The Urban Footprint Processor – Concept and Implementation of a Processing Chain within the TanDEM-X Mission

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Abstract

The TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) mission acquires two complete coverages of the earth's surface of the years 2011 and 2012 to generate a global digital elevation model (DEM). This unique dataset, acquired in the context of the TanDEM-X mission, provides new possibilities for additional analyses, such as the mapping of human settlements. Therefore, the Urban Footprint Processor (UFP) is developed at DLR to generate a global map of human settlements based on TanDEM-X data from 2011 and 2012. This paper focuses on the technical concept of the UFP processing system and its implementation.

1 Introduction

The TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) mission acquires two complete coverages of the earth's surface in the years 2011 and 2012 to generate a global digital elevation model (DEM) with unprecedented accuracy and resolution of about 12m x 12m. Additionally, the immense amount of data, acquired in the context of the TanDEM-X mission, provides an excellent opportunity for additional, global analyses, such as a worldwide inventory of human settlements.

The mapping of human settlements has gained more and more importance due to increasing and rapid global urbanisation and the various effects of this development. Earth observation sensors have shown their purpose for an area-wide and up-to-date mapping of human settlements. [1] stated the benefit of remote sensing systems to monitor urban land use processes and to analyse their influences on economic, social, and political systems.

Different projects have made available global maps of urban extent at a resolution of up to 300 m. [2] discusses various global maps of human settlements and their accuracy. Based on these global maps it is possible to identify and localise problems or trends of urbanisation and to develop strategies for sustainable development of cities.

The current global maps are based on images of optical sensors, but radar sensors have also shown their suitability in the context of mapping urban areas [3]. Therefore, the German Aerospace Center (DLR) deploys the potential of the TanDEM-X mission and develops the Urban Footprint Processor (UFP) to generate a global binary map of human settlements of the years 2011 and 2012 – the Global Urban Footprint (GUF).

2 The Urban Footprint Processor (UFP)

The Urban Footprint Processor (UFP) is subdivided into two main processing stages: The Basic Product Generation and and the Final Product Generation.

Within the Basic Product Generation, four processing steps are accomplished: An Amplitude calculation, a texture analysis to derive a Speckle Divergence image, a classification step to extract vertical urban structures and a multilooking step to reduce the immense amount of data. This first stage takes place fully inline with the DEM processing and lead to three image components, which are described in more detail in section 2.1.

The second processing stage (Final Product Generation) is a post processing step, in which the final result – the Global Urban Footprint (GUF) – is generated. This processing stage consists of four processing steps again: A generalisation is performed, which takes all image components of the first stage into account, to delineate a binary map of human settlements. Additionally, the Final Product Generation includes the geocoding of the generalised binary map and applies a slope correction based on a global DEM to eliminate false classifications in the map induced by highly textured mountainous regions. A mosaicking step merges various GUF maps of predefined spatial extent together. The final Product Generation is described in more detail in section 2.2.

The setup of the processor and its particular components is presented in **Figure 1**. Note that the basic image components are multilooked to a ground spacing of 4 m and a resolution of 8 m. The final product will be made available as a public domain product and will therefore have a resolution of 3 arcsecond, which corresponds to a resolution of about ~75 m.

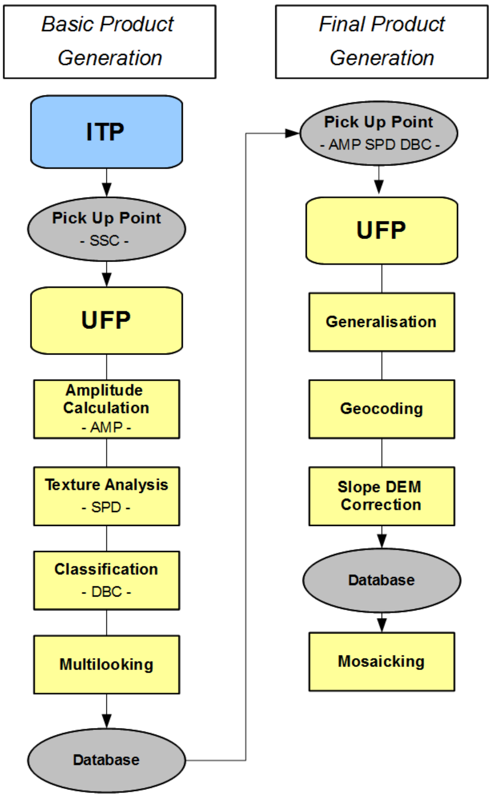

Figure 1: Setup of the Global Urban Footprint Processor (UFP).

