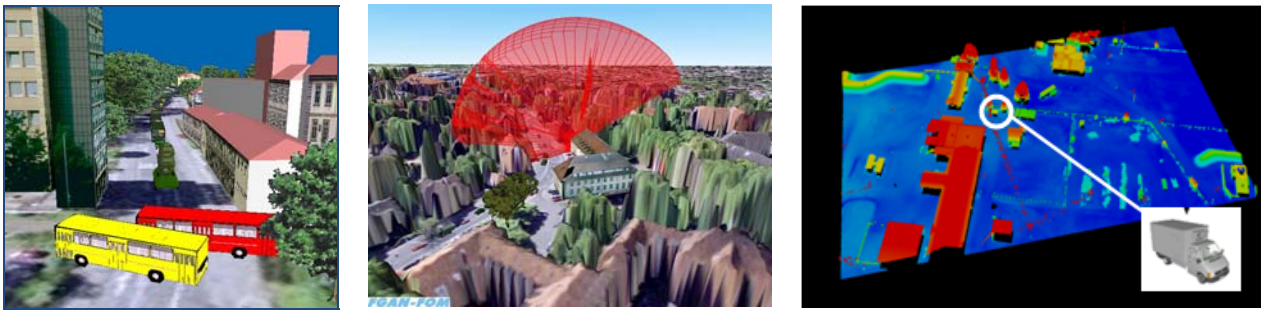
# Chapter 2 – MILITARY APPLICATIONS

Urban 3D models are currently exploited to conduct a small number of military tasks such as autonomous vehicle navigation and mission training. By increasing the availability of urban 3D models, it is believed that a larger number of military tasks will benefit from the great range of information provided in this type of representation. In many situations, military personnel presently rely on two dimensional geographic maps and hand drawn sketches to perform their duty. Having access to accurate and complete urban 3D models would enhance their ability to conduct operations in a more efficient manner. The aim of this section is to present current and potential military applications of 3D models of urban terrain. Table 2-1 gives a list of military applications of urban 3D models and the following sub-sections describe some of these applications in greater details.

**Table 2-1: Military Applications of Urban 3D Models.**

| **Military Application** | **Definition/Example** |
|---|---|
| Situational Awareness | A 3D model is generated and used to get a better knowledge of a given location. |
| Line of Sight (Visibility) | Model is used to evaluate the sight line of possible enemy posts. |
| IED Damage Simulation | 3D model is exploited to simulate what would be the damage done by an IED explosion. |
| Change Detection | Compare models generated for a given location at two different times to highlight differences. |
| Battlefield Area Evaluation | Perform an evaluation of an area where military operations are to be conducted. |
| Battlespace Management | Use a model to manage ongoing military operations in urban terrain. |
| Briefing | Use model as a support to brief personnel for a given mission. |
| Collateral Damage Assessment | Generate a model of an area that has been under attack to assess the damage done to civilian and Army infrastructures. |
| Cooperative Reconnaissance | Use cooperative vehicles (e.g., UAVs) to perform reconnaissance of a given area and store the information acquired by each vehicle in a common 3D model. |
| Mission Rehearsal | Rehearse a mission using a 3D model of the area where the deployment will take place. |
| Mission Planning | Perform mission planning using a 3D model of the target location. |
| System Assessment | Use of accurate terrain models in assessment of optical and other communication systems. |
| Sensors Simulation | Simulate the behaviour of sensors for different types of targets and materials under varying conditions. |

