# HWIL LIDAR imaging sensor, 3-D synthetic and natural environment, and temporal ATR

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## ABSTRACT

In this paper, LIDAR imaging sensors, 3-D synthetic and natural object-centric environment, and temporal (progressive) ATR *(Automatic Target Recognition),* are discussed in the context of *Modeling and Simulation* (M&S) and *Hardware-in-the-loop* (HWIL) testing.

**Key Words**:  HWIL, LIDAR, 3-D, ATR, M&S, imaging, sensing

## 1. INTRODUCTION

For *Modeling and Simulation* (M&S) [1], the LIDAR imaging sensors (and, so-called, *profilometers,* in a smaller scale) are important 3-D imaging devices for moving military targets, and static objects  (such as buildings), the latter ones for *damage assessment* purposes.  In order to obtain progressive, real-time, ATR, however, we need to provide 3-D comparison of objects of interest, for both **synthetic** and **natural** environment.  This challenging program leads to new emerging technologies and features such as:  **geometric invariants**[2] and **enhanced visualization**[1].  The ideal scenario would be to obtain a 3-D synthetic object in so-called **object-centric** (not *view-centric*) representation, and compare this synthetic object with its natural equivalent, obtained, for example, from imaging LIDAR experiments.  The imaging LIDAR is especially suited for this, **synthetic vs. natural environment** comparisons, because it is a priori, 3-D techniques.  In the case of 2-D photographs, we would need to synthesize them into 3-D object representation.  One of the most important synthetic objects of interest is GIS (*Geographic Information System*) topological terrain, obtained from GIS DETM (*Digital Elevation Terrain Map*) 3-D synthetic representation.  The other class of interest would be vehicles, humans, animals, tanks, and other objects organized in so-called *Classes of Equivalence* (CoEs).  A further important practical issue is **3-D autostereoscopic hardware** for 3-D visualization and M&S.  Important examples of geometric invariants are *topologic catastrophes*[3-8], or *manifold singularities* [6].  The geometric invariants [2] are important for both **computer vision** and **sensor fusion**.  The latter one is critical for advanced sensing, because it allows synthesizing of very diversified features from:  visible (VIS) sensors, IR sensors, and radar sensing.

In this paper, we will discuss and analyze the above issues in the context of M&S, real-time ATR [9] and digital video/image processing.  The generic imaging LIDAR military scenario is shown in Figure 1-1.
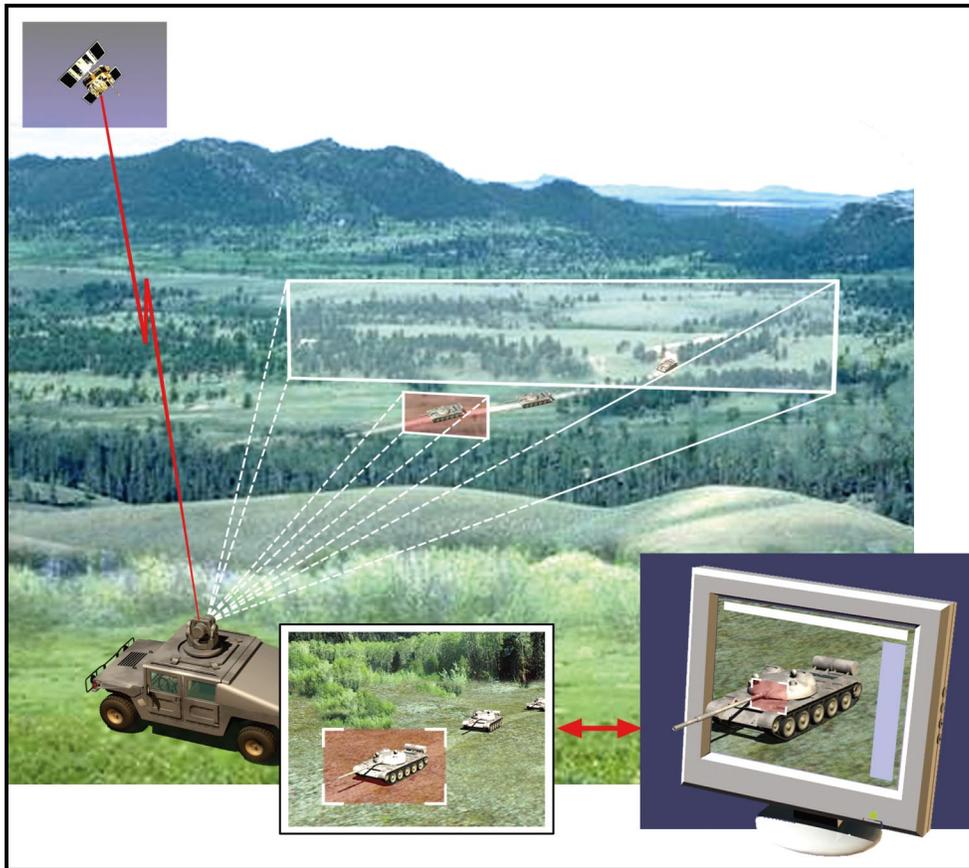
Figure 1-1.
3-D Object Representation obtained from Imaging LIDAR or, in a smaller scale, by 3-D profilometric device.

