Tell spotting - surveying near eastern settlement mounds from space

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ABSTRACT

Digital elevation models (DEMs) have become a recognized tool in the visualization of historical sites. Applications range through various scales from 3D presentations of the settings of individual buildings up to detailed GIS analysis of the hinterlands of archaeological sites. However, the development of space-borne instruments has seen the rise of high resolution DEMs even on the global scale. In the present study we demonstrate the use of such data sets, namely from the Shuttle Radar Topography Mission (SRTM), for a virtual survey on archaeological sites -- the detection and localization of ancient settlement mounds in the Near East. These so-called "tells" (the Arabic word for a settlement-mound) are the result of millennia of settlement activity and visible landmarks of the first human urbanism in Mesopotamia. Though a large number of the sites are very well studied, the best current listings of them on a region-wide basis are neither comprehensive (circa 1400 major sites) nor accurate (to 10km grid-square).
In order to obtain such a catalogue and to map these cultural monuments for the purpose of conservation and landscape archaeology, we set up a tool to process the SRTM data of this wide geographical region to be as automated as possible. Archaeological sites from a north Syrian plain provided the training and testing data for the design of a machine learning decision rule, which is able to show robustness against background variations and to control the number of false detection events . Landsat ETM+ image data is used to confirm sites proposed by this classifier and to allow a manual positioning of tell sites well below the DEM resolution.
In a first application of the classification algorithm to a region with known settlement mound positions --identified in a prior study on high resolution CORONA satellite images -- we were able to detect nearly all settlement higher than 5-6m which are of characteristic shape (85 out of 133), at a reasonable number of false positives. Present applications of the proposed method are the detection of tells in areas not yet studied, and the mapping of regions with a direct threat of these historical monuments by agricultural land-use.

Archaelogical Gis, SRTM, DEM, Digital Survey, Archaeological Remote Sensing

1. INTRODUCTION

The study of *tells* is a classic area of settlement-archaeology. *Tells* are settlement-mounds, which are found in the Near and Middle East, in an arc from the Balkans and regions to north-west India, and represent places which were occupied for long periods of time. A mud-based building technique caused building-debris to accumulate and raised the level of these settlements to significant heights, so leaving eminent landmarks of early human activity. The settlement-type began with the beginning of farming in the early Neolithic, and some grew to the size of urban centres during the Bronze Age. Although a few are still inhabited, most were abandoned two to three thousand years ago, and modern settlements exist on flat land nearby.Therefore these settlement mounds represent the remains of the earliest settlement systems, and a study of their spatial occurrence can reveal insights into the emergence, development and organization of the first complex human societies.

This demands comprehensive and accurate listings of these sites. Remarkably, after more than 150 years of archaeological research, information about the locations even of major sites is notoriously imprecise, while small mounds never made their way to a record. As a consequence, current compilations of published site positions are only available on coarse grids and do not contain more than a subset of the major sites [Sherratt 04].

Expansion of modern settlements, road-building, and the intensification of agricultural land-use implies an unprecedented threat to these historical monuments. Thus, beyond the academic interest in the analysis of settlement patterns, a comprehensive mapping of these mounds may also provide the understanding that this widespread phenomenon of human settlement activity deserves, and its importance as part of our cultural heritage.

The aim of the work is to propose and assess a (semi-) automatic tell detection strategy, which is based on

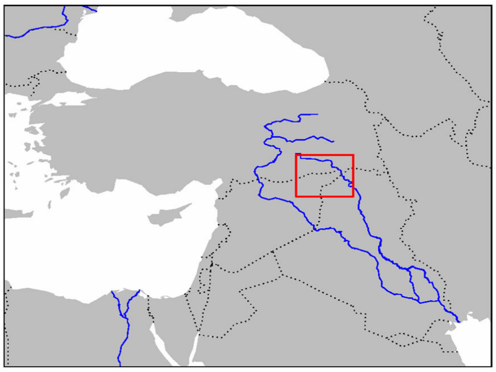

Fig 1: Map of the region under study. The Khabur basin is in the north of Mesopotamia (Euphrates and Tigris indicated).

SRTM digital elevation models and will allow a digital survey of ancient settlement mounds in wide geographic regions, under objective search criteria and at low operational costs.

