Development of Pediatric Intravenous Flow Rate Monitor for Humanitarian Settings

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ABSTRACT

In many humanitarian hospitals and pediatric wards, the absence of affordable infusion monitoring devices forces staff to rely on gravity-fed intravenous sets and minimal supervision, making continuous rate monitoring difficult and prone to dangerous errors.

This thesis presents *Dripito*, an open-source, low-cost, battery-powered optical intravenous flow monitor that clips onto the drip chamber and counts drops to estimate flow rate and total volume.

A prototype comprising an infrared light source and sensor, low-power embedded electronics, and a compact 3D-printed enclosure was developed and evaluated under benchtop conditions, with expert feedback collected on usability and deployment.

In a 15 minute test against a manual reference, Dripito differed by one drop out of 1,430 counted, an error of 0.07%. In a 10,minute gravimetric test, the device missed no drops but underestimated flow by 10% when a nominal drop factor was assumed. This discrepancy was traced to a worn dial in the flow controller, revealing a potentially useful quality-control signal.

Power modeling from component data predicts about 39 hours in continuous-Light Emitting Diode (LED) operation and about 20 days with intermittent sensing and microcontroller sleep from a single household battery (AA type). The bill of materials at 1000 units totals 9.17 Swiss francs per device, excluding assembly and compliance. Expert interviews endorsed the concept while highlighting priorities for refinement, including alarm, robustness, and power options.

Dripito achieves precise drop counting at very low cost and targets multi-day autonomy, addressing a clear need where infusion pumps are unavailable. Flow estimation remains sensitive to drop size. Trials incorporating calibration and usability testing are essential next steps toward safe deployment.

1 Introduction

1.1 Background

Critical care stabilizes patients with life-threatening conditions through intensive monitoring and intervention. Access is highly unequal: intensive care unit (ICU) bed availability ranges from fewer than 1 per 100 000 people in some low-income countries to over 30 in high-income countries (Adhikari *et al.*, 2010; Diaz *et al.*, 2019). In high-resource hospitals, both adults and children benefit from electronic infusion pumps, ventilators, and continuous vital-sign monitoring. These systems deliver precise therapy, issue alerts, and rely on stable electricity and regular maintenance.

In many rural clinics and field hospitals, conditions such as sepsis, severe dehydration, or shock must be managed without such equipment. Weak infrastructure delays awareness of deterioration, staff shortages limit observation, and scarce supplies hinder timely interventions such as oxygen therapy or rapid fluid resuscitation (Diaz *et al.*, 2019; Lee *et al.*, 2019).

Mortality in humanitarian crises can rise far above baseline. A crude mortality rate above 1 per 10,000 people per day signals an emergency ("Mortality Surveillance Threshold", 2025), compared with peacetime rates below 0.5. In the 2011 Somalia famine, under-five mortality exceeded 6 per 10,000 per day in some regions (United Nations Office for the Coordination of Humanitarian Affairs, 2011). Many deaths were from treatable conditions that became fatal without timely care (Lee *et al.*, 2019; Turner *et al.*, 2016). The 2014–2016 Ebola outbreak in West Africa again highlighted the consequences of inadequate capacity, with overwhelmed facilities, severe staff shortages, and inability to provide basic supportive care (Dickson *et al.*, 2018; Turner *et al.*, 2016).

Humanitarian organizations such as Médecins Sans Frontières (MSF) have shown that critical care principles can be adapted to low-resource settings, even without full ICUs (Lee *et al.*, 2019). Simple measures such as aggressive Intravenous (IV) fluid resuscitation can save lives, but only if delivered accurately and monitored effectively (Malkin, 2007; Shah *et al.*, 2015).

1.2 IV Fluid Therapy in Humanitarian Settings

In crises, IV fluid therapy is central to emergency care. In high-income pediatric wards, infusion pumps deliver precise, programmable rates with integrated monitoring and alarms. In many low-resource and humanitarian contexts, gravity-fed drips are the only feasible option (Lee *et al.*, 2019; Tomobi *et al.*, 2024). This method lacks precision, requires manual adjustment, and is prone to error, especially in pediatrics, where low body mass and narrow therapeutic margins mean small deviations can cause rapid deterioration (Lee *et al.*, 2019; Tomobi *et al.*, 2024).

Infusion pumps cost USD 1,200–4,000 and require stable electricity and maintenance, making them impractical for many field hospitals (Tomobi *et al.*, 2024). Staff therefore rely on manual drop counting, adjusting a roller clamp and timing drops per minute to estimate flow (Tomobi *et al.*, 2024). This approach provides no feedback, and changes in bag height or patient position can cause large errors. Under-infusion delays shock reversal; over-infusion can trigger pulmonary edema or heart failure (NICE, 2020; Shah *et al.*, 2015; Tomobi *et al.*, 2024).

Children are disproportionately affected. In MSF projects, over 60% of patients are under 15 years old, many with dehydration, severe malnutrition, or sepsis ("Child Health | MSF Medical Activities", 2023). In these cases, precise fluid administration is both critical and challenging.

Lower-cost devices such as manual flow regulators and battery-powered drop counters exist, but remain too expensive, closed-source, or insufficiently robust for humanitarian deployment (Losonczy *et al.*, n.d.; Tomobi *et al.*, 2024). No current solution combines low cost, pediatric dosing precision, ruggedness, and repairability. A frugal, user-friendly IV drip monitor could fill this gap, freeing nurses from continuous manual monitoring and preventing life threatening deviations in flow rate.

1.3 Research Questions, Objectives, and Scope

This work aims to design and preliminarily evaluate a low-cost, battery-powered optical IV drip monitor tailored for pediatric use in humanitarian settings, with emphasis on accuracy, autonomy, affordability, and basic usability under field-relevant constraints.

Research questions

- **RQ1 (Measurement accuracy):** What flow-rate estimation accuracy can an optical drop counter achieve across clinically relevant pediatric drip rates under benchtop conditions when calibrated using a simple per-infusion drop-size estimate?

- **RQ2 (Energy autonomy):** What is the expected battery life (in days) of a single-AA design with continuous use?
- **RQ3 (Affordability & manufacturability):** What is the approximate unit cost of the *Drip-ito* prototype, and is it feasible for large-scale deployment in humanitarian and pediatric care contexts?
- **RQ4 (Usability & acceptability):** Based on semi-structured interviews with frontline clinicians, which usability and safety requirements are essential for a stand-alone drip monitor, and how do these requirements influence the hardware and firmware design?

The scope of this thesis encompasses the engineering design of the prototype device, including hardware architecture and basic embedded software, as well as benchtop validation of its flow-rate measurement accuracy. The intended use case is monitoring gravity-driven IV infusions by counting drops and calculating flow rates. The device does not actively regulate or pump fluid; it is conceived as an add-on monitor for existing gravity IV setups, not as a replacement for electronic infusion pumps.

The following are outside the scope of this thesis:

- Clinical trials or in-situ evaluation in humanitarian hospitals.
- Environmental stress testing beyond standard laboratory conditions (e.g., extreme temperature, humidity, or dust exposure).
- Detailed manufacturing scale-up plans or regulatory approval processes.

The primary target group is pediatric patients, particularly infants and children under 15 years of age, who are most vulnerable to dosing inaccuracies. Nevertheless, the device can also be used for adult patients without modification. The outcome of this work is a functional prototype and associated performance data, providing a foundation for further refinement and eventual deployment.

1.4 Existing Alternatives

A range of commercial IV monitors exist, from integrated infusion pumps to portable clip-on sensors, but most face constraints in humanitarian or pediatric contexts, including high cost, proprietary lock-in, and power dependence. Open-source and academic prototypes address some of these gaps, notably the DripOMeter, but often trade integration and autonomy for simplicity. Full descriptions and comparative tables are provided in Appendix F.

1.4.1 Expert Interview: Related Work from 1Fusion

A semi-structured interview with **Jonas Gartmann**, co-founder of Zürich-based *1Fusion*, provided lessons from their 2022–2024 development of a hybrid IV monitor combining thermal micro-flow sensing and optical drop counting. Their clinically validated prototype was not commercialised due to market competition from integrated pumps, but the discussion highlighted environmental stressors, optical robustness, safety and regulatory considerations, and power optimisation. These insights informed *Dripito's* focus on resilient optical sensing and ultra-low-power operation. Full details are given in Appendix E.

2 METHODS

This chapter details the design and validation methodology for *Dripito*. It describes the research logic, engineering development path, experimental procedures, and reproducibility measures taken.

2.1 Study Design and Rationale

The engineering process integrated design, prototyping, and empirical testing. Requirements were defined through a needs assessment and literature review on IV therapy in low-resource settings, pediatric fluid management, and existing monitoring technologies. These informed performance targets, including accuracy and alarm thresholds, as well as cost and power constraints.

An agile, iteration-driven workflow was used: an Arduino-based proof-of-concept validated the sensing principle and firmware logic. Insights informed a lean Rev-A custom Printed Circuit Board (PCB) with integrated power management and an enclosure optimised for field usability.

Bench validation consisted of controlled drip scenarios using standard IV bags and tubing. Flow parameters such as drip rate, bag height, and tubing diameter were varied. Outputs (drops/min, total mL) were compared against manual and gravimetric references.

Alarm behaviours (no-flow and off-target rate) were spot-checked by transiently occluding the line and by fully opening the roller clamp.

To incorporate field relevance, the final prototype was demonstrated to three domain experts in short, semi-structured interviews. Feedback on usability, alarm clarity, and maintenance burden was thematically coded and used for the last design refinement sprint.

2.1.1 Prototype Evolution

Development followed a staged prototyping approach to de-risk core functions before committing to a custom PCB. An initial breadboard build using an Arduino Nano, discrete Infrared (IR) Light Emitting Diode (LED)/photodiode pair, and off-the-shelf buzzer/Liquid-crystal dis-

play (LCD) validated the basic beam-break sensing principle and firmware logic under bench conditions. The circuit was then transferred to a soldered perfboard assembly to reduce wiring capacitance, improve mechanical stability, and permit extended runtime tests. These early iterations informed component selection, pin assignments, and enclosure constraints, directly guiding the schematic and layout of PCB Rev A.

A custom Rev A printed circuit board (PCB) was designed integrating all key functional blocks; STM32G030C8T6 microcontroller, TPS610981 boost converter, BPV10NF photodiode with LMV331 comparator front end, VSLY5940 IR emitter, EA DOGS164 LCD, piezo buzzer, and tactile buttons. Full PCB schematics and layout images are provided in Appendix G. The mechanical enclosure was designed in CAD to clip onto standard IV drip chambers, 3D printed in PETG with M2 brass heat inserts for durability (Appendix H).

2.1.2 Hardware Architecture

The Dripito prototype integrates all sensing, processing, and user-interface functions into a compact clip-on enclosure (Figure 2.1). Its hardware is organised into three functional groups:

- **Power Supply:** Converts energy from a single AA cell into a regulated 3.3 V rail for all electronics.
- **Drop Sensor:** An optical module that detects individual fluid drops as they pass through the drip chamber.
- **User Interface:** An LCD, buttons, and buzzer for real-time feedback and alarms.

A low-power STM32G030 microcontroller coordinates all three groups, handling sensing, data processing, and interface control. This architecture enables tight integration, portability, and multi-week operation from a single battery.

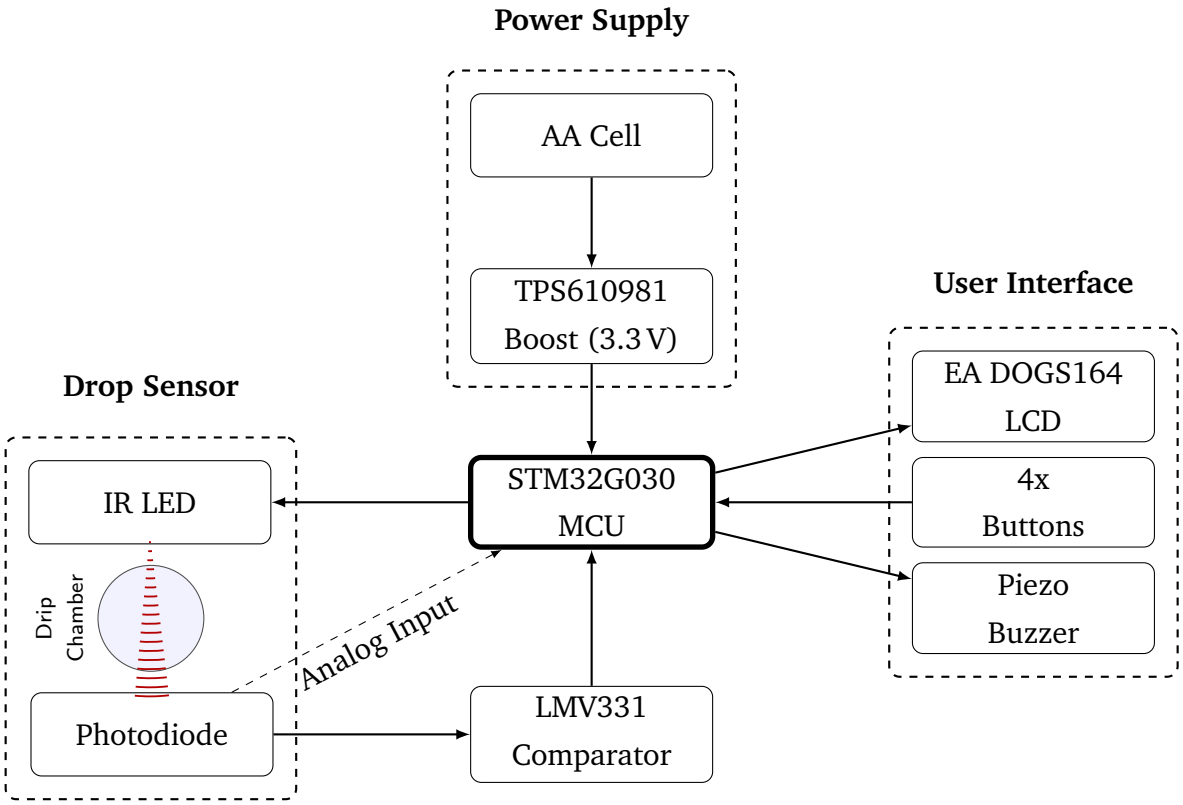

Figure 2.1. Block diagram of the Dripito prototype, showing the power supply, sensing, processing, and user interface components. The IR beam from the LED to the photodiode crosses the drip chamber.