## 2. LIDAR IMAGING SENSOR (PROFILOMETER) FOR ATR

Typical LIDAR imaging sensor (or, its small version, called profilometer) is a 3-D image device, for the synthesizing of 3-D objects such as **moving** objects: vehicles, humans, animals, etc., and **static** objects such as buildings. In a larger scale, an example of a 3-D synthetic object can be GIS DETM. Its natural environment version is a neutral topologic terrain.

Typical profilometer satisfies an approximate relation:

$$r \text{ [mm]} = 0.6 \text{ d [m]} \qquad\qquad (2\text{-}1)$$

Which, for specific characteristic values, is (r-describes resolution)

$$
\begin{aligned}
&d = 10 \text{ m}, r = 6 \text{ mm} \qquad\qquad (2\text{-}2)\\
&d = 20 \text{ m}, \qquad\quad r = 12 \text{ mm}\\
&d = 100 \text{ m}, \qquad\;\; r = 6 \text{ cm}
\end{aligned}
$$

We see, that for typical distances of interest (100 m), the smallest details are quite large (6 cm). This low resolution limits the ATR ability. We can still improve this resolution limit, however, for both *coherent* and *non-coherent* cases. Both cases are interesting from a practical point of view. The <u>coherent</u> case is represented by He-Ne laser (or other laser source), while the <u>non-coherent</u> case is represented by GaAs *Laser Diode* (LD) array. For both cases, the resolution limit, represented by

Eq. (2-1), can be improved by an approximate factor of three (3), but at the expense of laser beam waist (for the coherent case) adjustment, necessary to each specific distance (which requires an extra telescopic sub-system).

The most common profilometric light source is HeNe-laser at 635 nm wavelength. The typical profilometer control software is:

- Control end setting help menu
- MEC (Mesh Electronic Controller)
- DistoPro: coordinates and range

In fact, the profilometer operation is an integration of longitudinal range finding and transversal scanning. In order to provide a comparison between a 3-D synthetic object and its natural equivalent, we need to adapt advanced computer vision software M&S technologies, such as 3-D object rendering and its 3-D visualization.

