksum confirms whether the reconstructed character is plausible.

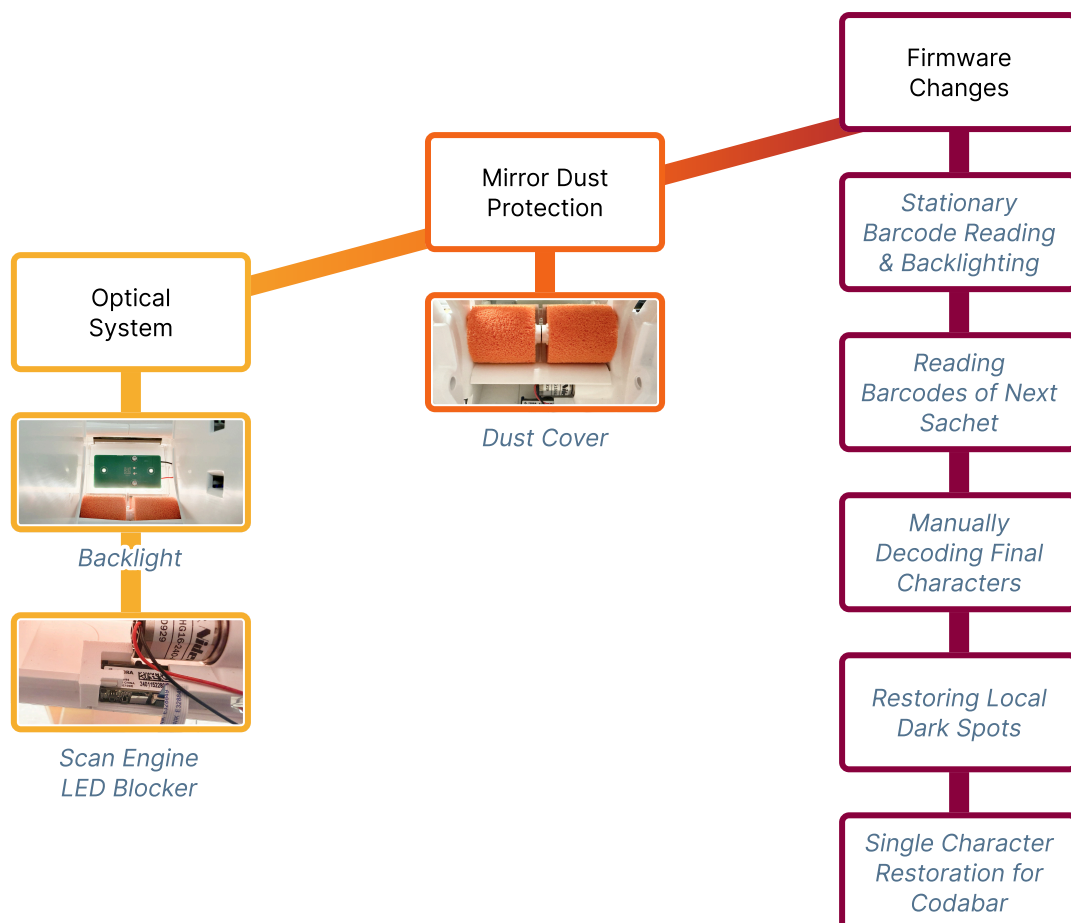
4.5 Integrated Concept

The final design (Figure 36) combines backlighting, protection against mirror contamination, and firmware-based barcode reconstruction to improve sachet identification. The revised USTL PCBA and Scan Engine LED Blocker provide more consistent illumination, while the Dust Cover reduces performance degradation caused by contamination of the mirror.

Stationary barcode reading and early acquisition of the next sachet barcode reduce variability and delays during the dispense process. When a full decode is not possible, partial decoding, local brightness correction, and checksum-based reconstruction provide additional recovery methods. Together, these measures form an integrated solution that improves barcode reading performance while remaining suitable for implementation during future M302 refurbishment cycles.

Figure 36

Final Integrated Design



4.6 Evaluation & Validation

4.6.1 Technical Evaluation

Both white sachets with top-positioned barcodes, the most challenging type for the backlight concept, and transparent sachets with bottom-positioned barcodes, the most challenging type for current M302 devices, were tested with the USTL PCBA, Scan Engine LED Blocker, and Dust Cover installed.

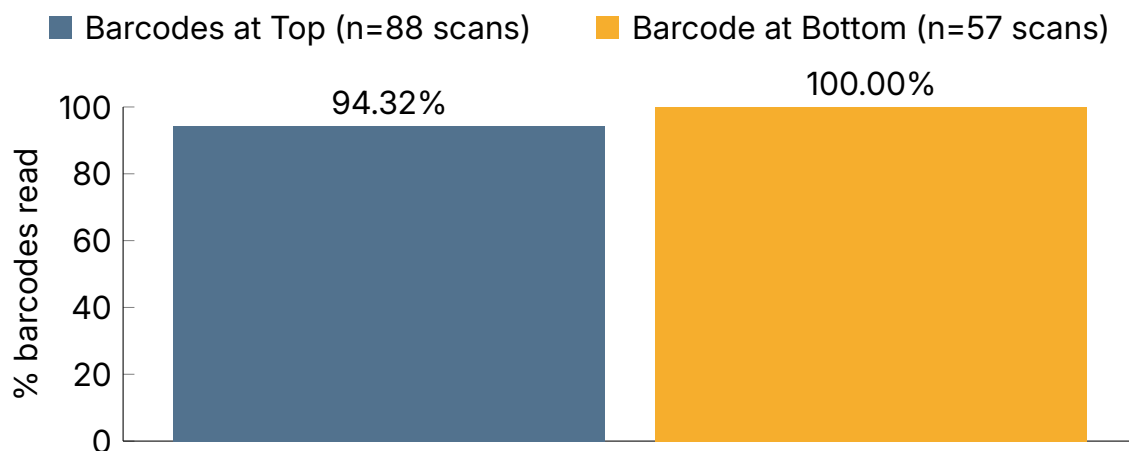
Each scan was qualitatively assessed for successful barcode scan engine decoding, visibility of the final digits for manual decoding, and whether dark regions retained sufficient detail for later brightening and reconstruction.

A representative 25-sachet medicine roll with top-positioned barcodes and 17-sachet medicine roll with bottom-positioned barcodes were each tested four times. Disregarding scans that had sachets positioned incorrectly, 88 scans of white sachets and 57 scans of transparent sachets were analyzed.

The new concept achieved successful decode rates of 94% for top-positioned barcodes and 100% for bottom-positioned barcodes (Figure 37). A comparison with field performance is provided in Confidential Annex Appendix C.

Figure 37

Barcode Reading Performance with New Concept



4.6.2 Refurbishment Evaluation

To evaluate the concept, the prototypes were presented to a senior member of the Evondos refurbishment team during an interview and handed over for inspection.

Revised Ultrasound Transmitter & Lighting PCBA

Replacing the Ultrasound Transmitter & Lighting PCBA can be incorporated into the existing refurbishment process. The procedure requires removing the back cover (which is already removed in the refurbishment process) and reservoir cover, disconnecting the flexible flat cable, loosening two screws, and removing the existing PCBA. The new PCBA is then installed by completing these steps in reverse order. The refurbishment technician estimated a maximum installation time of 10 minutes.

Dust Cover

The Dust Cover can be installed after removing only the battery cover. However, the refurbishment technician indicated that the lower transport rollers are typically removed to access the mirror for cleaning. It is therefore appropriate to combine mirror cleaning with installation of the Dust Cover.

The resulting procedure is to remove the back and battery covers, remove the lower transport rollers, clean the mirror, install the Dust Cover, reinstall the rollers, and replace both covers.

Scan Engine LED Blocker

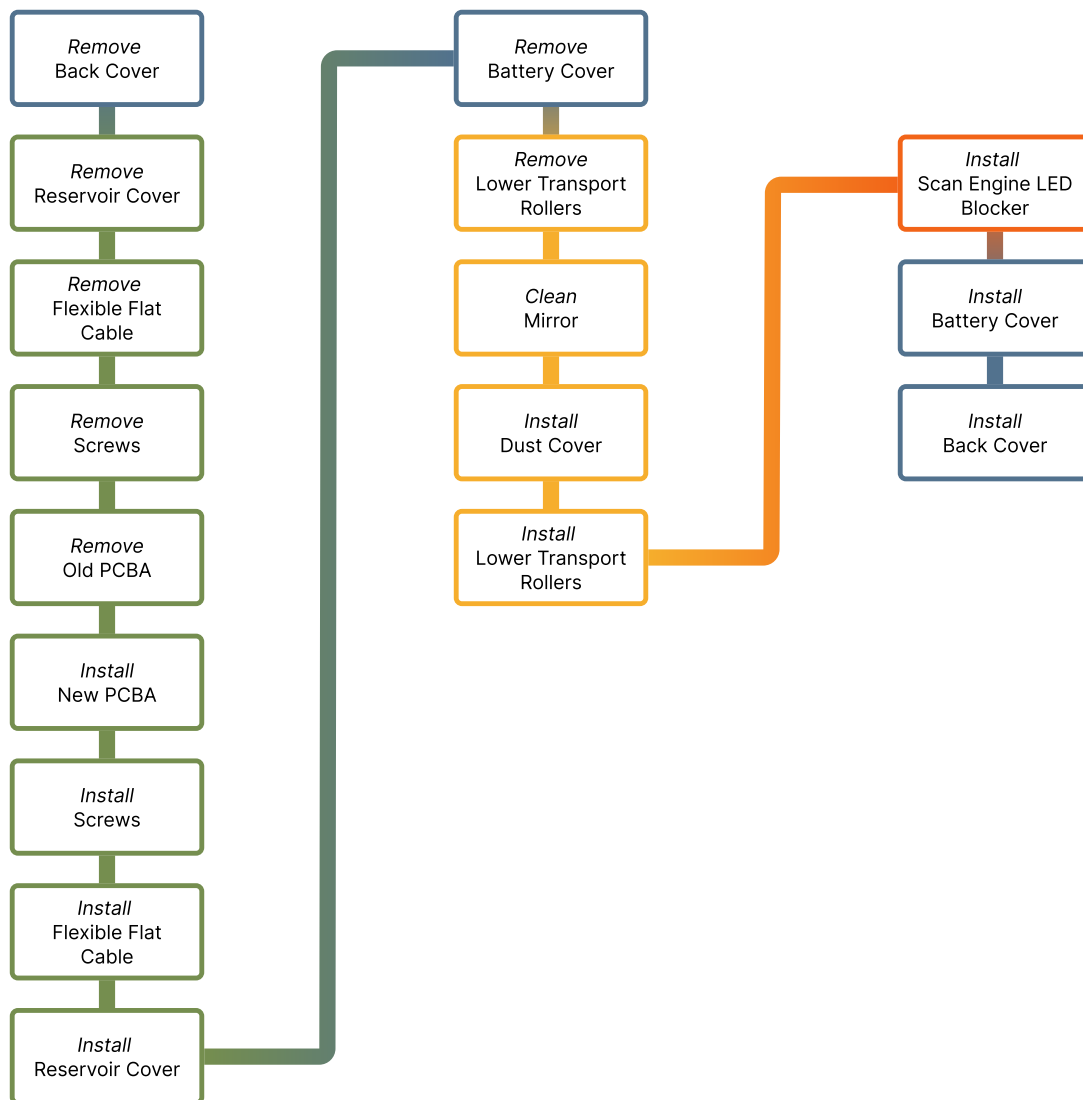
The Scan Engine LED Blocker can be installed without the need for any tools. The battery cover is removed by clicking it out, and the Scan Engine LED Blocker is installed by sliding it onto the frame diagonally and locking it into place by moving sideways. Installation of the Dust Cover and Scan Engine LED Blocker is estimated at 5 minutes.