2. REMOTE SENSING OF SETTLEMENT MOUNDS

From a plain physical point of view, tells are elevations of 5-50m height, 50-500m diameter and of conical shape. Also, they primarily consist of loam and mud-based materials.
Both features might be used in the identification of tell sites: Hyperspectral imagery, i.e. from LANDSAT, is a standard tool in the classification of soil types and ground cover. It is potentially helpful to identify the often uncovered and eroding tell sites. Digital elevation models reveal shape information. Their usefulness in the search for tells has been described recently [Sherratt 04].
Data for both approaches are freely available with a high resolution and a global coverage. Unfortunately, the spectral signature of known tell sites proves to be too unspecific for an automated classification, although there is no reason why certain diagnostic characteristics might not be isolated by future research. Thus, the detection of tell sites falls back to an optimal processing of the DEM data under the adjunct use of visual and thermal band high resolution satellite images.

In the present study we will describe, how the conical tell pattern of a settlement mound can be optimally identified in the natural topographic variation (section 3.2). Due to the high specifity we reach with this algorithm, we are able to use LANDSAT ETM+ maps for operator-controlled localisation the sites (section 3.3). Both detection accuracy and estimated area size will be discussed quantitatively on a test set of tells sites localized in CORONA images within an earlier study (section 4).

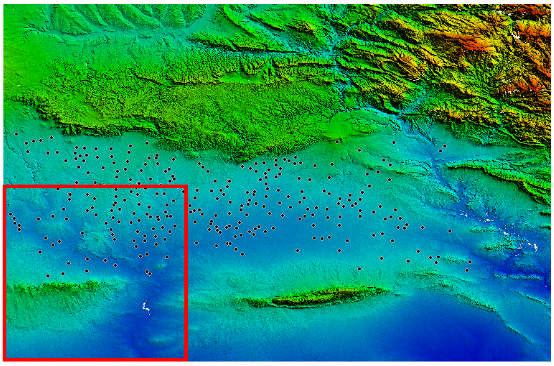

Fig 2: Digital elevation model of the Khabur basin with settlement mount positions indicated (black dots). Tells of the southwestern SRTM tile (red bordered) serve as test sites.

3. AUTOMATED SURVEY

3.1 Data

The algorithm is developed and tested on data from a prototype region in the north of former Mesopotamia: The upper Khabur catchment has an east-west extension of 320km and 120km in north-south direction. It saw the major expansion of nucleated settlements in the forth millennium BC and has been extensively studied in moden times.
Most of its area is on the Syrian territory, though the northern rim and the bordering mountains belong to Turkey and its eastern regions are part of modern Iraq (see fig). It is named after the Khabur river, which originates, together with its minor feeders, in the Taurus mountains and runs to the southern Euphrates (Fig: 2), after passing the Jebel Abd al-Aziz and the Jebel Sinjar at the southern border of the basin.
The area is covered by six SRTM one-degree-tiles (36-38 N, 38-41E) of 3 arc-second resolution (90m horizontal resolution, +/-6m 90% relative vertical accuracy). Landsat-7 ETM+ three band maps at 14.3m resolution were also used and, for the test region, declassified monochrome CORONA images at 2-3m resolution.

The algorithm was designed on data from a subset of five SRTM tiles and evaluated on ground truth for the sixth, southwestern tile (rf. fig. 2).:
For training, 184 tell sites were identified visually in the SRTM data and were confirmed with help of LANDSAT images and topographic maps. These sites, together with 50 000 randomly chosen positions, served as training and validation data in the design of the classifier. As input for the training, the elevation data from circular regions of 1km diameter, centered around the training sites, was used. The height differences relative to the

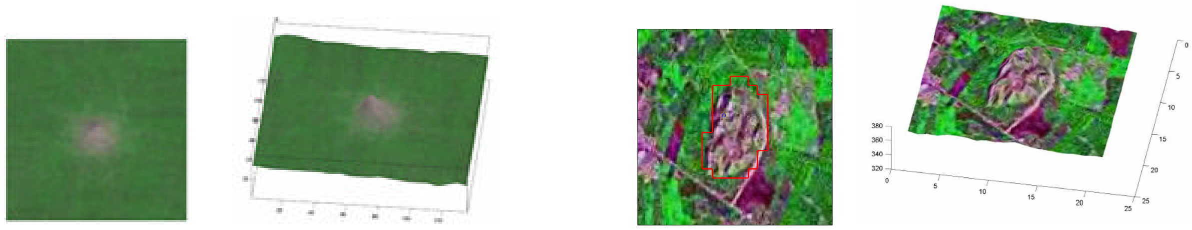

Fig. 3a: Landsat image and elevation model averaged over all sites of the test set. The majority of the tells is in direct vicinity to modern settlement, which is visible from the bright central spot.
Fig. 3b: Tell Brak, major settlement site in the Khabur basin.

