A Rudimentary Approach to Unmanned Aerial Vehicle Guided Improvised Explosive Device Shrapnel Dispersal Simulation

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Abstract. This paper proposes a methodology to compute, model and simulate a Directionally Focused Charge (DFC) explosive, delivered and deployed on an Unmanned Aerial Vehicle (UAV), with simple particle game engine physics heuristics, for estimating shrapnel trajectories and areas of impact on an urban terrain. As a preliminary study, we model a simple DFC explosive, also known as a directionally focused fragmentary charge, which is composed of a flat top and fixed sized metal canister containing nuts, bolts and ball bearings. The simulation models a small UAV capable of delivering a maximum payload of 10 kg within a flight distance of 5 km. The simulated UAV is modeled after a commonly available heavy lift commercial drone. The terrain dataset is obtained through Google Earth Engine's public data catalog – a standard Earth science raster dataset. We assert that this methodology can provide response and counter-IED teams involved in explosive threat detection with relevant information pertaining to the estimates of the risk associated with significant shrapnel impact in urban areas.

1 Introduction and Background

An improvised explosive device (IED) is a bomb constructed from military or other explosive material and deployed in unconventional ways - potentially resulting in property damage, injury and/or death [1].

The terms Unmanned Aerial Vehicle (UAV) and Unmanned Aerial System (UAS) specifically refer to any flight-capable vehicle that does not have a pilot on board and can be reused for subsequent flights [2]. Commercially available precision-guided UAVs have given rise to unique and new potential threats to populated areas from extremist activity [3]. UAVs that are equipped with explosives meant to inflict damage and harm have become a worthwhile investment for terrorist groups given the UAV's expendable nature, low size, and safe stand-off range from potential targets [4-5]. The use of this technology for the purposes of inflicting damage to people and property has created threats to public safety and therefore more attention is warranted. A potentially fruitful direction for counter threat assessment research for UAV-carried IEDs, is the detailed reasoning and situational awareness obtained from accurate system simulations – which may be useful tools for pre and post attack analysis and for preventative planning.

Since the very nature of real-world, UAV-carried, IED explosions will be relatively unique for any design and will vary in explosive power, it is important to study the potential impact that shrapnel will have on target surfaces. One method of obtaining this form of situational awareness is to employ simulations to analyze shrapnel impact points and trajectories in order to aid in counter-IED planning processes.

Fig. 1. UAV Guided IED Explosion Simulation, the simulation uses a DFC model where shrapnel is considered as an explosive dispersal of solid particles.

Simulations that provide reasoning and information regarding UAV guided explosions will need to be accurate and effective given the nature of the situation. They involve a multitude of factors such as the type of explosive payload, the design of the explosive, height of the explosion, the nature of target surfaces, the composition of shrapnel and consideration of other forces at play.

In order for our work to relate to reality and lead to an accurate simulation, we start with an assumption and focus on one type of liquid-based explosive, a DFC, a controlled explosive dispersal algorithm of solid particles [6], and a non-specific UAV to deliver the payload to a certain height and point above the 3D terrain. Our simulation is developed in the Unity game engine [7], and relies on the additional assumption of simple aerial heuristics. Our focus is limited to the initial forces at play – computed with game engine particle physics. The secondary effects of the explosion and shrapnel impact such as collateral damage from sympathetic secondary explosions are not considered [8].

We assert that our rudimentary method to computing, modeling and simulating the impact points and trajectory of shrapnel is a step towards a high-fidelity UAV-guided IED splatter analysis simulation.

DFC is a variation of an IED, with characteristics such as a flat top plate - as opposed to concave top plates, commonly seen in explosively formed penetrator/projectiles (EFPs) [9]. DFCs have canisters that are commonly designed from cast copper or cut metal, equipped with shrapnel as nuts, bolts and ball bearings [10].

