DETAILED DIGITAL SURFACE MODEL (DSM) GENERATION AND AUTOMATIC OBJECT DETECTION TO FACILITATE MODELLING OF URBAN FLOODING.

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ABSTRACT:

This paper investigates the necessity of detailed surface representation in order to generate a feasible platform for the detailed simulation of urban runoff and surface flooding caused by heavy rainfalls. In recent years, urban flooding has become one of the major environmental hazards and it has caused damage to the buildings and properties over billion of Euros. Expansion of urban catchment areas mainly to cater for increased demand of accommodation, transportation and financial activities has resulted in complex and sprawling urban surface pattern. Behaviour of surface runoff and flooding caused by storms would also tend to be complex over this urban surface. Tackling excess storm water from huge urban catchment by sewerage system is not alone a feasible solution as there is always limitation of sewer pipe capacity. Provision of overland flow management within distinct surface features as well as good knowledge of surface characteristics is logically a potential option left to support detailed modelling and analysis of urban flooding. With this aim in mind, high resolution (<0.5 m) Digital surface model (DSM) has been generated from airborne LIDAR data. Special emphasis has been put on identifying each tiny element (Triangle/pixel) of generated DSM. A 'dual reciprocal approach' of model based and pixel based automatic object identification has been applied in order to successfully describe relevant surface characteristics in terms of rainfall-runoff and surface flow. In contrast to traditional LIDAR Digital Terrain Model (DTM) generation, attention will be paid to generate LIDAR DSM which is believed to simulate surface runoff more accurately as it considers rainfall interception by trees and direct input of water to sewer system from building roofs and other impervious surfaces.

1. INTRODUCTION

1.1 Motivation

Terrain models have always been a topic of interest to military personnel, planners, landscape architects, civil engineers, as well as other experts in various earth sciences. Originally terrain models were physical models, made of clay, sand and plastic. Since 1950's, the computer has been introduced into this area and the modelling of the terrain surface has since then been carried out numerically or digitally leading to the current discipline – digital terrain modelling. Digital terrain modelling is a process to obtain desirable models of the land surface. Such models have found wide applications in various disciplines such as mapping, remote sensing, civil engineering, mining engineering, geology, hydrology, land planning and communications. Therefore, digital terrain modelling has become a discipline receiving increasing attention.

Traditional methods fail for the purpose of simulating the complete flow process in urban areas as a consequence of heavy rainfall and as required by the European Standard EN-752 since the bi-directional coupling between sewer and surface is not properly handled. The new methodology, developed in the EUREKA-project RisUrSim, solves this problem by carrying out the runoff on the basis of shallow water equations solved on high-resolution surface grids. Exchange nodes between the sewer and the surface, like inlets and manholes, are located in the computational grid and water leaving the sewer in case of surcharge is further distributed on the surface. Dense topographical information is needed to build a model suitable for hydrodynamic runoff calculations; in urban areas, in addition, many line-shaped elements like houses, curbs, etc. guide the runoff of water and require polygonal input. Airborne data collection methods offer a great chance to economically gather densely sampled input data.

The core focus of this research project is to construct detailed surface representation of a large area to support urban flooding. 'Dual drainage' is a term mostly used along with urban flood simulation techniques where pipe flow and surface flow are combined. A number of literatures are available describing this dual drainage urban flood simulation model. In most of the cases, these works either cover very small part of surface area (Street cross section) or relatively big area having lack of adequate integration of GIS and remote sensing technique. In today's research in the field of Geosciences, Hydrology and Environmental science integration of remote sensing and GIS technology has put an immense impetus of exploring every possible aspect. This research aims to integrate advanced remote sensing technology (airborne LIDAR data) and some forms of field data within GIS boundary to better visualize and characterize large urban area as accurately as possible. This is to mention that, the goal of the research work is to support urban flooding i.e., to make a supplementary platform with detailed information to represent surface of a large area which will eventually act as an input to dual drainage flood simulation model.

1.2 Scope of the Work

Urban Flooding has become an important issue in urban drainage planning and operation. The proper design of drainage

systems and analysis of their hydraulic performance to assure or improve flood protection require accurate simulation models applying dual-drainage modelling based on detailed system data.