## 3. RENDERING

In order to synthesize 3-D object data, we need to transfer 3-D numerical data (range, azimuth, elevation) into its computer vision equivalents. An example of such an operation is shown in Figure 3-1 for damage assessment purposes.
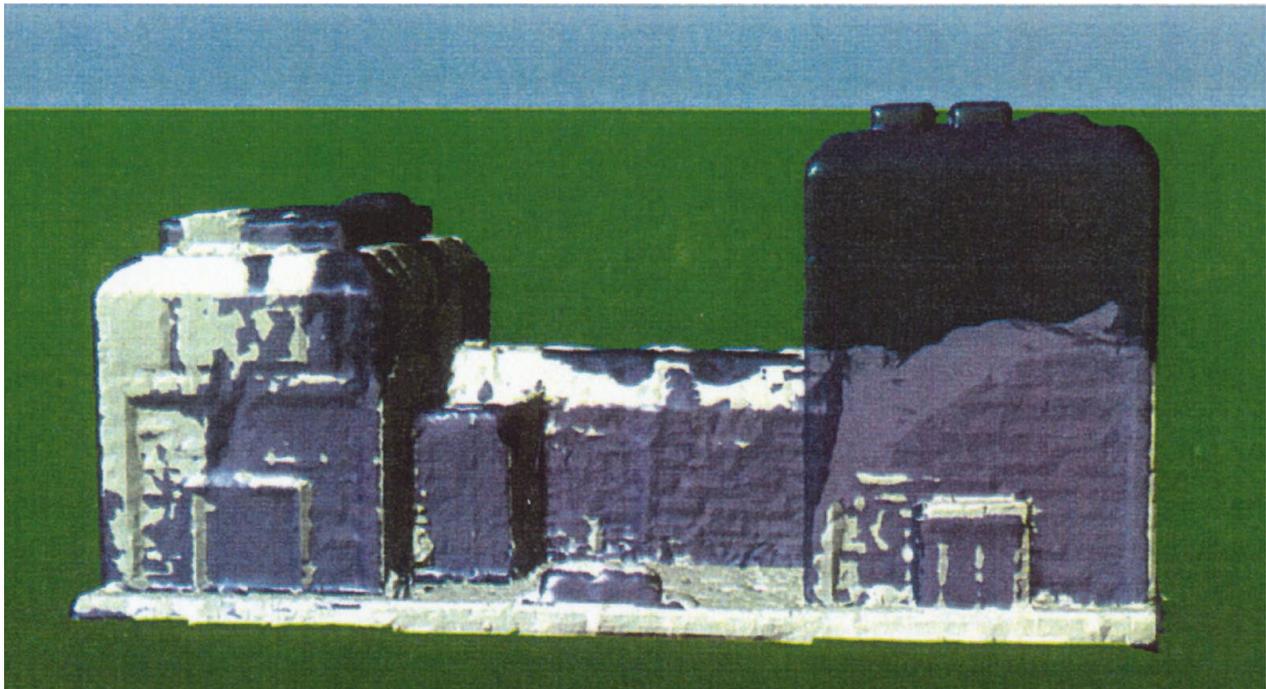


Figure 3-1
Rendering result.