2.1 The Basic Product Generation

Output of the Basic Product Generation are three image components: An Amplitude image (AMP), a Speckle Divergence texture layer (SPD) and a classification of distinct backscattering clusters (DBC). These layers are generated based on Single Look Slant Range Complex (SSC) image products of the TanDEM-X mission (single polarized HH and StripMap mode). The different image components are shown in **Figure 2-4** and depict exemplarily a inner-city area of Accra (Ghana). The highly detailed information of all layers can be seen in a 4 x 4 km section.
The SSC images are provided by the Integrated TanDEM-X Processor (ITP), which performs the interferometric analysis for the Global DEM [4]. A minimum of 400 SSC products per day are delivered to a seperate pick up point, from where the images are moved to the UFP cache. To save storage space and to reduce the amount of network transfer, this processing stage is performed fully inline with the ITP processing. All SSC products, which are acquired by the master satellite and are used to generate the global DEM (first and second coverage of the years 2010 and 2011), are delivered to the UFP. After finishing the Basic Product Generation for one SSC, the image components are stored in a geographical database.
Mention, that the Basic Product Generation is put fully into operation and has already begun to process the global TanDEM-X dataset. In the following two sections the main processing steps of the Basic Product Generation are described:

2.1.1 Amplitude Calculation, Texture Analysis and Cassification

[5] developed a pixel based classification approach, which is implemented in the UFP, to analyse speckle characteristics and to seperate highly structured urban areas from homogenous image regions.
In a first step the UFP derives an Amplitude image (AMP) by analysing the Real and Imaginary part of the complex information, which is stored inside a SSC image. SSC products are not radiometrically enhanced and show therefore unmodified characteristics of speckle development. This is the main reason for applying the classification methodology to the SSC images.
Based on this Amplitude image a Speckle Divergence texture image (SPD) is calculated by applying the local coefficient of variation. It can be calculated by analysing the local standard deviation versus the local mean in a moving window approach [6].
Thresholds are applied to every pixel in both the Amplitude and Speckle Divergence images to depict bright point targets in a heterogeneous environment, which represent distinct backscattering clusters (DBC). The resulting image provides point-wise information, which indicates the appearance of vertical structures within urban areas.

2.1.2 Multilooking

The multilooking step is carried out for two reasons: First of all to reduce the amount of data, which has to be processed and stored in the database, and secondly to create nearly square pixels on the ground.
The SSC image products are acquired in slant range imaging geometry and are featured by a slant range resolution of 1.2 m. This results in a pixel spacing in azimuth of about 2.0 m and a range pixel spacing of about 0.9 m. The complex representation of the dataset and the high resolution lead to an immense amount of data: To analyse a minimum of 400 products per day already an amount of 1 TB image data has to be handled.
The multilooking procedure to prepare the three image components (AMP, SPD and DBC) is as follows: The Amplitude calculation, the texture analysis, and the classification, itself is based on the full resolution information of the SSC products. Then the pixels of the full resolution layers, which are stored in slant range geometry, are projected to nearly square pixels on the ground. This approach lead to a pixel spacing of 4 m in azimuth and 4 m in ground near range and to a resolution of 8 m.

All image components of the Basic Product Generation are stored again in slant range geometry. Due to this reason a slight distortion in range direction occurs. This effect is fixed in the final product by applying a slant to ground range projection within the geocoding processor. After multilooking the file size is reduced to ~500 MB per product (compressed ~250 MB), which is a reduction of 75 % compared to the original SSC.

2.2 The Final Product Generation

The Final Product Generation prepares the GUF product, which is a geocoded binary representation of human settlements. This processing stage is a post processing stage, which takes all all three image compoenents of the Basic Product Generation into account: The image components AMP, SPD, and DBC are copied from a geographical database to a pick-up point, from where the next processing stage is executed. Within this stage there are three processing steps: A generalisation of the basic image components to derive a binary representation of human settlements, a geocoding step to project the binary layer to a square raster of the Universal Transverse Mercator (UTM), and finally a slope correction based on a global DEM. By making use of a geographical database different map tiles can be merged togther in the final mosaicking step.
The Final Product Generation is in its test phase and is therefore not yet fully operational. Therefore chapter 2.2 has to be seen as concept for further proceeding.

2.2.1 Generalisation

Main goal of the generalisation step is to derive the urban footprint based on the highly detailed image componenets of the Basic Product Generation. As explained in section 2.1.1 the DBC layer is calculated based on bright point targets (Amplitude information) and a heterogenous environment (Speckle Divergence texture image). Therefore the DBC is indicating mainly vertical structures within the urban landscape.
These vertical structures are represented as pixelwise informations and are leading to an information layer similar to a “point cloud”, which can be seen in **Figure 4**. To derive the final Urban Footprint image analysis techniques are applied to all three image components to calculate a generalised and extensive representation of human settlements.
The generalisation step can be based on a pixel based, as well as on an object oriented approach. To define the final global generalisation concept an established pixel based approach will be compared with an object based methodoloy, which is utilising a quad tree segmentation.

