A composite method to determine sample volumes and anisotropic peat shrinkage during evaporation experiments based on photogrammetry

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Introduction
Soils high in clay and/or organic content show distinct shrinkage/swelling characteristics with changes in water content. In soil science literature many standardised and non-standardised methods exist to determine these characteristics. The methods are often selectively applicable to the specific experimental conditions. Many are irreversibly destructive or imprecise.

Objectives
Hence, we introduce a method for determining the shrinkage of peat soil samples during transient evaporation experiments in the laboratory.

Principle
Fig.1: With photogrammetry a spatial vision of objects of arbitrary size and complexity is recreated. A 3D object point (P) with its coordinate components (X,Y,Z) must have homologues image points p in both images x₁, y₁ and x₂, y₂. The position of the perspective centre of each image is described by three translation parameters (dx,dy,dz) in relation to the origin of the coordinate system and three rotation angles (ω, φ, ψ) around the corresponding axis of the reference coordinate system. This exterior orientation is derived from known control point (CP) coordinates and the scale of the unknown object.

Digitalisation
Fig.3: Digitally identified and named points (green with numbers) (top). Reconstructed 3D sample coordinates calculated coordinate is ~1 μm. For the digitalisation procedure many (non-)commercially softwares exist.

Volume Calculation
Two straightforward methods are proposed to calculate the volumes from the X,Y,Z – coordinates

1. Cylindrical objects: Circle fits
The midpoint (a,b,r) and radius (r) of the circle are fitted simultaneously by minimising the squared sum of the orthogonal distances (d) between the digitilised coordinates (xᵢ, yᵢ) and the circle.

\[
d(a,b,r) = \sum_{i} (\sqrt{(x_i - a)^2 + (y_i - b)^2} - r)^2
\]

Total volume (Vₜₒₜ) is calculated by the sum of the truncated cones:

\[
V_{tot} = \sum_{k=1}^{n} (h_{k+1} - h_k) \times (r_k^2 + r_{k+1}^2 + r_k r_{k+1})
\]

k - number of truncated cone slices

2. Straight Edge Polygons: 3D Alphashapes
3D alphashapes are created from a set of finite points. Then the volume is calculated from the Voronoi volumes of the object.

Results I: Volume Change
Fig.4: Volume change as a result of evaporative water loss. Same depths show similar shrinkage patterns. Shaded areas show uncertainty of the circle regression. Photogrammetric error is < 0.05 cm³, and can be considered as minimal.

Results III: Shrinkage Curves
Fig.5: Shrinkage curves for all samples. Lines are for visual guidance only. Moisture ratio 0 is at oven dryness. With increasing depth, void ratio decreases. Very little volume change occurs during water loss, implying a reasonably strong fabric strength.

Results II: Anisotropy
Fig.6: Rs factors for all samples. Rs gradually increases from <3 to >3, i.e. initially, shrinkage is dominated by vertical and later by horizontal deformation. The erratic behaviour of the samples at depth 10cm is a cause of problems with the pins.

Conclusion
The method met our requirements set out in the objectives with a time effort of approx. 15 mins per time step.
Accuracy: Photogrammetric: ~0.01 cm³, volume calculation: ~ 2 cm³.
All peat samples reveal shrinkage, total shrinkage ranging from 5% to 15%. In tendency, total shrinkage increases with depth.
The shrinkage curves reveal increasingly lower void ratios with increasing depth, reflecting the trend in bulk densities.
Moderate anisotropy is evident with vertical shrinkage initially dominating while with time horizontal shrinkage is increasingly important.

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