| | |
|---|---|
| Mission Simulation | Use 3D models to perform simulation of different scenarios for a given mission. |
| Target Selection | Use a 3D model to precisely select the target of interest. |
| Battle Damage Assessment | Using a 3D model generated after an attack, assess the damages made to a specific target/area. |
| Terrain Analysis | Use 3D models to evaluate the density of vegetation of a specific area, determine the position of possible threats and/or determine line of sight regions for emplacement of assets. |
| Terrain Familiarization | Situational awareness / Mission rehearsal. Urban 3D models can be provided to soldiers to enable them to examine a given area from different points of view prior to actually being deployed in this area. |
| Threat Assessment | Capture in a 3D model possible threats (e.g., person, device, vehicles). |
| Wargaming | A 3D model is used to elaborate/test/refine strategies and theories of warfare. |
| Training | Urban 3D models can be used to create virtual environments where soldiers can train for different types of operations. |
| Automatic Target Detection (ATD) | Given a 3D model of an urban area, ATD algorithms aim at detecting the location of certain types of targets. |
| Automatic Target Recognition (ATR) | From a list of targets location output by ATD algorithms, ATR algorithms output possible target classification with corresponding probability. |
| System Assessment | Use of accurate terrain models in assessment of optical and other communication systems. |
| Calculation of Acoustic, Chemical and Electro-Magnetic Propagation | Simulations can be performed for various types of signals to assess how they would propagate in different types of built-up areas. |
| Terrain Reference for Autonomous Navigation and Path Planning | Autonomous vehicles have to be able to build a 3D representation of their environment in order to perform navigation and path planning tasks in an efficient manner. |



a) b) c)

**Figure 2-1: Some Illustrations of Military Applications – a) Mission Planning/Simulation; b) Threat Assessment; and c) Automatic Target Detection and Recognition.**

## 2.1 MISSION PLANNING/TRAINING

Urban mission planning requires taking into consideration several factors that may have a positive or negative influence on the mission. It is believed that providing mission planners with 3D models of urban terrain could improve their understanding of these factors and facilitate their work. Urban 3D models may be exploited at the planning, briefing and training stages.

3D models used in the context of mission planning and training may include terrain surfaces, roads, vegetation as well as information on buildings such as doors, windows, building materials, roof types and interior layout. When additional intelligence is available, 3D models may also be augmented with potential enemy locations, barriers location, objectives, sight lines and intelligence estimates [1].

Depending on the type of mission, urban 3D models may be used at the planning stage to identify possible enemy observation posts and identify line of sight for these posts, establish a strategy to clear a set of buildings, select the best approach routes to reach a given objective, etc.

Once the mission planning phase is complete, 3D models can be used to brief personnel. At first, commanders may use the 3D models as a support for explaining the mission to their troop. Depending on the time available, the 3D models may then be made available to the soldiers so they can explore the area of interest from multiple angles and with different zoom levels. Being able to perform fly-through and walk-through in an urban environment prior to mission execution would result in greatly enhanced situational awareness.

Research is ongoing to provide soldiers with simulation tools to perform mission training and operation rehearsal using synthetic environments built from 3D models of urban terrains. These tools can be used to train soldiers for a specific task (e.g., clearing a building) or to simulate a whole mission. Simulations are usually performed on a desktop computer using a 2D or 3D display. Immersive virtual reality environments such as a Computer Assisted Virtual Environment (CAVE) can also be used for this purpose. These simulation environments enable soldiers to evolve in a simulated urban area with a real sense of 3D. Figure 2-2 shows a soldier during a training session in a semi-urban environment using a CAVE system. Mission training and operation rehearsal using 3D models of urban terrain enables soldiers to develop abilities and gain situational awareness in an innovative and efficient way.

