Forest Friendly Flow Gauge: DIY Tipping Bucket for Precise Interception Loss Estimation!

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Abstract

Hydrological observation networks are inadequate and declining, hindering advancements in hydrology, particularly in hydrological budgeting, where interception loss remains unmeasured, and a subjective loss figure is assumed. Measuring net rainfall reaching the ground surface is crucial for precise water balance estimates. This involves measuring throughfall & stemflow fractions of precipitation on the canopy. Current methods use collector channels and static storage systems requiring periodic visits for measurements, which becomes extremely difficult and unsafe in inaccessible forests, leading to data losses. For time-resolved data, an array of standard rain gauges is placed under the canopy, or water is collected by troughs for throughfall (and collars for stemflow measurement), draining into a central pipe and directed into a tipping bucket flow gauge. Commercial flow gauges are expensive for use in throughfall & stemflow measurement, since, multiple instruments are required in each study location to capture the variability of the canopy. To address this, we designed and fabricated an open-source, low-cost Tipping Bucket Flow Gauge to automatically monitor flow rates of throughfall & stemflow. It is designed to have a larger adjustable tipping resolution (10 ml – 200 ml). The open-source Arduino-based data logger automatically collects time-resolved data and is powered using solar energy, ensuring remote functionality even in harsh environments. A modular electronics approach was followed for designing the datalogger, facilitating rapid prototyping, easy repair, and upgrades, enabling someone with even an introductory knowledge in Arduino to implement the design. Almost 75% of the instrument is 3D printed and can be fabricated using any standard desktop FDM 3D printer and assembled by hand. The instrument showed 86% accuracy in preliminary testing at a calibrated tipping resolution of 120ml. The cost of prototyping was 100$ - 120$, thus proving cost-effective for accurate hydrological budgeting as compared to the cost of the nearest available commercial solution (˜1800$). Through our research and product design, we intend to reduce the barrier of entry and simplify the steep learning curve faced in developing hydrological instrumentation.

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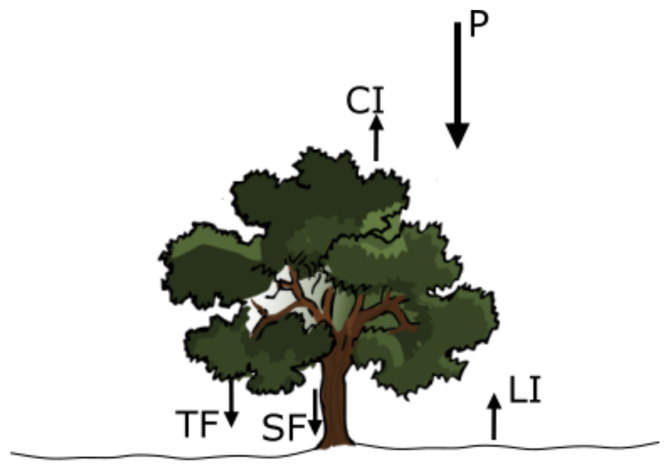
Background and Field Difficulty

Estimating Interception loss is crucial for accurate Hydrological Budgeting in forested watersheds



$$I = P - TF - SF$$

$$Q = P - I - ET + \Delta S$$

A. **Existing Solution:** Water from throughfall and stemflow is collected using a pipe and gutter system, and then measured in holding drums. However, this method is insufficient for gathering time-resolved data for rainfall event analysis and hydrological process modelling.

Existing Setup at Hydrological Study Field at Almora, Uttarakhand, India

B. Challenges to sampling Throughfall & Stemflow:

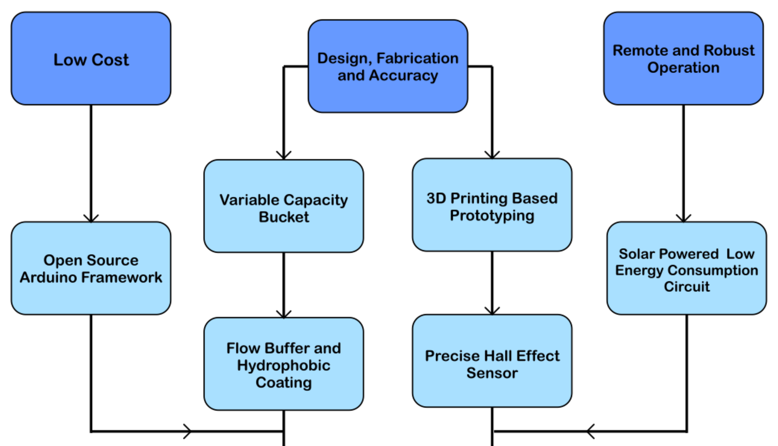
I. Manual sampling in collection drums is limited ⟶ Overflow of drums results in loss of data