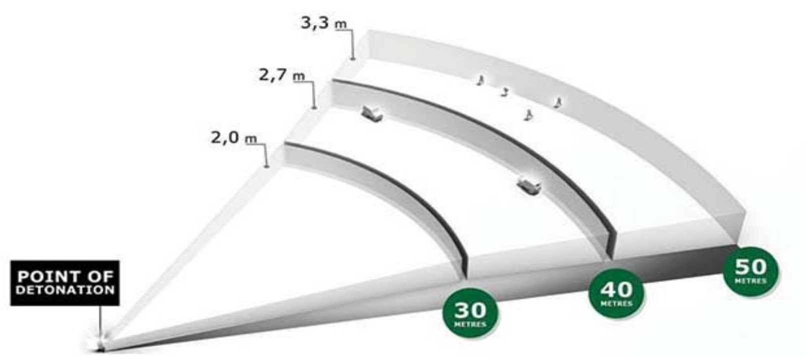

Fig. 2. Impact zone for a Directed Fragmentation Charge (DFC) – 30 meter distance with overall effective range of 50 meters [11].

These characteristics allow for digital models to determine trajectory with a higher degree of accuracy than DFC's counterpart – EFPs, in addition, the light-weight thin canister produces minimal effect on the trajectory of shrapnel, and the design of a flat top panel tends to produce a lower half spherical dispersal of shrapnel when subject to forces of a controlled liquid explosion [6].

2 Related Work

In the computer graphics community, many publications address modelling and simulating explosions based on physically based approaches [12–14], these works concentrate on the shockwave effects and modelling the propagation of a simple explosion through the air using computational fluid dynamic models in a closed system. These techniques are useful for generating and rendering special visual effects such as dust clouds, and fireballs, but may not be accurate or useful in determining impact and trajectories of debris and shrapnel.

For real time interactive simulations, particle systems and imaged-based techniques are commonly used, where the focus is to generate and render fire, explosions, and clouds in a more accurate dispersal of particles manner [15–17].

Simulations that compute, model and simulate explosions utilize closed system techniques to hone in on a viable predictive simulation for a very specific use case, which is often using a more computationally friendly approach and simplified method of mimicking the physical interactions involved in a real life explosion.

The closed system equations commonly used relate to the field of fluid dynamics [18], material point [19], and vortex particle method [20] – all of which are focused studies meant for a specific use case and are computationally viable for that specific purpose, such as reproducing a realistic visual model and special effect of a gas explosion resulting in dispersal of gas particles.

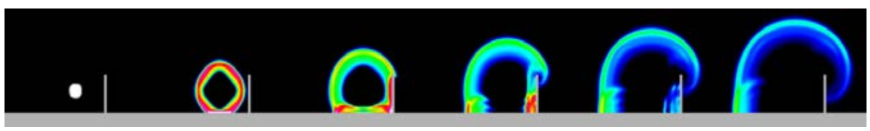

Fig. 3. A computer graphics implementation of animated cross sections of a blast wave for simulating an explosion near a barrier and the changes in blast wave at timed intervals [13].

Fluid dynamics applied to explosions allow for easier computation of forces - elements act as if they are enclosed in a viscous particle environment rather than a culmination of other forces that are inevitably at play in an open air, open system real explosion.

The most closely related work is a simulation which models terrain deformations and fractures from the impact of explosions [21]. The theory behind this work is heading towards the full scientific simulation of the real physical processes associated with explosions.

High fidelity simulations would be complex and computationally expensive, and are generally neglected in the field of computer graphics, in which the focus is mainly on the visualization of the explosion, blast waves, and visual impact on surrounding objects.

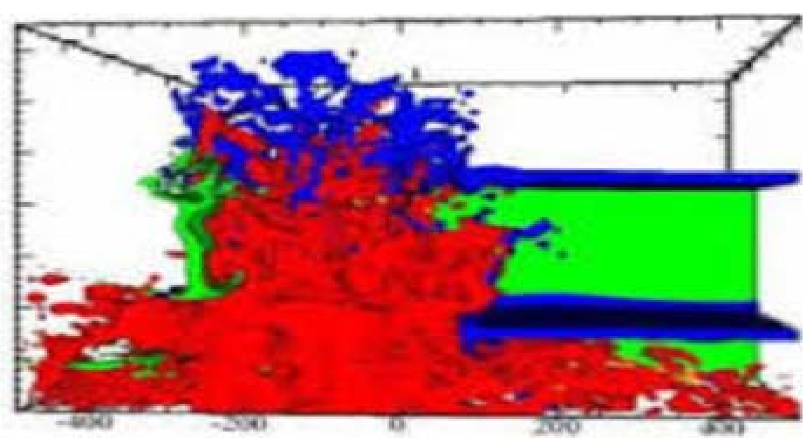

Fig. 4. Simulation of the detonation of an explosive device in a structure (closed system fluid dynamics simulation) [22].