## 4. M&S AND 3-D VISUALIZATION

Another important step in 3-D object synthesis and analysis is 3-D visualization of rendering results as in Figure 3-1, and as shown schematically in Figure 4-1.
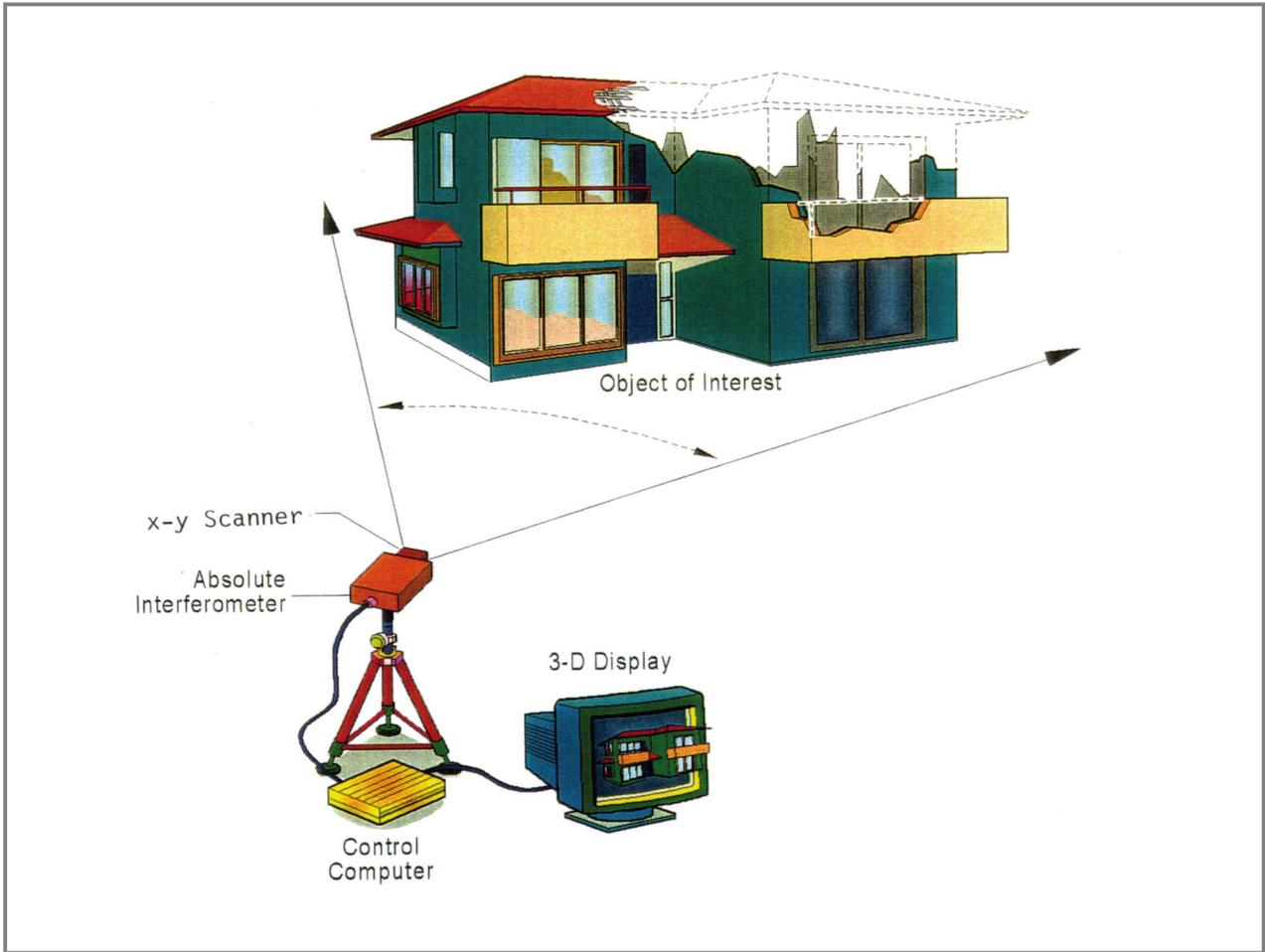
Figure 4-1
Schematic Vision of M&S and 3-D Visualization, by applying a profilometer, integrating laser ranging; x-y scanning and true 3-D display.