The installation process for the new hardware is outlined in [Figure 38](#). It can be completed in approximately 15 minutes using T9 and T10 screwdrivers. Assuming one technician currently refurbishes eight Medido units per day at 60 minutes per unit, the additional installation time would reduce this capacity to approximately six units per day at 75 minutes per unit.

Based on a Dutch refurbishment or maintenance technician wage of roughly €16–18 per hour, this corresponds to €4–4.50 in direct labor. Including a 40% employer overhead, the refurbishment labor cost is estimated at approximately €6 per unit.

Figure 38

Installation Process of New Concept Hardware



4.6.3 Economic Evaluation

The combined hardware cost is estimated at approximately €16 per Medido, including prototyping and startup costs. In addition, the amortized firmware development cost and hardware development cost are each estimated at roughly €1 per device (see [Section 4.7](#)). Combined with an estimated €6 in refurbishment labor, this results in a total implementation cost of approximately €25 per refurbished device.

Although the proposed upgrade introduces additional implementation costs, these costs should be considered in relation to the strategic value of improved sachet identification. Besides improving barcode reading performance in refurbished M302 devices, the proposed changes contribute to a more future-proof product architecture by adding controlled illumination, improved protection of the optical path, and firmware logic that can support more advanced validation methods. These capabilities are relevant beyond the immediate retrofit, as they may also inform future Medido variants and reduce the need for corrective hardware changes later in the product lifecycle.

The upgrade may also strengthen the commercial position of the Medido system. Care organizations increasingly expect reliable sachet verification, and international tenders may include stricter requirements regarding medication identification. Improving barcode reliability therefore not only addresses a technical limitation, but also supports future market access and the competitiveness of the Medido platform.

4.6.4 Validation Against Requirements

The concept meets all requirements (see [Section 2.9](#) and [Section 3.5](#)) except R1.1 Functional compatibility. Sachets with top-positioned barcodes, which account for approximately half of all dispensed sachets, achieved a decode rate of 94% rather than the required 95%. However, the overall decode rate, including sachets with bottom-positioned barcodes, reached 96%. The concept can therefore be considered a technical success.

4.7 Implementation Roadmap

The integrated design requires several coordinated hardware and firmware changes. Based on discussions with the Product Development Manager and Lead Product Developer, an implementation roadmap was developed for both development trajectories. Although several activities can proceed in parallel, dependencies such as component availability remain potential bottlenecks; the firmware to control the backlight is most likely completed before the sample PCBAs are delivered.

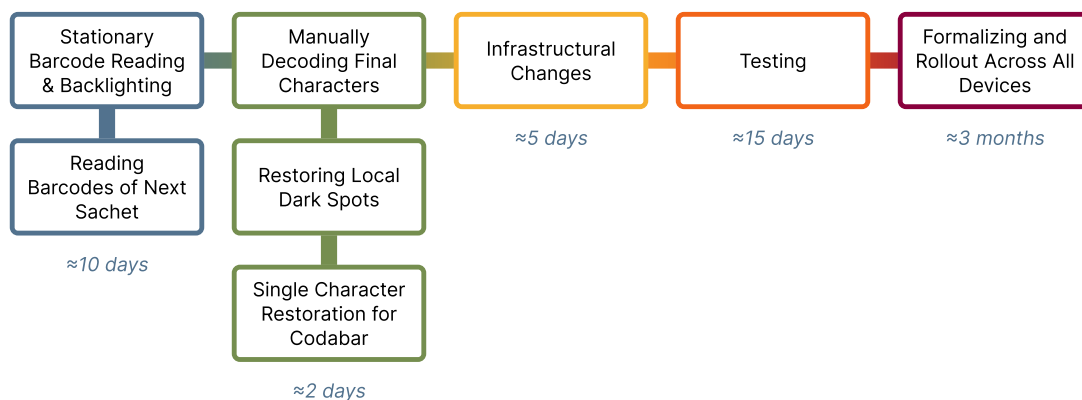
4.7.1 Firmware

The firmware and hardware development trajectories are strongly interdependent. A dedicated firmware version implementing the modified dispense and barcode reading logic must be available before field testing can take place. As a result, a significant portion of the firmware development effort must be completed in parallel with the hardware development process and before the execution of the combined hardware and firmware field trial [Figure 39](#).

The proposed firmware changes can be hidden behind so-called Feature Flags, meaning they are disabled by default but can be enabled by remotely sending a command. This allows for firmware features to be in place before the required hardware changes are completed.

Figure 39

Proposed Firmware Integration Timeline



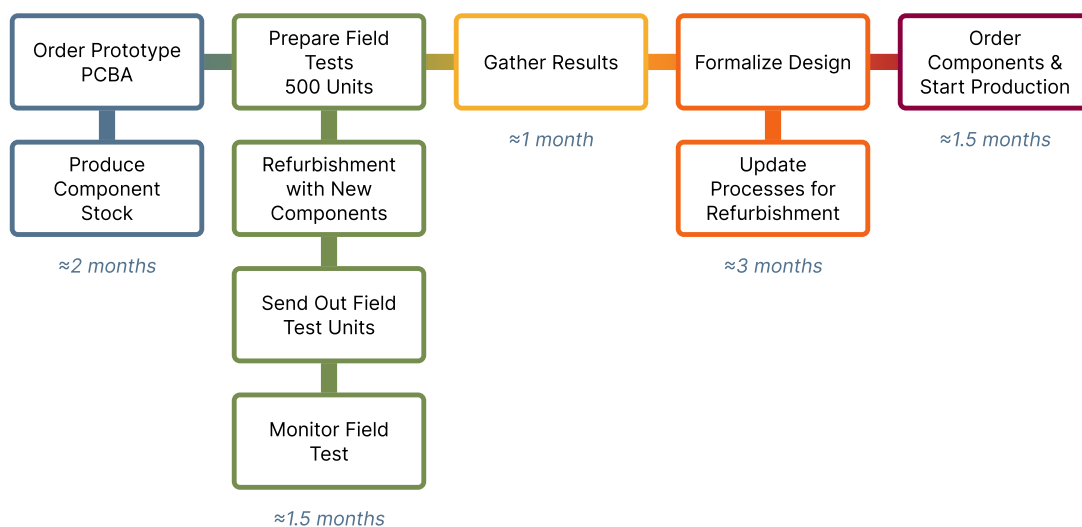
Approximately 6.5 weeks of development time is required to implement the new firmware features, combined with limited weekly support during the firmware rollout period. Since this software effort is largely independent of the number of devices being refurbished, it can be treated as a fixed implementation cost. When amortized across the installed base of M302 devices, the resulting contribution is in the order of €1 per refurbished unit.

4.7.2 Hardware

It was estimated that the proposed hardware modifications could be implemented following a development and validation trajectory of approximately 6 to 9 months (Figure 40). This trajectory would include a field trial involving 500 devices (approximately 2.5% of the total Medido installed base). Following successful validation, the design and associated refurbishment processes could be formalized and the required components procured. The upgraded parts could then be incorporated into Medido devices as they return from deployment and undergo refurbishment.

Figure 40

Proposed Hardware Integration Timeline



The hardware development is estimated to require approximately 300 hours of engineering effort, corresponding to roughly 7–8 weeks of work. When amortized over the relevant installed base, the estimated engineering cost remains low, at approximately €1 per device.

4.8 Conclusion

This chapter translated the research findings into an integrated hardware and firmware concept for improving barcode identification in the Medido M302. The proposed design combines backlighting through a revised Ultrasound Transmitter & Lighting PCBA, a Scan Engine LED Blocker, a Dust Cover, stationary barcode reading, and several reconstruction methods for incomplete scans.

Validation showed decode rates of 94% for top-positioned barcodes and 100% for bottom-positioned barcodes, resulting in an overall rate of 96%. Although the performance for top-positioned barcodes falls slightly below requirement R1.1, the concept meets all other requirements and can be considered technically successful.

The hardware can be installed during the existing refurbishment process in approximately 15 additional minutes. Implementation requires coordinated hardware and firmware development, followed by a combined field trial. With an estimated development trajectory of 6 to 9 months, the concept provides a feasible basis for improving barcode identification across refurbished M302 devices, at an approximated cost of €25 per refurbished device.

5 Discussion, Conclusion & Reflection

5.1 Discussion

5.1.1 Technical Trade-offs & System Complexity

The integrated concept improves barcode reading by combining hardware and firmware changes. The revised Ultrasound Transmitter & Lighting PCBA provides backlighting, the Scan Engine LED Blocker removes the scanner LED as a source of optical artifacts, and the Dust Cover protects the mirror from dust and debris. The firmware changes support stationary barcode reading, storage of the next sachet barcode, and additional processing when the scan engine cannot decode the complete barcode.

The advantage of this approach is that several causes of poor barcode performance are addressed at the same time. The research showed that barcode reading is affected by motion, reflections, contamination, scanner positioning, and incomplete scan information. Addressing only one of these causes would therefore likely result in a limited improvement. Combining the optical, mechanical, and firmware changes makes the concept more robust than a single intervention.

The downside is that the concept also makes the system more complex. Stationary barcode reading changes the dispense sequence, the backlight adds another active component, and the reconstruction methods require additional processing of scan engine data. The concept also introduces extra parts that must be produced, installed, inspected, and registered during refurbishment. As a result, the implementation is not a simple component replacement, but a combined hardware and firmware modification.

This also affects validation. The hardware and firmware changes need to be tested together, as the performance depends on the interaction between the transport system, scan engine, USTL PCBA, and main PCBA. In particular, the effect on emergency battery runtime, thermal behavior, electrical safety, and electromagnetic compatibility still needs to be assessed. The added backlight increases the electrical load, while stationary reading may increase the time during which components are active. These effects are not expected to prevent implementation, but they do need to be verified before the concept can be released.

