Land border permeability and irregular migration using geospatial intelligence from satellite data

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***Abstract*—Prediction about how migrants move in the pre-border terrain is important for effective border control. In this paper we present a method to obtain permeability indicators for accessibility and concealment on the basis of geographical terrain features, derived from high resolution satellite data. The indicators are used to estimate the mobility of migrants. A model to predict the density of migrants arriving at the border, and to assess the impact of security measures, is introduced and discussed. The model was implemented and tested. The results are used as value adding products in pre-operational services for border control. Validation has to be done using actual irregular-border-crossing geo-oriented statistics. By the time this paper was written no such statistics were available.**

***Keywords*—Border control; irregular migration; geospatial intelligence; border permeability; satellite monitoring.**

I. Introduction

The development of a European Border Surveillance System (EUROSUR) is relevant for EU border security. The system comprises three main objectives: preventing cross-border crime, contributing to protecting migrants' lives, and preventing irregular migration. The system will be used by FRONTEX (the European agency for the security of external borders) together with EMSA, EUSC, and the National Coordination Centres of the member states. Operational use of the system requires a so-called Common Pre-(EU) frontier Intelligence Picture (CPIP) [1]. This information may be shared through a distributed network with dedicated border control geo-oriented applications at each node [2].

This intelligence component aims to locate vulnerable areas of the border, taking into account the human as well as the physical terrain. The human terrain comprises social, cultural, behavioural and organizational aspects [3], such as the distribution of population, its attitude towards migration, legitimate commerce, and organised crime. The physical terrain comprises aspects of the environment which influences movement of migrants such as the ease of walking or driving (which is determined by the relief and landscape type, the presence of roads or paths, and ground suitability), the facility to hide (the presence of forests, canyons, and other suitable vegetation types), and the distance to ground surveillance infrastructure [4].

To produce a CPIP accurate mapping and monitoring of the border region is required in order to obtain up-to-date land use and infrastructural information. An important information layer in the CPIP indicates areas vulnerable to border crossing, also summarised as border permeability. A number of studies have addressed the issue of border monitoring and assessment of the border permeability with respect to irregular migration [3,5,6]. In these studies three topics are studied, that influence the border permeability: i.e. accessibility, hiding or concealment, and security.

The GMES Border Surveillance Concept of Operations (BS CONOPS) (http://ec.europa.eu/enterprise/) indicates three land phases for the strategic, operational and tactical level. In the first two phases up-to-date information about the CPIP has to produced, while at the tactical level information about the actual presence of potential irregular migrants is to be produced, including meteorological information. The GMES (Global Monitoring for Environment and Security) programme is currently known as Copernicus.

In the EU 7th Framework Programme, the project LOw time critical BOrder Surveillance (LOBOS) studies the production of such information as pre-operational services using satellite imagery based on the BS CONPOS. The activity comprises updating of reference maps and new ambient feature alerts. The high time critical counterpart, the project Services Activations for GRowing Eurosur's Success (SAGRES) focus on punctual monitoring of immediate pre-frontier or 3rd country specific locations, ports and beaches, and on producing near real time intelligence.

In this paper we focus on the use of geospatial intelligence from the physical terrain based on high-resolution satellite imagery for the Pre-Border Zone (PBZ). For the PBZ detailed information is required that contributes to the CPIP, such as vulnerability of this PBZ for crossing. Goal of the study is to define and assess permeability information derived from high-resolution satellite imagery that can be added as additional layers in the pre-operational services.

II. Method and results

We follow the approach introduced by Stephenne et al. [5], i.e. we take into account three indicators which influence the physical terrain permeability: accessibility, concealment (hiding) and security. For the first two type of indicators the principles of military terrain analysis apply, while the third kind is based on active security measures, e.g. observation points, check points and man-same barriers, such as fences and walls.

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Basically terrain analysis is based on five categories of terrain features: transportation, population and urban infrastructure, hydrology, land use and geographic relief. The Multinational Geospatial Co-production Programme (MGCP) aims at the worldwide production of a (military) geo-information reference data-set with scales of 1:50.000 or 1:100.000 and has set a standard in the description of terrain features (DIGEST, http://www.dgiwg.org/) which is adopted here as a basis to produce the permeability indicators.

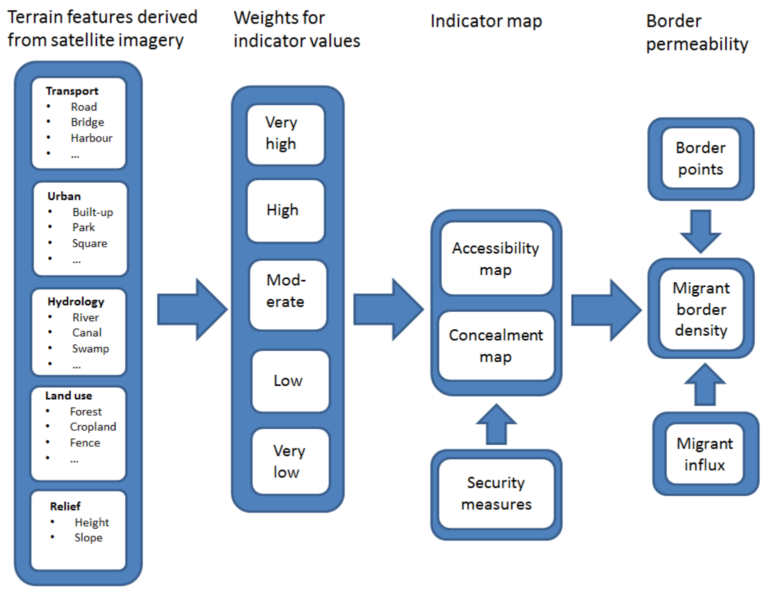

Fig. 1 Workflow for producing indicator maps from terrain features and the border permeability.

