COMPUTER ALGORITHM FOR ANALYSIS OF BEDFORM GEOMETRY

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Abstract

Sandy riverbeds are covered by periodic bedforms of different scales, from ripples to antidunes. Under certain flow conditions simultaneously more than one type of bedforms can occur - smaller bedforms are superimposed on bigger ones. The superposition of bedforms causes difficulties for determining individual bedform parameters. In flume experiments bedform data is averaged for entire flow field - sum of total lengths/heights is divided by number of present bedforms. This method has limited applicability to bedform field with uniformly shaped dunes over relatively mild sloped riverbed. If more accurate description of bedform geometry is required other methods for bedform description have to be utilized. This paper presents comparison of two methods for separating different scales of bedforms from Multibeam Echo Sounding (MBES) data: dune geometry components from the mega ripple component. One method determines manual decomposition of the MBES signal, and the other method uses computer algorithm developed for this purpose to calculate signal decomposition. Both methods are described and tested on multiple MBES data sets. As a first application of the separation method individual bedform parameters of bedforms are identified: more particularly wavelength and wave height of bedforms. Results from both methods are then compared in order to validate implemented algorithm logic in computer calculations. The described algorithm represents a more versatile option for accurate description of the shape of the complex bedform geometry, compared to conventional approach.

Keywords

Bedforms, computer algorithm, Multibeam Echo Sounding

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1 INTRODUCTION

When a unidirectional turbulent flow acts on a flat bed of non-cohesive sediments, complex interactions between turbulent flow, sediment transport and bed morphology give rise to various types of river bed configurations. A wide variety of bedforms is known to develop at an assortment of scales under unidirectional flow in rivers. There is general agreement in the literature that there are at least two distinct bedform scales formed in sand under unidirectional, lower-regime flow; relatively small scale ripples and relatively large scale dunes. Criteria to distinguish these two distinct bedform scales include (1) sediment caliber, (2) hydraulic roughness, (3) bed form shape or aspect ratio, (4) relevant length scale, (5) dimensionless excess shear stress (transport stage), (6) dimensional length, and (7) scaling with hydraulic system parameters, e.g. velocity, depth, sediment size, Shields' nondimensional shear, stream power, Froude number [1-4]. Dunes are the most common bed configuration in sand-bedded streams, forming in a range of sediment sizes from silt and sand through to gravel. Dunes in river flows determine hydraulic resistance, sediment transport, channel morphodynamics and hydraulic habitat for biota. They also often present a major problem for engineering structures (e.g., water intakes or discharges, pipelines, groynes, etc.) and may introduce severe restrictions to navigation. Knowledge of such phenomena, and of their effects on the flow characteristics, can greatly benefit the design of rivers and canals, estuarine and coastal modelling studies, flood studies, the estimation of the depth of erosion around structures and rates of sediment transport, etc. [1, 5].

Fig. 1 Dune field.

Experimental studies with medium to fine sand reveal that a number of dune states exist that are stable only between certain values of flow velocity/bed shear stress and sediment-size. For this reason, dunes developed in sand beneath steady flow have been well studied in laboratory conditions. In controlled laboratory conditions observation of dune field is relatively easy: after steady flow conditions have been established for given time period and dune field has formed water is drained from flume and measurement of dunes takes place. When measurement of dune field takes place in estuary or river, it is conducted in highly adverse environment: large areas covered in deep water have to be surveyed which is time consuming and eventually with time hydrological conditions change and exert forces on riverbed which change its morphology. Although dunes play significant role in river engineering and management their characteristics are not part of standard hydrological monitoring. Their presence may be noted during discharge measurements or occasional fathometer profiles, but bedform-mapping requires specialized equipment and data processing. In small hydrologic studies detailed channel topography can be measured using small boats with no built-in navigational hardware. Advances in development of measurement equipment led to invention of hydroacoustic equipment designed for data bathymetry data collection in riverine environment: multibeam echo sounders (MBES). This equipment has ability to collect data through the swath of acoustic beams which provide large coverage of the riverbed during mobile surveys (**Fig. 3**).