The concept therefore has clear advantages and disadvantages. It improves barcode decoding performance, supports future functionality such as Advanced Roll Loading, and can be implemented during refurbishment without replacing the complete device. At the same time, it increases refurbishment time, adds components, requires firmware changes, and increases the amount of validation work. The decision to implement the concept should therefore not only be based on barcode performance, but also on the added engineering effort and process complexity.

5.1.2 Implications for Other Medido Variants

Although the concept was developed for the M302, several findings are also relevant to other Medido variants. The M301 uses the same scan engine and could benefit from firmware changes such as stationary barcode reading and improved barcode positioning, even without implementing the full hardware concept.

The M303 should also be evaluated further. It already includes a newer scan engine and a backlight, but this does not automatically mean that its barcode reading is optimal under all sachet conditions. The results of this project show that the interaction between illumination, sachet material, barcode position, and scanner behavior is important. It may therefore be useful to test whether disabling or blocking direct scanner illumination also improves performance in the M303.

For future Medido variants, scanner alignment, optical contamination, and firmware control should be considered earlier in the design process. A more constrained scanner position, better protection of the optical path, access to raw scan data, controllable illumination, and scanner version reporting would make both troubleshooting and future upgrades easier.

5.1.3 Transferability to Refurbishment Projects

This project shows that refurbishment can be used not only to restore a product, but also to upgrade a product that is still functional but no longer meets current expectations. In the case of the M302, the device itself can remain in use, while the barcode identification system is improved during refurbishment.

A solution for a refurbishment context must fit the existing product architecture and the refurbishment process. A technically effective concept is less useful if it requires extensive disassembly, special tools, long installation times, or complex quality control. In this project, the feasibility of the concept depended strongly on whether the new components could be installed with existing tools and within the existing refurbishment workflow.

Another lesson is that selective upgrading can preserve most of the product while improving the parts that have become limiting. Not every component needs to be replaced when product requirements change. By identifying which functions no longer meet current requirements, an upgrade can be targeted more precisely.

These findings relate to Design for Future Proofing. Products with long service lives should allow for later changes in technology, regulations, user expectations, and market requirements. This does not mean that all future requirements need to be predicted. Instead, the product architecture should leave room for adaptation through accessible components, replaceable sub-systems, spare interfaces, and firmware that can be updated or extended.

5.2 Limitations

5.2.1 Limited Sachet Variety

The technical validation included only two sachet types: white sachets with top-positioned barcodes and transparent sachets with bottom-positioned barcodes. Although these represented the most challenging configurations for the proposed concept and the current M302 respectively, they do not cover all supported sachet layouts, materials, barcode types, barcode dimensions, and print qualities. The measured performance should therefore not be generalized to all sachet configurations without additional testing.

5.2.2 Proof-of-Concept Reconstruction Algorithms

The Python algorithms for partial barcode decoding, local brightness correction, and single-character reconstruction were developed as proofs of concept. They show that information can be recovered from incomplete scans, but they are not yet robust enough for implementation in the Medido firmware. Further development is required to automate region detection, handle more scan variation, and verify decoding reliability under realistic conditions.

5.2.3 Manual Test Configuration

The testing script requires manual positioning of the scan region and manual entry of sachet dimensions. This increases preparation time and introduces operator-dependent variation. A future version should use the sachet configuration data already stored in the Medido system to determine the required barcode position automatically.

5.2.4 System-Level Validation

The validation focused mainly on barcode performance and refurbishment feasibility. Before implementation, the concept also needs to be validated at system level. This includes emergency battery runtime, thermal behavior, electrical safety, electromagnetic compatibility, firmware reliability, and long-term durability of the added components.

5.3 Conclusion

This project investigated how barcode decoding performance in the Medido Medicine Clock could be improved and translated the findings into an implementable upgrade for the installed M302 device base.

The research showed that inconsistent barcode reading is not caused by one factor. Performance is affected by scanning while the sachet is moving, contamination of the internal mirror, variation in scanner positioning, and reflections caused by the interaction between the scan engine LED and the sachet material. Stationary scanning and alternative illumination were identified as the most effective directions for improving decoding reliability.

Based on these findings, an integrated concept was developed consisting of a revised Ultrasound Transmitter & Lighting PCBA for backlighting, a Scan Engine LED Blocker, and a Dust Cover that protects the mirror from contamination. These hardware changes are supported by firmware modifications that enable stationary barcode acquisition, early reading of the next sachet, and additional processing of incomplete barcode scans.

Prototype validation resulted in successful decode rates of 94% for sachets with top-positioned barcodes and 100% for sachets with bottom-positioned barcodes, corresponding to an overall decode rate of approximately 96%. The concept therefore meets all defined requirements except the 95% target for top-positioned barcodes, which was missed by less than one percentage point. Despite this, the overall performance improvement shows that the concept is technically successful.

The proposed hardware can be incorporated into the existing refurbishment process without replacing the complete device. Installation adds approximately 15 minutes to the refurbishment of an M302, reducing the estimated daily capacity per technician from eight to six units. A coordinated hardware and firmware development trajectory of approximately 6–9 months was established, followed by a proposed field trial involving 500 devices.

The design assignment was therefore fulfilled by identifying the main causes of inconsistent barcode decoding, developing and validating an integrated improvement, and establishing a feasible implementation roadmap. The resulting concept provides a practical means of improving medication sachet identification and supporting features such as Advanced Roll Loading while extending the functional life of existing M302 devices. Before release, the concept still requires system-level validation of software behavior, electrical performance, battery impact, thermal behavior, and electromagnetic compatibility.

5.4 Recommendations

5.4.1 New Barcode Scanner Interfacing Commands

New firmware commands should be implemented to operate the barcode scan engine in either DECODE or CAPTURE mode. DECODE mode should return the decoded barcode together with relevant diagnostic data, while CAPTURE mode should return the raw sensor values for processing by the Medido main PCBA. This would support stationary barcode reading, improved diagnostics, and reconstruction of incomplete scans.

5.4.2 Updated Barcode Locations in Sachet Configurations

Accurate barcode positioning becomes more important when the sachet is held stationary during reading. As barcodes may be only approximately 4 mm high, incorrect position data can place the barcode outside the scan line. The barcode locations stored in the sachet configurations should therefore be reviewed and updated to support reliable positioning in front of the scanner.

5.4.3 Barcode Scanner Version Reporting

The barcode scan engine should report its hardware and firmware versions to the Medido firmware. Including this information in diagnostic logs and service reports would improve traceability, support comparison between scanner batches, and facilitate root-cause analysis of performance differences observed in the field.

5.4.4 System-Level Validation of the Integrated Concept

Before implementation, the integrated hardware and firmware concept should be validated as one system. This validation should include barcode performance, dispense timing, emergency battery runtime, thermal behavior, electrical safety, electromagnetic compatibility, and robustness under repeated refurbishment and use cycles. Particular attention should be paid to the interaction between the backlight, modified dispense sequence, and firmware-controlled scanning behavior.

5.4.5 Sachet Layout Standardization

Evondos should develop a sachet layout guideline for new and existing prepackager integrations. For the M302, the preferred layout is a transparent sachet with a large Codabar barcode positioned at the bottom. Code128 is a suitable alternative where Codabar is unavailable. Regardless of symbology, the barcode should have sufficient dimensions and quiet zones.

When both 1D and 2D barcodes are present, the 1D barcode should preferably be positioned on the left side of the sachet, where the scan output is generally brighter. The guideline could be shared with prepackagers to improve consistency and support future layout changes.

5.5 Future Research

5.5.1 Backlight Optimization for Obstructed Barcodes

Further research should determine which backlight conditions provide the best balance between sufficient barcode illumination and reduced dark regions caused by medication positioned behind the barcode. Relevant variables include light intensity, diffusion, illumination uniformity, exposure time, and the relative position of the sachet, medication, and light source. Testing across a wider range of medication shapes and sachet layouts is required to establish robust operating conditions.

5.5.2 Improved Dark-Region Reconstruction

The proof-of-concept algorithm for correcting locally dark regions should be developed into a more automated and robust reconstruction method. Future work should focus on automatic detection of affected regions, adaptive brightness correction, preservation of barcode edge information, and validation against known barcode values. The method should also be evaluated for implementation within the processing constraints of the Medido main PCBA.

5.5.3 ML-Based Barcode Identification

Machine-learning methods could be explored for identifying barcodes from scans that cannot be decoded using conventional algorithms. A model could be trained to recognize distorted, partially obscured, or unevenly illuminated barcode patterns using labeled scan-engine data. Such an approach would require a sufficiently large and representative dataset. Reliability, explainability, computational requirements, and suitability for use in a medical-device context would also need to be carefully assessed.

5.6 Personal Reflection

5.6.1 Learning About the Design Profession

This project changed how I view the design profession. At the start, I approached the assignment as a relatively clear technical problem. The barcode reading performance was insufficient, so the task seemed to be to understand the optical limitations and develop a better solution. During the project, it became clear that the design problem was not fixed. It changed as more tests were performed, as assumptions were disproven, and as the limitations of the existing product became better understood.

This taught me that problem understanding and solution development are not separate phases. They influence each other throughout the project. Continuing the research for too long can delay decision-making, but moving too quickly into a solution can also lead to making something in the wrong direction. A design engineer therefore has to find a balance between understanding the problem well enough and accepting that complete certainty is not possible.

The project also showed the tension between academic research and practical design work. From a scientific perspective, it is valuable to isolate variables and build a complete explanation of the problem. From a practical perspective, the project also has to result in a solution that can be evaluated, implemented, and discussed with the organization. I learned that revising the design problem during the project can be a necessary part of the design process when new evidence changes the understanding of the problem.

5.6.2 Learning Through Prototyping & Failure

A second important lesson was the value of learning through prototyping. Several concepts did not work as expected, but they still produced useful knowledge. Tests with polarization, adjusted LED angles, diffusion, and backlighting helped clarify which assumptions were valid and which were not. In that sense, a failed prototype was not a failed project result.

This was especially important because several effects were difficult to predict theoretically. The interaction between transparent packaging, white packaging, reflections, scanner exposure, sachet curvature, contamination, and barcode position could only be understood properly by testing physical prototypes. Fast prototyping therefore became a way to answer questions that could not be answered reliably through theory alone.

When a test does not produce the expected result, it can feel as if progress has been lost. In practice, these moments often helped most in narrowing the design direction. They showed why certain intuitive solutions were insufficient and why more complex interventions were needed. This made the final concept stronger, because it was based on both successful and unsuccessful experiments.