Current modeling and simulation techniques are based on a very detailed computer representation of the underground sewer network. They allow accurate sewer flow modeling by dynamic flow routing. At the same time, the surface data to describe relevant rainfall-runoff processes, being the driving force of urban flooding, are still very coarse. It has been recognized, however, that surface flow processes heavily affect the occurrence and extend of flooding both in terms of water levels and damage. Modeling of urban flooding therefore requires a much more detailed representation of the catchment area on the surface. Available surface data, however, are extremely heterogeneous, fragmentary and highly unstructured. Requiring innovative and efficient methods of data mining and processing, visualization techniques are a promising approach to generate an adequate data base for modeling and simulation of urban flooding.

The concept of urban drainage through minor system, i.e., underground pipes and major system, i.e., parts of street cross-section was introduced in the eighties in North America. When both of these sub-systems are used as storm drains in a controlled manner, this is commonly referred to as dual drainage.

In conjunction with the advances in simulation techniques (Tomičić et al., 1999), the developments in data acquisition and GIS technologies (Prodanović, 1999) have enabled explicit and more consistent treatment of minor-major system interaction. That leads not only to more technically sound design of both sub-systems, but also to more reliable simulation of urban flooding and analysis of the consequences (Schmitt, 2002).

1.3 Related Work/ Literature Review

Digital elevation models (DEMs) play an important role in terrain-related applications. Researches on terrain data collection and DEM generation have received great attention. Traditional methods such as field surveying and photogrammetry can yield high-accuracy terrain data, but they are time consuming and labour-intensive.

LiDAR data have become a major source of digital terrain information (Raber et al., 2007) and have been used in a wide of areas, such as building extraction and 3D urban modelling, hydrological modelling, glacier monitoring, landform or soil classification, river bank and coastal management, and forest management. However, terrain modelling has been the primary focus of most LiDAR collection missions (Hodgson et al., 2005). Actually, the use of LiDAR for terrain data collection and DEM generation is the most effective way (Forlani and Nardinocchi, 2007) and is becoming a standard practice in the spatial science community (Hodgson and Bresnahan, 2004). LiDAR has been studied since the 1960s (Flood, 2001). Researches and design on airborne LiDAR for topographic data collection started from the 1980s (Krabill et al., 1984; Bufton et al., 1991). Commercial airborne LiDAR systems have been operational since the mid-1990s (Pfeifer and Briese, 2007), and it continues to be an active area of research and development (Flood, 2001). There has been a significant increase in the use

of LiDAR data for DEM generation over the last decade as more reliable and accurate LiDAR systems are developed (Sithole and Vosselman, 2003). Lohr (1998) and Kraus and Pfeifer (1998) are pioneers who demonstrated the suitability of using airborne LiDAR for DEM generation. Since then DEM generation from LiDAR data under various conditions has been documented by many authors (Lloyd and Atkinson, 2002; Wack and Wimmer, 2002; Lee, 2004; Lloyd and Atkinson, 2006; Kobler et al., 2007). With LiDAR data, high-density and high-accuracy DEMs can be generated.

As an active remote sensing technology, airborne LiDAR data are free of shadow. As such, LiDAR has advantage over photogrammetry for DEM generation in urban areas as well. However, raw LiDAR data can contain return signals from no matter what target the laser beam happens to strike, including human-made objects (eg, buildings, telephone poles, and power lines), vegetation, or even birds (Barber and Shortrudge, 2004; Stoker et al., 2006). The desired target for DEM generation is bare earth points. Therefore, it is crucial to filter or extract bare earth points from LiDAR data. Various filter methods have been developed to classify or separate raw LiDAR data into ground and non-ground data. However, none of automated filter processes is 100% accurate so far (Romano, 2004). Manual editing of the filtering results is still needed (Chen, 2007). Efforts are still needed to improve the performance of filter algorithms. Airborne LiDAR technology is still developing rapidly in both sensor and data processing. The competition between LiDAR sensor manufactures is mostly focused on increasing laser pulse repetition rates to collect more data points. The pulse repetition rate has increased from less than 50 kH in 2001 (Flood, 2001) to 250 kH now (Lemmens, 2007). High-density data make it possible to represent terrain in much detail. However, high-density data lead to a significant increase in the data volume, imposing challenges with respect to data storage, processing and manipulation (Sangster, 2002). Although LiDAR data have become more affordable for users due to the gradual dropping of the costs of LiDAR data collection, how to process the raw LiDAR data effectively and extract useful information remains a big challenge (Chen, 2007). Furthermore, because of the specific characteristics of LiDAR data, issues such as the choices of modelling methods, interpolation algorithm, grid size, and data reduction are challenging study topics for the generation of a high quality DEM from LiDAR data.

