Development of a tree volume measurement device

Laine Teemu[1, a], Lindholm Simo[2,b] and Pirttimaa Viljami[3,c]

[1]Full address of first author, including country

[2]Full address of second author, including country

[3]List all distinct addresses in the same way

[a]teemu.m.laine@aalto.fi, [b]simo.lindholm@aalto.fi, [c]juuso.pirttimaa@aalto.fi

* please mark the corresponding author with an asterisk

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Introduction

In Finland biomass has the highest proportion of total energy production compared to any other industrialized country. Most of that biomass used for energy production is wood (2017). [1] The usage of biomass for energy production has increased. Therefore, it is important to be able to measure how much biomass is stored in the forests. Another interesting future prospect is carbon storage in forests. In order to estimate the carbon storage capacity of the forest, accurate estimate of the biomass needs to be known. [2]

Accurate measurement system for tree volume is needed, because the volume estimation is currently done by using mathematical models. These mathematical models do not take branches into account, even though their volume is significant. [2] Accurate estimation of the volume is also necessary to determine the density of a tree. Many structural properties of the tree depends on its density. For example, tensile strength of a pine tree fell in spring is only 1/6 of pine fell in the summer. [3] This means that the applicability of a tree is determined by its density.

A traditional but still widely used method for estimating trunk volume is using a Biltmore stick. The Biltmore stick is a calibrated instrument that is held at an arm's length away from the eyes of the user. The stick has a scale that indicates the breast height diameter of the measured tree. [4] This method is quick, easy and non-destructive. However, it is only used as a rough estimate of the usable trunk volume but it is a poor estimate of the biomass of the whole tree.

A more modern method for volume measurement is using terrestrial laser scanning (TLS). This method allows tree volume measurement without cutting the tree into pieces. With this method, the tree is first digitized by TLS. Then the TLS data is processed by geometric fitting algorithms which can compute the total volume of the measured tree. This method does not take into account branches that are smaller than 7 cm in diameter, which leads to ±30 % error in branch volume measurement. This error is significant and the results do not include the density of the tree. [5]

University of Helsinki has a volume measuring device in Hyytiälä forestry field station, which has been developed in collaboration with Aalto University. The device measures volume of desired part by plunging it in water. Force sensor registers the buoyancy and determines the volume by using archimedes principle. However, based on the feedback the existing measurement device isn't reliable enough. While it's still currently being used, the need for a improved device is apparent. The goal of this paper is to showcase a new version of the measurement device.

Tree volume measurement

- General information about tree volume measurement
- Why measuring the biomass volume is important
- Existing solutions and methods