Power supply. Dripito operates from a single 2000 mA h AA alkaline cell. A low-loss P-channel MOSFET provides reverse-polarity protection. A TPS610981 boost converter regulates to 3.3 V for the MCU, IR sensor, and LCD, with raw battery voltage sampled via the STM32G030 Analog-to-Digital Converter (ADC) for low-battery alerts. Detailed schematic and PCB layout for this subsystem are provided in Appendix G.

Optical drop-sensor front end. A Vishay VSLY5940 IR LED ($\lambda_p = 940\,\text{nm}$) opposes a Vishay BPV10NF PIN photodiode. Reverse photocurrent through $R_{16} = 2.7\,\text{k}\Omega$ holds V_{PD} near 2.53 V under illumination; drops cause $\Delta V \approx 0.50\,\text{V}$. An LMV331 comparator compares V_{PD} to $V_{\text{REF}} \approx 1.65\,\text{V}$ (set by $R_{18} = R_{19} = 47\,\text{k}\Omega$) with 70 mV hysteresis via $R_{14} = 1\,\text{M}\Omega$. Schematic, PCB layout, and design notes for this circuit are in Appendix G, while full oscilloscope validation results are given in Appendix A.

Two drive modes are supported: (i) continuous LED, yielding high-Signal-to-Noise Ratio (SNR) pulses, and (ii) pulse-saving (150 μs at 8% duty) with synchronised sampling. 100 pF capacitors C_{15} and C_{16} provide $\tau \approx 1\,\mu\text{s}$ bandwidth shaping.

Photodiode oscilloscope validation. A breadboard experiment characterised the BPV10NF photodiode node under continuous IR illumination to finalise the analogue front end. A bias resistor sweep (2.0–4.7 kΩ) was tested using a Keysight MSOX-3024T oscilloscope at 22 °C under typical indoor lighting. Measured droplet "shadow" pulses ranged from 0.36 V to 0.78 V peak-to-peak with 2.6–2.9 ms rise times. Based on swing amplitude, noise, and headroom, $R_B = 2.7\,\mathrm{k}\Omega$ was selected, paired with an AC-coupling network ($4.7\,\mu\mathrm{F} \parallel 100\,\mathrm{nF}$) and 70 mV comparator hysteresis. Full methodology, raw data, and interpretation are presented in Appendix A.

Display module. An EA DOGS164-A LCD (SSD1803A controller) provides a 4×16 character display at 440 µA typical current, chosen for low power, compact form, and Serial Peripheral Interface (SPI). Interface circuitry and PCB layout for this module are shown in Appendix G.

2.1.3 Enclosure Design and 3D Printing

Material. Polyethylene Terephthalate Glycol (PETG) was selected for its impact strength, creep resistance, and chemical compatibility with disinfectants.

Design requirements. The enclosure aligns the optical emitter and detector across drip chambers ranging from 13 mm to 18 mm in diameter. It houses the electronics and battery within a 105 mm×38 mm×55 mm form factor, withstands repeated disinfection, and enables tool-less battery replacement.

Architecture. The front shell integrates the LCD window and button caps; the rear shell holds the switch, buzzer grille, programming port, and battery bay. Brass heat-set inserts (M2) provide fastening. A geared clamp, adapted from the open-source *Gravity Broom Holder* design by user LoboCNC on Printables.com (Printables user LoboCNC, 2022), centres and secures the drip chamber. The clamp geometry was resized and modified in CAD to fit standard IV drip-chamber diameters.

2.1.4 PCB layout and bring-up

The PCB is a two-layer FR-4 board manufactured and partially assembled by JLCPCB. Bring-up steps were: (i) solder TPS610981 boost converter and LMV331 comparator; (ii) solder buzzer bleed resistor, EA DOGS164 LCD, tactile switches, and AA battery holder; (iii) wire the IR LED and photodiode; (iv) verify 3.3 V regulation at VMAIN; (v) flash the MCU; (vi) confirm comparator interrupts and drop counting on live drips.

2.1.5 Firmware Summary

Firmware was implemented in C using STM32CubeIDE v1.18.1 and STM32CubeMX v6.14.1 (commit hash `87a9d11`; see repository link in Appendix J). Only essential peripherals were enabled to minimise code size and power consumption: ADC1, SPI1, TIM1 PWM channels, EXTI, and GPIO inputs for user buttons. The complete pin mapping and IOC configuration are given in Appendix J.2.

Comparator interrupts are processed to calculate drip rate and cumulative volume, triggering audio/visual alarms for no-flow, off-target rate, and end-of-bag conditions. LED drive mode and sampling windows are configurable. Validation occurred during integrated device tests with real drip flows.

The firmware samples the photodiode at ≈1 kHz, applies a fixed voltage threshold to detect drop events, and computes instantaneous and smoothed flow rates. Flow rate and total volume are derived from drop intervals using a nominal pediatric drip factor of 20 gtt/mL. Full source code listings and algorithm details are provided in Appendix J.3.

2.2 Materials and Instruments

- Standard IV bag/tubing with roller clamp (100 mL/h setpoint).
- Ringer Acetate (density 1.004 g/mL at 22 °C).
- Commercial precision balance, tared before runs; no external calibration weights were used.
- Mobile stopwatch application.
- CLA laboratory, 22 °C, fluorescent lighting.

2.3 Experimental Setup

The device was clipped concentrically around the drip chamber. The balance was placed under a tared beaker. The roller clamp was adjusted to 100 mL/h. Runs lasted 10 minutes (gravimetric) or 15 minutes (manual counting). Counts were recorded from the LCD and manually. For the gravimetric run, mass gain was read from the balance display at the end of the interval.

Two benchtop validation methods were used: (i) manual counting of drops with a stopwatch over a fixed period, and (ii) gravimetric measurement of fluid mass loss over time using a

precision balance. Tests used Ringer Acetate fluid at room temperature with a B. Braun Exadrop gravity set. Environmental conditions and complete raw results are reported in Appendix B.

2.4 Ethics

As the study involved interviews with identifiable healthcare professionals, prior permission and informed consent were obtained from all participants. The interview protocol was reviewed and approved by the ETH Zurich ethics committee (Approval No. 25 ETHICS-211). No patient data were collected. Further information, including the approval notice and interview guide, is provided in Appendix K.

2.5 Procedures by Research Question

2.5.1 RQ1: Accuracy

Two benchtop runs were performed:

1. **Manual reference (15 min):** Drops counted in parallel by mechanical tally and device (continuous LED mode).

2. **Gravimetric reference (10 min):** Mass gain converted to volume; mean drop volume calculated; compared to firmware constant.

These two benchtop runs were planned as proof-of-principle checks typical of early engineering validation; formal precision estimates and repeatability testing are left to future work.

2.5.2 RQ2: Power consumption and expected runtime

Battery life was estimated analytically from datasheet current draws, nominal AA-cell capacity, and boost-converter efficiency, without full depletion testing. Two modes were modelled: continuous LED drive and duty-cycled LED with MCU stop mode. Equations, assumptions, and sensitivity analysis are given in Appendix C.

2.5.3 RQ3: Cost Feasibility

Data sources. Component prices were taken from the cleaned Bill of materials (BOM) exported from the PCB design database (Rev A) and cross-checked against supplier quotations

obtained in August 2025. Where available, high-volume pricing tiers ($\geq$ 1,000 units) were used. All prices are expressed in Swiss francs (CHF).

The full BOM and per-device cost breakdown are presented in Appendix D.

Calculation procedure.

1. **BOM preparation:** The cleaned BOM included all components populated in Rev A, plus intended Do-not-populate (DNP) components (IR LED, photodiode) to reflect the intended final build.

2. **Electronics cost:** For each BOM line item, low-volume prices were replaced with the lowest available high-volume prices from Mouser, Digi-Key, or LCSC.

3. **PCB fabrication and assembly:** Unit cost for a two-layer FR-4 PCB with partial assembly was taken from a *JLCPCB* quotation at 1,000 units.

4. **Enclosure cost:** PETG mass was measured at 28 g. Material cost was calculated at CHF 35.80/kg giving an estimated total of $\approx$ CHF 1 per unit. Machine time cost was not included in this calculation.

5. **Other mechanical parts:** Brass inserts, screws, clamp hardware, and battery holders were priced from high-volume AliExpress listings.

Assumptions and exclusions. Assembly labour, shipping, and regulatory certification costs were excluded. The analysis reflects a single procurement batch of 1000 units as a plausible pilot scale; alternate volumes and local manufacturing feasibility were not evaluated.

2.5.4 RQ4: Expert Evaluation and Field Relevance

User needs were explored via semi-structured interviews with senior pediatric nurses and an emergency physician affiliated with the WHO EMT Initiative. Ethical approval was obtained from the ETH Zurich Ethics Commission (Ref. 25 ETHICS-211). The full interview guide and anonymised summaries are provided in Appendix K.

Participants. Three domain experts participated: an emergency physician affiliated with the WHO Emergency Medical Teams (EMT) Initiative, a senior pediatric nurse with over 25 years of IV therapy and anesthesiology experience, and a senior pediatric nurse and home-care specialist with over 30 years of clinical practice.

Procedure. Semi-structured interviews lasting 20–40 minutes were conducted either in person or via video call. Each interview followed the same thematic framework, covering perceived clinical need, usability, alarm behavior, maintenance requirements, and potential deployment scenarios in both high- and low-resource settings. Participants were encouraged to provide unstructured feedback beyond the guiding questions.

Data analysis. Notes taken during each session were thematically coded to identify recurring strengths, limitations, and design recommendations. Feedback was synthesized to highlight points of consensus and divergence across participants.

2.6 Reproducibility

All firmware, mechanical CAD, and PCB design files are openly available at https://github.com/Global-Health-Engineering/iv-flow-monitor. Appendices include schematics and detailed test descriptions sufficient for reproduction.

3 Results and Discussion

The following sections present the results according to the study's four research questions: device accuracy, power performance, cost feasibility, and usability. For each, we first present the experimental data, followed by an interpretation in the context of prior work and the intended use case in humanitarian pediatric care.

3.1 Research Questions

The final assembled Dripito prototype used in all benchtop evaluations is shown in Appendix I (Figure I.1).

3.1.1 RQ1 – Device accuracy

Research question: What flow-rate estimation accuracy can an optical drop counter achieve across clinically relevant pediatric drip rates under benchtop conditions when calibrated using a simple per-infusion drop-size estimate?

Two controlled bench-top tests assessed drop-counting and flow-rate accuracy. In Test 1 (manual reference), Dripito recorded 1,429 drops vs. 1,430 counted manually over 15 minutes, a relative error of –0.07%. In Test 2 (gravimetric reference), all 154 drops were detected, but flow rate was underestimated by ∼10% due to the nominal drop volume assumption (0.050 mL) differing from the measured 0.055 mL. This bias is inherent to drop-based monitors and underscores the need for calibration to actual drop size.

Both trials demonstrated sub-percent drop-counting error under stable lab conditions and showed Dripito's ability to flag gross miscalibrations in dial-set flow. Detailed gravimetric methodology and full results are provided in Appendix B.

3.1.2 RQ2 – Power Consumption and Expected Battery Life

Research question: What is the expected battery life (in days) of a single-AA design with continuous use?

Direct current measurement with a handheld digital multimeter proved impractical: the meter's burden voltage in current mode inserted significant series resistance, lowering the supply input voltage enough to interrupt the boost converter. This altered device behaviour and produced unrealistic readings. Instead, supply current was estimated from component datasheets and confirmed with oscilloscope measurements at the LED and 3.3 V rail.