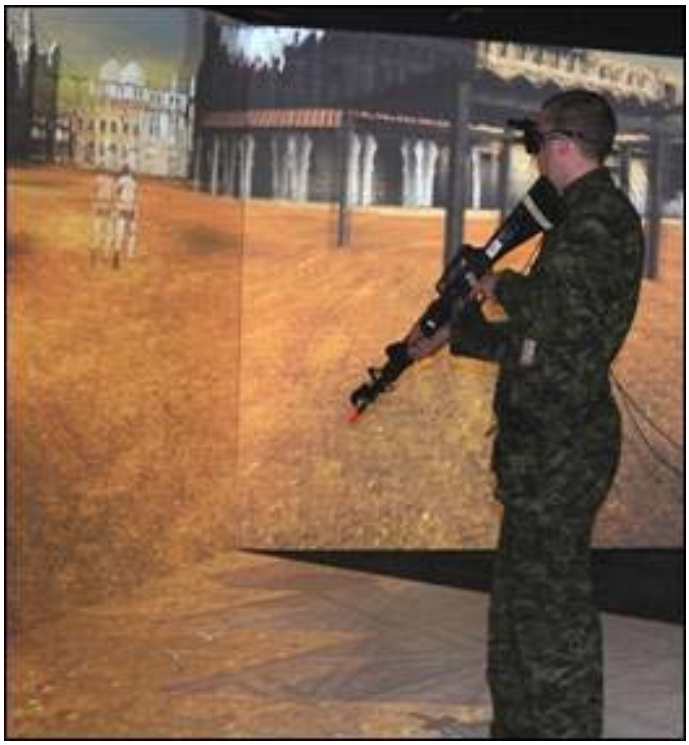


**Figure 2-2: A Soldier Training in a Semi-Urban Environment Using a CAVE System (DRDC).**

## 2.2 CHANGE DETECTION

Change detection consists in comparing 3D models of a given geographic area acquired at different points in time and highlighting the differences between the models. Depending on the resolution of the models, different types of change can be detected. Lower resolution models acquired using satellite data and/or high altitude airborne data may allow detection of construction and destruction of buildings and changes in terrain surfaces (newly constructed roads, new holes, collapsed terrain). Higher resolution models generated using low altitude airborne data and ground-based data may allow detection of vehicles, boats, man-made objects and IEDs. Change detection can be used to perform tasks such as battle damage assessment and urban development monitoring.

In Figure 2-3, an example is shown from a field trial conducted by FOI as part of a counter-IED project in 2009. In this trial, a section of a road (about 1.5 km long) was scanned twice with a mobile laser scanner system and a couple of changes (dummy IED objects) were introduced between the two measurements. By analyzing the spatial characteristics, geometrical changes corresponding to the IED objects could be identified. A main problem however, is that geometrical changes occur due to natural variations, such as non-identical sampling patterns, leaves moving in the wind, different viewing angles, etc. This indicates that post-processing, complementary sensor data and/or a priori information/assumption about the expected placement of the IEDs are probably needed in order to reduce the false alarm rates to acceptable levels.