The above described works are mainly related to LIDAR data processing in an attempt to make DTM or DSM as accurately as possible. There have been some works on the application of LIDAR data in the context of flood modelling. Very few of them have discussed applicability of LIDAR data to support flood modelling in a complex urban area. Schmitt et al., 2004 introduced the concept of urban surface detailing in a small area and connected it to urban drainage modelling. Norman, 2007 described detailing of complex urban areas including subtle surface distinction such as street, curbs and sidewalls. Haile and Rientjes, 2005 described the sensitivity of LIDAR DEM resolution on urban flood modelling.

2. MATERIALS AND METHODS

2.1 Test Data

The study area was part of Kaiserslautern University and its surroundings. Raw LIDAR (light detection and ranging) data

having spatial resolution of 0.25 m, was acquired form BSF SwissPhoto. It means that at every meter on the ground, we have got 4 points which is sufficient enough to describe many small surface properties apart from buildings and big objects. Other available supporting data are city polygon maps of buildings and streets, aerial imagery of 25 cm spatial resolution.

Figure 1: Aerial image of the study area

2.2 Model Generation

Figure 2 shows the main work flows of the research work. The work flow is mainly designed to develop a model which will take LIDAR data and other additional information as input and will produce desired surface model as output.
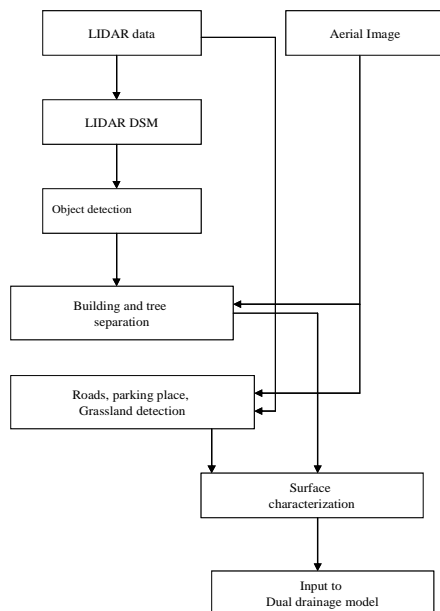

Figure 2: The work flow

2.3 Model Development

A morphological filter was designed based on the information of height and standard deviation to extract non ground objects such as building and trees. The objective of object separation

was to differentiate between buildings and trees and later object property attribution. The idea in mind was that the rain water falling on the roof top will go directly to the sewerage and in case of trees there will be initial interception before the water touches ground.
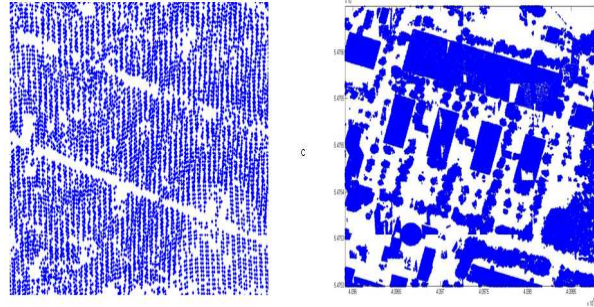

Figure 3: Objects (Buildings and Trees) extraction from LIDAR point cloud. Figure at the left shows Unstructured LIDAR data and figure at right shows extracted objects.

2.4 Object Clustering

After extraction of non ground objects from LIDAR point cloud, attention was paid to the discrimination of objects. Work has been done on the separation of buildings and vegetation. Most of the works use a variety of dataset such as infrared imagery, colour imagery, LIDAR data and combine them together to separate the objects.

Several studies have shown that LIDAR data has the potential to support 3D feature extraction, especially if combined with other types of data such as 2D GIS ground plans (Brenner and Haala, 1999; Weidner and Förstner, 1995). The calculation of DTM from a DSM with the help of image matching is describes in Jacobsen and Passini, 2001. The use of reflectance-based identification is described in Hug, 1997. Oude Elberink & Maas, 2000 describe the use of anisotropic height texture such as the co-occurrence matrix and contrast texture measures in LIDAR data used for unsupervised classification. This method allows to remove the vegetation. In this work an attempt has been made to separate buildings and trees from LIDAR point cloud only. The algorithm is based on the idea 'To make packet of all visible clusters' and later an individual treatment was applied to each of the cluster to recognize their patterns in terms of building and tree.