Two operating scenarios were analysed in detail (see Appendix C.1 for full assumptions and calculations): *Assumptions:* Usable cell energy was modelled at 3000 mW h (alkaline AA, typical at moderate drain), with sensitivity bounds at 2704 mW h and 3049 mW h. Boost converter efficiency of 0.93 was applied at the corresponding load (cf. TPS610981 datasheet efficiency curves for 3.3 V output at low/medium load (Texas Instruments, 2021)).

Estimated runtimes for continuous and duty-cycled operation are summarised in Table 3.1.

Table 3.1. Estimated power consumption and runtime for two operating modes using a 3000 mW h alkaline AA cell.

Mode	**Avg. current (3.3 V)**	**Est. runtime**
Continuous LED (worst case)	19.5 mA	36–40 h (1.5–1.7 days)
Duty-cycled LED + Stop mode	1.57 mA	18.6–21.0 days

The low-power mode uses 150 µs LED pulses every 1.80 ms (8.3% duty cycle), with the microcontroller unit (MCU) in Stop 1 between pulses. These timings match the validated drop-detection window and preserve signal-to-noise ratio at the comparator front-end.

3.1.3 RQ3 – Cost Feasibility

Research question: What is the approximate unit cost of the Dripito prototype, and is it feasible for large-scale deployment in humanitarian and pediatric care contexts?

To reflect realistic procurement for pilot deployments, all prices were calculated on a **1000-unit basis** using supplier bulk rates where available. At this scale, the bill of materials totals CHF 9.17 per device (Aug. 2025), excluding assembly labour, in-circuit test fixtures, enclosure finishing, packaging, certification, and quality assurance overheads. The LCD (CHF 3.54) and enclosure including printing (CHF 1.72) are the main cost drivers, followed by the microcontroller (CHF 0.65) and optical components (CHF 0.85). The complete component breakdown is given in Appendix D.

This cost structure leaves headroom to remain below CHF 10 per unit after adding reasonable non-BOM overheads. Even with additional expenses for assembly and compliance, the projected pricing supports feasibility for large-scale deployment in humanitarian and pediatric care contexts.

3.1.4 RQ4 – Expert Evaluation and Field Relevance

Research question: Based on semi-structured interviews with frontline clinicians, which usability and safety requirements are essential for a stand-alone drip monitor, and how do these requirements influence the hardware and firmware design?

Three semi-structured interviews with senior clinicians and humanitarian health experts confirmed that IV flow misadministration remains a significant problem where infusion pumps are unavailable. Experts valued Dripito's compactness, low cost, and portability, identifying clear use cases in humanitarian deployments, home therapy, patient transfers, and pediatric sedation. Key requirements included intuitive single-handed operation, mechanical robustness, hygiene compatibility, and rapid, clear alarms. Alarm tone revision was advised to avoid confusion with critical-care signals. Power supply preferences diverged: some favored AA cells for simplicity, others preferred rechargeable or solar options. These findings validate the device's clinical relevance and core design rationale while highlighting refinements, particularly alarm design, durability, and power strategy, for future iterations. Full interview summaries are provided in Appendix K.3.

3.2 Benchmarking against existing solutions

Dripito's benchtop performance was compared to two representative alternatives: the commercial *DripAssist* ("DripAssist - Shift Labs, Inc. - PDF Catalogs | Technical Documentation", n.d.) and the open-source *DripOMeter* (Venkatesh *et al.*, 2022). Both adopt passive optical drop counting, making flow accuracy dependent on actual drop volume. Compared to DripAssist, Dripito offers similar counting precision while being fully open-source, significantly lower in cost (BOM $<$ CHF 10 vs. $\sim$ \$300–\$400 retail), and able to surface gross set or dial errors. Compared to DripOMeter, Dripito maintains comparable accuracy with tighter integration and multi-week AA-cell autonomy. Detailed benchmarking is provided in Appendix K.4, and a summary comparison is presented in Table 3.2.

Table 3.2. Summary comparison of Dripito with DripAssist and DripOMeter.

Criterion	**DripAssist**	**DripOMeter**	**Dripito**
Sensing principle	IR drop counter	IR drop counter	IR drop counter
Openness	Closed	Full HW+FW open	Full HW+FW open
Power source	1 × AA battery	Rechargeable Li-ion	1 × AA battery
Autonomy focus	360 h	Few days	Multi-week
Display/UI	Custom LCD	0.96 in OLED	Off-the-shelf LCD
Cost class	∼ $300–$400	BOM < $60	BOM < $10
Counting accuracy	Clinical use, varies	∼ ±1%	Sub-percent, more testing required

Where *DripAssist* reports higher autonomy under clinical conditions, this likely reflects a more conservative duty cycle and lack of data on low-temperature discharge curves; in contrast, *Dripito's* projected autonomy is derived from transparent modeling and open validation, allowing reproducibility.

3.3 Limitations and Sources of Error

Acknowledging limitations is essential for setting realistic expectations for deployment. Transparent reporting also clarifies where further work is required to support safe clinical use.

Environmental and operational factors not replicated in tests. Tests were performed on a benchtop in a vibration-free, controlled-light environment. Field conditions introduce patient movement, variable ambient illumination, shock and vibration from bed adjustments.

Methodological constraints. The study comprised a small number of accuracy tests with short durations and a limited range of flow rates. Three different IV sets were evaluated, but only a single fluid type (Ringer Acetate) was used. The benchtop setup did not include nursing workflows, device repositioning, or prolonged operation, which are required to assess robustness and usability in practice.

Potential sources of measurement error. Gravimetric reference measurements may have been affected by scale resolution limits, evaporation losses, and the possibility that the scale had not been recently calibrated. Manual reference counts are prone to lapses at high drop rates. The use of a nominal drop factor instead of a measured drop volume led to systematic bias (see Sec. 3.1.1 for detailed analysis). Of these limitations, the greatest impact on generalizability arises from the small number of test runs and lack of environmental stress testing, as these directly constrain confidence in real-world performance. Potential measurement errors (scale calibration, manual counting) are comparatively minor and unlikely to alter the main conclusions.

4 Conclusions and Recommendations

4.1 Synthesis

This thesis developed and bench-validated Dripito, an open, low-cost optical IV drip monitor for humanitarian and pediatric care, where gravity sets remain standard and nurse supervision is limited. The design integrates robust optical sensing, low-power embedded electronics, and a compact clip-on form factor, validated in controlled benchtop trials and costed for 1 000-unit procurement. Every engineering choice, including the optical emitter–receiver pairing, ultra-low-power boost regulation, single-cell supply, and simplified interface, was mapped to field realities of intermittent power, high workload, and the need for reproducibility.

4.2 Key Findings

RQ1 – Accuracy. Dripito achieved drop-for-drop detection under controlled benchtop conditions with sub-percent counting error. In Test 1, the device differed from a manual reference by one drop over 1 430 counted (−0.07 % error). In Test 2, gravimetric validation confirmed zero missed drops but revealed a 10 % flow-rate underestimation due to using a nominal drop factor rather than the measured drop volume. The device also flagged a 95 % overstatement on the worn dial of the Exadrop set, demonstrating a potential secondary role as a quality-control tool. This meets the design aim of $< 1\,\%$ missed events in stable, ideal conditions, while highlighting the universal drop-size limitation of gravity-fed systems.

RQ2 – Power performance. Duty-cycled LED drive combined with MCU Stop 1 mode extended estimated runtime by over an order of magnitude compared to continuous operation. Direct in-series digital multimeter measurement was impractical due to regulator start-up and burden-voltage effects, so current draw was estimated from component data and confirmed with oscilloscope traces (full calculation in Appendix C.1). A continuous-LED worst-case draw of 19.5 mA yields 36–40 h runtime from a 3000 mW h alkaline AA cell,

whereas an 8.3 % duty-cycled 150 µs LED pulse train at 1.57 mA average extends this to 18.6–21.0 days. This satisfies the multi-day autonomy target and indicates that > 430 h is theoretically achievable with further optimisation.

RQ3 – Cost feasibility. At a 1000-unit procurement level, the bill of materials totals CHF 9.17 per device, excluding labour, packaging, and compliance. This cost positions Dripito well below commercial alternatives and within reach of NGO and ward budgets. This meets the affordability threshold for large-scale humanitarian deployment.

RQ4 – Usability and field relevance. Experts from humanitarian medicine and pediatric nursing endorsed Dripito's compactness, low cost, and portability as addressing a clear gap where infusion pumps are unavailable or impractical. High-priority refinements include re-tuning the startup alarm tone, improving mechanical robustness, preventing accidental activation, and ensuring intuitive single-handed operation. Divergent views emerged on power supply preference, with some favouring AA cells and others recommending rechargeable or solar options. This validates the core design as clinically relevant and suitable for targeted pilot deployment, contingent on addressing identified refinements.

4.3 Validation and Next Steps

The primary goal of this project was to produce a fully functional prototype that could be rigorously characterised under controlled benchtop conditions. Achieving this milestone established a reproducible baseline for accuracy, autonomy, and cost, enabling all core engineering decisions to be tested in an integrated system.

While these results are promising, they reflect performance in stable, idealised environments. Verification under real-world variability—across different IV sets, environmental conditions, and patient profiles—remains essential before large-scale deployment. Planned pilot studies will extend evaluation to field contexts, capturing factors such as handling by diverse user groups, long-duration operation, and exposure to environmental stressors. These data will guide iterative refinement of hardware and firmware to ensure a robust, intuitive, and safe final design for humanitarian and pediatric use.

4.4 Recommendations

The following recommendations, derived from the conclusions in Chapter 4, outline targeted follow-up work and potential starting points for subsequent thesis projects. Each specifies the addressed problem, proposed approach, and intended outcome.

4.4.1 Technical Improvements

- **PCB Rev-B Redesign (RQ1, RQ2).** *Problem:* Current PCB layout issues (absent MISO routing, unnecessary via stitching under the battery holder, suboptimal LED/photodiode placement) limit manufacturability and compactness. *Approach:* Add a bleed resistor to the buzzer, route the DOGS display MISO line to the MCU, remove redundant via stitching, and reposition optical components to enable a slimmer profile. *Outcome:* Slimmer, mechanically balanced PCB with improved assembly reliability and electrical robustness.

- **Battery Placement Optimisation (RQ4).** *Problem:* Current battery position increases bulk and shifts weight toward the drip chamber. *Approach:* Relocate the battery holder to the opposite side and adjust PCB form factor. *Outcome:* Improved balance for single-handed operation and potential reduction in enclosure thickness.

- **Power Optimisation (RQ2).** *Problem:* Current low-power strategy meets multi-day autonomy but not the upper bound projected in modelling. *Approach:* Implement pulse-save LED drive, add an external comparator to wake the MCU only on drop events, and optimise Stop mode usage. *Outcome:* Verified runtime exceeding 360 h from a single AA cell under typical duty cycles.

- **User Interface and Alarm System (RQ4).** *Problem:* Startup alarm tone is similar to some critical-care alerts, and current alarm logic lacks severity grading. *Approach:* Simplify UI interactions and implement a multi-tier alarm system with distinct tones and visual cues for no-flow, off-target rate, and end-of-bag events. *Outcome:* Faster user training, reduced false responses, and improved suitability for pediatric and humanitarian settings.

4.4.2 Field Validation

- **Pediatric Ward Pilot with Micro-Drip Sets (RQ1, RQ4).** *Problem:* Validation is currently limited to benchtop tests. *Approach:* Conduct ward-based pilot studies with micro-drip sets, recording setup time, drop sensitivity, false alarm rate, and occlusion detection time, using gravimetric spot checks as reference. *Outcome:* Real-world evidence of accuracy, robustness, and user acceptance under typical ward conditions.

- **Comparative Field Benchmarking (RQ1).** *Problem:* No direct field comparison exists with commercial drop counters. *Approach:* Deploy Dripito alongside a commercial drop counter and manual gravity set in patient care or simulated field environments. *Outcome:* Comparative dataset to guide regulatory positioning and NGO procurement strategy.

4.4.3 Manufacturing and Scaling

- **Enclosure Redesign for Mass Production (RQ3).** *Problem:* The current 3D-printed, screw–heat insert design is time-consuming to assemble and not optimised for high-volume manufacture. *Approach:* Replace screw–insert fastening with snap-fit shells; evaluate transition to injection moulding, including tooling cost and polymer selection. *Outcome:* Faster assembly, lower per-unit cost at scale, and greater durability in field use.
- **Custom LCD Development (RQ3).** *Problem:* The off-the-shelf LCD is a major cost driver and limits mechanical integration. *Approach:* Commission a custom LCD tailored to the device's electrical and mechanical needs; benchmark cost against current retail module at projected batch sizes. *Outcome:* Reduced BOM cost, smaller footprint, and improved UI integration.

4.5 Closing Statement

Dripito shows that accurate, low-cost IV monitoring within the constraints of humanitarian and pediatric care is possible. Its open design and bill of materials under CHF 10 provide a strong foundation for further development. However, substantial work remains to validate its performance under diverse real-world conditions and to refine it for consistent, safe use in the field. With continued testing, iteration, and collaboration, this approach has the potential to improve access to safer IV therapy where conventional solutions are unavailable.