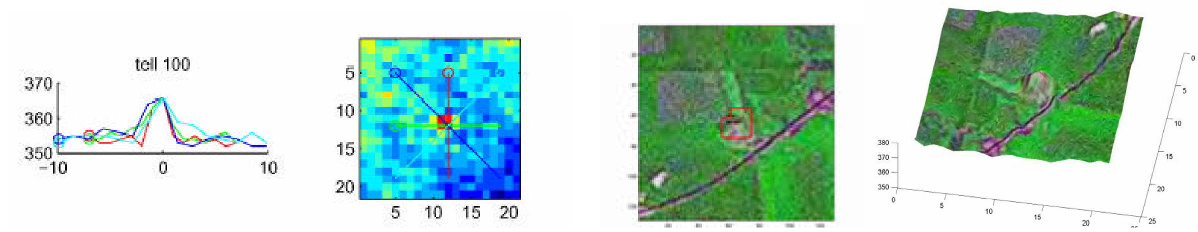

Fig. 4: Principle of point detection: The characteristic height profile of a tell site generates a typical point like pattern in the DEM. Under the resolution of the SRTM DEM, their elevation is often of nearly conical shape (height profiles left, as indicated in the DEM image patch).

center in this image patch were concatenated to parameter vectors of length 80.
The test data was acquired in an independent prior study [Ur 03]. CORONA images of the 1960s revealed the location of 133 sites with indications of settlement activity. The size of these sites ranges from one to 60ha (Tell Brak, see fig. 3b) in area and less than 2m to more than 30m in height (fig. 9).

3.2 Classifier design

In the DEM, the tell pattern is superimposed on natural topographic variation. Though the geographic region under study is a relatively flat plain, natural variation of the land surface can be observed on various scales, ranging from slowly varying slopes to steep canyon walls (see fig. 10). In addition to this 'background signal', small conical hills of volcanic origin, more recent artificial accumulations and structured artifacts of the DEM are likely to be misclassified as human settlement mounds.

The standard approach for the detection of a known pattern in a varying (additive white gaussian) background signal is a matched filter. However, elevation data of a physical land surface are highly correlated and the 'noise' of non-tell surface-structures is only poorly approximated by an independent gaussian error model. So a direct application of a matched or template filter in the detection of characteristic tell like mounds results in an unacceptable number of false hits (fig. 10).

Therefore ideas from high level image analysis, namely from face recognition, are used to allow a reliable and automated screening of SRTM tiles for tell patterns. A set of linear filters is learned from the training data to span a subspace for a multivariate decision rule. The purpose of these linear filters is a fast processing and low-dimensional mapping of the (80 dimensional) local image pattern in the first step, while the following multivariate classifier provides the desired adaptivity of the detection algorithm.

Partial least squares (PLS) filters were found to be superior to other linear methods (linear discriminant analysis, principal component analysis). In combination with a subsequent classsification by randomForest on a eight dimensional subspace, a sensitivity of 95.4% could be reached at a specificity of 98.8% in a ten-fold-cross validation of the training error [Menze 05].

3.3 Operator-controlled localisation

Applied to new data, the classification algorithm is able to provide ranked lists of positions with decreasing 'settlement mound probability' (compare Fig. 6). A tool, which simultaneously presents the different georeferenced modalities, e.g. specific ground cover maps, digitized topographic maps, can be used by an operator to localize the extensions of each of these sites in highly resolved LANDSAT images and to separate false positive hits within a short time.

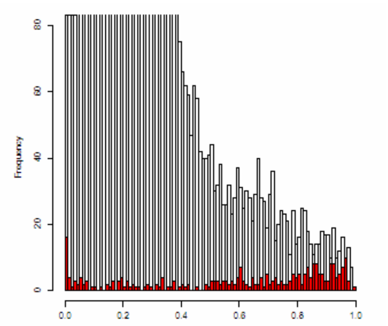

Fig 6: Histogram of the cross-validated classification results on the training data. While the majority of the 50 000 'non-tell' pixels (white) are assigned to low probability values (frequency truncated at 80), most of the tell-pixels (red) are gathered at high values.