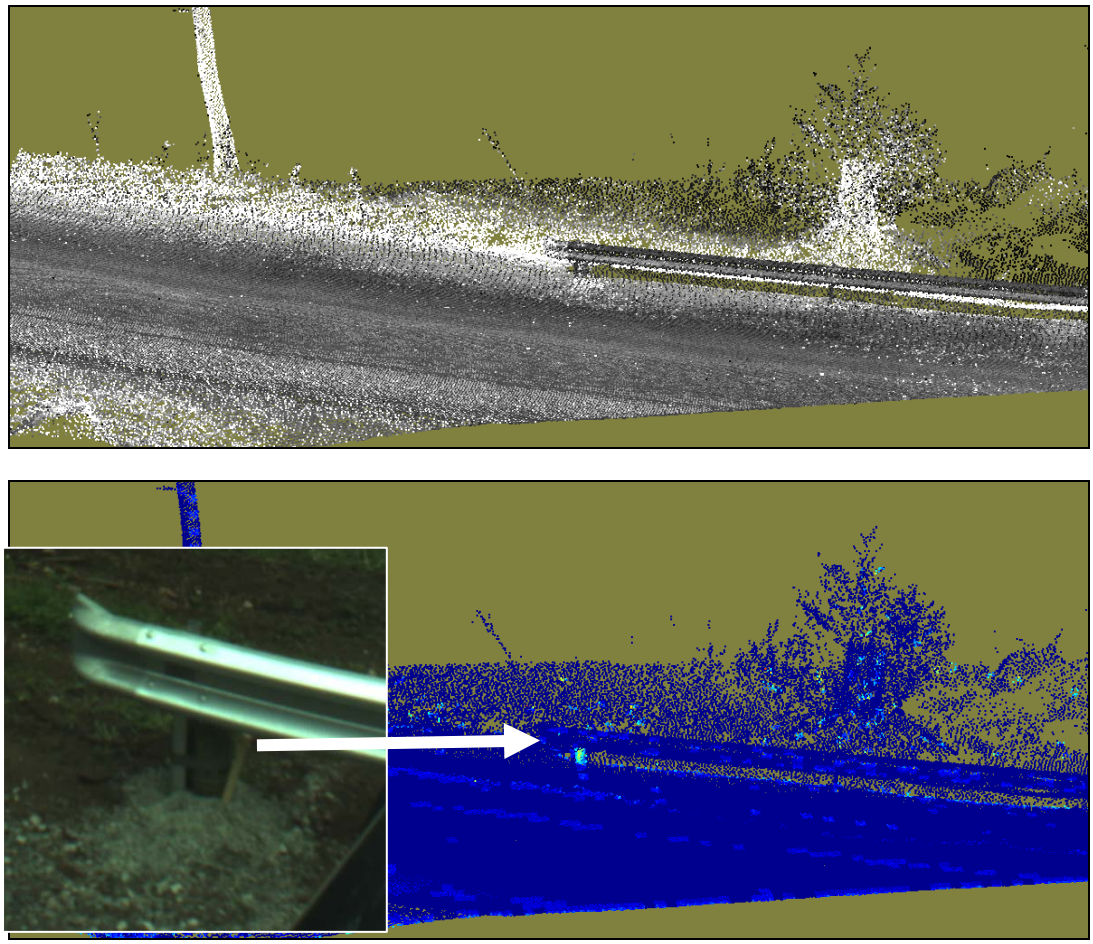
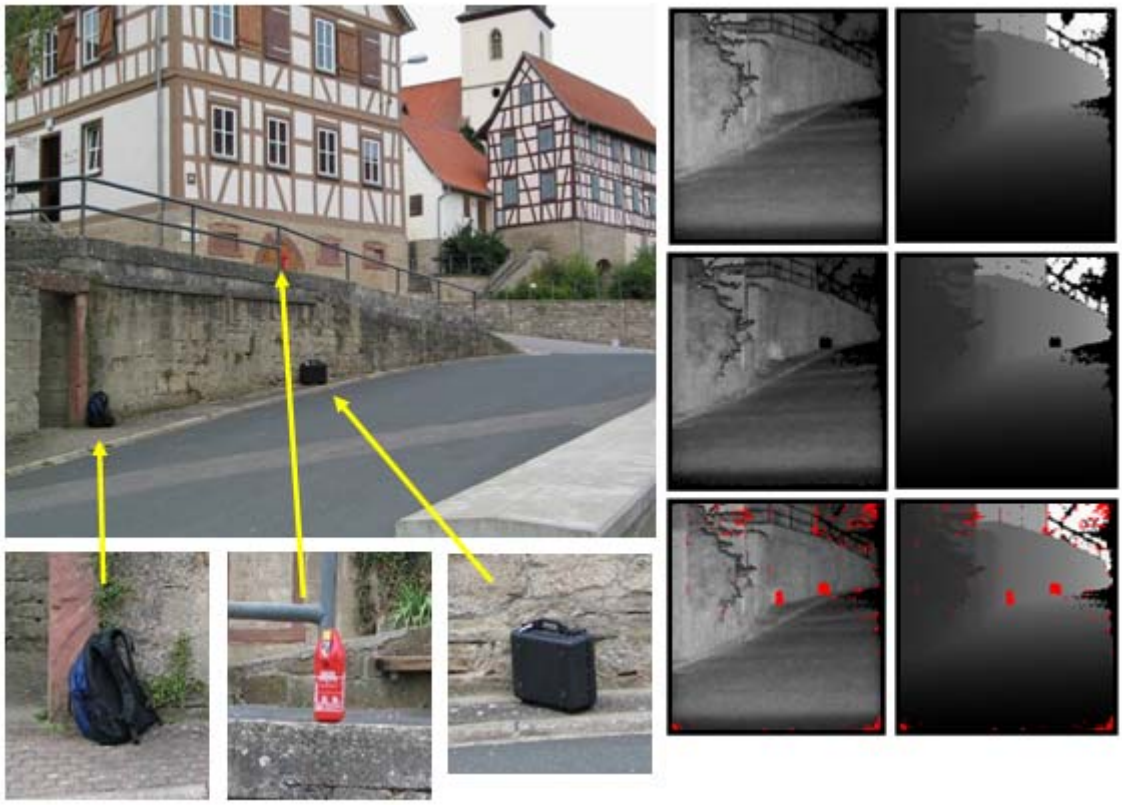