5.6.3 Design Decisions in a Business Context

The project made clear that design decisions are not only technical decisions. Early concepts were easier to implement, but they also performed less well. More effective solutions required greater changes to the product, which introduced higher costs, more validation work, and more implementation risk. The design challenge was therefore not simply to find the best-performing solution, but to understand the relationship between performance, cost, risk, and organizational benefit.

This is an area where the IDE at TU Delft could provide better preparation. Designers are often trained to keep the design space open and not limit creativity too early based on business constraints. This is valuable, but in a company context design proposals eventually have to be evaluated in terms of investment, risk, installed base, reliability, service capacity, and product image. Learning how to create implementation scenarios and cost-benefit considerations would help bridge the gap between creative design work and organizational decision-making.

At the same time, the designer should not think too much on behalf of the company too early. If business constraints are used too soon, they can reduce the ambition of the design work and prevent better solutions from being explored. The balance is to remain creative during exploration, while still preparing the information that allows the organization to make a realistic decision.

5.6.4 Working With an Organization

This project also taught me more about working inside an organization. The outcome depended not only on my own design work, but also on input from R&D, service, operations, production, and management. In hindsight, some internal parties could have been involved earlier, especially when the implications for refurbishment, electronics, firmware, and validation became clearer.

At the same time, it was useful not to be guided too strongly by existing opinions from the beginning. A fresh perspective made it possible to question assumptions and explore directions that might otherwise have been dismissed too quickly. The challenge is therefore to involve stakeholders early enough to make the project realistic, but not so much that the design direction is fully shaped by existing routines and constraints.

The project also showed the importance of communication and soft skills. In earlier educational projects, there were often clear guardrails, predefined roles, and limited direct interaction with external stakeholders. In this project, I had to plan tests, ask for input, explain uncertain findings, defend design choices, and keep people involved while the project direction was still changing. These skills are difficult to learn from design methods alone, but they strongly influence whether a design project can move forward.

5.6.5 Design Methods & Design Practice

The project changed how I view design methods. Methods from sources such as the Delft Design Guide are useful, but real design work is less linear and less clearly structured than the methods often suggest. In practice, the process was more fuzzy. Research, prototyping, analysis, stakeholder input, and decision-making overlapped continuously.

This does not make design methods irrelevant. Instead, it shows that they should be used as tools rather than fixed procedures. For example, the Weighted Objectives method was not used exactly as a final decision-making instrument. It was used to structure comparison, make assumptions explicit, and move the process forward. This was still valuable, even though the practical use differed from the textbook version.

The project also showed how new AI tools can make digital prototyping and technical exploration more accessible. AI support made it easier to write scripts, process scan data, explore reconstruction logic, and iterate on documentation. This did not replace design judgment, but it lowered the threshold for testing ideas digitally and made it possible to explore directions that would otherwise have taken more time.

5.6.6 Friction & Persistence

A final personal lesson is that a designer has to keep believing in the value of the idea, even when the process becomes uncertain. During the project, there were moments where tests failed, where the design direction had to be revised, or where others questioned whether a proposed direction was realistic. These moments are part of design work, especially when the solution affects an existing technical system.

I learned that resistance does not always mean that an idea is wrong. People respond from their own responsibilities, risks, and constraints. Service may focus on installation effort, R&D on technical feasibility, management on investment, and users on reliability. These perspectives can create friction, but they also make the design more complete when they are handled properly.

The project therefore taught me that design engineering is not only about producing a good technical solution. It is also about building enough understanding, evidence, confidence, and communication around that solution so that it can be taken seriously. The designer has to remain critical, but also persistent.

5 Discussion, Conclusion & Reflection

New chapter on the next page. ►

6 AI Use Declaration

During the preparation of this work, *ChatGPT 5.2*, *ChatGPT 5.3*, *ChatGPT 5.5*, and *ChatGPT 5.5 Thinking* were used to identify grammatical errors and improve the clarity and conciseness of the text. As generated output occasionally became overly verbose, all suggestions were reviewed and manually edited to preserve brevity and maintain the intended meaning.

All conversations were organized within a single project workspace. The settings "Reference Saved Memories" and "Reference Chat History" were enabled to maintain consistency in writing style, terminology, and vocabulary throughout the report (e.g., the consistent use of "sachet" rather than "pouch").

At multiple stages during the writing process, PDF versions of the report were analyzed using *ChatGPT* to identify duplicate or overlapping content. The identified passages were subsequently reviewed and manually revised to improve conciseness. In addition, *ChatGPT* was consulted for advice on restructuring sections of the background chapter to improve the overall narrative and flow of the document.

The contents of the literature review (Section 2.6) are derived from a previously prepared literature review. The methodology and specific AI Use Declaration associated with that work can be found at <https://edu.nl/7jyky>.

ChatGPT Codex was used in conjunction with Visual Studio Code to develop, review, and iterate on the Python code used throughout this project.

Evondos' internal *Microsoft Copilot* was used to search for documents and retrieve information from internal systems and SharePoint.

Following the use of these tools, all generated content and code were reviewed and edited by the author as necessary. The author takes full responsibility for the contents of this publication.

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A Sachet Layout Information

This Appendix is an addition to [Section 2.4](#), and explains the different attributes that make up the layout of medication sachets. These attributes are documented in individual layout configurations, which are loaded into the Medido for correct identification of the seal location and barcode.

A.1 Sachet Color

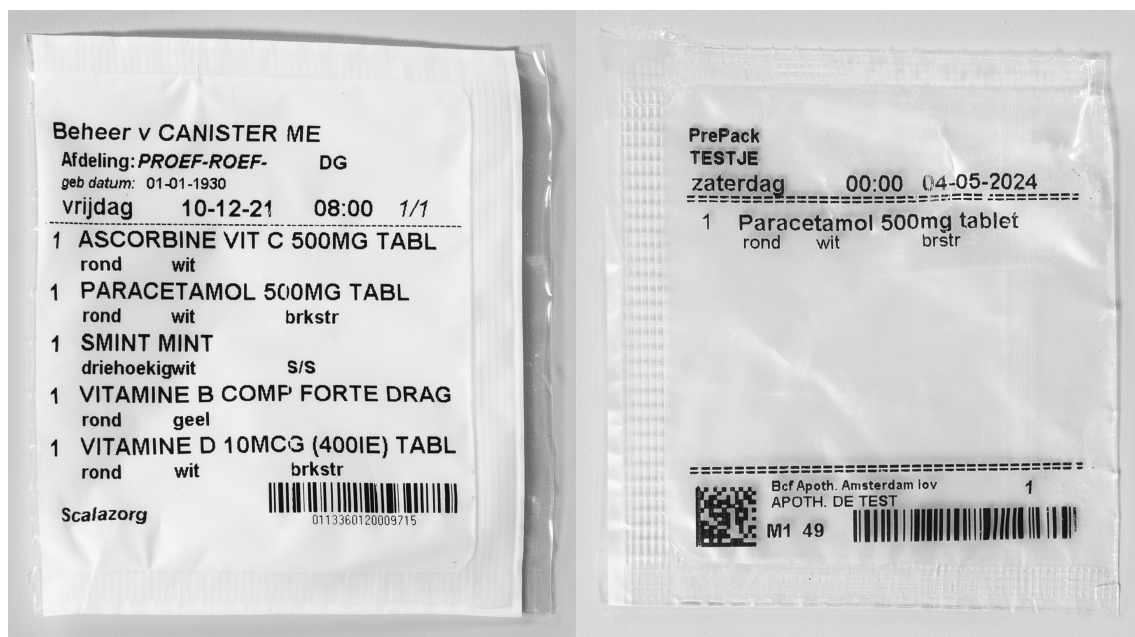
Medication sachets are manufactured either as fully transparent units or with a white front layer. Each sachet contains printed information used both for patient identification and for communicating the contents of the medication. For transparent sachets, barcode readability is enhanced by ensuring a white background is present on the side opposite the barcode scanner. This provides a uniform, high-contrast surface that improves the detection of the printed barcode elements.

A.2 Printed Information

Each medication sachet layout contains printed information elements to ensure accurate identification, traceability, and safe administration of the medication. These elements are structured to support both healthcare professionals and automated systems of the prepackager in verifying the contents and intended use of each sachet. The placement of elements differs per layout, but most sachets contain roughly the same information ([Figure 41](#)). No standardization in layouts is present yet.

Figure 41

Medication Sachets with Various Layouts



A Sachet Layout Information

Patient-specific information includes the client's name and date of birth, which together provide a primary means of identification and reduce the risk of medication errors. Temporal information is also included, consisting of the day, date, and time of administration. This ensures that medication is taken at the correct moment within the prescribed schedule.

In addition, the sachet specifies the medication details, including the name of the drug, the prescribed amount, and the dosage. These parameters are critical for confirming that the correct medication and quantity are administered. Finally, physical identification characteristics of the medication are provided, such as color, size, and the presence of a score line ("breekstreep"). These descriptors make visual verification of the medication possible, aiding the pharmacy or care staff in removing certain medication if needed.

A.3 Marker

In the early days of Medido, only optical sensors were used to determine the location of the sachet seal. For this reason, a distinct dark feature on the sachet was necessary. Especially older packaging machines did not have software capable of printing barcodes, so a 'marker' was printed on sachets instead through the means of a row of vertical dashes (Figure 42). In many cases, this layout with an extra marker is different than the default layout of that packager, meaning the pharmacy has to place the client in a special Medido group so that the prepackager uses the correct layout for use in the Medido medication dispenser.

Figure 42

Medication Sachet with Marker at the Top Right



A.4 1D Barcodes

Many current layouts make use of a one-dimensional (1D) barcode to store machine readable information (often the sachet serial number). 1D barcodes encode information as a sequence of parallel bars and spaces with varying widths. Each pattern corresponds to a specific character or digit, which is interpreted by a scanner through the measurement of reflected light. Numerical information is typically represented by predefined encoding schemes in which combinations of bars and spaces map to digits (0–9). The data is read linearly, meaning the scanner processes the code in a single direction, converting the optical pattern into a digital string.

Different 1D barcode types are supported by the Medido firmware, but the following are used in Dutch sachet layouts:

Code128

Code 128 is a compact and versatile barcode type that can represent a wide range of characters, including letters, numbers, and symbols. It uses different encoding modes (A, B, and C), of which C is optimized for numbers by storing two digits at a time. This makes it particularly efficient when large amounts of numerical data need to be encoded in a small space ([International Organization for Standardization, 2007](#)). See [Figure 43](#).