The algorithm starts with the first numerical point of the dataset supplied as text (*.txt) file to the system. Let the point is P1. P1 searches the nearest point P2 within a given threshold value. Then P2 searches its nearest point P3 within the threshold and stores all the points in a packet until the last point Pn does not find any point within given proximity. The formation of a 'cluster packet' is thus completed and the algorithm then fixes the next point sequentially from the text file list and allows it to grow into a new cluster. When the point P1 does not find any point in its threshold proximity, it makes a cluster alone itself.
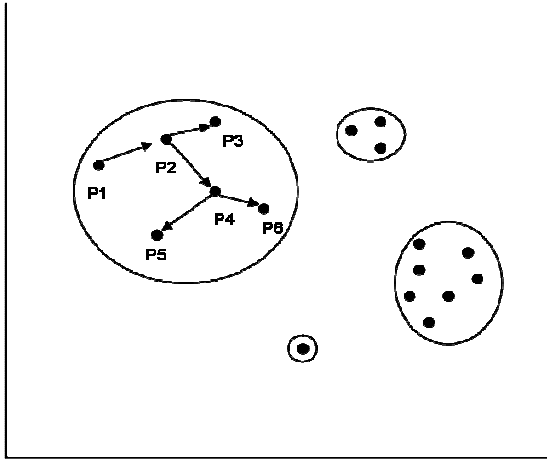
Figure 4: Automatic object packeting technique

After making segmentation of all the visible clusters, each of the 'packet clusters' was investigated.

2.5 Object Classification

The object clustering approach not only 'packets' an object but also gives each packet a numerical identity. This numerical identity helps better classify the object followed by the 'Pseudo gridding' algorithm. Pseudo gridding is an approach to break the whole objects into small square block. Then each of the small grids was checked to designate that grid as either 'building' or 'tree'. Height profile was the criteria that were investigated for each grid. The assumption behind this checking is that tree surfaces have more irregular height profile whereas building surfaces have regular height profile.

3. RESULT AND DISCUSSION

Object separation approach solely from point cloud data applied in this research was highly satisfactory but not 100% accurate. Because the study area has got buildings with complex boundary and irregular roof surface. As the algorithm looks into the smooth height profile, errors occurred in case of rugged roof surface. As a result the classification accuracy suffered partly. Figure 6 shows the classified objects (Red: Building, Blue: Tree) in LIDAR point cloud. There is clear misclassification in some of the packets of point cloud. The main reason is that the part of the study areas had buildings with very irregular rooftops. In figure 7 it can be seen the irregularities of buildings both in shapes and roof surface height profile.
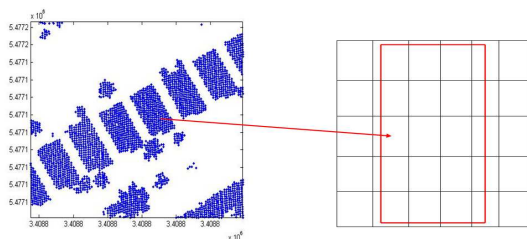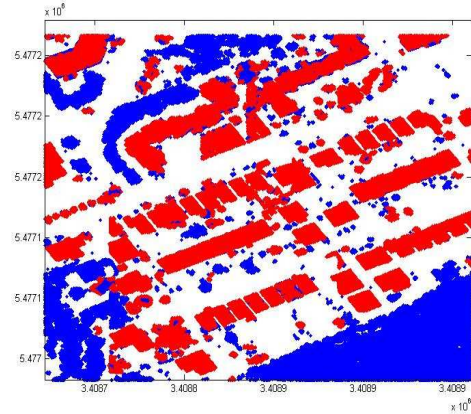

Figure 5: Concept of Pseudo Gridding

Figure 6: Object classification in point cloud data (Red: Building, Blue: Trees)

Figure 7: Aerial image of part of the study area where object classification was investigated

These shortcomings could be overcome by looking deep into pattern matching in height profile distribution. Generally chimneys, stair house, water tanks and other objects cause abrupt change in height profile of buildings with flat roof. But still these abrupt changes are different from continuous rough surface that usually trees have.

Apart from looking only into point cloud to explore intact pattern of building and trees, other additional studies can be made and linked to the previous approach as supplementary information. This additional study in this research is the potential source of information that can be derived from aerial photo of the study area. In case of infrared imagery, it is easy to separate pixels containing chlorophyll information i.e., trees. As there is no infrared image in this project, and there is only colour image available, it was difficult to extract trees from the aerial image.