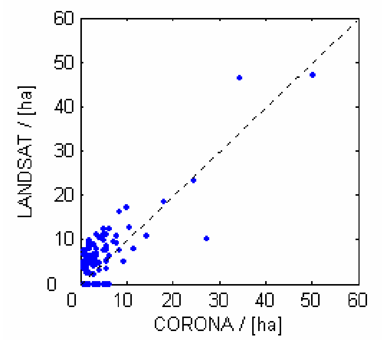

Fig 7: Area sizes from LANDSAT imagery at 15m resolution tends to overestimate the size, as estimated from 2-3m CORONA images.

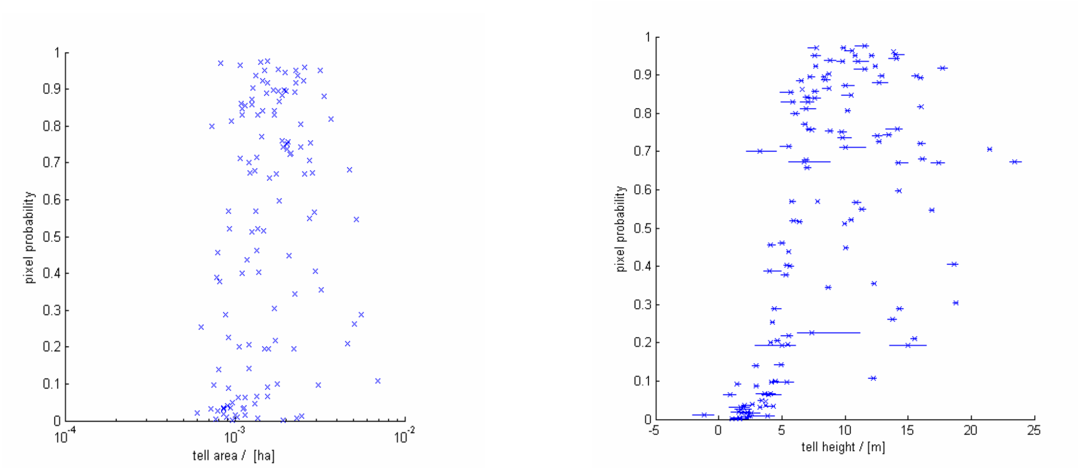

Fig 8: While no relation between settlement mound area and detection probability can be observed (left), the probability increases considerably for tells sites with a height of more than 5-6m (right). Error bars indicate the quartiles of the resampled height estimation (see text).

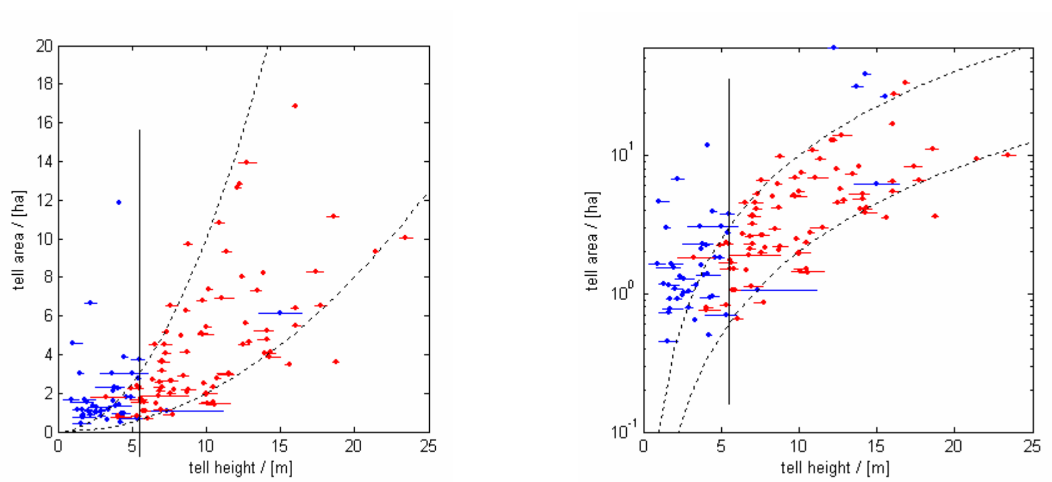

Fig 9: Out of the 133 tell in the test set 85 could be detected (red points) at the chosen threshold of 0.3 (rf. fig. 8). The plot of tell area vs. tell height (left: linear area-scale, right: log area-scale) reveals that detected sites are typically higher than 5-6m (black line) and follow a quadratic area-height relation (dotted lines, see text).