Figure 43

Medication Sachet with Code128 Barcode

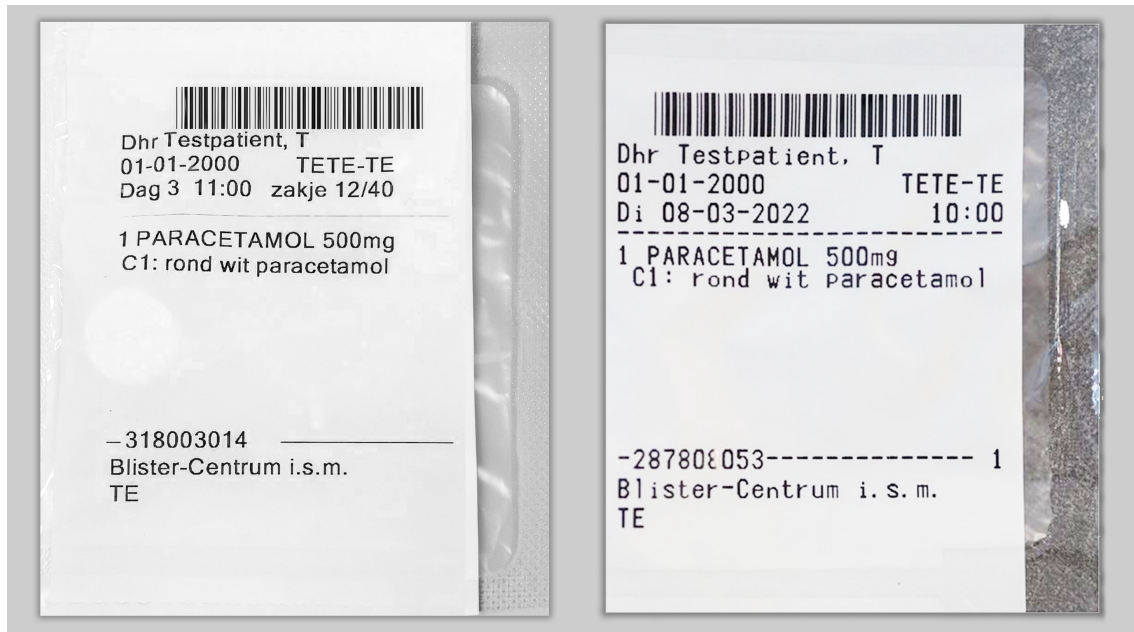


Code39

Code 39 is a simpler barcode format that can represent both letters and numbers. It is easy to read and reliable, which is why it is commonly used in industrial environments. However, it requires more space to store the same amount of information compared to more advanced barcode types ([International Organization for Standardization, 2023](#)). See [Figure 44](#).

Figure 44

Medication Sachet with Code39 Barcode

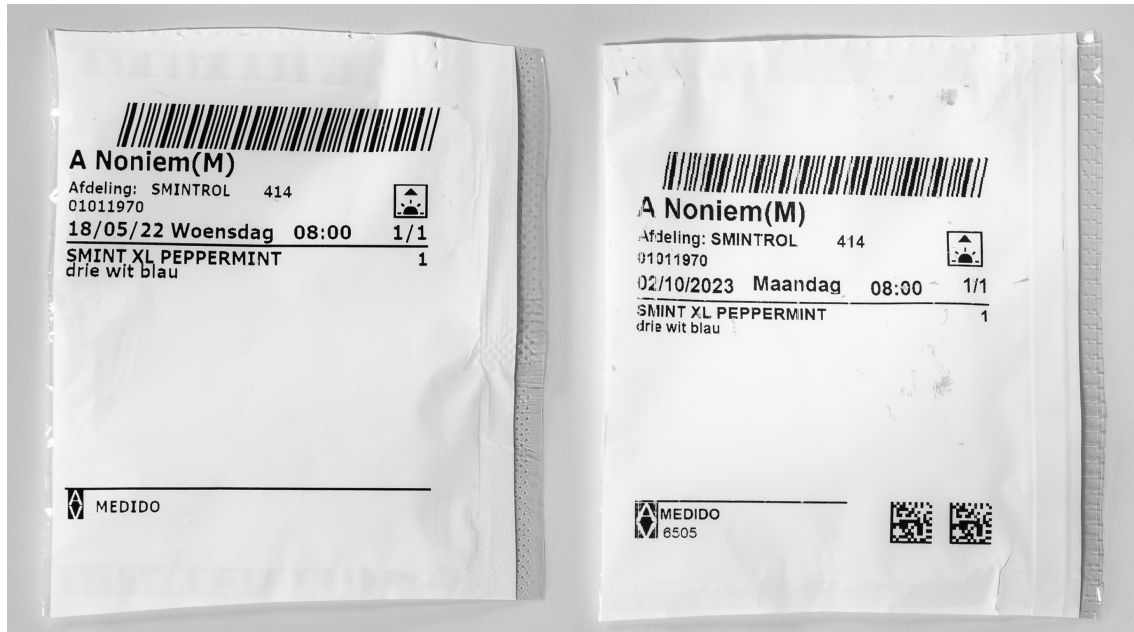


Codabar

Codabar is mainly used for numerical data and a small number of additional symbols. It is easy to print and can still be read accurately even if the print quality is not perfect. Because of this, it has been widely used in applications such as libraries and healthcare systems (Brady, n.d.). See Figure 45.

Figure 45

Medication Sachet with Codabar Barcode



A.5 2D Barcodes

Two-dimensional (2D) barcodes store information in both horizontal and vertical directions, using patterns of squares or dots arranged in a grid. This allows them to encode significantly more data than 1D barcodes within a smaller area. Numerical information is converted into binary data and distributed across the grid, which can then be read by imaging devices such as cameras. Many 2D barcodes also include built-in error correction, enabling accurate decoding even if part of the code is damaged or obscured.

The following 2D barcodes are used in sachet layouts:

QR (Quick Response)

QR (Quick Response) codes are designed for fast readability and can store large amounts of data, including numerical, alphanumeric, and binary information. They are widely used in consumer applications due to their ability to be scanned quickly from multiple angles and their high error correction capability (DENSO ADC, 2011). See Figure 46.

Figure 46

Medication Sachet with QR Code



Data Matrix

Data Matrix codes are highly space-efficient and are particularly suitable for encoding data in very small areas. They are commonly used in industrial and healthcare contexts, where small components or packaging require reliable marking. Data Matrix codes also offer strong error correction, allowing them to remain readable even when partially damaged (Leibinger, n.d.). See Figure 47.

Figure 47

Medication Sachet with Data Matrix



B Barcode Scanner Performance Research Discussion

This Appendix serves as a substantiation of the hypothesis evaluation in [Section 3.4](#).

B.1 Effect of Motion

The improvement observed with controlled scanning confirms that motion during transport of the sachet (as is the case in the current Medido firmware) reduces read reliability. Limited exposure time and positional misalignment during transport likely contribute to missed detections. This supports **H1**: Barcode reading performance is negatively affected by scanning during motion.

B.2 Effect of Added Diffuse Light

Contrary to initial expectations, increased diffuse light improved performance, while reduced external light degraded it. This indicates that the system benefits from broader illumination rather than focused illumination from the barcode scanner itself operating in a shielded environment. This supports **H2**: Using diffuse illumination improves barcode decoding reliability compared with illumination from the scanner LED.

B.3 Effect of Mirror Contamination

The mirror was found to be highly sensitive to contamination. Even small dust particles caused reading errors or complete failures, while larger debris had a more severe impact. This supports **H3**: Contamination of the mirror negatively impacts barcode detection accuracy.

B.4 Effect of Scanner LED

Disabling the internal LED resulted in near-perfect performance. This suggests that the LED introduces optical disturbances such as glare or overexposure, reducing contrast and detection accuracy. This strongly supports **H4**: Small variations in scanner alignment and positioning reduce barcode decoding consistency between otherwise identical devices.

B.5 Device Variability

The large performance difference between identical units suggests sensitivity to internal alignment and positioning of optical components. Small variations likely alter the effective scanning area, significantly impacting performance. This supports **H4**: Small variations in scanner alignment and positioning reduce barcode decoding consistency between otherwise identical devices.

B.6 Scanning Dynamic Range

Baseline testing using white and transparent sachets showed that only approximately 45% of the available 8-bit dynamic range of the scan engine was utilized. This indicates that the measured white intensity values remain relatively low compared to the theoretical maximum, suggesting that there is considerable room for improvement in the brightness and contrast of the captured scan image. This supports **H5**: The barcode scanner under-utilizes the available grayscale dynamic range, limiting barcode contrast.

B.7 Effect of Exposure Time

Longer exposure times visually resulted in higher contrast within the captured scan data, improving the differentiation between black and white regions of the barcode. Although no statistical correlation was found between exposure time and barcode decode time, multiple experiments showed that exposure times around 400 μs produced noticeably improved contrast. This improved contrast is beneficial for accurately detecting the boundaries between thin and wide barcode bars.

At an exposure time of approximately 125 μs , which appears to be close to the scanner's default operating value, the contrast became substantially lower. Under these conditions, distinguishing between thin and wide bars became more difficult, increasing the likelihood of decoding errors. This supports **H6**: Increasing barcode scanner exposure time improves barcode contrast and barcode decoding reliability.

B.8 Effect of Reflected Light

In various experiments, clear reflections originating from the scan engine illumination LED were visible both around the barcode and within certain barcode bars themselves. These reflections caused local overexposure in the captured scan data, resulting in white regions appearing where black barcode bars should be present. These reflections were not visible in setups where the illumination LED was diffused.

Such reflective blind spots hinder barcode decoding, as the decoding algorithm interprets these regions as white spaces rather than black bars. The algorithm does not appear to compensate for or reconstruct these missing black regions, which can lead to failed barcode reads. This supports **H7**: Specular reflections from black barcode regions can be interpreted as white space by the barcode scanner, leading to decoding errors.

C Weighted Objectives Procedure

This Appendix serves as a substantiation of the weighted objectives method used in [Section D.1.1](#).

C.1 Introduction

A weighted objectives method ([van Boeijen et al., 2020, p. 187](#)) was used to evaluate and compare design concepts in a structured and transparent manner.

The method assesses each concept against a predefined set of criteria and recognizes that not all criteria are equally important by assigning a weighting factor to each objective. This allows both qualitative and quantitative considerations to be incorporated into the decision-making process while maintaining traceability between project objectives and concept selection.

By scoring concepts against the evaluation criteria and multiplying these scores by their respective weights, an overall performance score can be calculated for each alternative. The method is particularly suitable when multiple design concepts satisfy the project requirements to varying degrees and a systematic comparison is required to identify the concept that provides the greatest overall value. Based on Roozenburg and Eekels (1995), the weighted objectives method was therefore selected to support the concept selection process and ensure that the final design concept aligned with the priorities established through the project requirements.

The selected metrics ([Figure 48](#)) were derived directly from the requirements established in [Section 2.9](#) and [Section 3.5](#). Together, these requirements emphasize three key objectives: improving barcode decoding performance, ensuring reliable operation under real-world conditions, and enabling practical implementation within the existing Medido platform. The weighted objectives method was therefore structured to ensure that all functional, technical, implementation, and lifecycle requirements were represented within the concept evaluation process.