Simulations for military applications such as modeling high-precision guided missiles and their impacts are abundant [23–25], but little work has been done with the primary focus of UAV guided IED explosions and impact on target surfaces.

3 Methodology and Experiments

3.1 Explosive Dispersal of Solid Particles

In our game simulation, we consider 100 equal game objects as shrapnel (nuts, bolts, and ball bearings). For simplicity and computation sake, these game objects representing shrapnel are equal in sizes. These game objects are scaled to 1/100 the size of the UAV model in the game. The objects are attached to the UAV and move with it when it is in flight. Each individual game object is associated with the Zhang et. al. implementation of explosive dispersal of solid particles [6]. The important feature of this dispersal process is the initial geometry of dispersion. Based on our DFC model, we apply a spherical geometric dispersal to each shrapnel game object – and by applying concentration profiles, and velocity information, the shrapnel disperses as a solid particle cloud as a function of time.

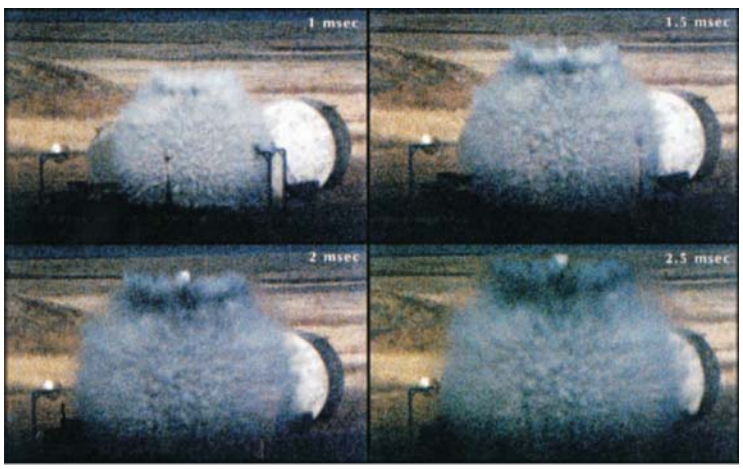

Fig. 5. Explosive dispersal of solid particles, modelled using Zhang et. al. gas-solid flow model, which incorporates material density and pressure [6].

Zhang et. al. uses flow topology to account for the shockwave sling-shot effect, and propagation of waves. There are other factors at play, such as uncertainties in pressure, sound speed and random inelastic collisions, which inherently add too much complexity to the equations. For the purposes of our rudimentary simulation, we do not implement these factors. However, the addition of such complexities should be implemented as future work.

In our simulation, we use the basic flow topology equation, which takes into account material density, pressure and initial forces with a geometric spherical explosion under the assumption of a closed system. This heuristic model also assumes no external forces are applied other than material density, pressure, force and direction.

3.2 Game Engine Heuristics

We assume a closed system environment in our simulation, so the UAV and trajectories of shrapnel are not subject to turbulence and/or wind gusts. A 3D 10 km by 10 km 3D swath of terrain is taken from the public dataset provided by Google Earth. The size of the UAV model, DFC, and shrapnel are adjusted to scale - proportionate to the size of the terrain. Manual adjustment of this process is required.

3D Google Earth Terrain

Google Earth [26] provides a 3D virtual map and geographical information created with a catalog of satellite imagery and geospatial datasets for research purposes. Our simulation imports any 10 km by 10 km 3D Google Earth terrain, as shown in figure 6, and the geospatial data allows for spatial analysis of significant points of impact from debris and shrapnel.