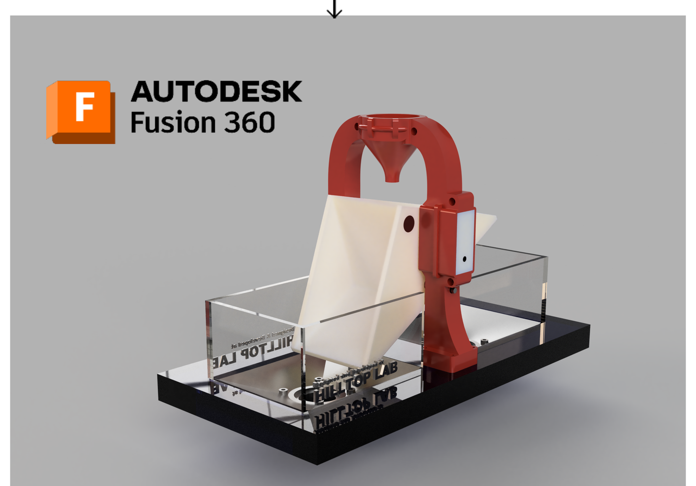
II. Standard TB rain gauge ⟶ Small collection area requiring many rain gauges to be used

III. Standard TB flow gauges can be installed ⟶ Very Expensive (Small Market/Demand)

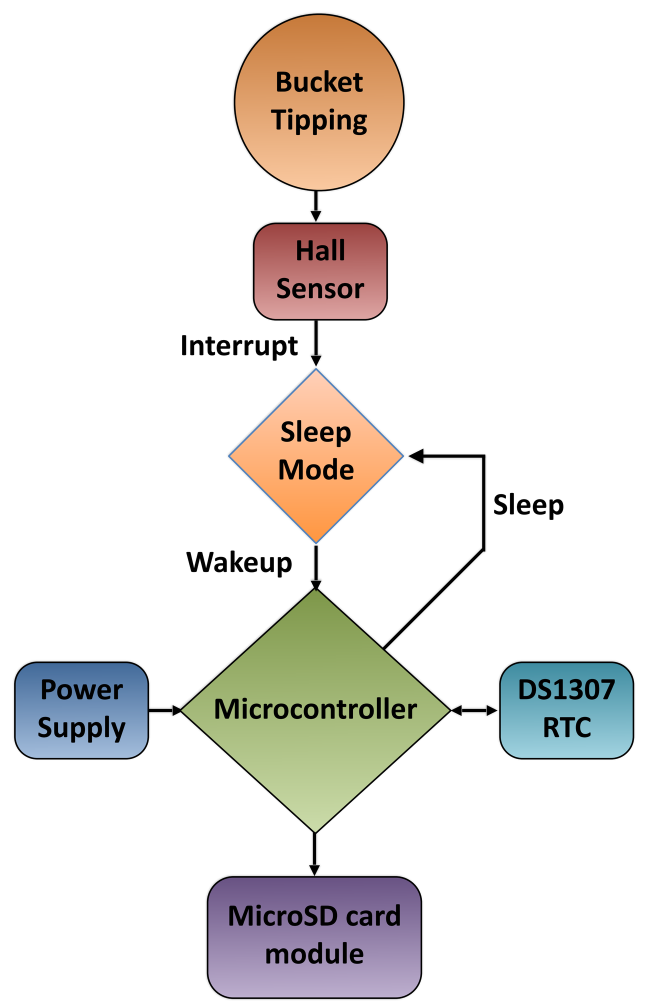
Hence, an open-source low-cost tipping bucket flow meter is required that can measure and record time-stamped flow rates in remote locations.