C.2 Metrics

C.2.1 Reading Performance

Reading Performance (30%) received the highest weighting because the primary objective of the project is to improve barcode verification reliability. This metric directly reflects Functional Compatibility (R1.1), Optical Performance Compatibility (R1.4), Optical Performance (R2.2), Barcode Decoding Performance (R2.4), and Stationary Scanning Capability (R2.5). Together, these requirements define the core functionality of the solution: reliably decoding all supported barcode types and sachet configurations while providing optical

C Weighted Objectives Procedure

conditions that maximize barcode distinguishability and overall reading performance. Since the project exists to improve barcode verification, concepts that fail to substantially improve decoding performance cannot be considered successful regardless of their implementation advantages.

C.2.2 System Robustness

System Robustness (25%) was weighted almost as heavily, as performance improvements must remain reliable under realistic operating conditions. This metric captures Robustness to Operational Variation (R1.2), Operational Compatibility (R1.5), Contamination Robustness (R2.1), and Robustness to Mechanical Variation (R2.3). These requirements address known failure drivers identified during the exploratory investigation, including dust accumulation, sachet positioning variation, scanner alignment differences, assembly tolerances, and other environmental or operational disturbances. A concept that performs well only under controlled conditions would provide limited value in practice, making robustness a critical evaluation criterion.

C.2.3 Integration Complexity

Integration Complexity (15%) reflects the engineering effort and technical feasibility associated with implementing a concept within the existing Medido architecture. This metric is primarily derived from Hardware Integration Compatibility (R1.3), Optical Performance Compatibility (R1.4), and Operational Compatibility (R1.5). Concepts that require modifications to the mirror-based optical path, major changes to the dispensing process, extensive software adaptations, or incompatibility with the existing Zebra Technologies SE655 scan engine were considered less favourable due to increased development complexity and validation effort.

C.2.4 Remanufacturing Effort

Remanufacturing Effort (10%) addresses the feasibility of deploying a solution across the existing installed device population. This metric directly reflects Retrofit Compatibility (R1.6), Minimal Installation Impact (R1.7), Existing Tooling Compatibility (R1.8), and Installation Repeatability (R1.9). Since the preferred solution should be suitable for implementation during refurbishment activities, concepts requiring extensive device modifications, specialized tooling, lengthy installation procedures, or device-specific calibration were penalised within this criterion.

C.2.5 Maintenance Demand

Maintenance Demand (10%) captures the lifecycle implications of the proposed concepts and is derived primarily from Serviceability (R1.10) and Contamination Robustness (R2.1). Concepts that obstruct access to existing components, require frequent cleaning, increase contamination sensitivity, or complicate maintenance procedures would negatively impact long-term opera-

tional efficiency and serviceability. Lower maintenance requirements therefore result in higher scores within this category.

C.2.6 Production Cost

Production Cost (7%) was included to account for the economic implications of large-scale implementation. While no individual requirement explicitly addresses cost, requirements such as Retrofit Compatibility (R1.6), Minimal Installation Impact (R1.7), Existing Tooling Compatibility (R1.8), and Hardware Integration Compatibility (R1.3) all indirectly influence implementation cost. Concepts requiring additional custom components, manufacturing processes, or installation effort therefore score less favorably within this criterion.

C.2.7 Material Impact

Material Impact (3%) represents the environmental consequences of implementing a concept, including material usage, replacement parts, and waste generation throughout the product lifecycle. Although sustainability is not explicitly represented by a dedicated requirement, it is indirectly related to the project's emphasis on retrofit implementation (R1.6), minimal installation impact (R1.7), and maintainability (R1.10), which collectively encourage efficient use of resources and minimize unnecessary component replacement.

Together, these metrics ensure that every design requirement is represented within the evaluation framework. Functional requirements (R1.1–R1.5), implementation requirements (R1.6–R1.10), and performance requirements (R2.1–R2.5) are translated into measurable assessment criteria, enabling a structured and defensible comparison of concepts while maintaining alignment with the overall project objectives.

C Weighted Objectives Procedure

C.3 Scoring Table

A scoring table was constructed with defined criteria for each metric to ensure that all concepts were evaluated consistently and with minimal bias (Figure 48). As the concepts were assessed a priori and therefore lacked objective performance data, the scoring was based on informed designer judgment, drawing on the author's knowledge of the product, the identified requirements, and the expected behavior of each concept.

Figure 48

Weighted Objectives Scoring Table

No. Element	Rationale	Scoring	Weight
1 Reading Performance	Core objective; directly measures success of the redesign	1 No measurable improvement or worse than baseline 2 Minor improvement (<10% increase in successful reads) 3 Moderate improvement (≈10–20%) 4 Significant improvement (≈21–30%) 5 Major improvement (>30%) or near-elimination of read failures	30%
2 System Robustness	Prevents performance degradation in real-world conditions (dust, misalignment, pouch variability)	1 >30% drop in read rate under any single test condition 2 15–30% drop in read rate under one or more conditions 3 5–15% drop; noticeable degradation but still functional 4 <5% drop across all conditions; stable performance 5 <2% drop AND no systematic failures in any condition	25%
3 Integration Complexity	High impact on feasibility and engineering effort; can block adoption	1 Major redesign (PCB + housing + architecture changes) 2 Significant redesign (multiple subsystems affected) 3 Moderate changes (mechanical or electrical, not both heavily) 4 Minor changes (localized adjustments, no architecture impact) 5 Plug-and-play or near drop-in replacement	15%
4 Remanufacturing Effort	Important for scaling and retrofitting installed base	1 Not feasible to retrofit or requires full disassembly + specialized tooling 2 Complex retrofit; time-consuming and tool-intensive 3 Moderate effort; standard tools, partial disassembly required (10–15 min per unit) 4 Low effort; quick modification or module swap (5–10 min per unit) 5 Very low effort; simple, fast retrofit (<5 min per unit)	10%
5 Maintenance Demand	Drives operational cost and service burden over lifecycle	1 High maintenance; frequent cleaning/intervention required 2 Regular maintenance needed to maintain performance 3 Occasional maintenance required 4 Low maintenance; infrequent intervention 5 Minimal to no maintenance required over normal lifecycle (normal return cycle)	10%
6 Production Cost	Relevant but secondary to reliability in this context	1 Significant cost increase (>20% BOM increase) 2 Moderate cost increase (≈10–20%) 3 Slight cost increase (≈5–10%) 4 Cost-neutral or negligible increase (<5%) 5 Cost reduction compared to current design	7%
7 Material Impact	Low priority unless sustainability is explicitly targeted	1 Significant increase in material use and/or use of complex/non-recyclable materials 2 Moderate increase in material use or less favorable material types 3 Neutral impact (similar material use and types) 4 Reduced material use or improved material selection 5 Significant reduction in material use and/or clearly more sustainable materials	3%

View the filled-out Excel sheet via <https://edu.nl/r9fjj>.

D Design Iterations

D.1 Optical System

D.1.1 Weighted Objectives

Based on the findings in [Section 3](#), each of the 22 concepts from [Section 4.2](#) was ranked using a Weighted Objectives system, in which each concept was awarded a score from 1 to 5 on seven different elements with varying weights (see [Table 2](#), based on the 15 requirements from [Section 2.9](#) and [Section 3.5](#)). These scores were based on design intuition and preliminary technical judgment, and used a scoring matrix to ensure fair scoring. See [Appendix C](#) for a full explanation of the procedure; view the Excel sheet via <https://edu.nl/r9fjj>.

Table 2

Weighted Objectives Elements and Weights

Element	Weight
Reading Performance	30%
System Robustness	25%
Integration Complexity	15%
Remanufacturing Effort	10%
Maintenance Demand	10%
Production Cost	7%
Material Impact	3%

D Design Iterations

The output score of the Weighted Objectives method was normalized (0 for the lowest and 10 for the highest scoring concept), and the top three concepts were selected to explore further (Table 3). The other concepts were rejected based on the projected benefits in contrast to the integration effort and costs.

Table 3

Preliminary Concept Selection

Number	Title	Score
Concept 5	Different LED Angle	10.0
Concept 4	Diffusion Filter in Front of LED	9.7
Concept 11	Limit LED Beam Width	9.4
Concept 13	Different Positioning Scan Engine	9.2
Concept 22	Machine Vision Barcode Comparison	8.3
Concept 7	Internal Ribs to Break Scatter Light	8.0
Concept 9	Block Everything Outside FOV	7.8
Concept 8	Black Coating on Internals	7.2
Concept 15	Matte Mirror	6.9
Concept 2	Extra Lighting	6.3
Concept 19	Direct Line of Sight with Barcode	5.1
Concept 3	ND/Polarization Filter	3.5
Concept 17	Different Mirror Position	3.4
Concept 12	New Barcode Scanner	3.0
Concept 10	Periscope-style Enclosed Light Path	2.9
Concept 1	Less Bright LED	2.1
Concept 14	IR Lighting + Sensor	2.1
Concept 21	Dirt/Glare Detection	2.1
Concept 20	Matte Sensor Frame	1.6
Concept 16	First-surface Mirror	0.7
Concept 6	Ring Light Around Sensor Frame	0.1
Concept 18	Curved Mirror	0.0

D.1.2 Preliminary Concept Development & Evaluation

Different LED Angle

The scan engine LED was obstructed, and an external red LED was positioned above the scan engine and directed toward the mirror. This configuration ensured that the barcode was illuminated while changing the illumination angle relative to the original scan engine setup.

However, due to the material properties of the transparent medication sachets, the sachet surface frequently showed significant wrinkling. The curvature of the sachet proved to be highly variable, depending on the size and quantity of medication, medication placement within the sachet, and crinkling introduced during loading or transport of the medicine roll.

As a result, illumination from an alternative angle still produced reflections from both the sachet surface and the barcode itself that were redirected into the sensor (Figure 49). During testing, it proved difficult to sufficiently reduce glare without simultaneously reducing the illumination intensity to a level at which the sensor could no longer reliably detect the barcode. These findings suggest that the illumination requires substantially greater diffusion without significantly reducing the available light intensity.

Figure 49

Scan Results with Different LED Angle

scan #12, type 0 "unknown", code "unknown", exposure 963 μ s, decode 0 ms, black 38/255, white 115/255



Diffusion Filter in Front of LED

Several filters, manufactured using transparent PLA through 3D printing, were positioned in front of the scan engine LED in an attempt to diffuse the emitted light sufficiently to reduce sharp reflections.

As a result of the added filter, the barcode received less illumination, causing the automatic exposure algorithm of the scan engine to increase the exposure time to its maximum value of 1500 μ s. Although the white areas of the scan output appeared more gray due to the reduced illumination intensity, sharp reflections remained visible across the full tested filter thickness range of 0.4 mm (Figure 50) to 2.0 mm (Figure 51), making successful barcode decodes impossible.