Examples of terrain features are road (AP030), build-up area (AL020), river (BH140), fence (AL070) and forest (EC3030), where the DIGEST code is given within the brackets. Geographic relief information is based on digital terrain elevation data (DTED), e.g. derived from the SRTM mission [7].

In this study we present an analysis of the permeability indicators for a CPIP with scales down to 1:5000 where the terrain features are derived from high-resolution satellite imagery with resolutions of 1 to 5 meter, such as SPOT5 (VHR) multispectral data.

To derive the accessibility and concealment indicators we have developed procedures for processing the terrain features into indicator values for accessibility and concealment. Figure 1 shows the global workflow.

Each terrain feature is assigned to an indicator value in the model, which is specified in five categories from very high to very low. Slope and height value ranges are also specified for a specific indicator value. The procedures for the accessibility and concealment indicators are comparable, but obviously different indicators values are assigned to the terrain features. Assignments are done by terrain analysts with experience on border control. Models have been made flexible so that assignments can easily be adapted based on progressive insight. In Figure 2 we show sample data for an anonymous border region.

In Figure 2 only the data for the PBZ (here a buffer of a few kilometres wide) is elaborated, where the border is to the left. The indicator values are considered here as friction values, expressing a measure of difficulty to traverse the PBZ. For example forest is not easy to pass through so a high accessible indicator value is applicable, while concealment is easy in forest giving a low concealment indicator value. The indicator values used are on a scale 0-100 (see colour bar in Figure 2).

The accessibility and concealment indicator maps give more direct insight in how easy migrants may move in the PBZ compared to a topographical reference map and are therefore useful layers to add to the pre-operational service products for the CPIP. For these services we have implemented the procedures into ArcGIS ModelBuilder so that these indicator maps can automatically be calculated on basis of the reference map data.

For effective border control and to be able to apply security measures it is necessary to predict where migrants will show up at the border line itself. The accessibility and concealment indicator maps allow computation of the density of migrants arriving at the border depending on the influx of migrants at the far-side of the PBZ.

Therefore we have developed a border permeability model (see Figure 1 to the right) for assessing the density of migrants arriving at the border A_j at location j by integrating the contributions of influx of migrants at the far-side of the PBZ which has been modified by the amount of friction in the PBZ (see Equation 1).

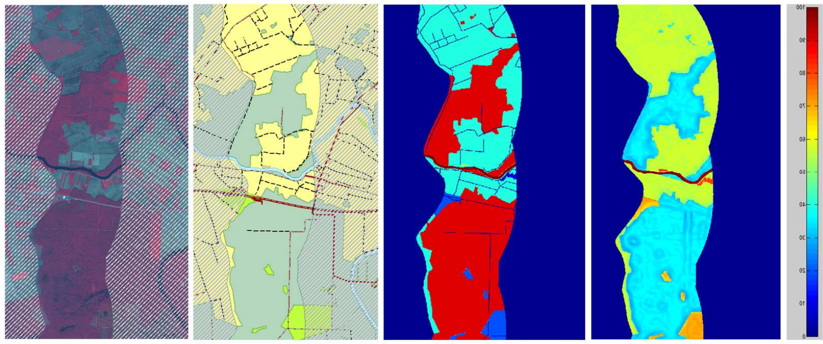

Fig. 2. Sample data for a PBZ. From left to right: SPOT5 false colour data, the reference map, the accessibility and concealment indicator values, and a corresponding colour bar.

In this model we calculate how much travel time T_{ij} it takes from a far-side departing point i to a border point j where the travel speed is reduced by a friction parameter *F(s),* which is a function of the indicator map values along path s though the PBZ. This function contains parameters that have to be derived from expert knowledge of the specific situation at the border area. The density at arrival A_j is the weighted sum of all contributions from the far-side departing points, where a weight is inversely proportional to the travel time:

$$A_j = \sum_i W_{ij}\, D_i\,, \quad W_{ij} = {}^{1}\!/_{T_{ij}}\,, \quad T_{ij} \propto \int \frac{ds}{F(s)} \qquad (1)$$

Here the integral is along the path through the PBZ which gives minimum travel time between the departing location i and arriving location j. Obviously only departing points D_i at the far side of the PBZ contribute, which are more or less opposite to the border point of consideration. In the summation we therefore consider only departing points belonging to a limited far-side segment, which has a length corresponding to the width of the PBZ. This part of the model, i.e. assessment of migrant densities at the border based on the indicator maps, is implemented in MATLAB®.