Ideation and Design of Solution



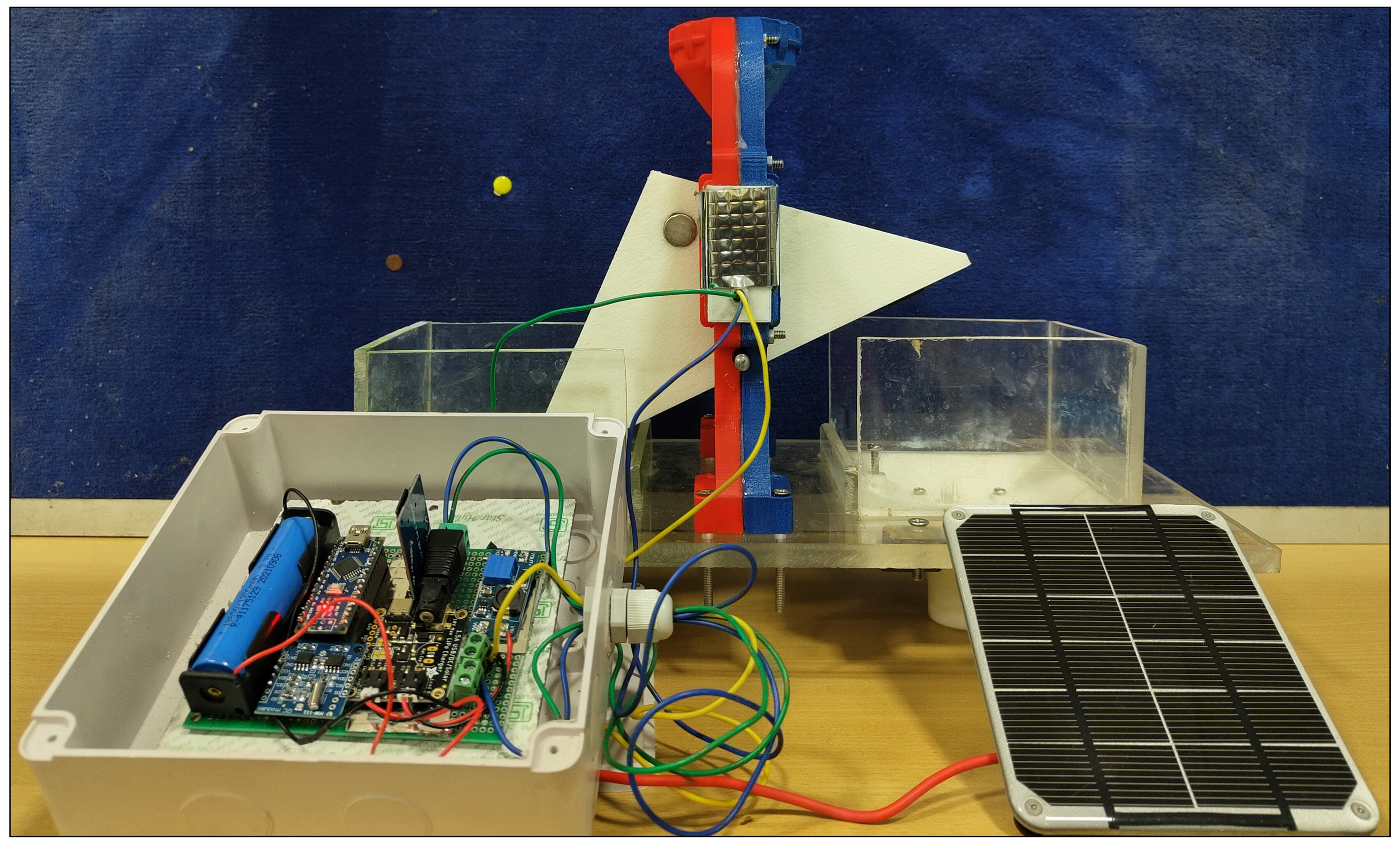


3D Model Render of the Tipping Bucket Flow Gauge



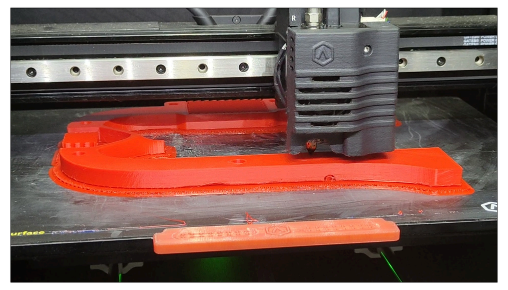
Data Logger firmware Logic Diagram

Development of Instrument



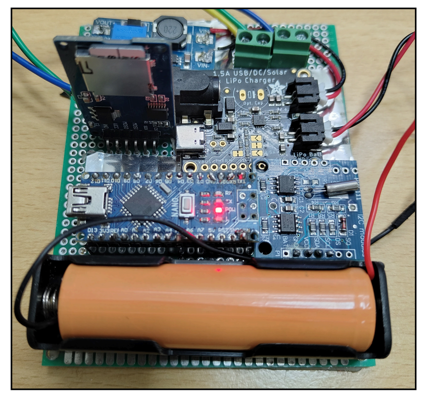
A. DIY Fabrication

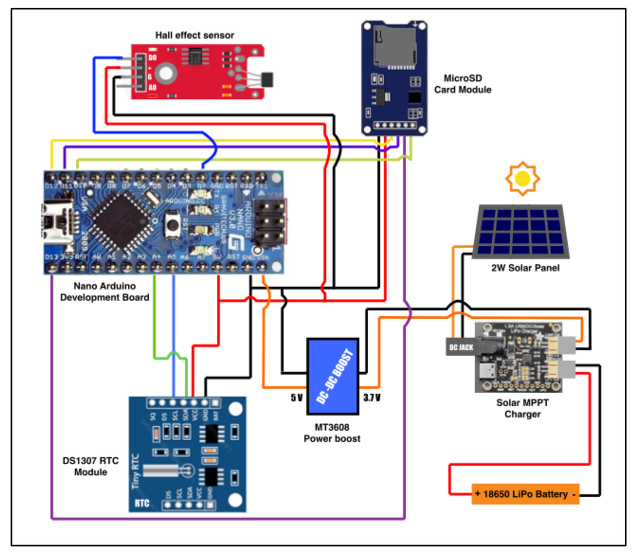
We used Fused Deposition Modelling (FDM) 3D printing technology with PLA+ material. Around 75% of the instrument can be 3D printed using any standard desktop FDM 3D printer and assembled by hand, requiring no advanced technical skills.



FDM 3D Printing on Raise3D

B. DataLogger - Modular Electronics & Open Source





Electronics – Modular approach

The Data logger was built using the following low-cost and easily available modules :

(1) Microcontroller – Nano R3 Arduino Development Board

(2) Sensor – Magnetic Hall effect sensor

(3) 18650 Li-Po 3.7V battery; 2W solar panel

(4) DS1307 RTC (real-time clock)

(5) MicroSD card for data storage and reader

(6) MPPT Solar Charger

(7) MT3608 Power booster

GitHub

ARDUINO OPEN-SOURCE COMMUNITY

ARDUINO

Why use a Hall Sensor?