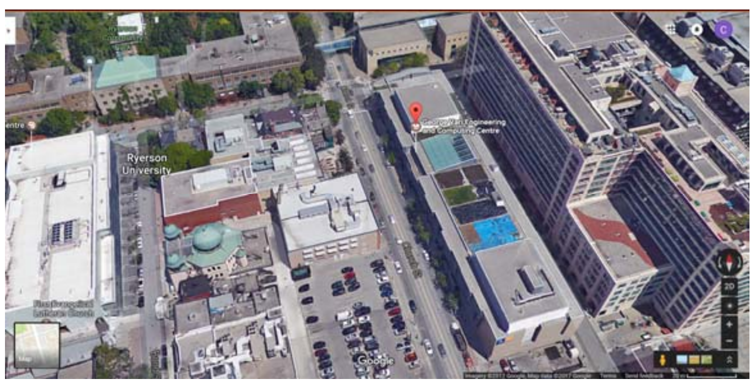

Fig. 6. 3D virtual geographical map taken from Google Earth of the area around Ryerson University, Toronto, Canada [26].

The scale of this model is imported with a unit 1, and all game objects (UAV model and shrapnel model) are scaled proportionately in reference to this terrain. It should be noted that special care should be taken when scaling all models accordingly, as the implementation of explosive dispersal of solid particles is directly affected by the size of the shrapnel model.

UAV Model

The simulated UAV is modeled after the Freefly ATLA 8, capable of delivering a

10kg payload and providing a standoff distance of 5 km.

Fig. 7. Left: Freefly ATLA version 8, with 6 rotors [27], represented by the image on the right: a standard mini airplane model to fly to a location and deliver a payload.

One UAV model is imported into the game and simulates simple flight capability - maintaining its relative altitude at all times. The UAV model operates only to deliver the payload to a desired height and location above the 3D terrain. The UAV model's current capabilities are sufficient for the purposes of our simulation, however additional features, such as the ability to evade detection, may be added later as future work.

Shrapnel Models

In our simulation, shrapnel is represented as a spherical game object, equipped with mesh tight bounding boxes. We assume that if any of the 100 shrapnel game objects collides with the 3D terrain, then it is considered a significant point of impact. The spheres moves in the simulation according to user-defined volume, pressure, force and directional values [6] and are configured to detect collisions to the mesh of the 3D terrain. We assert that the point of collision with the 3D terrain suggest a likely point of impact in a real-world environment. An additional bounding box with a radius of 0.5 km is marked after the explosion occurs, and is provided as a potential visual indication of shrapnel impact. Caution should be used in the interpretation of the marked bounding box, as it may not necessarily encompass all shrapnel surface impacts – this actual real-world evaluation requires further empirical study that is beyond the scope of this paper.

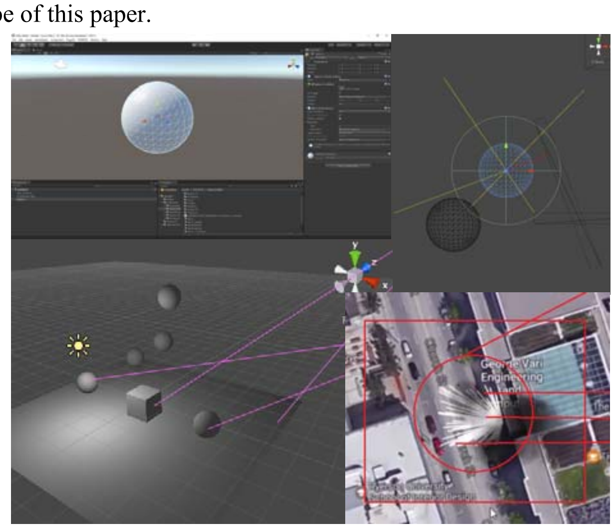

Fig. 8. Left: Freefly ATLA version 8, with 6 rotors [27], represented by the image on the right: a standard mini airplane model to fly to a location and deliver a payload.

DFC Implementation

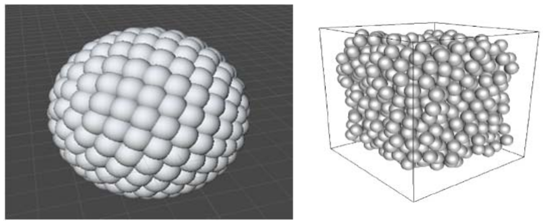

Fig. 9. Left: Multiple spherical unity game objects representing shrapnel, grouped together as a sphere. Right: Shrapnel game objects enclosed in another game object representing the DFC's 'canister'.

Shrapnel game objects are grouped together representing the canister of a DFC. No actual model is in place for the charge, the explosion is simulated by the algorithm attached to each shrapnel game object. The entirety of these objects is placed under the UAV model which move in the simulation as a unit.

