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Enhancing Autonomous Systems' Awareness: Conceptual Categorization of Anomalies by Temporal Change During Real-Time Operations

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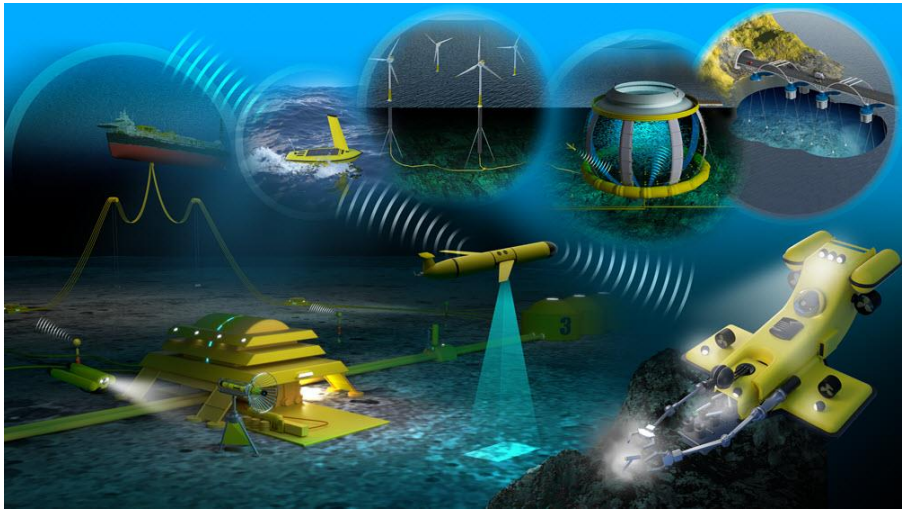
Introduction

- Unmanned Autonomous Systems (UAS)
  - Permanent role in offshore oil and gas operations
  - Real-time operations: monitoring and inspecting assets and the environment
  - Collecting data and real-time data analysis
  - Alert operators of hazardous occurrences that occur as anomalous trends in data



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Time series data, collected by sensors that detect environmental phenomena, enables the observation of anomalous data as dynamic instances of the dataset.

Contribution:

A *conceptual categorization of anomalies according to patterns of their temporal change, through a case study of potentially hazardous occurrences during an underwater pipeline inspection by UAS*

Provide more information about current environmental changes and allow for the early detection of anomalous, potentially hazardous occurrences in real-time.

Assist in minimizing false alarms by allowing for the more certain elimination of noisy data.

Background

Anomaly categorization

Data Structure	• Data-centric • Cross-sectional, time-series, graph, tree, spatial, etc.
Occurrence in Data	• General categorization • Global, collective, contextual
Data Source	• Origin and cause of anomaly • Environment, system, network
Application-defined	• Based on specific applications • Safety-critical software, forecast-system anomalies, etc.

Anomalous Change Detection

- Methods for detecting anomalous changes, most frequently in images, by suppressing background and emphasizing alterations on the image
- Application-specific: purpose, data availability and automation degree
- Predictable changes versus minor changes: insertion, deletion, movement of objects between images

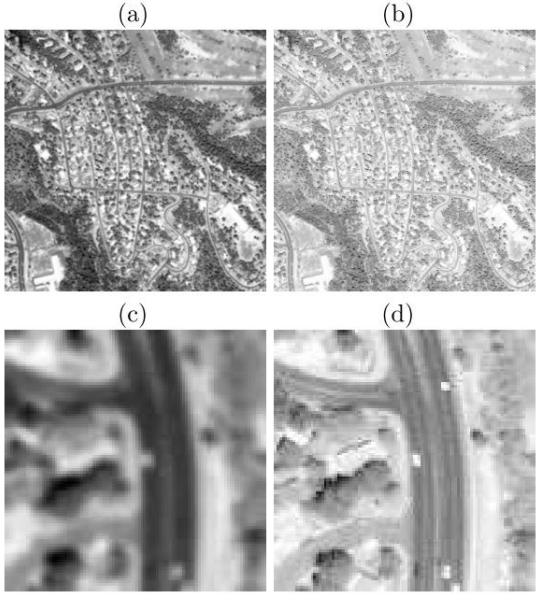

Fig. 1. (a,b) Predictable change in image contrast and brightnes; (c,d) Interesting change with (artificially) added vehicle, adapted from [4]

Time-Series Anomaly Detection

- Requires multiple data sources for anomaly detection
- Approaches:
  - frequent pattern mining methods
  - embedding of mixed-type time series

- Complex, underdeveloped problem

"Anomaly detection is a target detection with unknown targets and objectives"
–Theiler, 2015, How to measure what you can't define?

Categorization of Anomalies Based on Their Temporal Change

Frequent or Recurring Anomalies	Disappearing and Reappearing Anomalies	Expanding Anomalies

Time series data, collected by sensors that detect environmental phenomena, enables the observation of anomalous data as dynamic instances of the dataset.