**Figure 2-3: Example of Change Detection in 3D LIDAR Data for IED Detection Purposes. Top: A snapshot of part of the point cloud (greyscale level corresponds to laser intensity). Bottom: Result after nearest neighbour analysis, where the most recently collected point cloud is compared with a reference point cloud. The brighter pixels (cyan colour) indicate the presence of the (dummy) IED. Also note the changes detected in the vegetation next to the road.**

Another example is shown in Figure 2-4 where an urban scene was imaged at two different times using a flash LADAR system with potential IED objects placed in the scene prior to performing the second acquisition. The objects of interest placed in the scene included a fire extinguisher, a briefcase and a backpack. A change detection process based on comparison of laser range and intensity data was applied to the scene in order to highlight the differences due to the addition of the objects in the scene. As can be seen in Figure 2-4, the objects positions are correctly highlighted. However, as discussed in the previous example, other factors such as moving leaves influence the final result. Post-processing and filtering techniques are therefore required to effectively identify in the scene the differences that actually correspond to the introduced objects from the differences that are caused by natural changes in the environment.



a) b)

**Figure 2-4: Change Detection in Urban Setup – a) Different objects were placed in an urban scene; and b) By comparing the intensity data (left) and the range data (right) before and after adding the objects to the scene, changes can be highlighted (shown in red).**

## 2.3 SENSOR SIMULATION

Given a 3D model of the terrain, synthetic sensor data can be produced through physics-based simulation. Such data can be used to predict or assess the performance of a certain sensor in various conditions in order to estimate the effective operational range of the sensor, predict the signature of potential targets, supply automatic data analysis tools (e.g., ATD/ATR) with synthetic training data, etc. Normally, in order to enable accurate simulation, the geometry of the 3D model has to be complemented with additional attributes such as material properties. Figure 2-5 and Figure 2-6 show some examples of simulated sensor data from FOI.