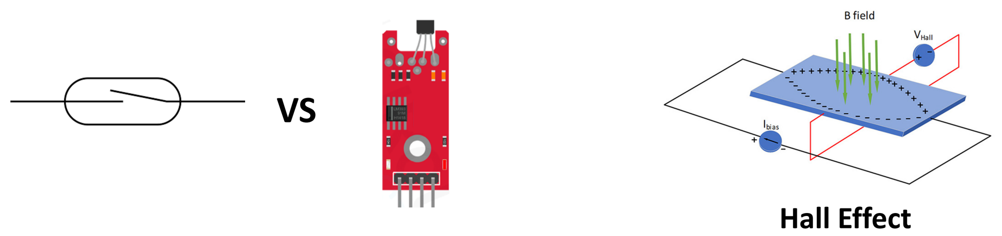
Drawbacks of Reed Sensor

I. Debouncing Error

II. EM Interference

III. Limited Life

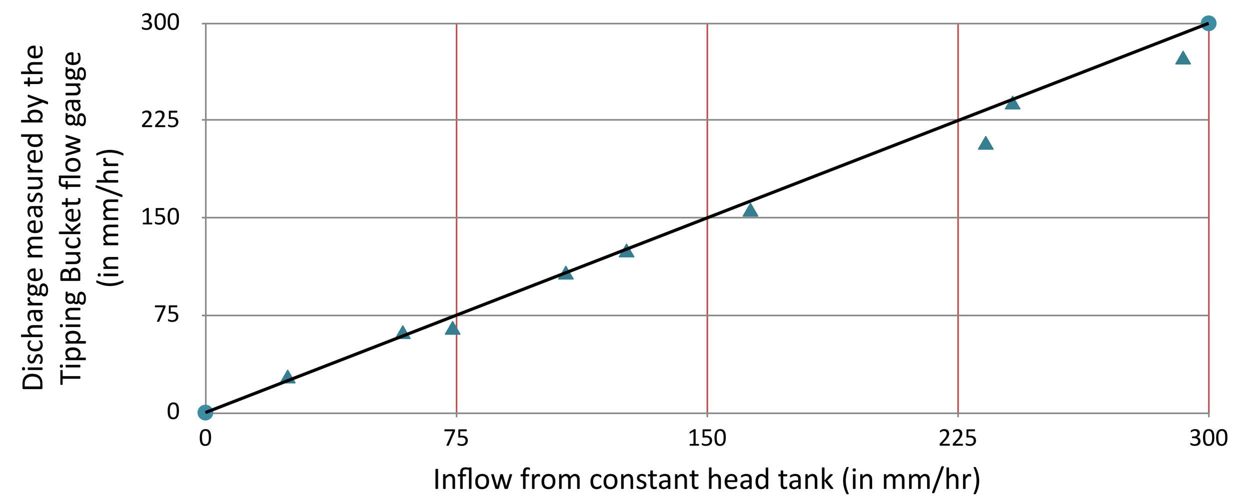
IV. Issues from Mechanical Shocks and Vibrations



When the Magnet on the Tipping Bucket moves in front of the Hall Sensor, it sends a signal (Interrupt) to the Microcontroller (Nano), which wakes it from sleep mode to record the event. By multiplying the number of tips per second with the calibrated tipping capacity, we can calculate the flow rate.

Results and Applications

A. Performance and Specifications



I. The Instrument demonstrated ⟶ 94.29% accuracy during preliminary Lab testing.

II. Variable Tipping Resolution ⟶ 10ml - 160ml (set by adjusting calibration screws)

III. Its wide range of tipping resolutions makes it versatile for many use cases.

IV. It can function as a tipping bucket rain gauge in the 10ml tipping resolution configuration.

B. Low Cost

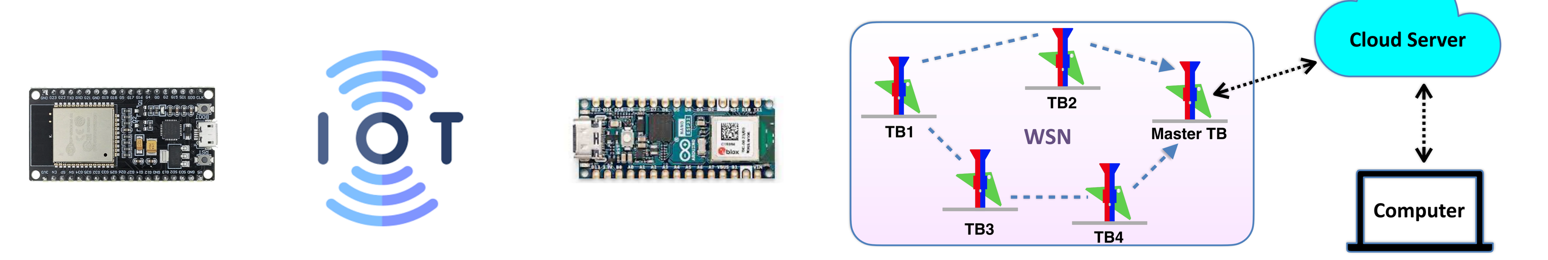
Sl. No.	Description	Unit	Qty.	Unit Cost	Cost in INR	Cost in USD
1.	Rapid prototyping	Hours	100	40/-	4000/-	50/-
2.	Electronic components	Bulk	1	2000/-	2000/-	25/-
3.	Cost of Prototype Field Testing & Miscellaneous	Bulk	1	6000/-	6000/-	75/-
Estimated per unit cost of manufacturing					₹ 12,000/-	**$ 150/-**
Market cost of nearest available solution					₹ 1,39,000/-	**$ 1600/-**

C. Application

New Setup at Hydrological Study Field at Almora, Uttarakhand, India

Way Forward

Internet of Things, Wireless Sensor Networks, Data Telemetry, ESP32, what's next?



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