Data collected with multibeam contain hundreds of thousands of elevation points and that makes its analysis time consuming. Field datasets also contain large number of noise data due to vegetation cover, man-made trash, remains of constructions, etc. Noise data has to be identified and filtered out which can be done in post processing, but not to absolute amount. Also, rivers and estuaries have sloped beds which influence dune placing - reference plane cannot be established for entire dune field (*e.g.* as flume bottom) and has to be redefined for different parts of surveyed area. All of the above results in numerous man-hours needed for visual recognition of dune field in order to describe characteristics of dunes in natural environment. Purpose of this paper is to develop computer algorithm which uses pattern approach to decompose recorded riverbed profile into individual dunes. Proposed separation method identifies individual dune parameters: more particularly wavelength λ and wave height Δ. Results obtained from algorithm are then compared to conventional, visual pattern recognition method in order to validate implemented algorithm logic in computer calculations and identify its weaknesses and strengths.

2 FIELD SURVEY

A reach of the Drava River at Nemetin was chosen for study because it provided: (1) “pseudo-steady” flow conditions for duration of data collection of 10 to 15 hours; (2) natural flow environment undisturbed by presence of river training works; (3) extensive database of flow and bathymetry data collected since 2006; (4) good logistics with a boat launch adjacent to the data collection reach (**Fig. 2**).

Fig. 2 Surveyed Drava River reach with defined longitudinal profile (magenta).

In 2012 3D riverbed morphology of dunes was collected on longitudinal profile with MBES (**Fig. 3**). Longitudinal profile was selected in such way that passes through high velocity filaments of river cross-sections where dunes of highest magnitude arise. Survey was conducted on 2 km long river reach of which upper section is in natural conditions and lower section in man-made river cutoff (**Fig. 2**). This reach is suitable for development of computer algorithm because of this various flow conditions - lowland natural flow in upper section with low mean flow velocity, accelerated flow on entrance in cutoff and high flow in narrowed profile of lower section. Distinct flow conditions of these two sections ensure that riverbed is not going to be covered with uniformly shaped dune, but with complex forms which are suitable for validation of logic programming introduced in developed algorithm.
Multibeam unit used for bathymetry survey was ODOM ES3 with an array of transducers that simultaneously transmit pings (sound pulses) at a specified frequency to cover a large area in short time. Multibeam ODOM ES3 uses swath of 420 acoustical beams, with up to 3° width each, transmitted towards bottom in direction perpendicular to boat orientation (**Fig. 3**).

a) b)

Fig. 3 Multibeam echo sounder: a) boat mount, b) operation scheme.

Transmitted signal reflects from hard bottom and returns in active transducer sensors which calculate distance traveled through equation:

$$l = \frac{t}{2} \cdot v \text{ [m]}, \tag{1}$$

where: l - distance traveled by acoustic signal [m], t - elapsed time [s], v - measured sound velocity in water [m/s].
Width of region ensonifed by swath of beams is dependent of water depth, with maximum of 80 m at water depth of 60 m and sector size of 120°.

3 PATTERN RECOGNITION METHODOLOGY

Bathymetry data collected with MBES consist of numerous points defined in wide band along boat track. In order to analyze profile of dune covered riverbed this data has to be defined as longitudinal profile perpendicular to dune crests. Therefore, section through collected data was defined with vertical plane through defined idealized longitudinal profile (**Fig. 2**). Since

defined profile isn't straight, longitudinal profile is straightened in a way that distance between consecutive points is drawn following course of longitudinal profile.
Generally, dunes have an asymmetrical shape, with a long stoss side slope, sharp crest and short steep lee side slope causing a flow separation zone (**Fig. 4**). These descriptive characteristics were used as guidelines for definition of dunes geometrical characteristics. Both visual pattern recognition method (VM) and algorithm pattern recognition method (AM) used three characteristic points for dune description: stoss toe P1(X1,Y1), brink point P2(X2,Y2) and lee toe P3(X3,Y3).