Sensors in volume measurements

- Comparison of different sensor options for measuring the tree volume

Load cell for buoyancy measurement

Distance sensor for liquid level measurement

Dimensiometer

Mechanical concept

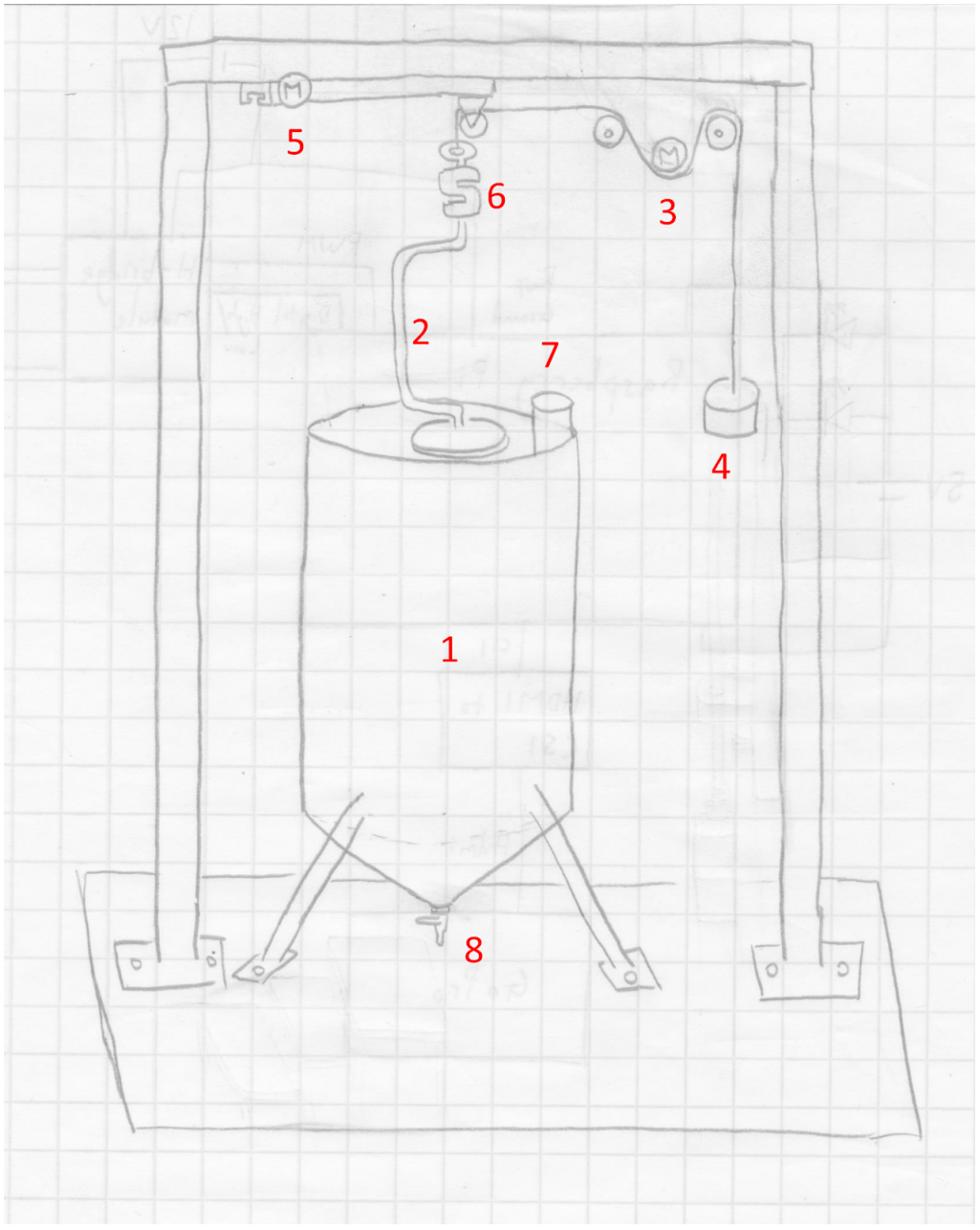

Fig. 1

Volume measurement is started by filling the water tank (1) and powering up the system. Operator of the machine attaches the specimen to a holder (2). The holder is on the ground in the beginning of the measurement. Measurement cycle is started by the operator. The machine starts to lift the holder by rotating a stepper motor (3), which is connected to a gear wheel. Counter weight (4) makes sure that the timing belt does not slip from the gear wheel. When the holder is lifted up, the machine starts to move the holder in horizontal direction. This is done with linear actuator (5).

Stepper motor rotates at the same time so that the holder does not move vertically. When the holder is on top of the water tank, it is lowered with the stepper motor. Force that is acting on the timing belt is measured with a force transducer (6). Volume of the measured part can be calculated from the buoyancy effect (change in force readings). Calculations take into account that the immersion depth depends on the water level. Water level is measured with ultrasonic sensor (7), which is placed inside a tube. Volume can be also calculated by measuring the rise of the water level. Measurement cycle ends when the machine has moved the holder back on the ground, next to the water tank. After the measurement, operator can drain the water tank with a valve (8).