Acronyms

ADC Analog-to-Digital Converter. 7

BOM Bill of materials. 10, 14

DNP Do-not-populate. 11

DRC Democratic Republic of the Congo. 63

ICU intensive care unit. 1

IR Infrared. 5, 7, 36

IV Intravenous. iii, ix, 1–6, 8, 9, 11, 15–17, 20, 35, 37–39, 52, 59, 61, 63

LCD Liquid-crystal display. 5, 7–9, 14, 20

LED Light Emitting Diode. xiii, 5, 7, 14, 17–19

MCU microcontroller unit. 14

MSF Médecins Sans Frontières. 1, 2

PCB Printed Circuit Board. 5, 10

PETG Polyethylene Terephthalate Glycol. 8

SNR Signal-to-Noise Ratio. 7

SPI Serial Peripheral Interface. 8

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A Photodiode Oscilloscope Test Report

Test Report — Photodiode IR Drop-Detector Breadboard

Date: 23 May 2025
Location: DFA
Temperature: 22 °C
Lighting: Overhead LED panels

1 Objective

Validate a reverse-biased photodiode stage and choose bias resistor, AC-coupling constant, and comparator hysteresis for reliable detection of IV-drip "shadow" pulses. Data informed the frozen analogue front-end values for PCB Rev A.

2 Set-up

- **Photodiode:** Vishay BPV10NF, capacitance 11 pF typ.
- **LED drive:** 100 Ω series resistor, 18.8 mA forward current (constant for all runs).
- **Supply:** 3.3 V bench supply ($< 10\,\mathrm{mV_{pp}}$ ripple).
- **Oscilloscope:** Keysight MSOX-3024T, 5 ms/div, 500 mV/div, 1 MSa/s, 1 Mpts.
- **Environment:** 22 °C, overhead LED panels; phone charger nearby introduced ≈ 5 mV bursts (EMI).
- **Data files:** 9 waveform CSV for $R_B = 2.0, 2.7, 3.3, 4.7\,\mathrm{k\Omega}$ (three trials each) plus ambient-light references (`bright_R2700`, `dark_R2700`).

3 Raw Observations

Table A.1. Oscilloscope Readings.

R_B (Ω)	$V_{baseline}$ (V)	V_{peak} (V)	ΔV_{pp} (mV)	Rise 10–90% (ms)
2000	2.76	3.12	360	2.8
2700	2.53	2.96	500	2.9
3300	2.40	3.04	640	2.6
4700	2.38	3.16	780	2.8

Ambient-light references (R = 2.7 kΩ): dark ≈140 mV_{pp}, bright ≈160 mV_{pp} (FFT peaks at 50 Hz and 150 kHz).

4 Interpretation & Design Decisions

- **Bias resistor:** Smallest R with $\Delta V \geq 0.40\,V \rightarrow 2.7\,k\Omega$ (E24).
- **Photocurrent:** $(3.30 - 2.53)\,V / 2.7\,k\Omega \approx 285\,\mu A$.
- **AC coupling:** $\tau \approx 15$ ms (≈ 5 × 2.9 ms rise); 4.7 µF X5R (0805) ‖ 100 nF (0603).
- **Comparator threshold:** 47 kΩ/47 kΩ divider to 1.65 V; 70 mV hysteresis via 1 MΩ.
- **Comparator:** LM393 (SOIC-8) open-collector.
- **EMI mitigation:** LED/photodiode trace pair ≤ 30 mm, tight differential routing; optional 10 Ω bead/ferrite.

5 Conclusion

$R_B = 2.7\,k\Omega$ selected for PCB Rev A; supports ≥ 0.5 V droplet swing with ample headroom and low noise.

B Dripito Accuracy Validation

B.1 Objective

The purpose of these experiments was to validate the Dripito prototype's drop-counting and flow-rate accuracy under controlled laboratory conditions, using both manual counting and gravimetric measurement as independent references. The tests aimed to quantify counting error, assess flow-rate bias, and identify potential sources of systematic deviation in preparation for field and clinical evaluation.

B.2 Set-up

All tests were conducted indoors at the CLA laboratory (22 ℃, overhead LED lighting) using Ringer Acetate at room temperature. The infusion set in both tests was a B. Braun Exadrop gravity set of unknown nominal drop factor, previously used in multiple trials. Two reference methods were applied:

1. **Manual counting** of visible drops over a 15-minute period.
2. **Gravimetric measurement** of total mass lost over a 10-minute period, converted to volume using the fluid density.

The Dripito device used in both tests was the Rev. A PCB design with BPV10NF photodiode, STM32G030 MCU, and standard firmware configuration. The flow-dial was set to 100 mL/h in all runs.

B.3 Test 1: Manual Count Reference

Method

Drops passing through the drip chamber were counted manually by an observer with a stopwatch, while Dripito logged drop events internally.

Raw Observations

- Test duration: 15 min
- Manual drop count: 1,430
- Dripito drop count: 1,429
- Absolute error: 1 drop
- Relative error: –0.07%

Conclusions

Dripito's count differed by one drop from the manual reference, confirming sub-percent counting accuracy under stable laboratory conditions.

B.4 Test 2: Gravimetric Reference

Method

A precision balance (readability: 0.001 g) measured mass loss during a 10-minute infusion. Density of Ringer Acetate was assumed $\rho = 1.004$ g/mL. Drop volume was calculated from the measured volume and total detected drops.

Raw Observations

- Mass lost: 8.550 g
- Volume lost: 8.516 mL
- Drops detected (Dripito): 154
- Calculated drop volume: 0.0553 mL/drop (≈18 gtt/mL)
- Dripito-reported average flow: 46.0 mL/h
- True flow rate: 51.1 mL/h
- Flow-rate error: –10%
- Flow dial overstatement: +96%
- Missed drops: 0

Conclusions

No drops were missed, but the use of a nominal drop factor (0.050 mL) introduced a ∼10% underestimation in flow rate. This bias is set- and fluid-specific and can be reduced via per-infusion calibration. The extreme dial overstatement illustrates Dripito's potential as a quality-control tool for infusion sets.

B.5 General Remarks

Both tests confirm that Dripito can achieve sub-percent drop-counting accuracy under ideal conditions. Flow-rate accuracy depends on matching the assumed drop factor to actual drop size, which varies with set type, fluid, and conditions. These findings reinforce the importance of calibration and motivate further testing under field conditions.

C Power Consumption Modeling

C.1 Assumptions and Source Parameters

- **Cell:** VARTA Longlife Power AA, IEC LR6, alkaline Zn–MnO_2.
- **Datasheet capacities:** Typical 2960 mA h at high-resistance load; representative delivered energy 2704 mW h to 3049 mW h under moderate and higher drains (Type 4906 datasheet, 2016-05-30).
- **Nominal energy for calculations:** $E_{\text{batt}} = 3000\,\text{mW h}$, with sensitivity evaluated at 2704 mW h and 3049 mW h.
- **Boost converter efficiency:** $\eta = 0.93$ at 3.3 V, 50 mA load.
- **Test conditions:** Ambient temperature 25 °C; fresh cell at 1.5 V.

C.2 Continuous LED Mode

The supply current and expected runtime are estimated using:

$$I_{\text{LED}} = \frac{V_{\text{rail}} - V_{F,\text{IR}}}{R_{\text{LED}}}, \quad I_{\text{load}} = I_{\text{LED}} + I_{\text{MCU}}, \quad I_{\text{batt}} = \frac{I_{\text{load}}\, V_{\text{rail}}}{V_{\text{batt}}\, \eta}, \quad t = \frac{E_{\text{batt}}}{I_{\text{batt}}\, V_{\text{batt}}}. \tag{C.1}$$

Where:

- $V_{\text{rail}} = 3.3\,\text{V}$ (regulated supply voltage)
- $V_{F,\text{IR}} = 1.9\,\text{V}$ (IR LED forward voltage)
- $R_{\text{LED}} = 100\,\Omega$ (LED series resistor)
- $I_{\text{MCU}} = 1.5\,\text{mA}$ (MCU active current)
- $V_{\text{batt}} = 1.5\,\text{V}$ (fresh alkaline cell)

From these:

$$I_{\text{load}} \approx 19.5\,\text{mA}, \quad I_{\text{batt}} \approx 50.4\,\text{mA}, \quad P_{\text{batt}} = I_{\text{batt}} V_{\text{batt}} \approx 75.6\,\text{mW}.$$

Runtime estimates:

$$t \approx 39.7\,\text{h} \quad \text{at } E_{\text{batt}} = 3000\,\text{mW h},$$

with sensitivity:

$$t \approx 35.8\,\text{h}\ (2704\,\text{mW h}), \quad t \approx 40.3\,\text{h}\ (3049\,\text{mW h}).$$

C.3 Duty-Cycled LED with MCU Stop Mode

With LED pulsed and MCU in stop mode between pulses:

$$D = \frac{t_{\text{pulse}}}{T}, \quad \bar{I}_{\text{LED}} = D\, I_{\text{LED}}, \quad I_{\text{load}} = \bar{I}_{\text{LED}} + I_{\text{MCU,STOP}}. \tag{C.2}$$

Where:

- $t_{\text{pulse}} = 150\,\mu\text{s}$ (LED on-time per cycle)
- $T = 1.80\,\text{ms}$ (pulse period)
- $I_{\text{LED}} = 18\,\text{mA}$ (LED current during pulse)
- $I_{\text{MCU,STOP}} = 65\,\mu\text{A}$ (MCU stop-mode current)

From these:

$$D = 0.083, \quad I_{\text{load}} \approx 1.565\,\text{mA}, \quad I_{\text{batt}} \approx 4.04\,\text{mA}, \quad P_{\text{batt}} \approx 6.06\,\text{mW}.$$

Runtime estimates:

$$t \approx 495\,\text{h}\ (\approx 20.6\,\text{days}),$$

with sensitivity:

$$t \approx 446\,\text{h}\ (18.6\,\text{days}), \quad t \approx 503\,\text{h}\ (21.0\,\text{days}).$$

Note. The runtime range reflects load dependence reported in the VARTA datasheet. Field performance will also vary with temperature, manufacturing tolerances, and component variation.

D Costing Details

D.1 Bill of Materials - 1000 Units

Table D.1. Bill of materials priced at 1000 units. Prices per device in CHF (Aug. 2025). Values rounded to two decimals; totals computed from precise prices then rounded.

Component	Qty	Unit (CHF)	Line total (CHF)
EA DOGS164W-A LCD	1	3.54	3.54
STM32G030C8T6 microcontroller	1	0.65	0.65
TPS610982DSET boost converter	1	0.55	0.55
IR LED VSLY5940	1	0.50	0.50
Photodiode BPV10NF	1	0.35	0.35
ABS07 32.768 kHz crystal	1	0.32	0.32
MPL2016S4R7MHT inductor	1	0.02	0.02
LMV331 comparator	1	0.08	0.08
SI2302 MOSFET	2	0.01	0.02
AO3401A MOSFET	1	0.10	0.10
SK12D07VG5 switch	1	0.01	0.01
1TS005F-2500-5001 button	4	0.02	0.08
SFN-1407PA7.6 buzzer	1	0.03	0.03
PZ254V-11-05P connector	1	0.01	0.01
BK-92 battery holder	2	0.22	0.44
Resistors and capacitors (all values)	set	0.33	0.33
PCB fabrication (1000 pcs)	1	0.25	0.25
PETG enclosure material (20 g)	1	0.72	0.72
3D printing (1 h; electricity and wear)	1	1.00	1.00
M2 heat inserts	4	0.05	0.20
M2 screws	4	0.02	0.08
AA alkaline cell	1	0.20	0.20
Total per device			**9.17**

E Expert Interview: Insights from 1Fusion

E.1 Context

In the beginning of the Dripito project, a semi-structured interview was conducted with **Jonas Gartmann**, co-founder of Zürich-based start-up *1Fusion*. From 2022 to 2024, 1Fusion developed a stand-alone IV flow-rate monitor using a hybrid sensing concept:

1. A thermal calorimetric micro-flow sensor for continuous measurement.

2. An opto-electronic drop counter for redundancy.

The prototype achieved clinical-grade accuracy in extended trials at *Triemli Hospital* but was not commercialised due to competition from integrated peristaltic and syringe pumps that had already secured procurement contracts in target markets.

E.2 Key Insights

1. **Physiological variance and environmental stressors** — Flow accuracy was strongly affected by:

   - *Back-pressure* from patient venous pressure.
   - *Head-height changes* altering gravitational pressure.
   - *Atypical drop sizes* in formulations with surfactants that reduce surface tension.

   These effects were mitigated by combining accelerometer data (to measure set orientation and height changes) with optical drop detection, enabling real-time compensation for pressure and height fluctuations.

2. **Optical robustness** — Direct sunlight could saturate the IR photodiode and trigger false alarms. Optical shielding reduced this but increased bulk, while opaque housings blocked visual drip-chamber inspection. Balancing stray-light rejection with clinical visibility remained a key design challenge.