2.2.2 Geocoding and Slope Correction

The resulting binary map is geocoded by applying the geocoding chain of the TerraSAR multimode SAR processor (TMSP). Geocoded products are characterized by a horizontal accuracy of up to 1 m, if science orbits are used [7].
The most important benefit of the TMSP geocoding is that terrain induced distortions can by corrected by considering a global DEM of the Shuttle Radar Topography Mission (SRTM). The binary Urban Footprint map is projected to the UTM system based on the WGS84 geodetic datum.
The final GUF map contains false classifications, which are caused by highly textured areas and occur especially in mountainous regions. The main goal of the slope correction step is to eliminate these false classifications. Thus the slope of hillsides or other steep terrain is analysed by using the same DEM, which is used for the geocoding processor. A high slope value indicates the appearance of mountainous areas and indicates therefore false classifications in the map.

2.2.3 Mosaicking

Every geocoded Urban Footprint covers an area of about 50 km x 30 km. Goal of the mosaicking step is to merge GUF tiles of predefined geographical areas together, which can be done easily by making use of the UTM projection. A specific area of interest can be defined by the user to generate GUF maps of selected regions worldwide. All tiles within this selected area are mapped together by using both time intervalls of 2011 and 2012. **Figure 5** presents the final mosaicked GUF product, which is focussing an area of 60 x 50 km of the metropolitan area of Accra (Ghana).

3 Conclusion and Outlook

This paper presented a processing chain to map human settlements from world-wide SAR data. With this processing chain, DLR will provide a global map of human settlements based on the data of the years 2011/2012 with an unprecedented resolution. The final product will be made available as a public domain product with a resolution of about ~75m.
Thus the Global Urban Footprint will be an up-to date geoinformation layer and will be suitable to address different scientific questions in the field of urban analysis and land-use planning. Different studies show promising results by applying the Global Urban Footprint for the estimation of building density [8] or for spatio-temporal analysis of urban sprawl [9]. Future application will also focus on the research of urbanisation patterns and population assessment.

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Figure 2: Amplitude Image (AMP)

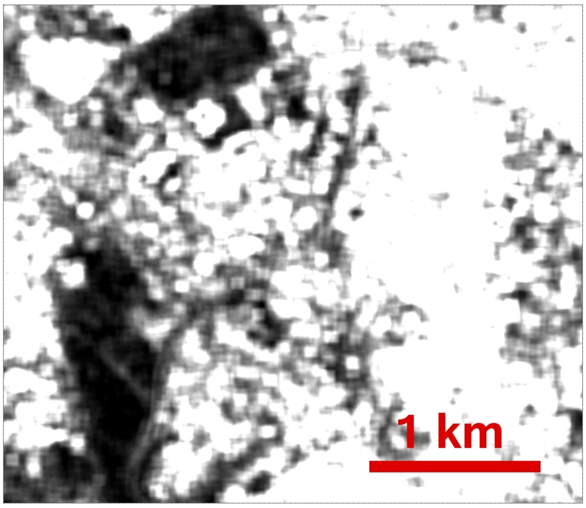

Figure 3: Speckle Divergence (SPD)

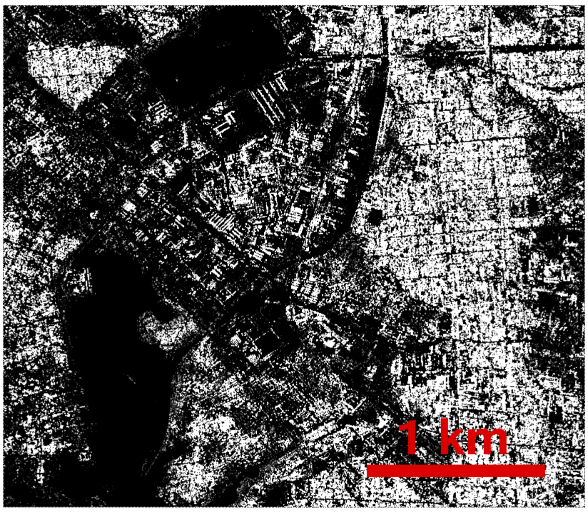

Figure 4: Distinct Backscattering Clusters (DBC)

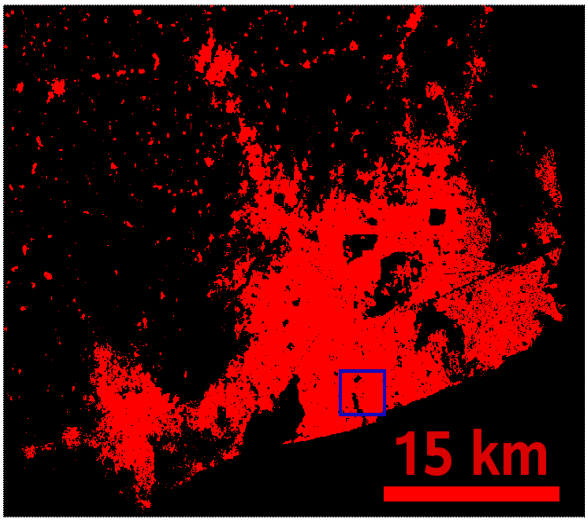

Figure 5: Mosaicked Global Urban Footprint (GUF)