Component choices

Component	Selected part	Reason
Tank	270 liter air tank, 54 x 195 cm	Tall and narrow, mounting feet, price vs. custom made stainless steel tank.
Lifting mechanism	Belt drive with stepper motors.	Economic way of producing long liting movement. Open-loop control is sufficient so the lowering height does not have to measured.
Water level measurement	Ultrasonic sensor MB7369	Does not need a float to sense the water surface.
Load cell and amplifier	PSD-S1 50 kg S-type load cell and Sparkfun HX711 amplifier	Price, suitable for measuring tension. Sparkfun version of the HX711 has better power filtering than other versions.
Temperature measurement	DS18B20 digital thermometer	Easy to use 1-Wire interface, ±0.5°C Accuracy
Software	Python, possibly interactive IPython shell with a Jupyter notebook interface that can be used with a browser.	No licensing costs, easy development
Computer hardware	Raspberry Pi 3B+	GPIO enables easy attachment of sensors, price

Testing measurement accuracy

The accuracy and repeatability of the dimensiometer was tested with a reference object whose dimensions and weight are known. Comparing the measured volume against a calculated value at different submersion heights shows the measurement error of the system. Comparing the results between multiple measurements makes it possible to evaluate the repeatability of the measurement system.

The reference object was turned on a lathe. It consists of straight sections that should show a steady increase in volume/height in the measurements. In addition to the straight parts the object has

steps of different diameters that show up as changes of the volume/height slope in the measurements. These can be used to evaluate the accuracy of the submersion depth measurement.

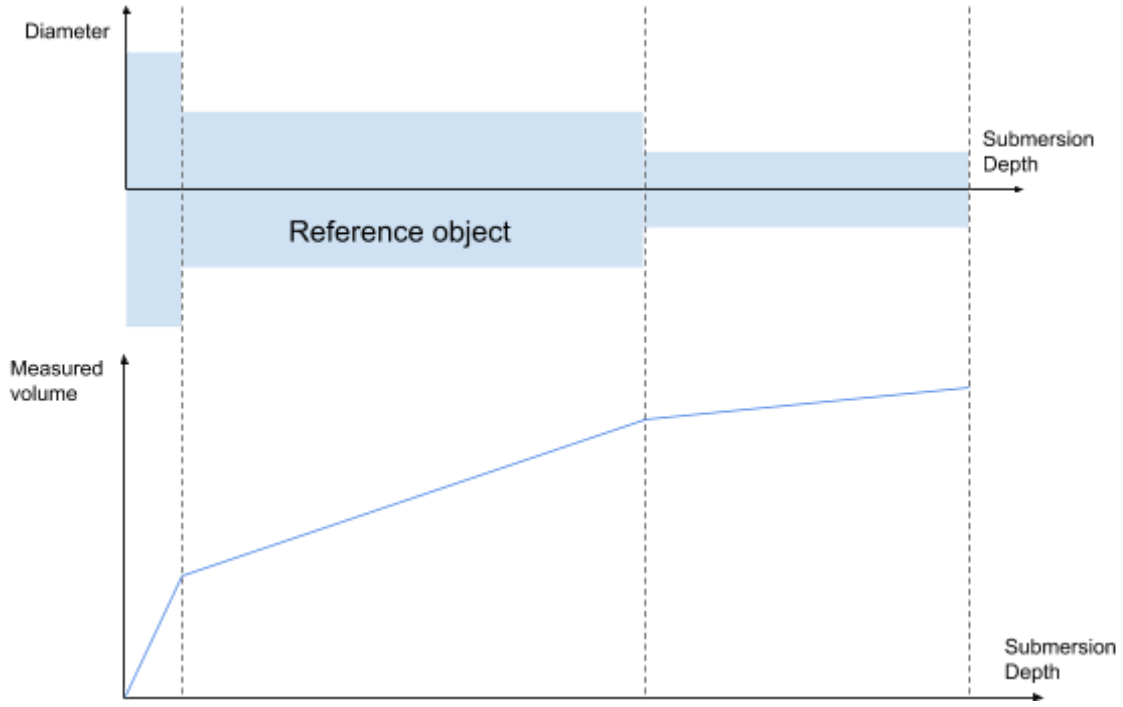

Fig. 2

Conclusion

- Are the results as expected
- Analysis of the results
- Further improvement ideas

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