3. **Safety and regulatory pathway** — Compliance with IEC 60601-2-24 required safeguards such as automatic system reset and backup power capacitors. Achieving *CE marking* was estimated at two years. Even in humanitarian contexts, early alignment with recognised safety standards was considered essential.

4. **Energy autonomy and manufacturability** — Ultra-low-power microcontrollers and modular firmware allowing selective hibernation of high-draw subsystems were highlighted as critical for extending battery life.

E.3 Relevance to Dripito

These observations reinforced the need for:

- An optical sensing stage resilient to ambient-light interference while preserving visibility of the drip chamber.
- Ultra-low-power electronics enabling multi-week autonomy from a single AA cell.

F Existing Alternatives

F.1 Commercial Devices

Commercial IV monitoring technologies range from fully integrated infusion pumps to small clip-on optical sensors. While effective in the environments for which they were designed, most face limitations in humanitarian or pediatric contexts where infrastructure, budgets, and staffing differ substantially from high-income hospital norms.

Volumetric infusion pumps, such as the **Hospira Plum A+** series, deliver fluid with high precision, support programmable dosing, and integrate with drug libraries, but require stable mains power, regular maintenance, and trained operators — factors often unavailable in low-resource wards.

Simpler optical drop-counting modules avoid pumps entirely. The **B. Braun Drop Sensor** (B. Braun, n.d.) clips onto compatible drip chambers and counts drops via the host pump, but is single-use (USD 190) and proprietary to B. Braun sets. Such sensors can also reduce visual access to the drip chamber, removing a manual redundancy.

Portable, battery-powered monitors aim to bridge these gaps. The **ShiftLabs DripAssist** runs on a single AA cell and measures drip rate and volume (Tomobi *et al.*, 2024), but its USD 300–400 retail price and closed design limit accessibility. The **Evelabs Dripo** links via Bluetooth to a phone app, introducing dependencies on device availability, connectivity, and charging — unreliable in many humanitarian settings.

Recurring constraints across these categories include high lifecycle cost, reliance on proprietary consumables or interfaces, dependence on mains power or fragile charging, and lack of open-source designs.

Table F.1. Representative commercial IV monitoring devices and key characteristics.

Device	**Price (USD)**	**Power Source**	**Limitations in Target Context**
Hospira Plum A+	1,200–4,000	Mains	Requires stable electricity, maintenance, trained staff
B. Braun Drop Sensor	∼190	Powered via host pump	Proprietary to B. Braun sets
ShiftLabs DripAssist	300–400	1×AA battery	Cost; closed-source
Evelabs Dripo	∼150–200	Rechargeable	Requires smartphone/app; connectivity/charging dependent

F.2 Open-source and Academic Prototypes

Open-source and academic projects aim for affordability, adaptability, and transparency, avoiding proprietary lock-in.

DripOMeter (Venkatesh *et al.*, 2022) uses IR drop counting with pulsed illumination, delivering ±1% accuracy at a BOM < $60. Limitations include modular board design (increasing size, cost, and quiescent draw), short autonomy (few days on AA cells), tall mechanical stack, cabled sensing head, and limited ambient light shielding. This thesis adopts its sensing principle but addresses these constraints through integrated electronics, low power, and compact design.

Other examples include:

- **Low-Cost Digitisation** (Hossain *et al.*, 2019) — Arduino Uno with IR sensor, keypad, LCD, and Wi-Fi link; very low cost (< $15) but reliant on continuous connectivity.

- **IoT IV Control** (Arfan *et al.*, 2020) — ESP32 with servo-actuated flow control and remote interface; offers high control resolution but limited autonomy (one day) and higher mechanical complexity.

- **Accuflow** (Shroff *et al.*, 2007) — clinically tested reusable optical drop monitor with alarms; accuracy matched manual counting, but evaluation was short-term and not in very young infants.

Table F.2. Representative open-source and academic IV monitoring prototypes.

Device / Study	Sensing Method	Control	Connectivity	Openness	Validation
DripOMeter (Venkatesh *et al.*, 2022)	IR drop counter	No	None	Full HW+FW open	Bench
Low-Cost Digitisation (Hossain *et al.*, 2019)	IR drop counter	No	Wi-Fi (ESP8266)	Partial	Bench
IoT IV Control (Arfan *et al.*, 2020)	IR + PID actuator	Yes	Wi-Fi/BLE	Not open	Bench
Accuflow (Shroff *et al.*, 2007)	IR drop counter	No	None	Not open	Clinical (n=47)

F.3 Synthesis

These systems illustrate trade-offs between integration, autonomy, cost, and maintainability. Designs adding active regulation or remote features tend to increase complexity and reduce off-grid runtime. The present work prioritises passive optical monitoring with low power and tight integration, aligning with humanitarian pediatric needs.

G HARDWARE SCHEMATICS AND PCB

G.1 PCB Layout Images

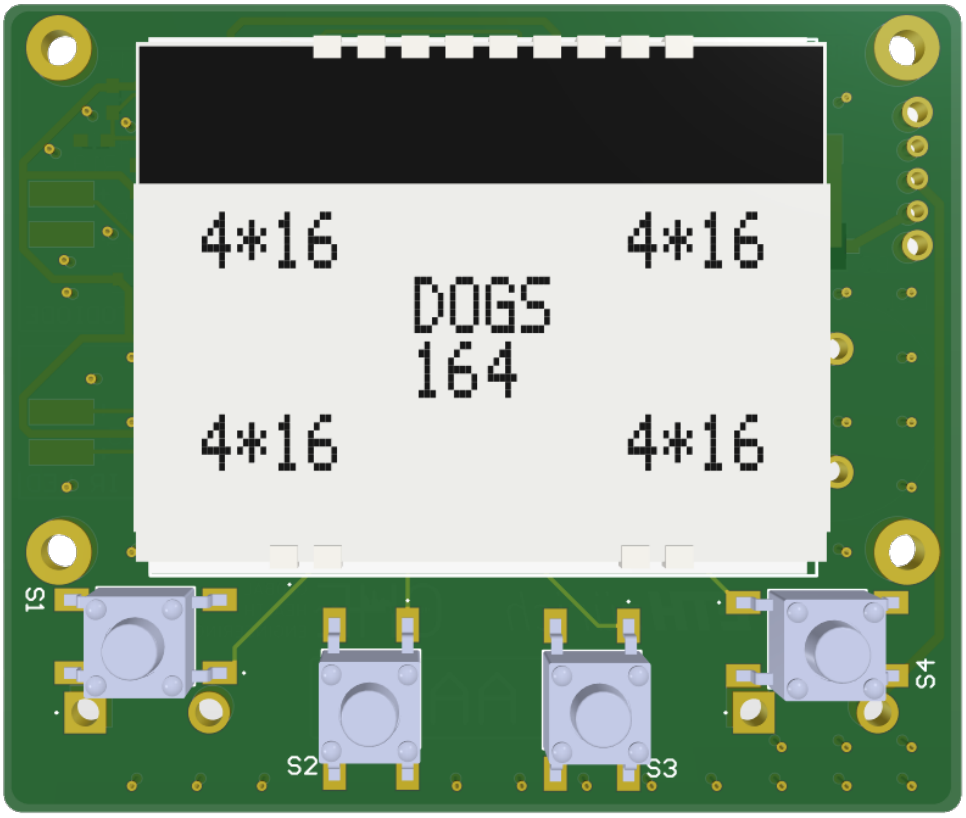


Figure G.1. PCB layout, front side (Rev A).

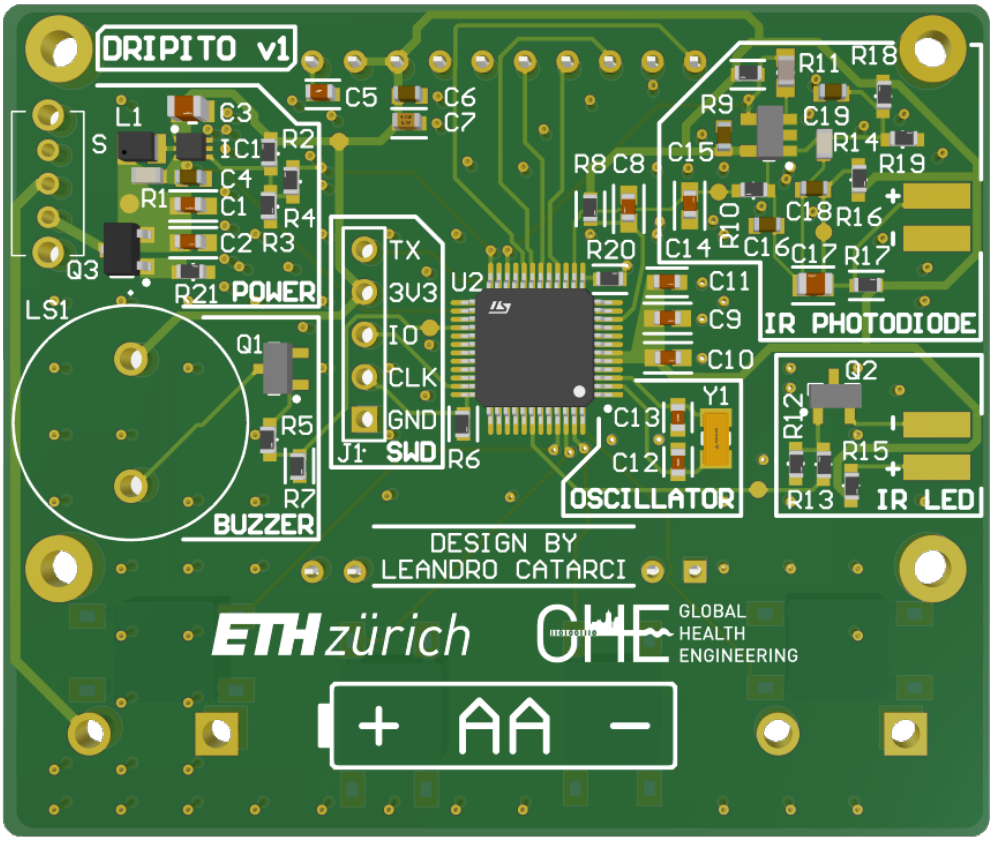
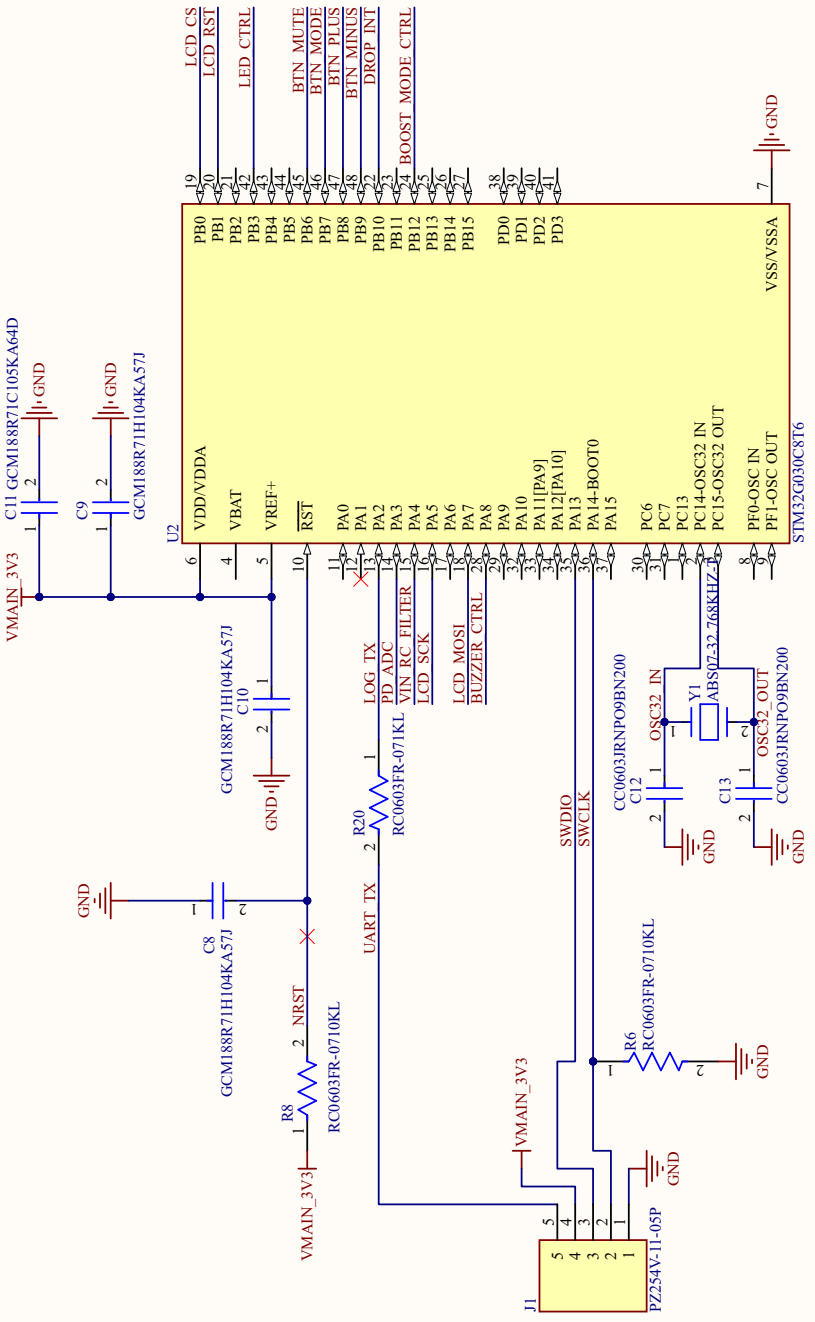


Figure G.2. PCB layout, back side (Rev A).