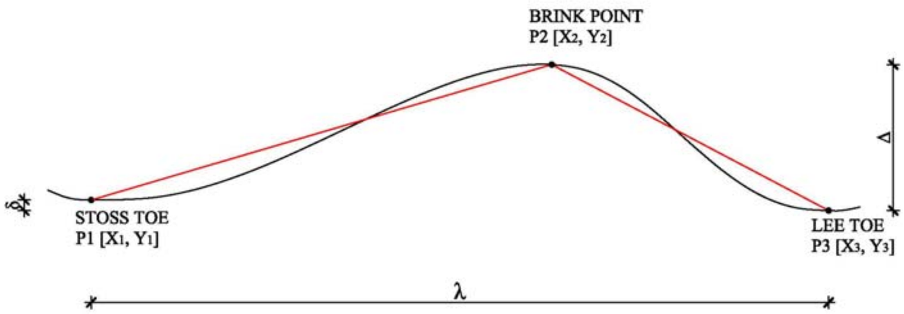

Fig. 4 Idealized dune profile with characteristic points.

VM method consisted of manual definition of dune geometry with drawing of individual polylines through points P1, P2 and P3 successively. These points are defined through visual inspection of distorted longitudinal profile with regard to defined boundary conditions. Set of defined boundary conditions included minimum dune length λ_{MIN}, minimum dune height Δ_{MIN}, and maximum vertical difference δ_{MAX} between two toes, P1 and P3. Dune characteristics were calculated from geometrical characteristics of lines describing dune. Dune length was calculates as absolute distance between points P1 and P3, and dune height as distance from point P2 to its orthogonal projection on line P1P3.
AM method used logic programming algorithms introduced by authors to define dune geometry. Dunes were also described with three points as in VM method. Input in AM method is extended to include minimum number of points defining stoss slope n_U, and lee slope n_D (**Fig. 5**). Minimum number of points that define slopes is used for elimination of noise data that have small number of points that reflect triangular geometry similar to dune.

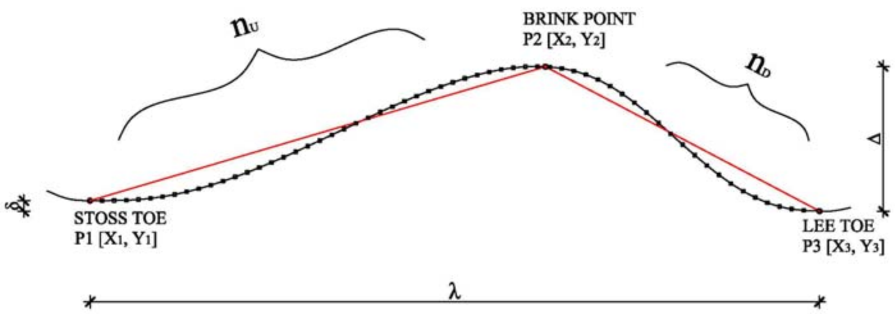

Fig. 5 Dune profile as "seen" by AM method.

4 RESULTS

Characteristics of dune field are determined with VM and AM method for two surveys, S1 and S2. Comparison of determined characteristics of dune field with VM and AM method is shown graphically. Histogram of recognized dune lengths is given on figure (**Fig. 6**), with S1 values in top row and S2 values in bottom row. Algorithm recognized significantly more dunes than visual method for both surveys: 362 to 107 on survey S1 and 320 to 82 for survey S2. Next figure shows histograms of recognized dune lengths (**Fig. 6**). Recognized dune lengths for both methods are found in same span (3 m to 25 m for survey S1 (**Fig. 6**a; **Fig. 6**b) and 3 m to 10 m for survey S2 (**Fig. 6**c; **Fig. 6**d). AM method defined more dunes for both smaller and longer dune lengths, though this difference is more pronounced in range of dunes shorter than 11 m.