## 5. PRACTICAL REALIZATION OF 3-D VISUALIZATION

We have ready a fourth-generation *Holographic Autostereoscopic Display* (HAD) advanced prototype with horizontal (a table) 3-D projection capabilities as shown in Figure 5-1; see also Figure 5-2, for a more detailed engineering description.

Figure 5-1.
Physical Optics Corporation (POC)'s fourth-generation Holographic Autostereoscopic Display (HAD) advanced prototype for horizontal (a table) 3-D Projection.

(a)

(b)
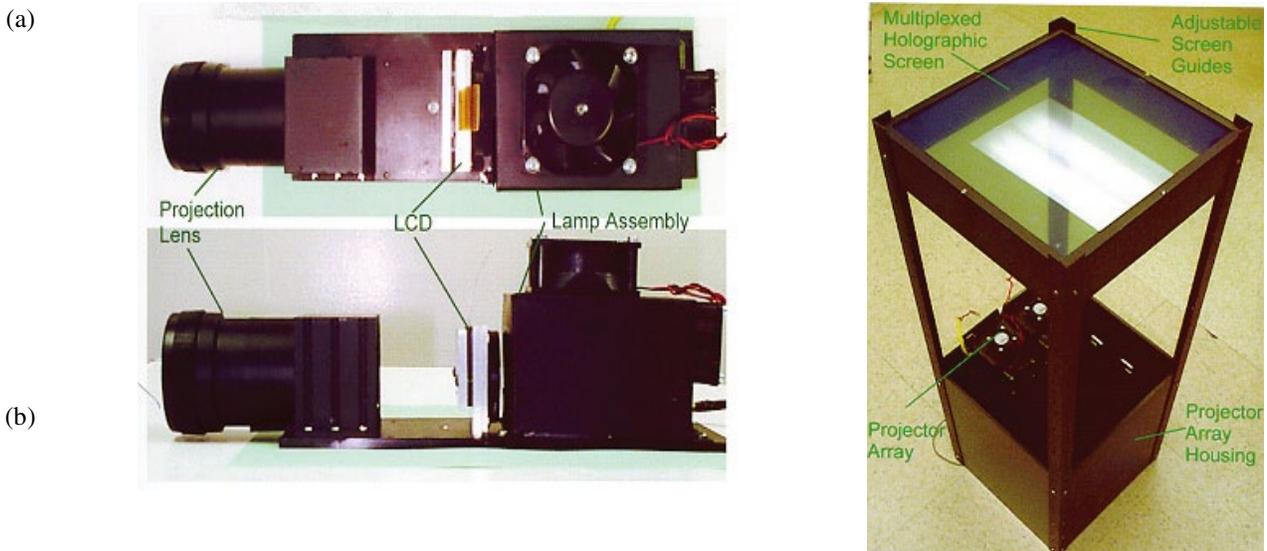


(a) top and (b) side views of the prototype video channel

Figure 5-2
Engineering (HAD) illustration including two LCD *Commercial Off The Shelf* (COTS) compound stereoscopic projection.

POC 's HAD is Autostereoscopic (i.e. without glasses) 3-D display which has several critical  true 3-D properties:
1)  Very high **in-depth 3-D** view, in front of observer (i.e., it can not be simulated by typical 2-D pseudo-stereoscopic visualization).

2) **3-D cluster** features: different 3-D views of the same 3-D objects are presented at the same time.
3) Unusual **horizontal** (not vertical) 3-D visualization.

Features 2) and 3) are illustrated in Figures 5-1 and 5-3, respectively.
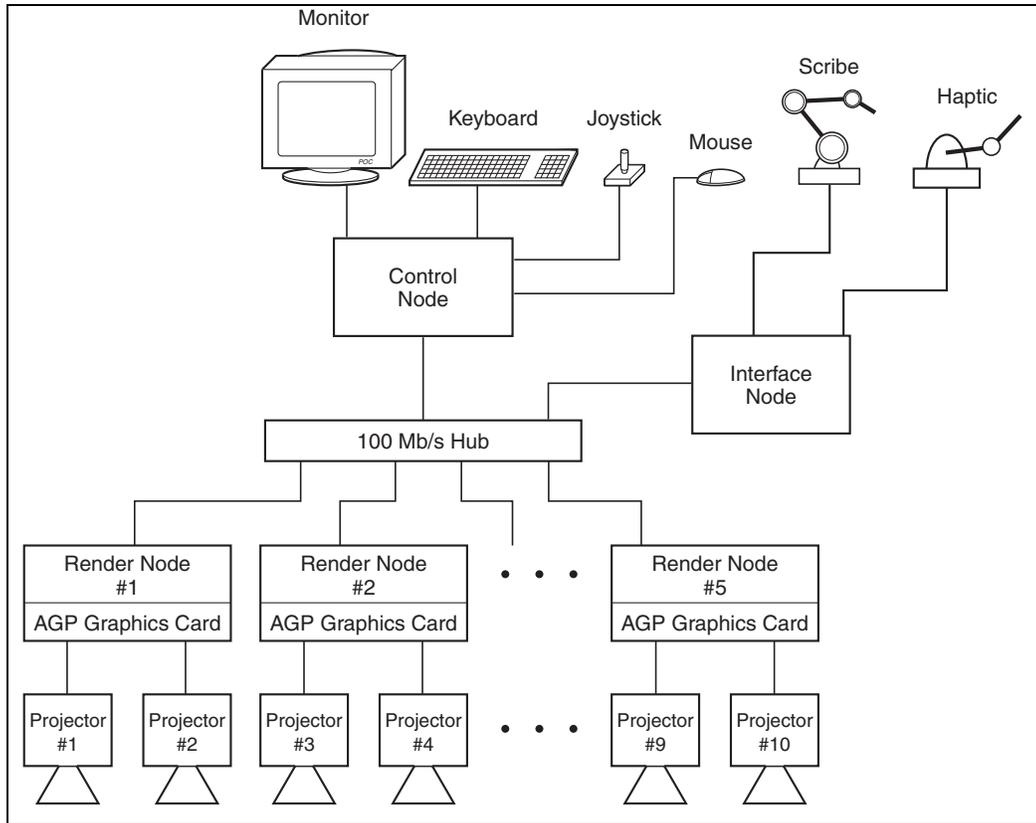


Figure 5-3
POC's 3-D Visualization Cluster View Schematic; presenting various 3-D views from different perspectives of the same 3-D object.