3.3 Gameplay Modes

Pre-explosion Flight Mode

The user controls and directs the UAV model to any point on the 3D terrain, real-time geospatial information is provided on a "debug panel" such as longitude, latitude, distance above ground, and geographic coordinates (eg. Degrees, minutes, and seconds (DMS): 41°24'12.2"N) for the user to accurately place the UAV at a specific point above the 3D terrain. The user can activate the explosion and the subsequent explosive dispersal of shrapnel game objects which will automatically compute and simulate their trajectories and possible collision points with the mesh of the 3D terrain.

Post-explosion Exploration Mode

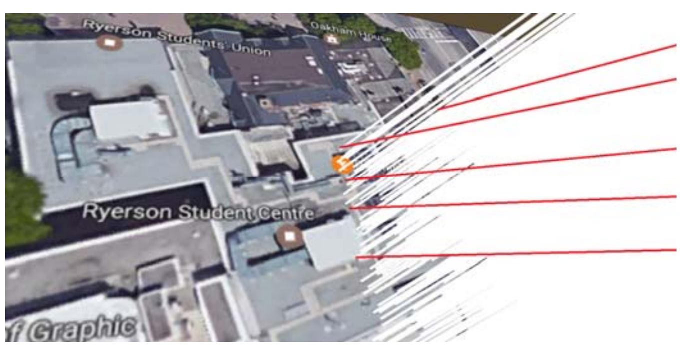

Fig. 10. Exploration of the possible area and points of impact of shrapnel after an explosion occurs.

After the explosion occurs, users are able to move the in-game camera anywhere above the 3D terrain to analyze and view the impact points more closely. All the impact points are recorded as a list of geographical coordinates with their corresponding elevation above ground that the game object collided with. For example, a typical collision point may be somewhere along a wall of a high-rise building in an urban area.

4 Results

Table 1. Suggested short list of recorded shrapnel game objects that collided with certain geographical coordinates.

Shrapnel Object ID	Geographical Coordinates	Distance above ground (km)
1	43°39'29.0"N 79°22'40.8"W 43.658060, -79.377991	0.005
2	43°39'28.6"N 79°22'40.8"W 43.657943, -79.377990	0.004
3	43°39'27.9"N 79°22'40.5"W 43.657762, -79.377902	0.010
4	43°39'29.2"N 79°22'39.8"W 43.658100, -79.377709	0.003
5	43°39'28.4"N 79°22'39.2"W 43.657899, -79.377555	0.011
6	43°39'27.9"N 79°22'39.4"W 43.657748, -79.377619	0
7	43°39'27.7"N 79°22'40.0"W 43.657682, -79.377791	0.004
8	43°39'27.1"N 79°22'40.2"W 43.657534, -79.377823	0.003
9	43°39'27.2"N 79°22'40.7"W 43.657545, -79.377973	0.002
10	43°39'27.9"N 79°22'40.9"W 43.657758, -79.378040	0.001

The table suggests a possible list of geographical coordinates of shrapnel impact points when a UAV and its explosive package was at 43°39'28.4"N 79°22'40.2"W, Longitude: 43.657890, latitude: 79.377825 and hovering at 0.039 km above the ground.

Based on our simulation for this particular scenario, we have estimated possible geographical coordinates of shrapnel impact points of a given UAV guided DFC explosion. The validity of the simulation will require further empirical analysis, but should be sufficient for a proof-of-concept theoretical application of IED shrapnel dispersal and impact on 3D terrain.

5 Conclusion and Future Work

We have proposed a simulation that suggests possible reasoning for a UAV guided DFC IED attack on any target given an arbitrary 3D terrain surface. We assert that this simulation is an approach towards a high-fidelity UAV guided IED explosive dispersal of shrapnel analysis simulation, which has yet to be fully conceived, given the complexity of the forces and many unknown elements at play. The simulation provides ample room for additional factors, which are relevant to calculating a more accurate shrapnel trajectory and impact onto 3D terrain, to be implemented along with the current features.

Future work may include verification of the use of a closed system fluid dynamics flow topology algorithm, and an empirical study with a real drone, a simple reproducible controlled explosive, and a payload of trackable inert and other debris.

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