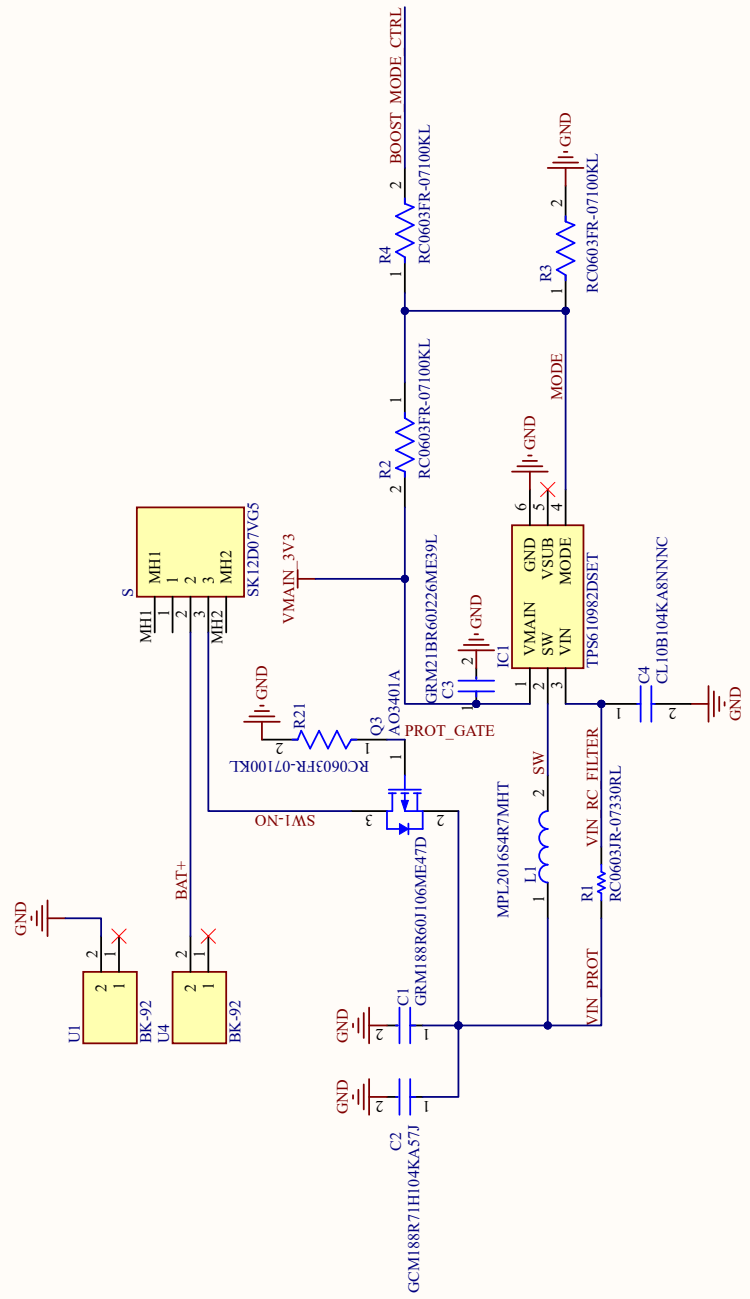
G.2 Schematic and Layout Diagrams

The following pages include the Rev A schematic sheets.

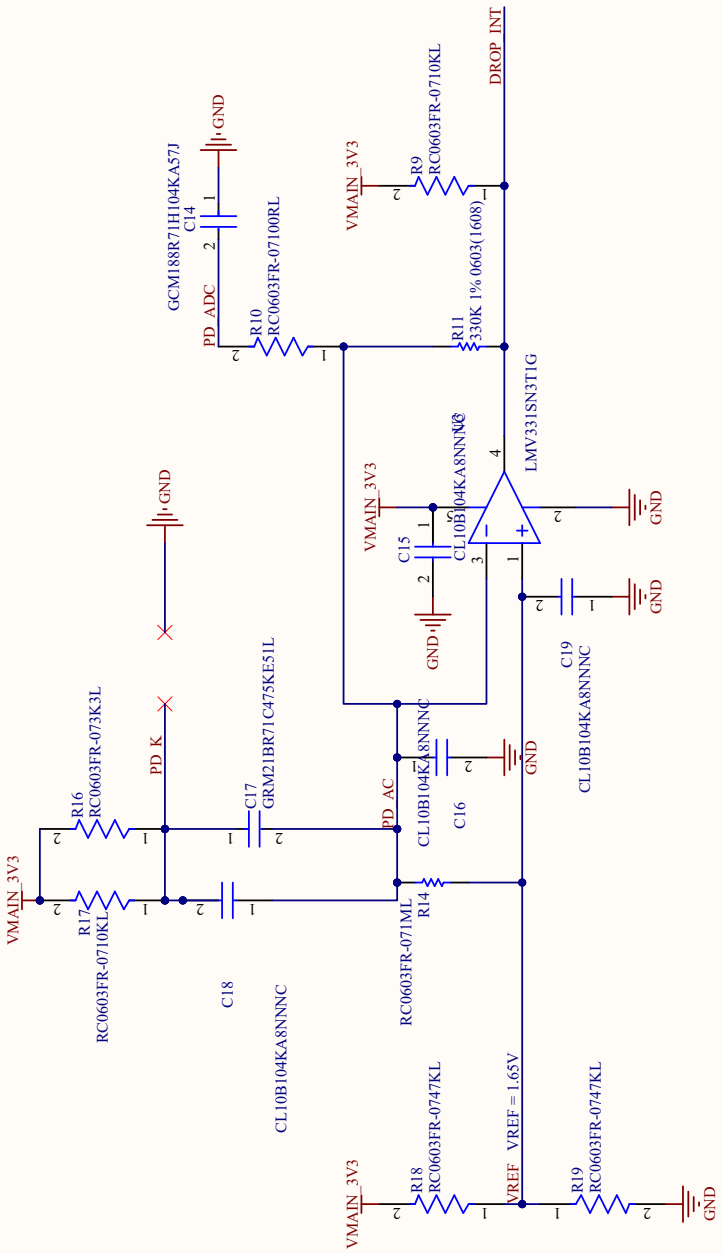
Schematic - Microcontroller and UART Logging



Schematic - Power Supply and Boost Converter

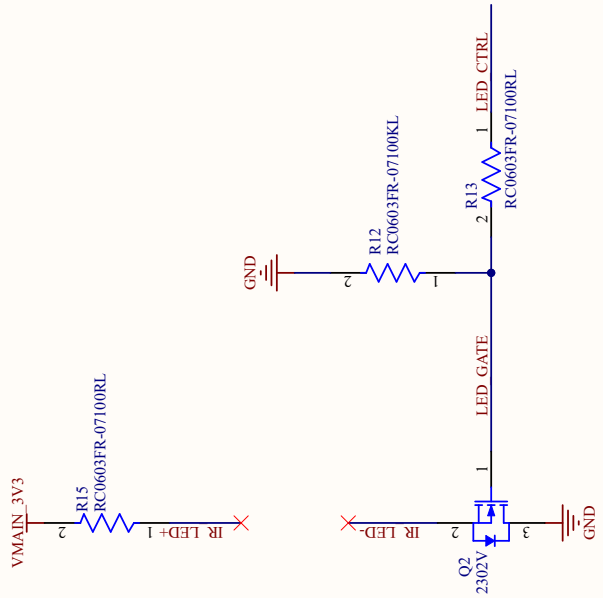


Schematic - Drop Sensor Front End

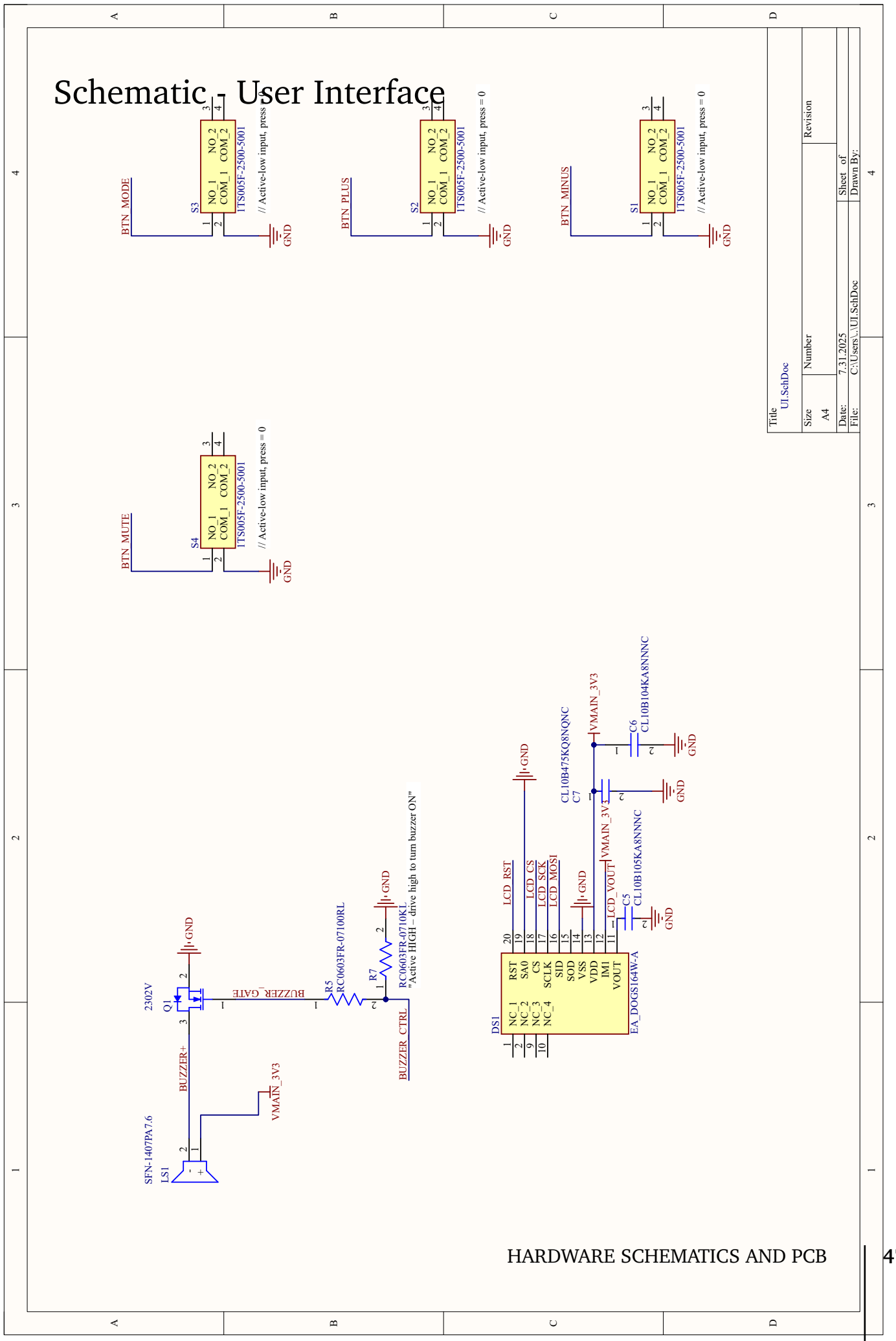


Title: IR_Sensor.SchDoc
Size: A4
Number:
Revision:
Date: 7.31.2025
Sheet of
File: C:\Users\...\IR_Sensor.SchDoc
Drawn By:

Schematic - IR Emitter Driver



Title	IR_Emitter.SchDoc		
Size	Number		Revision
A4			
Date:	7.31.2025	Sheet of	
File:	C:\Users\...\IR_Emitter.SchDoc	Drawn By:	


Schematic - User Interface
BTN_MODE
S3
1TS005F-2500-5001
// Active-low input, press
GND
BTN_PLUS
S2
// Active-low input, press = 0
BTN_MINUS
S1
BTN_MUTE
S4
Title
UI.SchDoc
Size
A4
Number
Revision
Date: 7.31.2025
Sheet of
File: C:\Users\...\UI.SchDoc
Drawn By:
SFN-1407PA7.6
LS1
BUZZER+
VMAIN_3V3
2302V
Q1
BUZZER_GATE
R5
RC0603FR-07100RL
R7
RC0603FR-0710KL
"Active HIGH – drive high to turn buzzer ON"
BUZZER_CTRL
DS1
EA_DOGS164W-A
LCD_RST
LCD_CS
LCD_SCK
LCD_MOSI
LCD_VOUT
CL10B475KQ8NQNC
C7
C6
CL10B104KA8NNNC
C5
CL10B105KA8NNNC