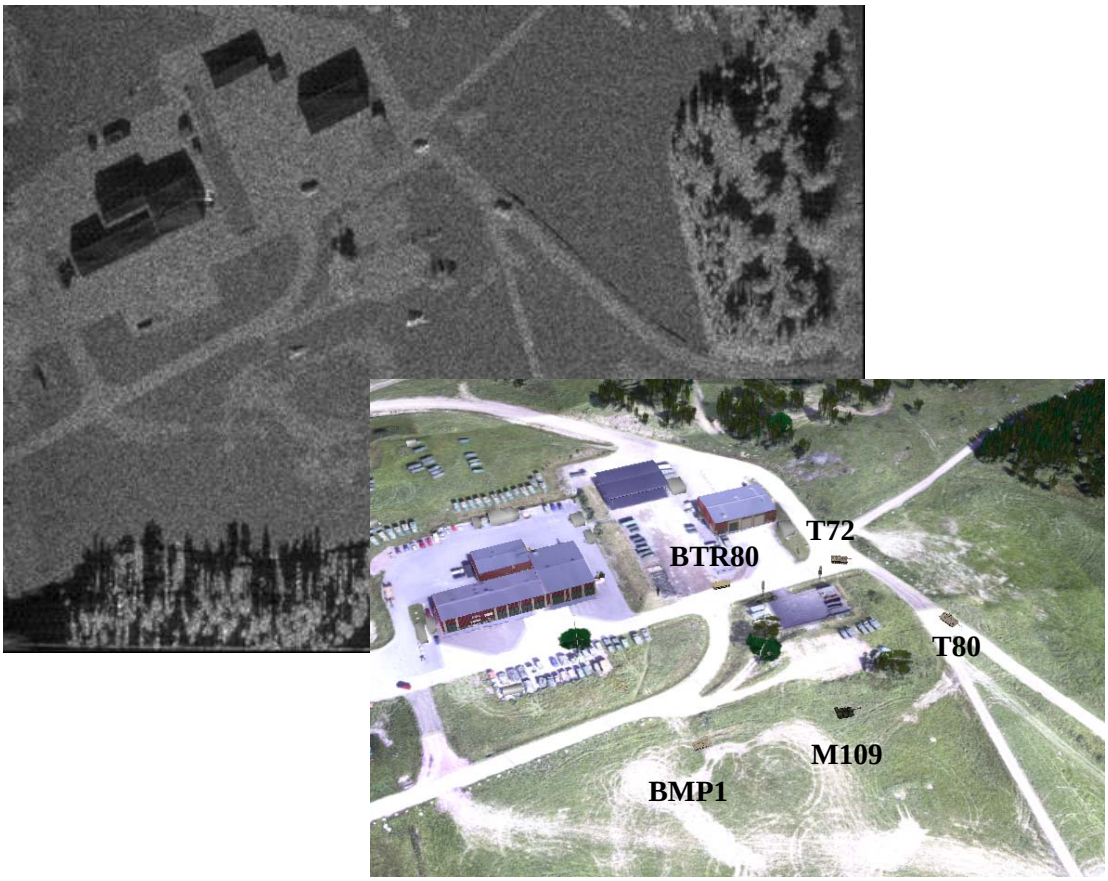



**Figure 2-5: Simulated SAR Image and a View of the 3D Model Including Five Military Vehicles (FOI).**

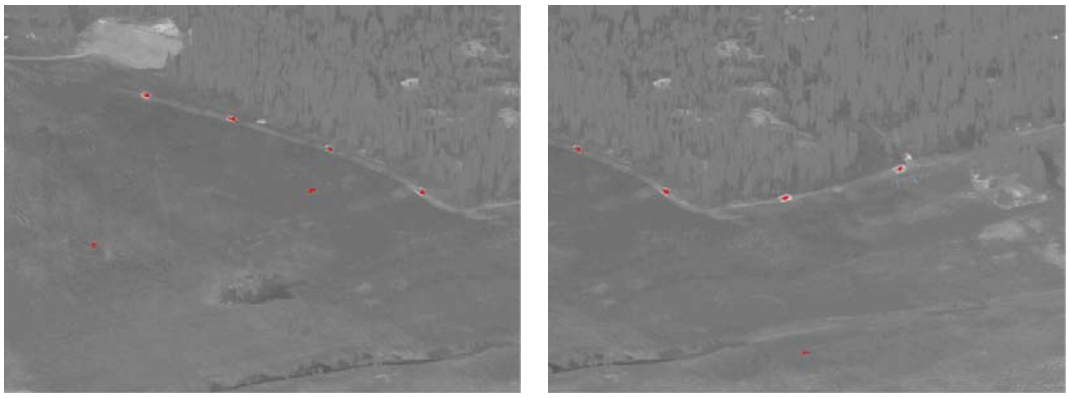


**Figure 2-6: Snapshots from a Sequence of Simulated IR Images. The output from an automatic detection algorithm is marked with red pixels (FOI).**

## 2.4 AUTONOMOUS NAVIGATION

Unmanned vehicles which have the capability of operating with autonomy are valuable assets to the military, both in wartime and in response to natural disasters. The ability of vehicles to effectively navigate and perform designated tasks within extremely harsh or dangerous environments and without the

requirement of operator intervention, provides a distinct advantage over conventional operations. A typical mission would be for a vehicle, perhaps after receiving only high level commands from a human operator, to perform certain tasks while moving from point A to a point B through a cluttered, unknown, highly dynamic urban environment. Possible objectives of the mission could be to:

1) Gather intelligence or provide surveillance along the preliminary route;
2) Provide a detailed map, or perhaps identifying changes to a previously provided base-map of the area;
3) Detect and identify potential targets (geometric and otherwise) along the route; or
4) Precisely deliver a payload.