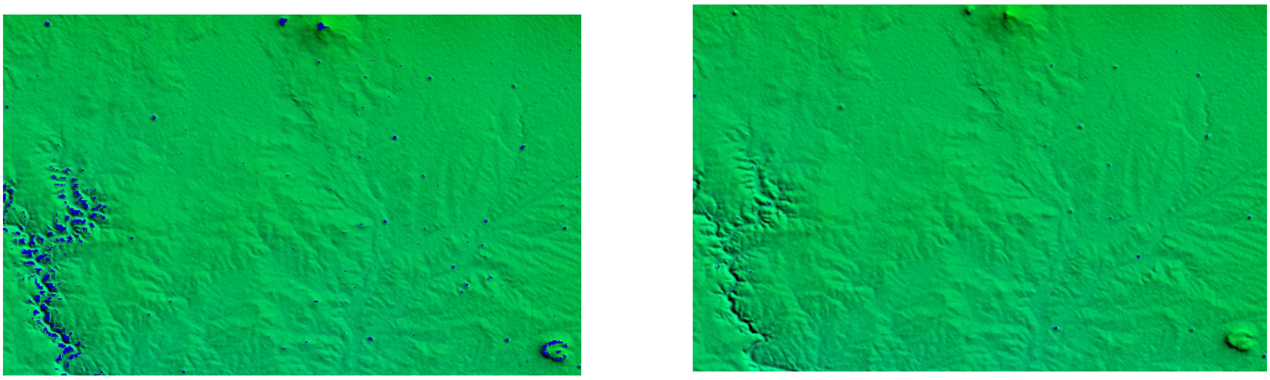

Fig 10: While a standard matched filter (left image) marks a considerable number of false positive hits (see blue labeled pixels), preventing any computer-aided detection of settlement mounds, the designed classifier (right image) flags only a limited number of pixels with high specifity, allowing a time-efficient localization in high resolution LANDSAT images in a subsequent step.

4. RESULTS

When applying the classification algorithm to the SRTM test tile, it is possible to detect 85 out of the 133 test sites at a threshold, which results in 327 false positives for the 1200^2 pixels of the whole area. This number can be handled with an appropriate tool within short time.

High resolution imagery, e.g. CORONA or SPOT, can be used for the outlining of a site and an area assessment, but is only available for limited regions and at relatively high (monetary) costs. So we have compared area sizes from a LANDSAT positioning at 14.3m resolution with the highly resolved CORONA 'ground truth' from 2m resolution (Fig. 7). A high accordance can be observed for major tell sites, while the circumscribed area of small sites seems to be overestimated by the latter.

Beside a detection of ancient settlements, the processing of a DEM also allows for the determination of a physical site parameter, which is new in the description of tell distributions: the height of the settlement mound above the surrounding area at the present time (though the actual mound may be deeper than the present land-surface) .
On our test data, it was assessed as follows: A linear plane was fit repeatedly (20 times) onto varying subsets (2/3) of the neighbouring SRTM pixel of each tell site, in order to serve as an approximation for the base of the tell. The tell height was estimated by the maximum difference between tell surface and ground plane. We find, that the smallest sites are not higher than 2m, while the biggest settlement mound rises as high as 30m above the surrounding area (fig. 8). While the variation of the height is often well below 1m - even for major tells - significant errors can be observed for small sites, which hardly stand out from the ground or on settlement mounds, which are likely to be missed by the tell detection algorithm (fig. 8, 9).

In a comparison between tell area (from CORONA images) and height, a cubic relation (area = c* height^2) can be found, with the majority of the sites within certain ranges (between c=0.02 and c=0.1 [ha]/[m^2]), fig. 9).

When comparing the assessed height of a tell with the classifier's probability measure, a sharp increase in the detection probability can be noted for sites with a height of more than 5-6m (fig. 8), which coincides perfectly with the limit of data accuracy. A low number of major sites, which were not easily detected, show an untypical height/area ratio, which has not (yet) been learned from the test data set.

5. DISCUSSION

We are able to propose a search strategy for the detection of ancient settlement mounds with high sensitivity and specifity. This digital survey is primarily based on the automated classification of data from a global DEM, but also incorporates information from other remote sensing modalities in a final localization and confirmation step by a human operator. We are able to formulate the implicit search criteria of this algorithm, and observe that more than 90% of the sites being higher than 6m were successfully detected.

Currently, registers are compiled for remote or not easily accessible regions in Iraq, Iran, Syria and Turkey. Besides highly exact positions, these listings will for the first time record information of such physical parameters as size, height and (satellite) images of these sites. They will be input both to studies of settlement distributions and conservational issues.

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