H Enclosure CAD and Fabrication

H.1 Design and Print Illustrations

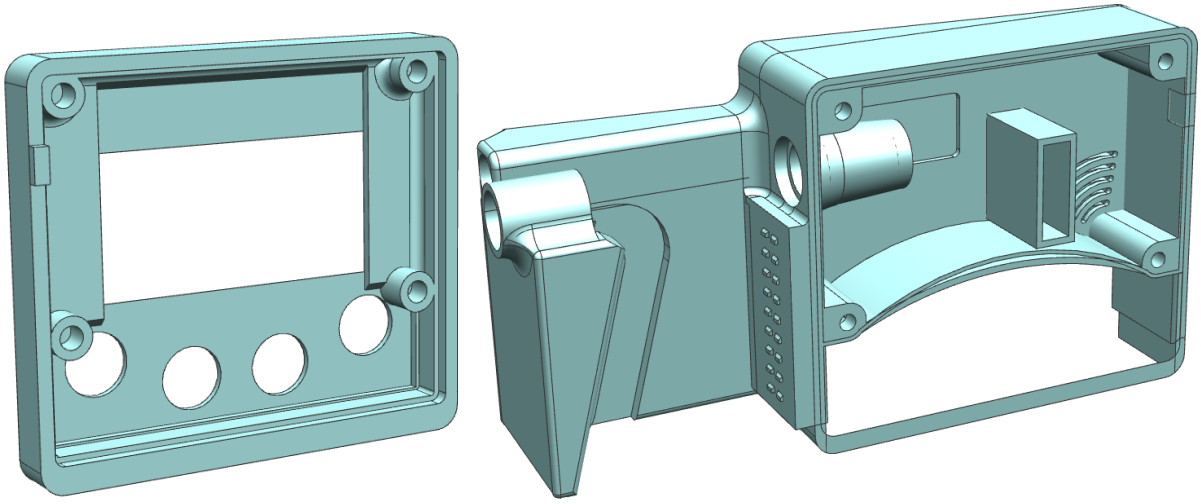


Figure H.1. Front (left) and back (right) shells of the enclosure showing mounting posts for M2 brass inserts and component cut-outs.

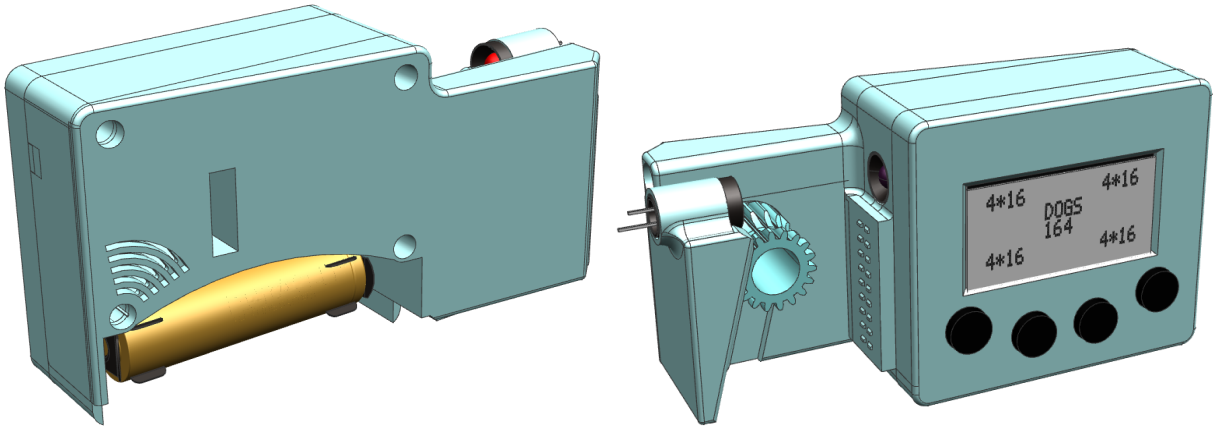


Figure H.2. Two CAD perspectives of the fully assembled device, highlighting sensor arm, LCD interface, and clip geometry.

I Prototype Photograph

Figure I.1. Final assembled Dripito prototype clipped to a standard IV drip chamber during benchtop testing. The LCD displays real-time flow rate, target rate, infused volume, and drop count.

J Firmware and Algorithms

J.1 Version and Build

Repository: https://github.com/Global-Health-Engineering/iv-flow-monitor
Commit hash for this thesis: `87a9d11`
IDE: `STM32CubeIDE 1.18.1)`

J.2 Pin Mapping and IOC Configuration

Figure J.1 shows the STM32CubeMX `.ioc` pinout configuration for the STM32G030C8T6 microcontroller used in Dripito. The configuration was created in STM32CubeMX v6.14.1 and imported into STM32CubeIDE v1.18.1 (commit `87a9d11`). Only required peripherals were enabled to reduce code size and power consumption.

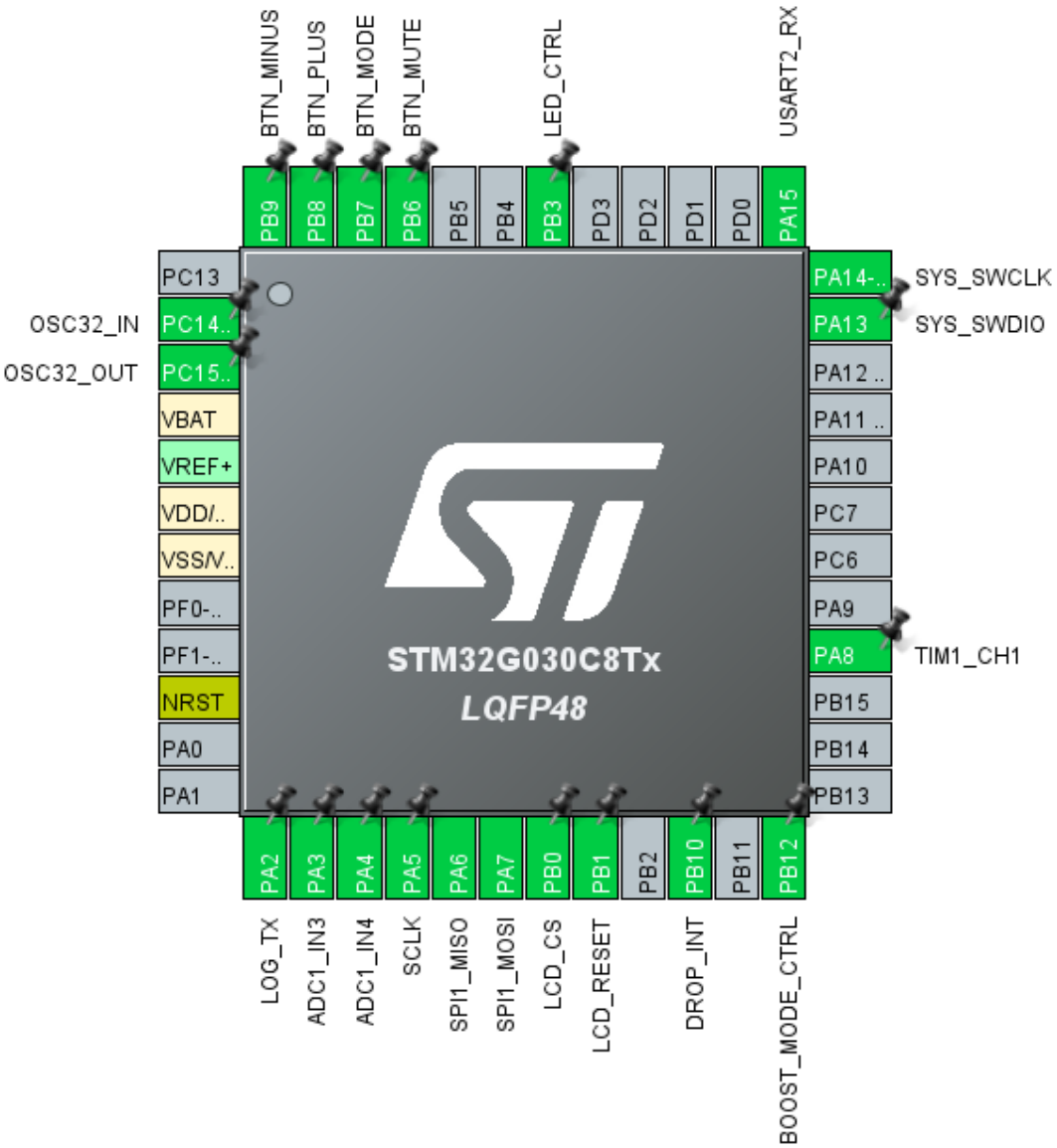


Figure J.1. STM32CubeMX IOC configuration for the STM32G030C8T6 microcontroller.

Function Assignment

PC13 `BTN_MINUS` — decrease flow rate.

PB8 `BTN_PLUS` — increase flow rate.

PB7 `BTN_MODE` — cycle display modes.

PB6 `BTN_MUTE` — mute alarms.

PB3 `LED_CTRL` — PWM for IR emitter (TIM1_CH2).

PA2 `LOG_TX` — UART2 TX for debugging.

PA3 ADC1_IN3 — photodiode signal (PD_ADC).

PA4 ADC1_IN4 — auxiliary analogue channel.

PA5 SPI1_SCK — LCD clock.

PA7 SPI1_MOSI — LCD data.

PB0 LCD_CS — LCD chip select.

PB1 LCD_RESET — LCD hardware reset.

PB10 DROP_INT — EXTI from drop sensor comparator.

PB12 BOOST_MODE_CTRL — TPS610981 mode pin.

PA8 TIM1_CH1 — reserved for buzzer PWM.

PA13/PA14 SYS_SWDIO/SYS_SWCLK — programming/debug.

Key IOC Parameters

Relevant MicroXplorer settings are summarised here; the full '.ioc' file is included in the project repository.

ADC1

- Channels: IN3 (PA3) and IN4 (PA4)
- Sampling time: ADC_SAMPLINGTIME_COMMON_1
- Conversions: 1 (rank 1)

SPI1 (LCD Interface)

- Mode: Master, 2-line
- Prescaler: 128 ($\approx$ 500 kbit/s)
- Polarity: High, Phase: 2nd edge

TIM1

- CH1 (PA8): PWM for buzzer
- CH2 (PB3): PWM for IR LED
- Prescaler: 63, Period: 31 (for short LED pulses)

USART2

- TX only (PA2), Async mode
- Overrun disable, DMA disable on RX error

GPIO

- Buttons: PB6, PB7, PB8, PB9 — input with pull-up
- Outputs: PB0, PB1, PB3, PB12 — default high where applicable

Clock

- SYSCLK: 64 MHz from PLL (HSI16 source)
- LSE enabled on PC14/PC15 for RTC

J.3 Drop Detection Algorithm

The firmware implements drop detection by sampling the photodiode output at ≈1 kHz, looking for voltage spikes above a defined threshold, and computing flow rate and volume from the detected events.

Core Drop Detection Code

```
// Global state
#define DRIP_FACTOR_GTT_PER_ML   20      // 20 gtt = 1 mL
#define FLOW_AVG_WINDOW           5

volatile uint32_t drop_count           = 0;  // total drops detected
volatile uint32_t last_drop_ms         = 0;  // timestamp of previous drop
volatile uint32_t dt_ms                = 0;  // time between last two drops
```

```
volatile float    inst_flow_mlh        = 0.0f;   // instantaneous mL/h
volatile float    flow_window[FLOW_AVG_WINDOW] = {0};
volatile uint8_t  flow_idx             = 0;      // circular buffer index
volatile float    flow_mlh             = 0.0f;   // moving-average mL/h
volatile float    total_volume_ml      = 0.0f;   // accumulated volume

void Monitor_ADC_Drop_Spikes(void)
{
    const float   spike_threshold_mV    = 1700.0f;   // trigger level
    static float  previous_voltage_mv   = 0.0f;      // last reading
    const uint32_t sampling_interval_ms = 1;         // ~1 kHz sampling

    // --- acquire sensor voltage ---
    uint32_t vdda_mv = Read_VDDA_mV();              // supply reference
    ADC_ChannelConfTypeDef adcConfig = {0};
    adcConfig.Channel      = ADC_CHANNEL_3;         // photodiode on PA3
    adcConfig.Rank         = ADC_REGULAR_RANK_1;
    adcConfig.SamplingTime = ADC_SAMPLINGTIME_COMMON_1;
    HAL_ADC_ConfigChannel(&hadc1, &adcConfig);

    HAL_ADC_Start(&hadc1);
    HAL_ADC_PollForConversion(&hadc1, HAL_MAX_DELAY);
    uint32_t adc_raw = HAL_ADC_GetValue(&hadc1);
    HAL_ADC_Stop(&hadc1);

    float voltage_mv = ((float)adc_raw * vdda_mv) / 4095.0f;

    // --- spike detection ---
    if ((voltage_mv > spike_threshold_mV) && (previous_voltage_mv <= spike_thres
    {
        uint32_t now = HAL_GetTick();               // ms since boot

        if (drop_count > 0)                         // skip dt on first drop
        {
            dt_ms        = now - last_drop_ms;
            inst_flow_mlh = (3600.0f * 1000.0f) /
                            ((float)dt_ms * DRIP_FACTOR_GTT_PER_ML);
```

```
            flow_mlh      = MovingAvg_Add(inst_flow_mlh);  // smooth rate
        }
        last_drop_ms  = now;
        drop_count++;
        total_volume_ml = (float)drop_count / DRIP_FACTOR_GTT_PER_ML;

        // single-line log
        uint32_t elapsed_ms = now;
        uint32_t elapsed_s  = elapsed_ms / 1000;
        printf("DROP %lu | deltat: %lums | Rate: %.0f mL/h | Total: %.2f mL | Time
               drop_count, dt_ms, inst_flow_mlh, total_volume_ml,
               elapsed_s / 60, elapsed_s % 60);
    }

    // optional display update
    char flow_str[17];
    snprintf(flow_str, sizeof(flow_str), "Rate: %4.0f mL/h", inst_flow_mlh);

    previous_voltage_mv = voltage_mv;              // prepare for next sample
    HAL_Delay(sampling_interval_ms);               // 1 ms loop delay
}
```