Edge detection technique was applied to segment building and tree boundaries in the aerial image. Canny edge detection technique was applied and then each of the segmented object was identified and numbered vector array. Now performing some kind of shape matching to each of the object would discriminate between building and trees. In future, application of fractal dimension and other suitable shape matching

technique will be applied to distinguish building and trees. The idea is that building boundaries has got relatively regular shape whereas tree boundaries have irregular or round shape. Some buildings happen to be round shape also or there might be trees or bushes attached to a building structure. These kinds of situations can be solved after combining both sources of information coming out from point cloud and image analysis. This approach will be named as 'dual reciprocal approach'.
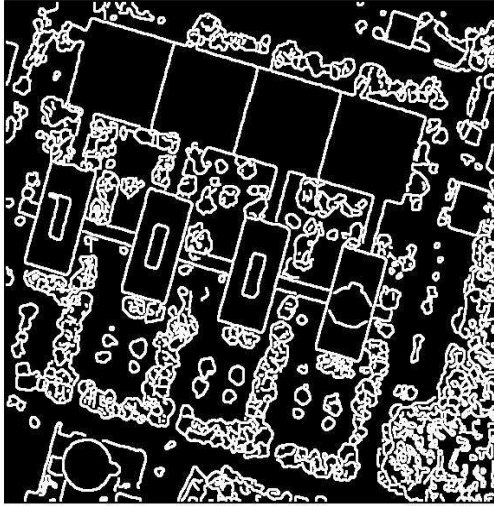

Figure 8: Object segmentation by edge detection technique

4. IDEAS ON STREET EXTRACTION

Street detection in a digital surface model has got immense importance in terms of surface runoff. The openings of street inlets and manholes are on it which leads the surface water into the underground sewer system. In dual drainage flood simulation model, the exact delineation of manholes and street inlets are very important. The more accurate is the street extraction from LIDAR point cloud the better will be the simulation platform for urban flooding. Another important emphasis of this research is the detailing of streets, sidewalks and the height of the curbs. Usually height of the curbs range from 5 to 10 cm. At the same time LIDAR data has vertical accuracy of 3 to 5 cm. It is a challenging task to determine the curb height accurately because in many places the curb height is too small or there is no curb at all. The curb height is important in simulation model because of the location of street inlets. Street inlets are located at the foot of curb wall. In case the street inlets are located on the top of curb wall by mistakes, flood modelling is going to be affected.
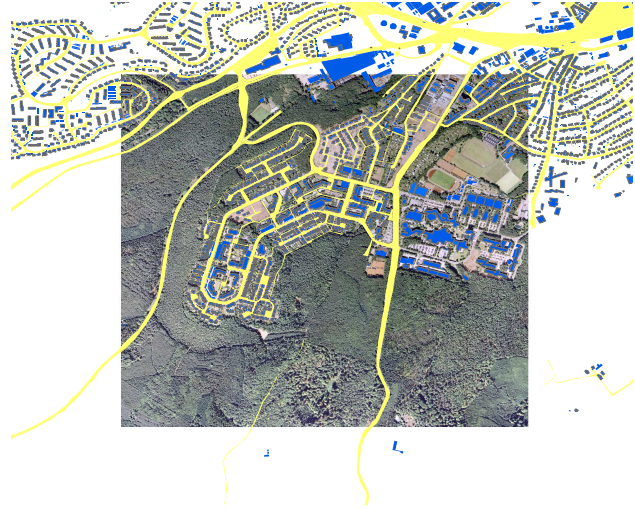

Figure 9: City street polygon map overlaid on aerial image

The process street extraction from the LIDAR data can be guided by city polygon streets map. Usually these maps are provided in vector format. It needs to transform into raster image format and then can be combined with gray scale raster image produced from LIDAR point cloud.

5. IDEAS ON PARKING PLACE AND OTHER PAVED SURFACE SEPARATION

The most difficult part in detecting surfaces like parking places and other paved areas solely from LIDAR data is that there is no characteristic height information about paved surfaces and grassland or bare soil. But image information can be a potential source for different types of surface detection and characterization.

When we look at buildings or roads in a street, it seems quite simple to discriminate urban materials: they all have specific colours and roughness. However, this discrimination remains more difficult from airborne acquisitions using automatic classification. This is mainly due to illumination conditions and especially shaded effects, and also directional properties of urban materials (Meister, 2000). Indeed, some urban materials such as tiles reflect different amount of energies depending on their relative orientation towards light sources and observation directions. These phenomena could be nearly corrected by using a radiative transfer algorithm (Richter, 2002; Martinoty, 2004). On the other hand, some misclassifications could come directly from spatial variability of the urban material regardless of irradiance conditions. This section addresses this problem by analysing and quantifying spatial variability of typical urban material spectral signatures.

