Investigation of the potential of hyperspectral sensors for bathymetry applications using airborne HyMap data from Lake Constance

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Introduction

- This work describes the analysis of the accuracy in the determination of bottom depth (ZB) for optical remote sensing data (400 to 800 nm) in shallow water by means of an inversion technique.
- A theoretical sensitivity analysis and experimental results using HyMap hyperspectral data from a flight over Lake Constance on the 30th of June 2004 were used.
- The aim was to determine the critical depth up to which it is possible to expect reliable bathymetry results when:
  1. The water media optical conditions are controlled (simulations).
  2. They are determined by airborne hyperspectral data.

Figure 1: Location of the Obersee in Lake Constance (area of study). The image on the right corresponds to the HyMap data used for the analysis.

Methodology

The theoretical analysis consisted of a combination of forward and inverse calculations based on non-linear optimisation combined with analytical equations. The accuracy of ZB determination was investigated as a function of ZB for low concentrations of suspended matter (X= 1 mg/l), Gelbstoff (Y= 0,2 m^{-1}) and chlorophyll (C[0] = 1 µg/l) and 6 bottom types (constant albedo 10%, sand, silt, and 3 macrophytes: Chara *aspera,* Potamogeton *perfoliatus,* Potamogeton *pectinatus*). The stability of the inversion was analysed by increasing the number of "unknown" parameters to be retrieved during the inversion (fit parameters). An error propagation of X, Y, C [0] was studied as well. All simulations are done with the Water Colour Simulator WASI (Gege, 2004).

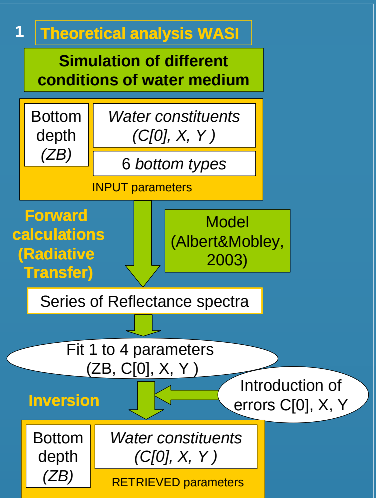

Figure 2: Theoretical analysis with WASI.

The retrieval of bottom depth from hyperspectral data was made by inverting the same model as before, using an automated processing chain system called Modular Inversion & Processing System MIP (Heege *et al*., 2003b). HyMap *at sensor* radiance spectra are inverted by adjusting modeled spectra to the measured radiance values. In the final step bottom depth is determined for all pixels, with fixed concentrations of all water constituents (values retrieved in 1st inversion). In this procedure, bottom reflectance, bottom depth and bottom coverage are inverted iteratively from the subsurface reflectance.

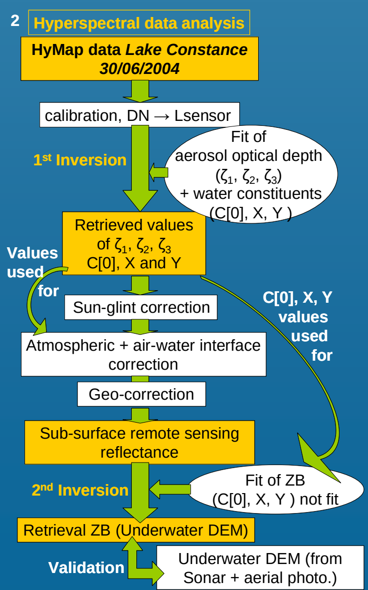

Figure 3: Hyperspectral data analysis with MIP.

Results

Theoretical limits of bottom depth determination

- An accuracy of bottom depth determination better than 10 % is theoretically possible for low concentrations of water constituents C[0], X and Y between 2 and 8 m, independent of the bottom type.
- The number of fit parameters ("unknown" parameters to be retrieved) affects the accuracy of bottom depth. For up to 4 fit parameters WASI software is stable during the inversion.