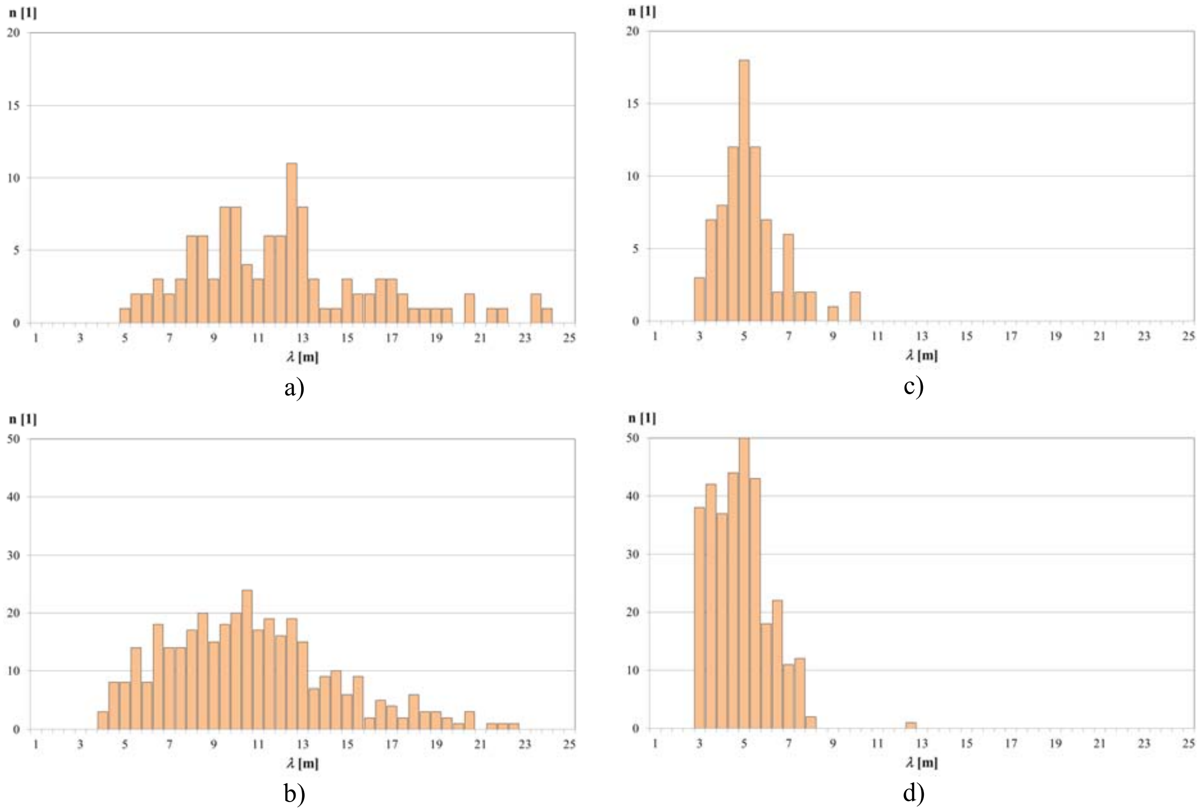

Fig. 6 Histogram of dune lengths for survey: S1 [a) VM; b) VA] and S2 [c) VM; d) VA].

Second survey (S2) is conducted in conditions of lower discharge and smaller water depth, which resulted in significantly shorter dunes recorded than ones on survey S1, while total number of dunes is approximately the same. Next figure (**Fig. 7**) gives comparison of dune lengths defined by two methods, VM and AM. There is visible good alignment of data for second survey, while first survey has more scatter in data. Generally, significant scatter is present for dune lengths that weren't recorded on second survey, while best alignment is present for smaller dune lengths that weren't recorded on first survey. For situation when VM method defined longer dunes there is significant gap between outlier values and ones placed next to line of agreement (**Fig. 7**). When VA method defined longer dunes outliers are placed closer to line of agreement.

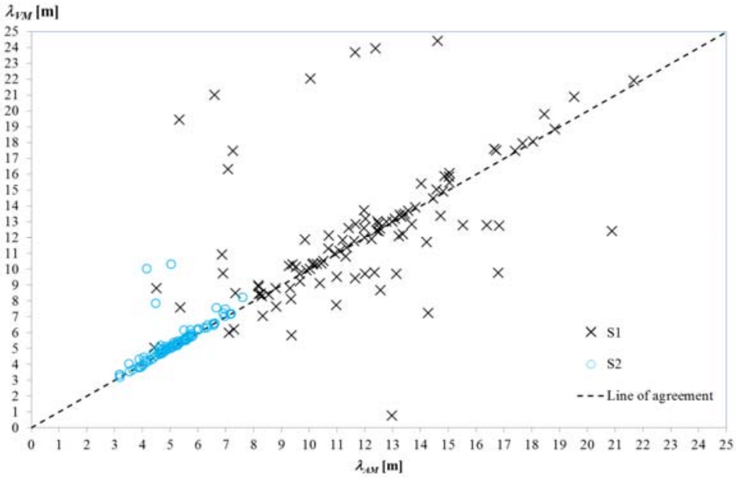

Fig. 7 Comparison of dune lengths for surveys S1 and S2 recognized by VM and VA method.