Study of spectral signature from any multispectral image (Such as IKONOS, Quickbird) is a potential technique to discriminate different types of urban surfaces.
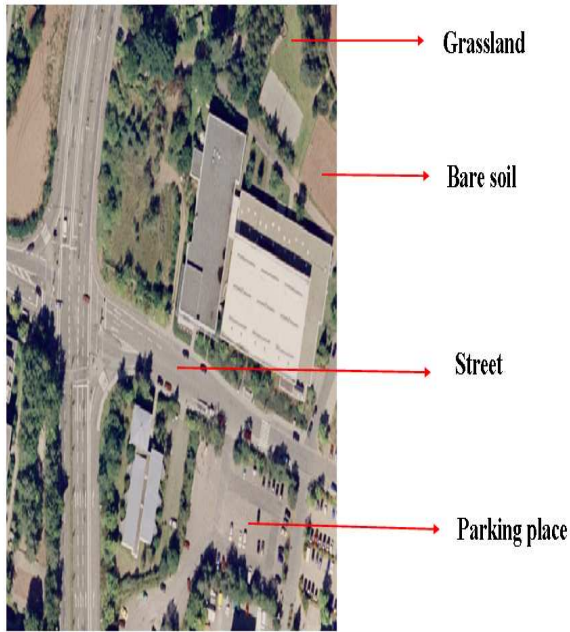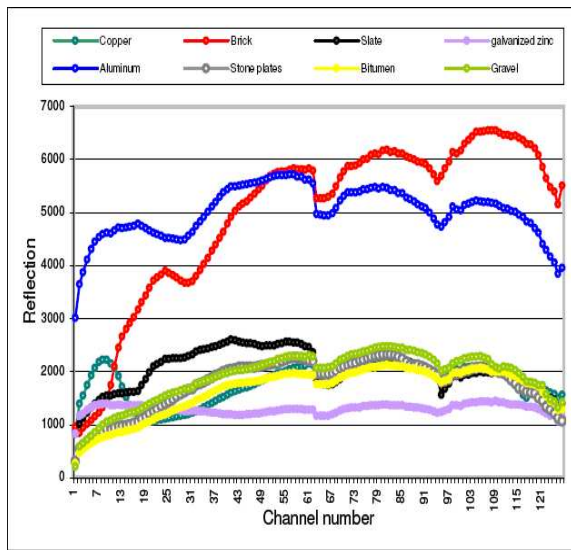
Figure 10: Different types of urban surfaces

Figure 11: Hyperspectral reflectance of urban surfaces

6. SURFACE CHARACTERIZATION

'Surface characterization' is an important term in this research. The main idea of this research work is to build a DSM to support the concept of dual drainage simulation model. LIDAR data helps to generate a digital surface model (DSM) and automatic object detection is the approach to tell the computer about the identity of the objects. After detection of objects in the DSM such as buildings, trees, streets, parking place, grassland, bare soil and other paved surface, an unique surface property will be assigned to each of them in terms of rainfall-runoff and surface flow. For examples, storm water falling on the trees will have interception period before touching surface. Water falling on the building tops will directly go to the sewer system. Rain falling on the street will start runoff process and go inside the inlets and manholes whereas rainfall on the grassland will start infiltration. Paved and partially paved areas will exhibit their percolation/infiltration and runoff properties.

7. CONCLUSIONS

This paper has presented three new techniques; one for object extraction form large and unstructured LIDAR point cloud data and another for automatic object packeting algorithm to facilitate better handling of each object cluster. And the third one is the idea of 'Pseudo Gridding' to distinguish between buildings and trees. It is necessary to mention here that object extraction from point cloud data was done through designing a morphological filter. Like many other filtering algorithms, it searches object on the basis of height information but with the exception of additional standard deviation criteria. The object packeting algorithm is based on the concept of linear distance calculation among points within a certain threshold to put them into a 'Packet'. The pseudo gridding algorithm breaks the cluster down to small square grid and then checks the height profile of each grid in order to designate the whole cluster either as building or tree. The result of object classification (Buildings and trees) only from point cloud was highly satisfactory with the presence of some misclassification. The idea has been proposed here to overcome this inaccuracy by using other mode of information such as aerial image. Buildings and tress separation in a DSM is only the first major steps towards generating very high resolution surface model with every details of urban drainage elements as accurately as possible. The future idea of this research project has been discussed briefly to give an overview about the ultimate products of the project.

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