## 6. CATASTROPHES AS GEOMETRIC INVARIANTS AND PROGRESSIVE REAL-TIME ATR

It is important to realize **progressive** and **real-time** ATR for target identification and recognition purposes.

In conventional linear non-progressive view-centric Fourier-Based ATR we can only operate in a friendly (cooperative) environment; i.e., a target *"needs to position itself properly"* in order to be recognized. This is, of course, an impractical scenario in a hostile environment (exactly the same problem exists for face recognition).

In contrast, to view centric SOTA, we need to develop an ATR that could be **non-linear**, **progressive**, and **object-centric** one in order to be effective in hostile environments. Such a method must be based on some type of **geometric invariant**, which is only characterized, by topologic features or other object-centric features of a given 3D object. One such invariant is a motion signature, discussed in Reference [9]. They can work for *Class of Equivalence* (CoE) recognition, i.e., we find that an object is a *tank*, but we do not know what type of a *tank* it is. The second object-centric catastrophe [3,8] feature is geometrically-invariant in a more advanced sense, with respect to:

A. Sensor platform
B. Illumination
C. Color
D. View
E. Scale

## 6.1 Sensor platform invariance

There are three (3) basic sensors to be considered:

- VIS (low-light)
- IR
- Radar

The VIS sensor (a camera) is mostly sensitive to non-organic objects. The IR sensor is mostly sensitive to organic objects. The Radar sensor is very sensitive to climatic changes. For example, in the presence of wind, the lake's radar cross-section can be very high, and for the same lake, without wind, the radar cross-section can be very low. The geometric invariant such as *Thom's catastrophe*, [4] however, or manifold singularity, is a topologic invariant insensitive to a type of object (organic or inorganic) and as to climate changes (a lake). Its topographic invariance is shown in Figure 6-1, where it is clearly shown that catastrophic fold is describing "*object-boundary-to-infinity*" and nothing else. Therefore, the catastrophe is a singularity not rigidly attached to an object [6] in contrast to common singularities. We see that, with object rotation, a fold catastrophe "moves" in respect to an object, while regular singularities are fixed into an object. This is because the catastrophes are specifically defined by parallel projection. In other words, a catastrophe is an object-centric element, topologically related to an object.
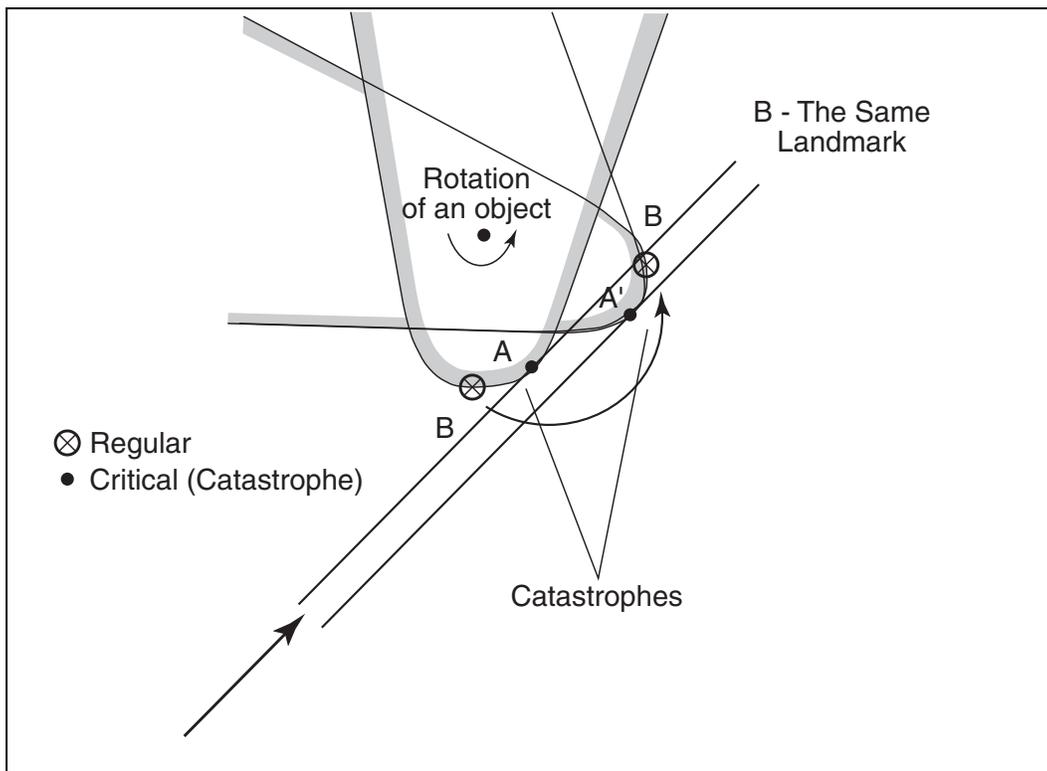