Flow Rate Calculation Code

```
#define DRIP_FACTOR_GTT_PER_ML   20
#define FLOW_AVG_WINDOW          5

volatile uint32_t dt_ms                = 0;
volatile float    inst_flow_mlh        = 0.0f;
volatile float    flow_window[FLOW_AVG_WINDOW] = {0};
volatile uint8_t  flow_idx             = 0;
volatile float    flow_mlh             = 0.0f;

static float MovingAvg_Add(float new_val)
{
    flow_window[flow_idx] = new_val;
    flow_idx = (flow_idx + 1) % FLOW_AVG_WINDOW;
```

```
    float sum = 0.0f;
    for (uint8_t i = 0; i < FLOW_AVG_WINDOW; ++i) sum += flow_window[i];
    return sum / FLOW_AVG_WINDOW;
}
```

How It Works

Sampling the Photodiode. The photodiode's analogue output (PA3, ADC1_IN3) is read once per loop iteration. The supply voltage (`Read_VDDA_mV()`) is used to scale the 12-bit ADC reading to millivolts.

Spike Detection. A drop passing through the IR beam causes a transient increase in the photodiode voltage. When the reading rises above 1700 mV from below, the event is classified as a drop.

Timing and Flow Rate. The time between consecutive drops (`dt_ms`) is measured using `HAL_GetTick()`. Instantaneous flow rate is calculated as:

$$\text{flow (mL/h)} = \frac{3600 \times 1000}{\texttt{dt\_ms} \times \texttt{DRIP\_FACTOR\_GTT\_PER\_ML}}$$

For a pediatric IV set, the drip factor is 20 gtt/mL.

Smoothing. `MovingAvg_Add()` maintains a small circular buffer (`FLOW_AVG_WINDOW` entries) and returns the mean, producing a smoothed `flow_mlh` for display.

Volume Counting. Each detected drop increments `drop_count`; volume is computed as:

$$\texttt{total\_volume\_ml} = \frac{\texttt{drop\_count}}{\texttt{DRIP\_FACTOR\_GTT\_PER\_ML}}$$

Logging and Display. A formatted line with drop number, interval, instantaneous rate, total volume, and elapsed time is sent over UART; an optional LCD string is prepared for user feedback.

State Update. The measured voltage is stored for the next loop to prevent double-counting, and the loop delays 1 ms to maintain the ≈1 kHz sampling rate.

K Ethics and Interview Materials

K.1 Approval and Notices

ETH Zurich Ethics Commission reference number: *25 ETHICS-211*. Project title: *Development of a Pediatric IV Flow-Rate Monitor for Humanitarian Settings*. Approval date: 08 July 2025.

The Vice President for Research of ETH Zurich approved this proposal without reservations.

K.2 Interview Guide

This guide was used to conduct semi-structured interviews with pediatric healthcare professionals experienced in intravenous (IV) therapy. The aim was to identify needs, challenges, and preferences relevant to the user-centered design of the Dripito IV flow-rate monitor. The interview duration was approximately 30–45 minutes. Questions could be adapted or supplemented depending on the conversation flow.

I. Introduction

1. Please describe your professional background and experience with IV therapy in pediatric care.

2. In what contexts have you worked with IV infusions for children? (e.g., hospital, emergency care, humanitarian missions)

II. Work Routine and Challenges

3. What challenges do you encounter when monitoring infusions in children?

4. How often do infusions deviate from the intended flow (e.g., too fast, too slow, stopped)?

5. What typical error sources or risks have you observed?

6. How do you determine whether the drop flow is correct or disrupted?

III. Technical Support / Device Use

7. Do you currently use any technical aids to monitor drop flow? If yes: Which ones, and how useful are they?

8. What features would an ideal device have to support infusion monitoring?

9. What would be absolutely essential? And what would be nice-to-have but non-essential?

IV. Context Factors and Usability

11. What requirements would you have for such a device in low-resource settings (e.g., power supply, robustness, ease of use)?

12. How important is quick interpretation? (e.g., visual signal, sound, app connection)

13. How important are hygiene and ease of cleaning?

14. Are there specific requirements for pediatric use (e.g., non-threatening appearance, small size, quiet operation)?

V. Reaction to Prototype (Optional)

15. What is your first impression of this prototype?

16. Could you imagine using this device in your daily work?

17. What would you change or improve spontaneously?

VI. Closing

18. Are there any other thoughts, ideas, or concerns you would like to share?

19. Would you like to be informed about the results of this work?

K.3 Interview Summaries

Dr. Janis Tupesis, MD (WHO EMT Initiative)

To evaluate the field relevance and design direction of Dripito, a 20-minute interview was conducted with Dr. Janis Tupesis, an emergency physician affiliated with the WHO Emergency Medical Teams (EMT) Initiative. Dr. Tupesis confirmed that IV flow misadministration remains a serious concern in both humanitarian and low-resource clinical contexts. He emphasized that "in many remote health clinics, no IV infusion rate monitors are available, and nurses must still count drops over a set time interval by hand." introducing significant risk due to variation in training levels and fatigue. While supportive of the drop-based sensing approach, he advised that AA batteries may not be consistently available in conflict zones or remote settings, and suggested exploring solar-based or rechargeable alternatives in future iterations. Importantly, he broadened the expected impact of Dripito beyond emergency deployments, noting that the device may be particularly valuable in chronically underfunded health systems (e.g., in South Sudan or the Democratic Republic of the Congo (DRC)), where infusion pumps are rare and unreliable. This expert feedback affirms both the clinical need and the general design rationale, while also shaping the direction for future improvements.

P1 – Senior Pediatric Nurse (25+ Years Experience)

An in-depth semi-structured interview was conducted with a senior pediatric nurse (hereafter "P1") with over 25 years of experience in IV therapy and anesthesiology at a Swiss children's hospital. The participant is also involved in the training of medical professionals and has international field experience, namely two deployments to Mozambique for pediatric cardiac anesthesia support.

P1 confirmed that infusion pumps are standard in high-resource pediatric wards, but emphasized that reliance on manual drip-rate estimation persists in certain cases, particularly for older children, during transport between departments, or in resource-limited settings. The nurse described manual calculation of dosages and drip rates as time-consuming and error-prone. Especially in high-stress situations or where standard protocols are omitted, rapid uncontrolled infusion can occur.

P1 evaluated the Dripito prototype positively, noting its compactness, low cost, and potential use during internal patient transfers, in sedation procedures, or in humanitarian contexts where infusion pumps are unavailable. P1 stressed that any device replacing an infusion pump must be mechanically intuitive, universally compatible, single-handedly operable, and "fool-proof" meaning fail-safe and impossible to misconfigure. For continuous medication delivery (e.g. Ketamine, Propofol), visual on-screen feedback and real-time monitoring were essential for trust.

Additional requirements included quick alarm response, compatibility with hygiene protocols, and safe handling in pediatric settings, especially for neonates requiring very small volumes. Notably, the device's startup buzzer sound was flagged as acoustically similar to a resuscitation alarm and should be re-evaluated for clinical suitability.

P2 – Senior Pediatric Nurse and Home-Care Specialist (30+ Years Experience)
Another semi-structured interview was conducted with an experienced pediatric nurse (hereafter "P2") who has worked over 30 years in a major Swiss children's hospital and also spent eight years in pediatric and adult home-care therapy. The participant highlighted familiarity with a wide range of infusion devices, including both modern infusion pumps and more compact, improvised setups used in domestic care environments. P2 emphasized that while hospitals are well-equipped, she highlighted a need for smaller, streamlined monitoring solutions.

P2 identified simplicity, compactness, and robustness as key attributes for any monitoring device used in resource-limited settings. Unintentional activation should be prevented, especially in pediatric contexts, and controls must be clear and physical (e.g. tactile buttons rather than touchscreens). While P2 considered flow monitoring without direct control over the infusion rate acceptable, an integrated start-stop function and basic programmability (e.g. bolus followed by maintenance rate) were suggested as valuable features for future versions.

Regarding the prototype, P2 described the Dripito unit as small, compact, and handy, praising the design's clarity, portability, and self-supporting clip mechanism.. The participant could imagine clear use-cases for such a device in home therapy, or general practice clinics, where traditional infusion pumps may be impractical. The device's color, visibility, and general aesthetic were considered less important than user handling and reliability. Final advice focused on securing external elements like cables and ensuring mechanical durability.

In general, the interviews confirmed that Dripito addresses a clearly recognized gap in contexts without reliable infusion pumps, aligning both humanitarian and pediatric needs. All experts valued its compactness, low cost, and portability, while stressing refinements to ensure intuitive single-handed use, avoid alarm confusion, and enhance robustness. Divergent emphasis emerged around power supply: some favored AA batteries for simplicity, others preferred rechargeable or solar options. These findings validate the core concept while pinpointing high-priority improvements for the next design iteration.

K.4 Detailed Benchmarking Against Existing Solutions

To address the measurement accuracy and autonomy aspects outlined in RQ1 and RQ2, Dripito's benchtop results were interpreted in the context of two representative alternatives:

the commercial *DripAssist* (Tomobi *et al.*, 2024) and the open-source *DripOMeter* (Venkatesh *et al.*, 2022).

DripAssist. A single-AA, clip-on optical monitor that reports drip rate and cumulative volume. Robust but proprietary and relatively costly for humanitarian scale-up. Like Dripito, it infers flow from drop counts, making accuracy sensitive to drop volume. In our tests, this led to measurable bias despite sub-percent counting error. Per-infusion calibration or adaptive drop-size estimation would benefit any such monitor. Dripito also surfaced a severe dial overstatement (+95%), indicating a useful quality-control function.

DripOMeter. Open-source hardware and firmware with reported ±1% drip-sensing accuracy and a sub-$60 BOM. The reference build uses modular boards (Arduino Nano, 0.96 in OLED) with higher quiescent draw, yielding only a few days' AA-cell autonomy. Dripito achieves comparable or better accuracy under controlled conditions while prioritising integration and low-power operation for multi-week autonomy. A simple per-infusion calibration option reduces flow-rate bias from nominal drop factors.

Synthesis and limitations. All three devices adopt passive optical drop counting. Dripito trades DripAssist's proprietary robustness for openness, local repair, and basic quality-control functions, and advances beyond DripOMeter in integration and power management. Comparisons are preliminary; tests were in controlled lab settings. Head-to-head field studies and replication of DripOMeter's benchmarks under varied fluids, sets, lighting, and motion are recommended.

L Use of Large Language Models in Thesis Preparation

During the preparation of this thesis, I used large language models (LLMs), primarily *ChatGPT 4o* (OpenAI), as a writing-support tool. The assistance was limited to improving sentence formulation, orthography, and punctuation. All technical content, data interpretation, and conclusions are my own work.

LLM interactions were conducted with the aim of:

- Rewording sentences for improved clarity and flow.
- Correcting grammar, spelling, and punctuation.
- Enhancing readability while preserving the intended technical meaning.

No LLM-generated text was accepted without review; every suggestion was critically evaluated, edited, and integrated only when it accurately reflected the intended content and context of the thesis.

M Stylistic Intent

The prototype developed in this work is named *Dripito*. The name is derived from the English word “drip”, reflecting the device’s primary function of monitoring intravenous drip rates, combined with the diminutive suffix “-ito” from Spanish and Italian, which conveys smallness or endearment. This emphasizes the device’s compact form factor and approachable design. The playful name also aims to make the device more memorable to users, while remaining neutral and easy to pronounce across languages.

The device enclosure was produced in a translucent light-blue color. This choice was informed by feedback from pediatric nurses, who noted that blue is often perceived as calm, clean, and non-threatening in medical environments. The color aligns with common clinical aesthetics that signal hygiene and professionalism while maintaining an approachable appearance for pediatric care contexts.