Other objectives may be for example, to autonomously land rotorcraft to resupply war fighters or perform search and rescue operations. It is easy to imagine many variations and extensions of these scenarios which may also rely upon line of sight and navigational stealth within the urban setting. Moreover, these operations may be performed by solitary agents or collaboratively.

There are numerous technical challenges that must be addressed in order for unmanned vehicles to operate autonomously in cluttered urban environments. An autonomous aerial vehicle, for example, will encounter a diverse range of obstructions in such an environment including buildings, trees, power poles and lines, road signs, and moving objects such as people or other vehicles. Flight of a small vehicle through an urban warfare environment will involve frequent blockage of communication with other vehicles/ground stations, periodic obscuration of GPS signals, and jamming from enemy forces. This means that reliable communications from or with other vehicles and satellites cannot be assumed and, therefore, a UAV under these circumstances cannot rely on external sensing and processing resources for extended periods of time. Naturally, an autonomous vehicle should always take advantage of information from other sources when available, but must independently sense its surroundings and conduct path planning exclusively with onboard assets when external information is not available. Therefore, the onboard sensor suite and the ability to utilize sensor data for obstacle avoidance and path planning are critical in order for the autonomous vehicle to operate effectively in an urban canyon.

Another critical technology for autonomous navigation is the ability to synthesize sensor data for Guidance, Navigation, and Control (GNC), including obstacle avoidance manoeuvres. As briefly described earlier, the user provides high level commands to the autonomous vehicle, such as, for example, monitor specific objects in a loiter pattern, search along specific paths, or follow some predefined search logic. In each case the guidance and control system must satisfy the mission objective while taking action to avoid sensed obstacles in its path. In the case of aerial vehicles, flight control algorithms must necessarily plan ahead for more than one maneuver, so that required collision avoidance tactics do not deleteriously affect the vehicle's later options and prevent it from recovering to complete its mission. The control system of a small autonomous aircraft must be able to accomplish these tasks in the presence of local disturbances such as wind gusts and simultaneously deal with complex, uncertain dynamics. The (near-) optimal control algorithms for 3D flight path planning are computationally expensive and require up-to-date reconstructed geometry from the current 'sensing horizon' of the vehicle's on-board sensors. The overall flight control problem is formulated as a *receding horizon control* optimization [2],[3],[4], which entails extremizing a performance functional over a moving window in time to determine the optimal control inputs. Receding horizon control represents an extremely general framework for addressing the problem of autonomous flight in urban environments. Most importantly, it allows for the incorporation of multiple constraints in the optimization problem so that obstacle avoidance can be achieved by enforcing constraints on the aircraft states. Although still computationally intensive and subject to instabilities, the receding horizon controller formulates the equations of motion with reduced-order representations of the non-linear aircraft-sensor dynamics and solves many small-scale optimization problems with updated constraints based on new information such as updated estimates of obstacles and the current reconstructed geometry of its environment.

Necessarily, autonomous navigation requires the development of complex 3D models of urban terrain in real time from data, either generated progressively or updated, depending upon the collection context, by sensors onboard the vehicle. The sensors typically provide ranging estimates of structures and obstacles in the operating environment, which may be derived from passive cameras (using optical flow or stereographic methods such as Structure from Motion as described in Section 3.1.2) or active laser measurements (LIDAR). At this stage of assimilation the measurements are registered relative to the vehicle and are available for reactive control and emergency avoidance. To register the range data within a global map, transformations must be performed after accurate geolocation and pose estimations, using either an internal navigation system, involving GPS and internal measurements (e.g., accelerometers, gyros, and magnetometers), simultaneous localization and mapping algorithms (*SLAM*, [5],[6],[7]), or hybrid combinations of the two. As the sensor data is assimilated into an obstacle map in three dimensions, the vehicle must then adaptively modify its path planning and motion control mechanisms, using receding adaptive control.