Figure 50

Scan Results with 0.4 mm Thick Transparent PLA Filter

scan #2, type 0 "unknown", code "unknown", exposure 1500 μ s, decode 0 ms, black 43/255, white 94/255



Figure 51

Scan Results with 2.0 mm Thick Transparent PLA Filter

scan #2, type 0 "unknown", code "unknown", exposure 1500 μ s, decode 0 ms, black 24/255, white 47/255



Limit LED Beam Width

An add-on containing two side walls to constrain the width of the LED beam was positioned in front of the scan engine LED. Variants with wall depths of 3 mm (Figure 52), 4 mm (Figure 53), and 5 mm (Figure 54) were evaluated.

While the side walls successfully prevented illumination of the internal walls of the Medido surrounding the optical path, they did not significantly reduce the glare originating from the medication sachets themselves. Reflections on the sachet surface and barcode area remained visible and continued to interfere with the scan output, while dark areas next to the barcode were visible, possibly interfering with the automatic exposure time adjustment.

Figure 52

Scan Results with 3.0 mm Deep Side Walls

scan #5, type 0 "unknown", code "unknown", exposure 297 μ s, decode 0 ms, black 29/255, white 99/255



Figure 53

Scan Results with 4.0 mm Deep Side Walls

scan #5, type 0 "unknown", code "unknown", exposure 331 μ s, decode 0 ms, black 20/255, white 98/255



Figure 54

Scan Results with 5.0 mm Deep Side Walls

scan #5, type 0 "unknown", code "unknown", exposure 276 μ s, decode 0 ms, black 16/255, white 98/255



D.1.3 Second Ideation Round

Since reflections originating from the sachet surface were identified as the primary cause of unreliable barcode decoding, rather than stray light entering the sensor, a new series of concepts was developed aimed at minimizing reflections reaching the scanner sensor. These concepts were informed by insights gained during the evaluation of earlier prototypes and were explored in an iterative sequence guided by designerly judgment and emerging experimental findings.

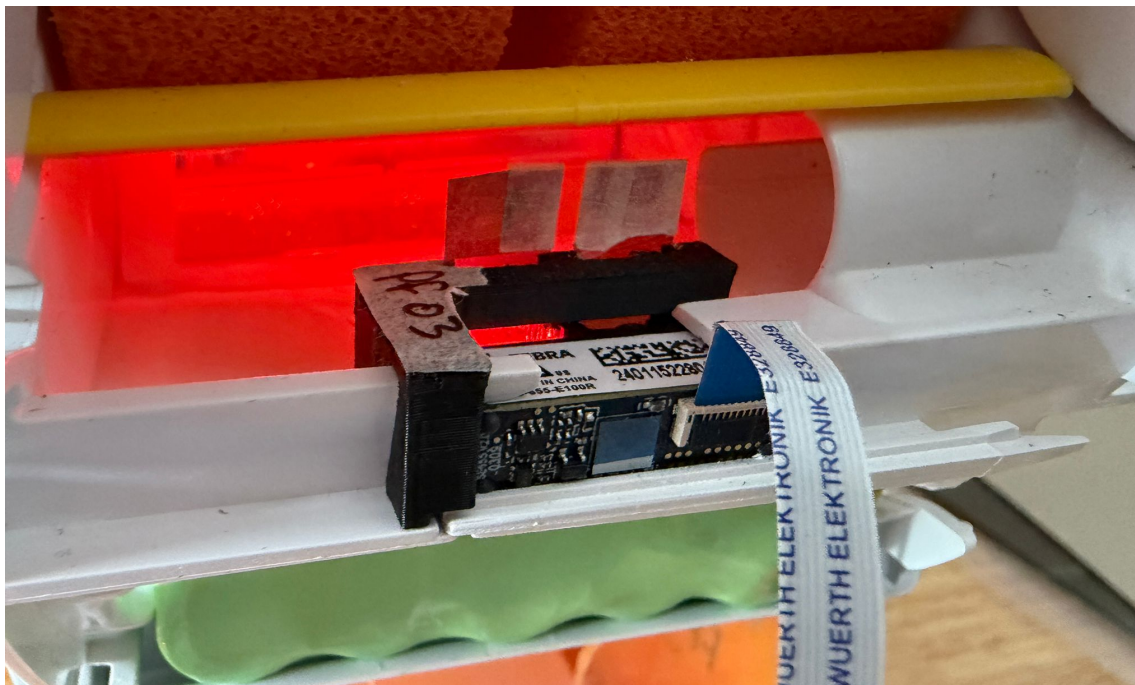
(Cross) Polarization

The concept of using (cross) polarization originated during the initial brainstorming phase but was initially rejected due to the expectation of only moderate performance improvements and continued sensitivity to sachet variability.

A 3D-printed bracket was developed to mount polarization film in front of both the LED and the sensor (Figure 55). Two configurations were evaluated. In the first configuration, the sensor polarizer was rotated by 90° relative to the LED polarizer (cross-polarization, see results in Figure 56). In the second configuration, identical polarization films with the same orientation were placed in front of both the LED and sensor (see results in Figure 57).

Figure 55

3D-Printer Polarization Film Bracket Installed



As expected, the polarization filters reduced the amount of light reaching the sensor, causing the automatic exposure control algorithm to increase the exposure time to its maximum value of 1500 μs . Despite the reduced illumina-

tion, sufficient grayscale contrast remained to allow visual inspection of the barcode, suggesting that decoding should *theoretically* remain feasible.

However, substantial glare remained visible, particularly on the irregularly crinkled surfaces of the tested sachets. Large white regions remained in both the polarization and cross-polarization configurations, showing that the reflected light could not be sufficiently suppressed under realistic sachet conditions. These findings rejected the hypothesis that polarization alone could reduce reflections to a practically workable level.

Figure 56

Scan Results with Cross Polarization

scan #7, type 0 "unknown", code "unknown", exposure 1500 μ s, decode 0 ms, black 16/255, white 102/255



Figure 57

Scan Results with Polarization

scan #10, type 0 "unknown", code "unknown", exposure 709 μ s, decode 0 ms, black 13/255, white 101/255

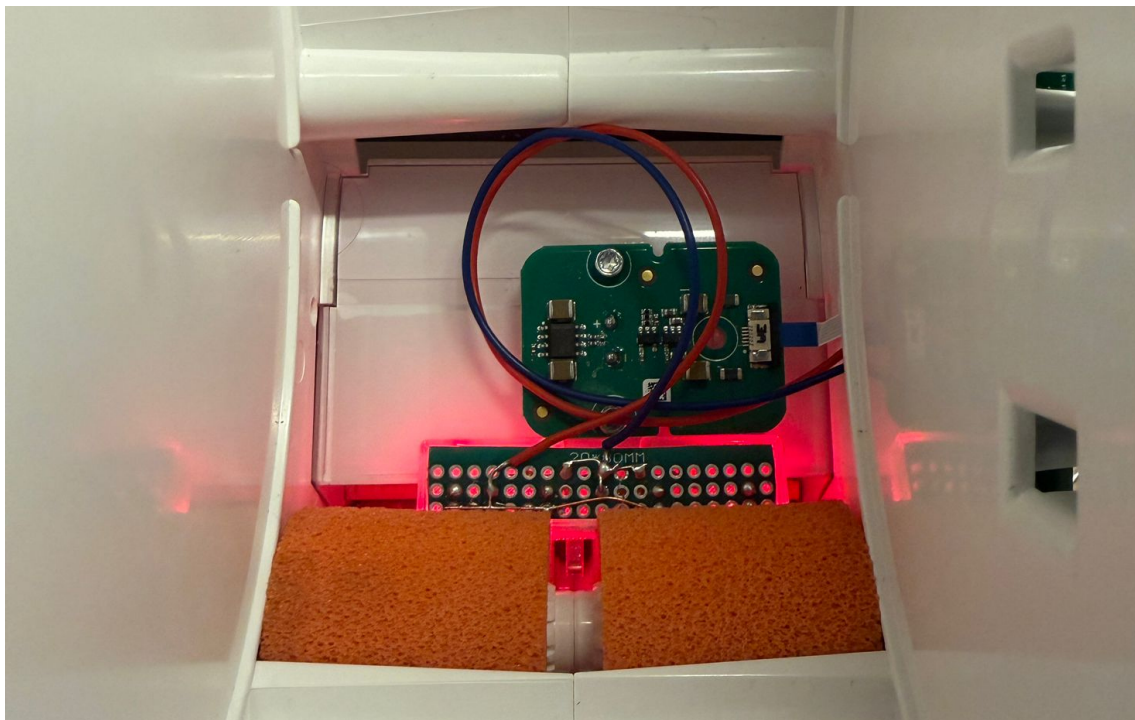


Illuminating Sachets from the Back

Rather than illuminating the sachet from the front, a backlight array was integrated into the top section of the sensor frame, positioned next to the ultrasound sensor PCBA and upper transport rollers (see [Figure 58](#)). The array illuminated the sachet from behind by projecting light through the sensor frame. To isolate the effect of the backlight, a 3D-printed cover was installed to block the scanner's integrated LED, leaving the backlight array as the only light source ([Figure 59](#)).

Figure 58

Backlight Installed (Top View)



The backlight resulted in a very even illumination of both white ([Figure 60](#)) and transparent sachets ([Figure 61](#)) while completely eliminating surface reflections. However, the resulting images used only a small portion of the available grayscale dynamic range (roughly 8%). Even at the maximum exposure time of $1500 \mu s$, the captured scans appeared extremely dark and were illegible to the human eye (see the Figures for both the raw scans and contrast-corrected versions).

Despite this low intensity, the scan engine was able to decode the barcodes reliably, demonstrating that enough barcode information remained available for successful decoding even under these dim illumination conditions.