Error propagation at the determination of bottom depth

- Errors in the concentration of the water constituents X and Y may have a significant negative effect on the accuracy of ZB determination if considered as constant during the inversion. Critical depths are 2 m and 1 m respectively.

Parameter	Error propagation effect on accuracy of bottom depth determination	Number of fit parameters during inversion
Chlorophyll	NO significant effect	More fit parameters do not compensate error in bottom depth determination
Suspended matter	Significant negative effect *if the parameter is FIXED during inversion* (for depth > 2 m)	
Gelbstoff	Significant negative effect *if the parameter is FIXED during inversion* (for depth > 1 m)	More fit parameters compensate error

Figure 4: Error propagation results summary table.

HyMap data processed by MIP

- The depth range for which the HyMap sensor in combination with MIP processing produced reliable results was 0.1 to 3 m for the investigated image of Lake Constance.
- The retrieval of bottom depth by applying MIP resulted in an average difference of 39 cm (standard deviation) as compared to echo-sounding data (reference data set for the validation).
- The statistical error of the data analysis is 20 cm (linear regression).
- There are systematic errors in the MIP calculations which decrease the accuracy to 39 cm.
- The offset of 0.23 may be caused by a different water surface level between both data sets.
- The slope of 0.56 means that the MIP calculations underestimate bottom depth of that image systematically by 44 %.
- If the source of the systematic error can be identified and eliminated, then the STDev. is 20 cm for the depth range of 0.1 to 3 m.

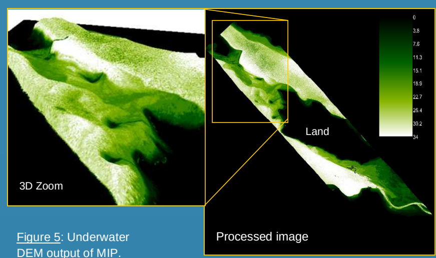

Figure 5: Underwater DEM output of MIP.
Black areas represent land. The gradual change in color from darker to lighter corresponds to increasing depth values.

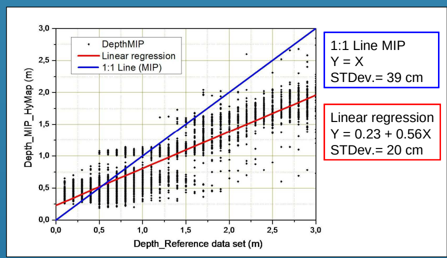

Figure 6: Comparison between depth information from HyMap processed image and reference data set (echo-sounding measurements). A linear regression on the 1:1 line was made by MIP (blue line) and a linear regression fitting gain and offset was made using another software (red line).

Conclusions

The major achievements of this research are:

- Airborne hyperspectral sensors applied in shallow inland waters can reliably determine bottom depth at least up to 3 m for the case where the optical properties are similar to Lake Constance.
- The retrieval of bottom depth by applying MIP to the HyMap image of Lake Constance resulted in an average difference of 39 cm (standard deviation) as compared to echo-sounding data. The statistical error of the data analysis is 20 cm. This accuracy of bottom depth retrieval can be achieved using HyMap data and MIP if systematic errors are eliminated.
- Possible sources of systematic errors are changes of Sea level of the water surface and the fact that the concentrations of the water constituents (in particular Y and X) were kept constant during inversion.
- The error of 39 cm is lower than the one from the reference data set (error 30 to 50 cm). The compilation of the reference data set (consisted of echo-sounding measurements and aerial photographs) took more than 3 years. This means that the application of HyMap sensor in combination with MIP system gives the same accuracy much faster .

References: Albert, A. and Mobley, C. D. (2003). "An analytical model for subsurface irradiance and remote sensing reflectance in deep and shallow case-2 waters." Optics Express,11(22), 2873 -2890; Gege, P. (2004). "The water colour simulator WASI: An integrating software tool for analysis and simulation of optical in-situ spectra." Computers & Geosciences 30: 523– 532.; Heege, D. T.; Bogner, A. & Pinnel, N. (2003b). "Mapping of submerged aquatic vegetation with a physically based processing chain." SPIE- The International Society for Optical Engineering.