Identified outliers positioned above the line of agreement on scatter plot (**Fig. 7**) are isolated on next figure (**Fig. 8**). Discrepancy between AM and VM method occurs when dune has two (or more) peaks. If both peaks are defined with more than minimum number of points n_U and n_D AM method defines both of them as dunes and takes their dimensions into calculation. VM method, on the other hand, in these cases recognizes only one dune, dismissing the smaller one (pointed out with arrows on **Fig. 8**). In such cases dune defined with VM method is longer than the two dunes which defined VA method.

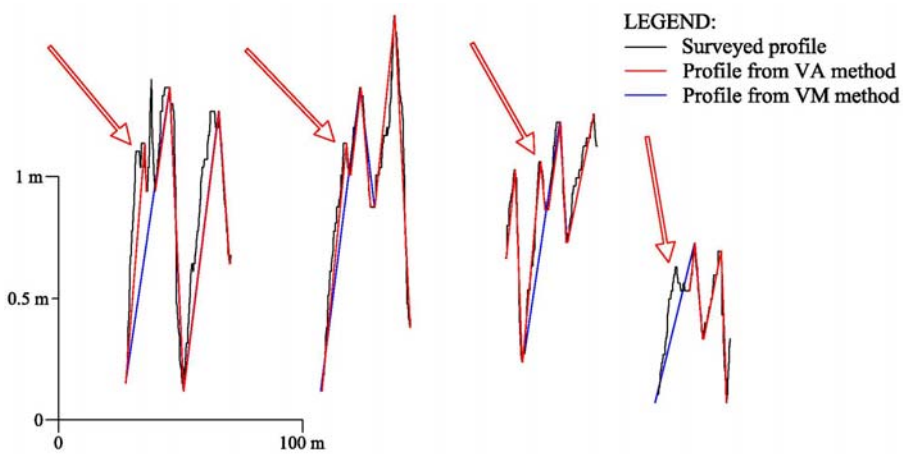

Fig. 8 Identified outliers in profile.

Outliers positioned below the line of agreement on scatter plot (**Fig. 7**) originate from similar discrepancy in pattern recognition approach between VM and AM method when lee toe of dune is located on long slope that ends in a depression. AM method then calculates this geometry as for normal dune while VM method filters this dune so that stoss toe and lee toe are in same level, resulting in shorter dune lengths. In this case difference between calculated lengths by two methods is not as large as for first group of outliers.

Next figure shows histograms of recognized dune heights, which are found in same span for both surveys (0.15 m to 1.20 m for survey S1 (**Fig. 9**a; **Fig. 9**b) and 0.10 m to 0.60 m for survey S2 (**Fig. 9**c; **Fig. 9**d). AM method defined more dunes for both smaller and longer dune lengths, though this difference is more pronounced in dune range smaller than 0.40 m.