Figure 6-1
Catastrophic invariance in respect to an object. While regular singularity (B) is rigidly attached to an object, the catastrophic singularity (B) is not.

## 6.2 An example: digital elevation terrain map as a synthetic (environment) object

The DETM (*Digital Elevation Terrain Map*), in the form of (x,y,z)-grid is an example of a synthetic 3-D object. Its natural equivalent is a topologic representation of true terrain. The catastrophes are reference baselines for both natural and synthetic object representations, as it was shown in Figure 6-2.
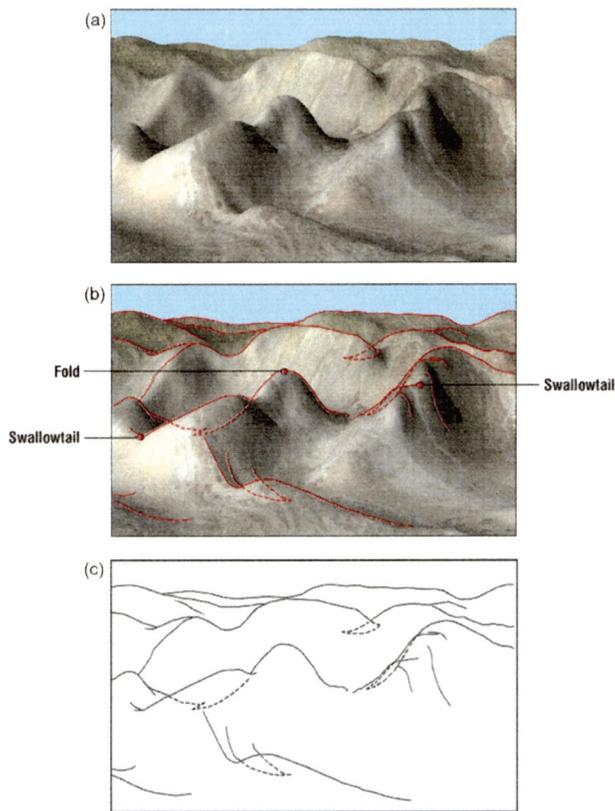
Figure 6-2
Catastrophes as reference baseline for both natural and synthetic DETM object versions, including: (a) topographic terrain; (b) terrain with catastrophes; (c) catastrophes, alone.

## 6.3 Catastrophe invariance to illumination

For imaging LIDAR, illumination comes from the direction of an observer, and not from the object side. For such a case, light is forward-scattered into an object, rather than backward-scattered from an object; thus, catastrophes will be recognized by low light (dark) areas, independently on illumination.

## 6.4 Catastrophe invariance to color

Since catastrophe represents dark areas of an object, these low-intensity areas look colorless; thus, providing physical arguments, supporting catastrophic invariance to color.

## 6.5 Catastrophe invariance to view

This invariance is illustrated by Figure 6-1. Since catastrophe is not rigidly attached to an object, it represents its object-centric, not view-centric feature. The catastrophic invariance to scale is obvious, as shown by Figure 6-2, where no scale is needed to illustrate catastrophic locations (i.e., terrain on Figure 6-2 can be either synthetic or natural).

## 7. SUMMARY

a)  We present here a diversified object M&S concept, including such objects as:

- DETM
- Vehicle

- Face

b) Profilometer (a small imaging LIDAR) can be integrated with a time 3-D display.
c) Temporal ATR is possible, which is:

- Progressive
- Real-time
- Object-centric

d) By applying catastrophes, as a special type of geometric invariant, we can compare 3-D synthetic and natural environment, as well as provide automated sensor fusion (VIS, IR, and Radar).

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