Figure 59

Backlight Installed (Bottom View)

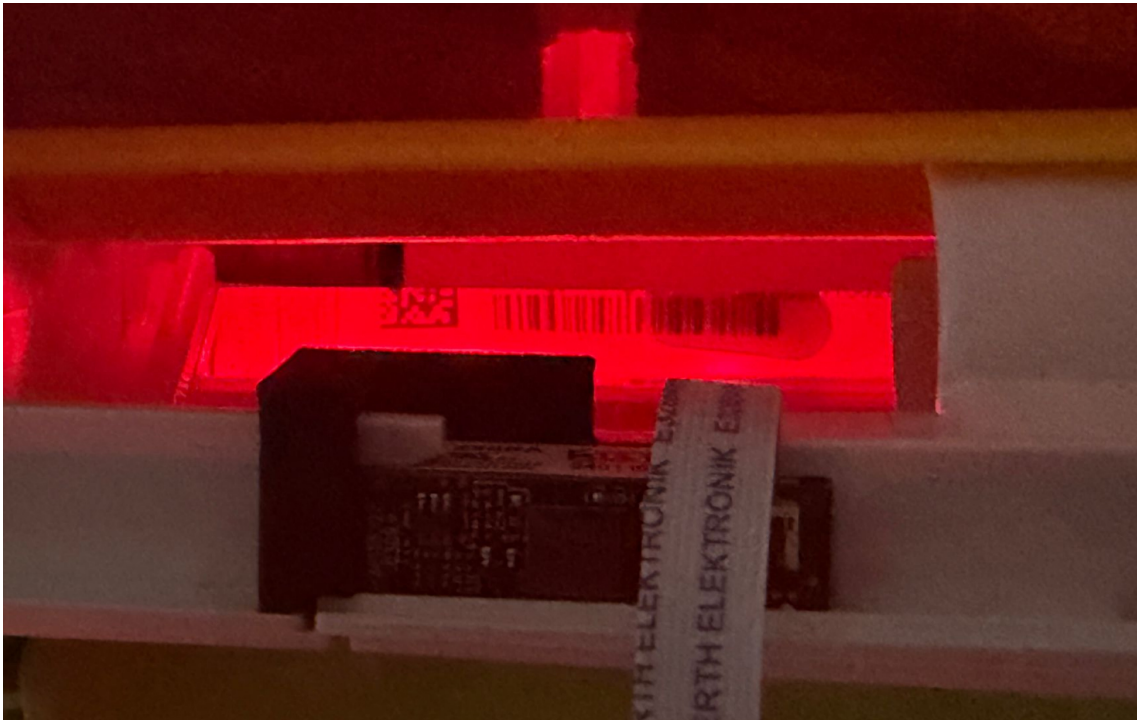


Figure 60

Scan Results of White Sachet with Backlight Installed, with Brightness Correction

scan #33, type 2 "Codabar", code "27734589440", exposure 1500 μ s, decode 58 ms, black 5/255, white 20/255



Figure 61

Scan Results of Transparent Sachet with Backlight Installed, with Brightness Correction

scan #7, type 3 "Code 128", code "0361200100800142", exposure 1500 μ s, decode 173 ms, black 5/255, white 28/255



D.1.4 Refining Concept

The backlighting method seemed very promising in removing any glare in the scan. However, this method requires enough light to be passed through the sachet to remain viable. While the scans in [Figure 60](#) and [Figure 61](#) did have successful decodes, due to the incredibly small amount of light being passed onto the sensor, even the smallest obstruction could hinder barcode decoding.

To test this, several test runs were done where a pill was placed deliberately behind the barcode in the sachet, to simulate possible real world use. As expected, this immediately made successful decoding impossible due to dark spots in the scan results (see [Figure 62](#) and [Figure 63](#)).

Figure 62

Scan Results of White Sachet with Backlight Installed and Pill Behind Barcode, with Brightness Correction

scan #5, type 0 "unknown", code "unknown", exposure 1500 μ s, decode 0 ms, black 4/255, white 19/255



Figure 63

Scan Results of Transparent Sachet with Backlight Installed and Pill Behind Barcode, with Brightness Correction

scan #10, type 0 "unknown", code "unknown", exposure 1500 μ s, decode 0 ms, black 4/255, white 28/255



As sachets are fed through the Medido upside down, only sachets with a barcode at the top have the possibility of a pill being positioned behind the barcode. As all transparent sachets, which have the highest risk of producing glare in the current setup, have the barcode at the bottom, they are inherently suitable for use with the backlight.

However, 53% of all sachets dispensed by the Medido M302 are white sachets with the barcode at the top, meaning a large portion of the sachets in use are at risk of developing a dark spot when illuminated using the backlight.

To evaluate this risk, a test was conducted using white sachets containing multiple pills per sachet, representative of real-world use. These sachets were manually fed through the Medido while the backlight was engaged to determine whether pills positioned behind the barcode could obstruct the illumination and negatively affect barcode readability under realistic conditions.

D.1.5 Concept Evaluation

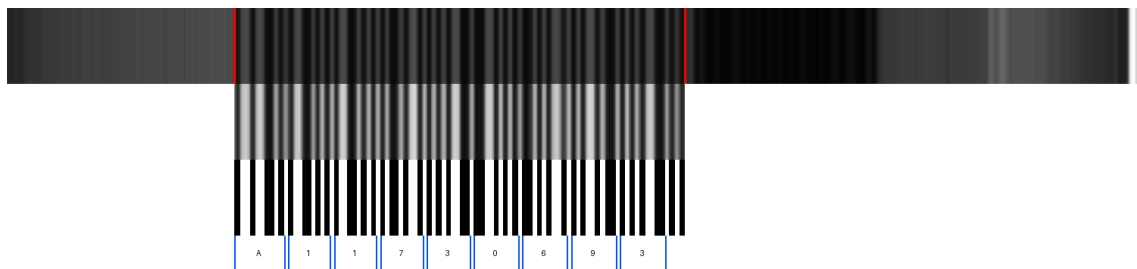
A representative white medicine roll containing sachets with varying numbers and sizes of pills was tested with the backlight enabled and the scan engine LED disabled.

In 46% of the tested sachets, medication was positioned behind the barcode, creating an obstruction that prevented the scan engine from successfully decoding the barcode. However, in approximately two-thirds of these cases, the final characters of the barcode remained visible. This suggests that a custom decoding algorithm implemented in the Medido firmware could process the raw scan data and reconstruct the remaining barcode information, allowing the sachet to be validated despite the partial obstruction.

A custom Python script was created to prove the barcode reconstruction, as shown in Figure 64.

Figure 64

Final Character Decoding Proof-of-Concept with Dark Spot



Note. From top to bottom: 1) Original scan, 2) Contrast corrected scan, 3) Binarized scan, 4) Decoded characters

With barcode reconstruction implemented, the backlight concept achieves a decoding rate of 85% for white sachets with a barcode positioned at the top, representing a small improvement over the current decoding rate of 81%.

For all other sachet layouts, including both white and transparent sachets with barcodes positioned at the bottom, decoding performance increases to nearly 100%. This is because the barcode area remains unobstructed by medication, allowing the backlight to generate a high-contrast barcode image without interference from reflections.

D.1.6 M303 Ultrasound Transmitter & Lighting PCBA

The Medido M303 already uses a backlight PCB (*Ultrasound Transmitter & Lighting PCBA* / USTL PCBA) in combination with a new barcode scan engine. This existing USTL PCBA was tested in the M302 using an external 3.3 V DC power supply, as the M302 main PCB does not include the connector or dedicated electrical interface required to power and control it.

The test results were positive. White sachets produced clearly legible sensor images at exposure times of approximately 50–80 μs . Medication positioned behind the barcode still prevented complete decoding in some cases, although sufficient barcode information remained visible for potential reconstruction using digital image processing.

Transparent sachets could initially not be decoded because the backlight intensity was too high. At a supply voltage of 3.3 V, the USTL PCBA drew approximately 0.22 A, causing the barcode image to become overexposed. When the LED current was manually limited to approximately 0.04 A, the sensor images showed sufficient contrast and all tested barcodes were successfully decoded.

These results indicated that the LED drive current could be selected or actively controlled to provide sufficient illumination for both white and transparent sachets without saturating the scan engine sensor. The optimal current was found to be approximately 0.08 A.

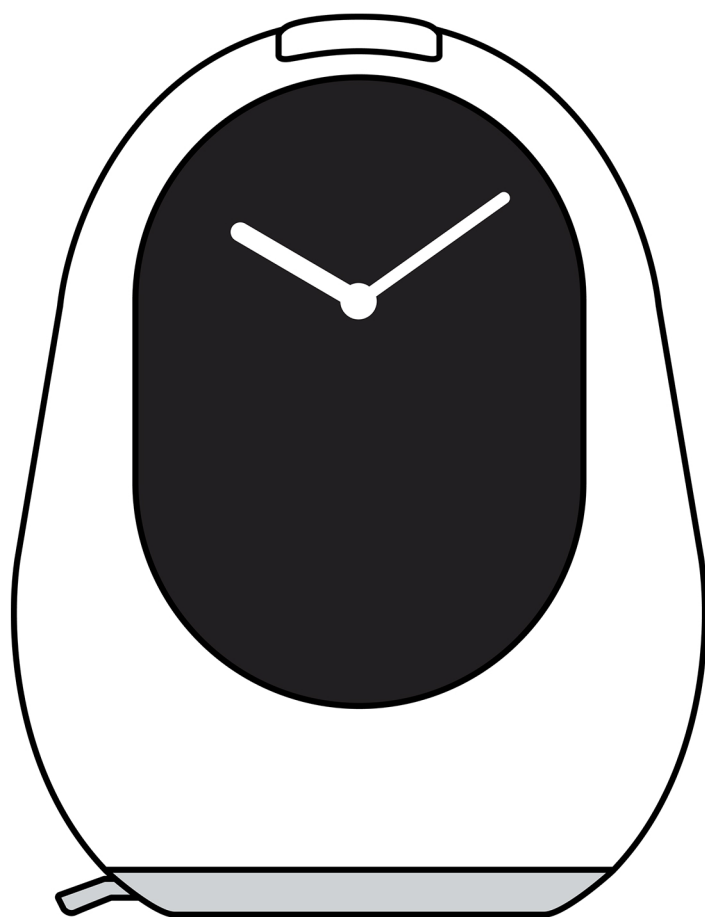
The M302 main PCB does not provide the dedicated eight-pin flexible flat cable (FFC) output required to connect the new USTL PCBA directly. In this pin-out, six pins are used for the ultrasound transmitter, and two pins for the lighting. The easiest and cheapest option would be to create a revised USTL PCBA with a six-pin input, that triggers both the lighting and the ultrasound transmitter at the same time. This would not affect the detection process of the Medido.

If the lighting has to be controlled separately of the ultrasound transmitter, the M302 main PCBA does include a normally unused JTAG debugging header that provides a 3.3 V supply, ground, and several GPIO connections. A GPIO signal could be used to enable or disable the backlight, but it should not be used to supply the LED current directly. A suitable switching circuit (already in place on the M303 main PCB) would therefore be required between the GPIO output and the USTL PCBA.

A revised USTL PCBA could be developed with an integrated connector for the M302 JTAG header and the required LED driving and current-limiting circuitry. This would allow the backlight to be used with the older M302 main PCB without requiring a separate interface PCB.

D Design Iterations

Alternatively, an implementation option is to develop an interface PCB that connects to the existing six-pin flexible flat cable and the JTAG header, and provides the eight-pin flexible flat cable connection required by the M303 USTL PCBA.



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