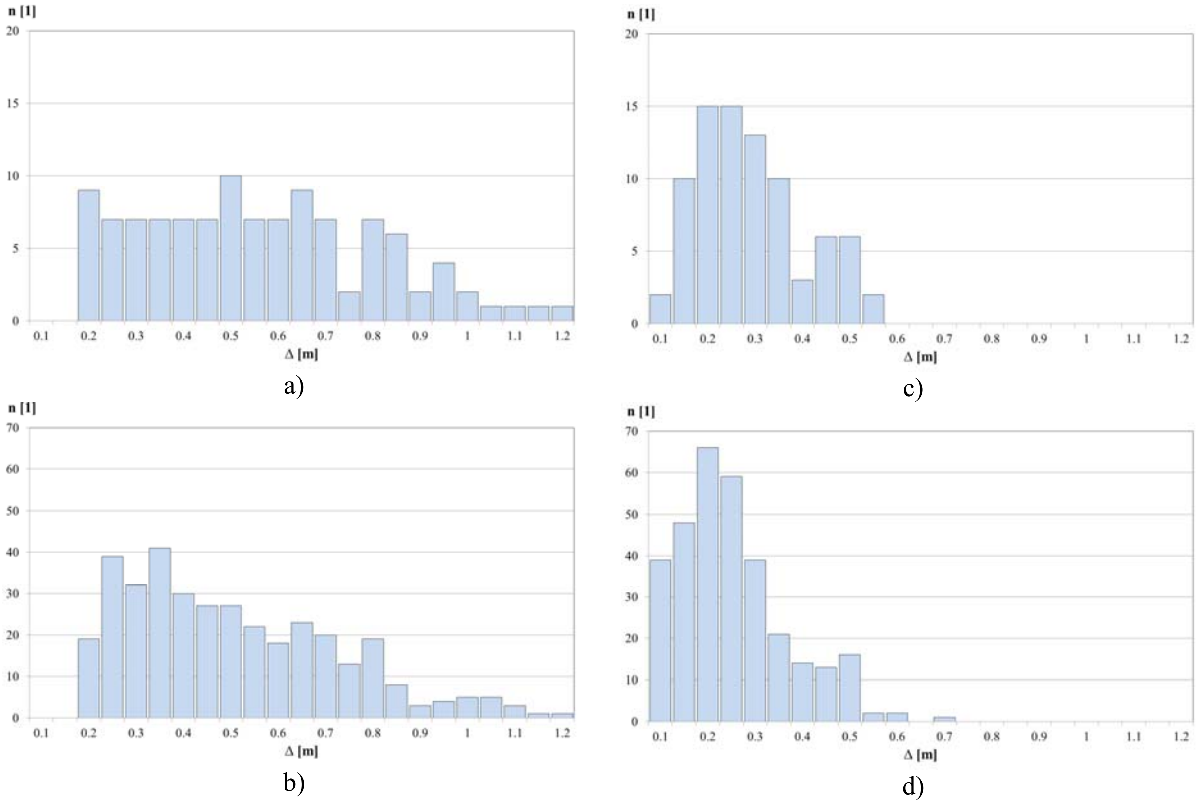

Fig. 9 Histogram of dune heights for survey: S1 [a) VM; b) VA] and S2 [c) VM; d) VA].

Next figure (**Fig. 10**) gives comparison of dune heights defined by two methods, VM and AM.

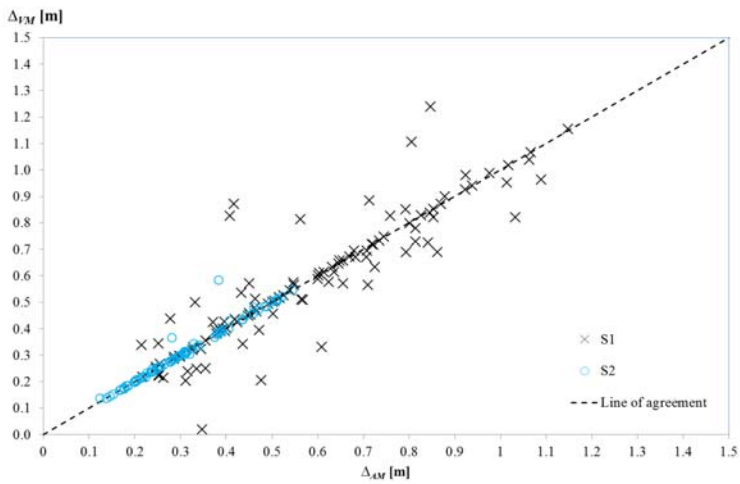

Fig. 10 Comparison of dune heights for S1 and S2 recognized by VM and VA method.

Discrepancy of dune height data around line of agreement (**Fig. 10**) is smaller than for dune lengths (**Fig. 7**). Better agreement between data is for survey S2, as for dune lengths. Origin of identified outliers is same as ones described for dune lengths: outliers positioned above the line of agreement on scatter plot (**Fig. 10**) occur when dune has two (or more) peaks; outliers positioned below the line of agreement originate when lee toe of dune is located on long slope that ends in a depression. Number of outliers above and below line of agreement and their distance is of same order of magnitude.
Next figure shows scatter plot of dune height to length ratio for both surveys (**Fig. 11**). There is no visible relationship between them, and threshold for dune steepness is approximately 0.12 (red line).