In Figure 3 (left panel) we show the accessibility indicator map with a number of border points (yellow crosses) which were assessed. Also shown in Figure 3 (middle panel) for one border point (red dot) is a travel time map, where the values indicate how much time it takes to reach the border point. For the calculation described above only the travel times for the departing points at the far-side segment of the PBZ are relevant.

In Figure 3 (right panel) we show the summation result giving the (relative) density based on the accessibility indicator map. The influx of migrants at the far-side of PBZ is assumed to be uniform. In reality this influx depends on the political, economic, social, technological, legal, and environmental situation outside the EU border, which is not considered here since this topic is outside the scope of this paper.

The higher the density the more permeable the border is. Figure 3 clearly shows that the more permeable border points are due to the low friction in the PBZ (blue areas to the north and in the middle of the indicator map). In the middle of the PBZ a river is present which is difficult to cross. This explains why the density is locally lower near the river area. In the travel time map this becomes clear, it takes large travel times to reach the border points located south of the river from the area north of the river.

Permeability of the border can be reduced by security measures such as an observation post. Using the border permeability model we can assess the impact of the presence of such posts. Therefore we also take into account the concealment indicator map for the area which has line of sight with the observation post, in addition to the accessibility indicator. Treating the friction due to concealment in the same way as due to accessibility, we can combine both indicators maps into one combined map.

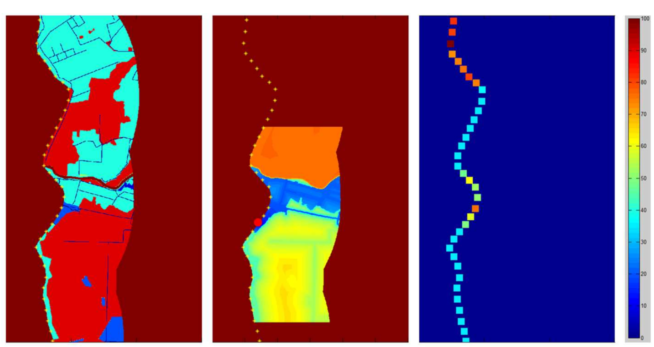

Fig. 3. The accessibility indicator map for the PBZ and border points (yellow crosses) used in assessments (left panel). A travel time map for one border point (red dot, middle panel), and the relative density of arriving migrants at the border (right panel).

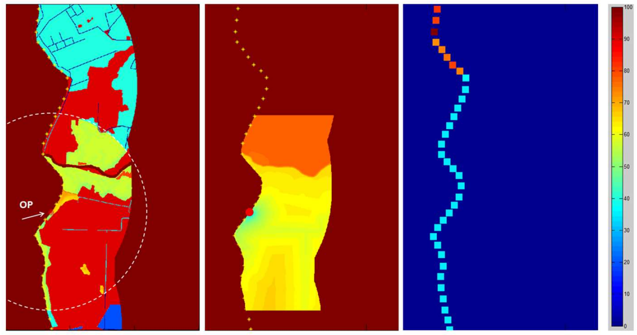

Fig. 4. The combined accessibility and concealment indicator map for the PBZ and border points (yellow crosses) used in assessments (left panel).The position and influence of the observation post is also indicated. A travel time map for the border point coinciding with the OP (red dot, middle panel), and the resulting relative density of arriving migrants at the border (right panel).

In Figure 4 (left panel) we show this combined accessibility and concealment indicator map with the observation post (OP) indicated. The influence of the concealment is visible in the area of the PBZ near the OP when it is compared to the indicator map in Figure 3. The influence results in larger travel times (see travel time map, Figure 4 middle panel). Using the border permeability model we have calculated the (relative) density based on the combined map (Figure 4, right panel). The density is reduced in the area near the observation post. Again, this becomes clear when it is compared to Figure 3.

III. Validation

To validate the border permeability model and implementation, the results should be compared to actual irregular-border-crossing geo-oriented statistics about migrant flows and densities. For example, Rossmo et al. [8] have analysed data for the US-Mexican border to derive geographical patterns which can be related to terrain features. Such information can be used to evaluate the weighting parameters in the indicator map procedures and permeability models. Statistics that are used in this study are obtained from the US Border Patrol ENFORCE system where data is geotagged with border distance markers.

IV. Conclusions

We have implemented a method for assessing the ease of movement of migrants in the terrain. Using this method we have produced accessibility and concealment indicator maps which can be added as layers to services for reference products for border control. We have developed a border permeability model that uses these layers as input and that can be used to assess the impact of security measures. Parameters in the method and model will be derived from expert knowledge of the actual situation in the border area.

With that we have presented a number of information elements that add value to pre-operational services for EU border control, now studied in the EU Seventh Framework Programme. The added products help the border guards to assess how migrants will move in the pre-border terrain and where migrants may show up at the actual border, so that more effective control measures can be applied.

Validation of the method requires actual irregular-border-crossing geo-oriented border statistics, preferably shared by the EU member states using a standardised data collection system. By the time this paper was written no such statistics were available.

Acknowledgement

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