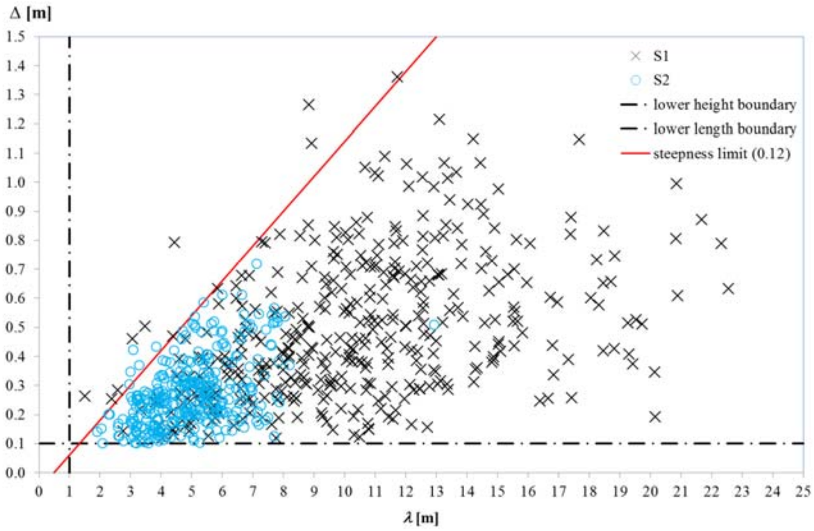

Fig. 11 Relationship between dune lengths and heights for S1 and S2.

Lower limits for dune heights and lengths are drawn in dash-dot lines. Recognized data for heights lies on this boundary, which implies that there is possibility of existence of smaller dunes. Recognized dune lengths are well above set limit of 1 m, *i.e.* there are no dunes shorter than 2 m in both surveys. Since pattern recognition with lower limits set at λ_{MIN} = 1 m and Δ_{MIN} = 0.1 m describes longitudinal profile well (**Fig. 12**) it can be assumed that there is no dunes with Δ smaller than 0.1 m and that smaller forms are ripples or dunes in beginning of forming.

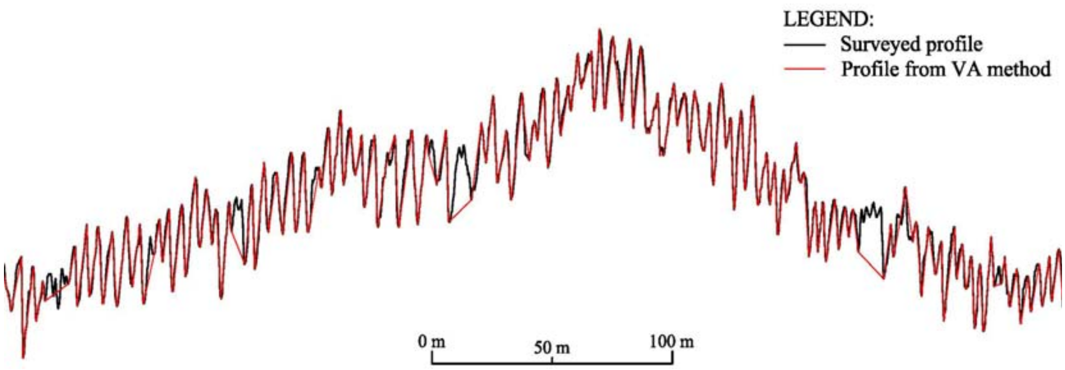

Fig. 12 Surveyed longitudinal profile vs. profile pattern from algorithm method.

5 CONCLUSION

Conducted research has shown applicability of developed algorithm for description of dune geometry from longitudinal riverbed profile. Dunes recognized with both visual and algorithm method show strong correlation for both dune lengths and heights. Limitation of algorithm are dunes with two brink points distant enough to have large number of points between them which cause algorithm to describe it as two smaller dunes. Visual method is heavily influenced by biased judgment of researcher outlining the dune profile. Pattern approach in visual method is has to be done on distorted profile which makes recognition of single dunes more difficult. Developed algorithm can be used as first iteration in pattern recognition of dune profile, because it can filter out noise data quickly and produce reliable and fast approximation of riverbed profile. Results from algorithm method then have to be supplemented by visual inspection in order to correct recognized dunes with two peaks.

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