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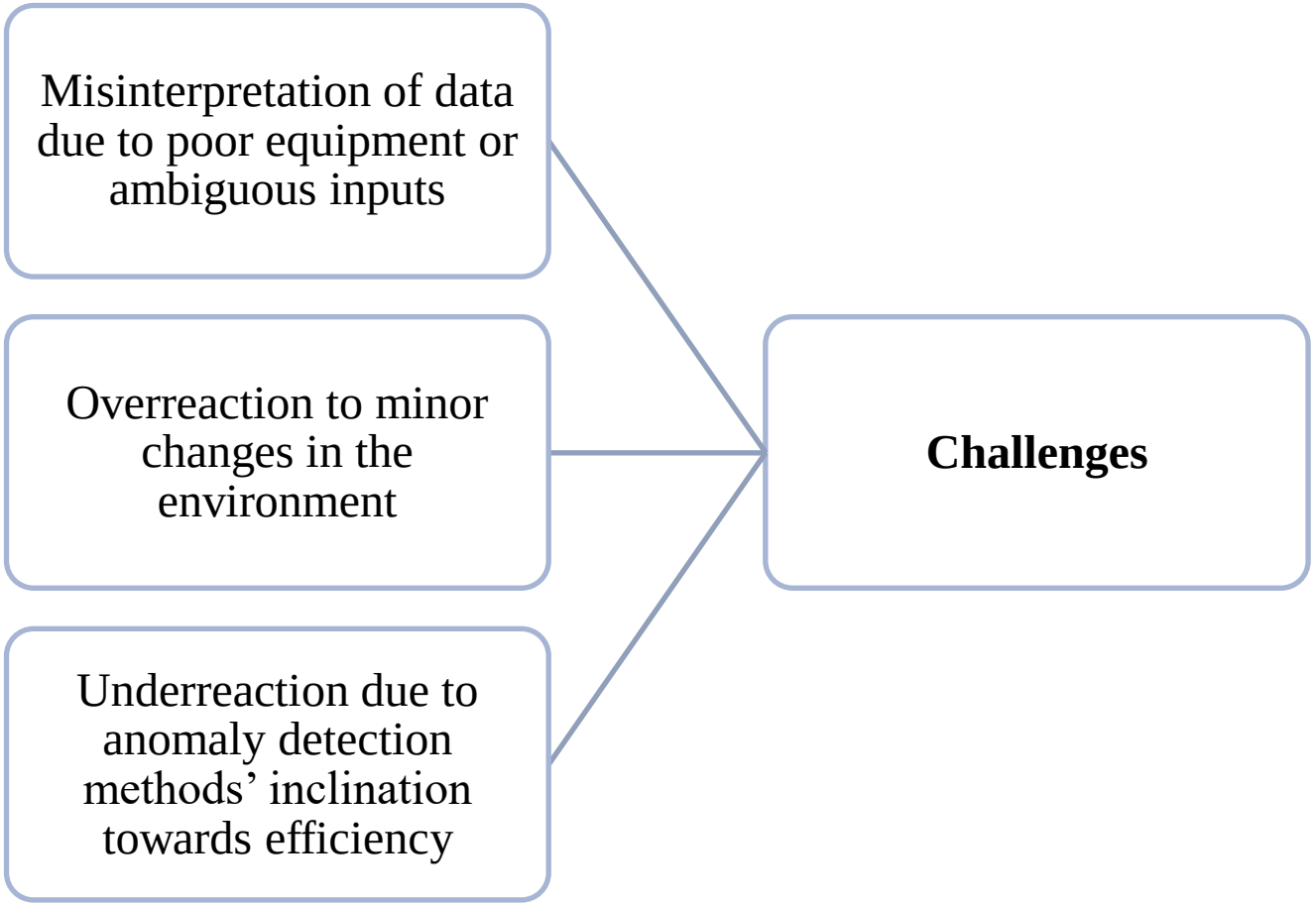
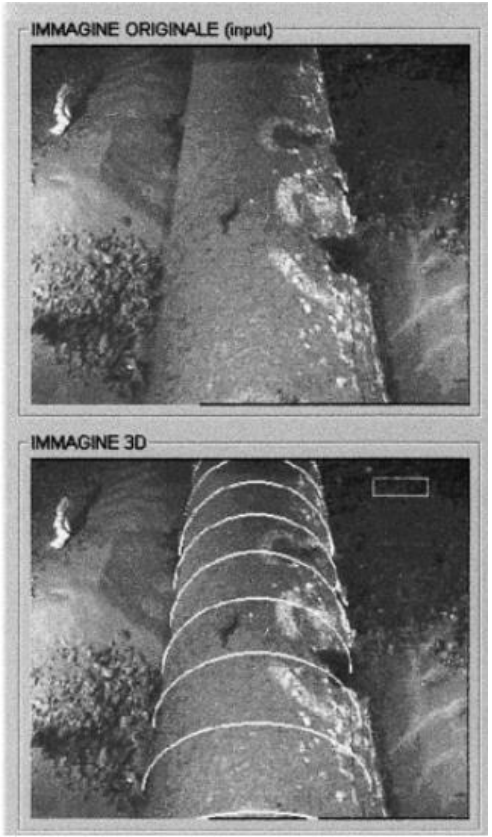
isolate and analyze changes
in anomalies based on their geospatial context


Misinterpretation of data due to poor equipment or ambiguous inputs
Overreaction to minor changes in the environment
Underreaction due to anomaly detection methods' inclination towards efficiency
Challenges

Frequent or Recurring Anomalies



- Frequent pattern data analysis distinguishes normal from anomalous data
- Assumption that anomalous data occurs infrequently
- Challenge: persistent anomalous data mistaken for normal data

Figure 2. (a) Visual inspection of underwater pipeline, images taken by autonomous underwater vehicle, adapted from [20]; (b) 3D scan over the underwater pipeline

Disappearing and Reappearing Anomalies

- Well-known type of anomalies in stock market
- Seasonal and predictable anomalies *should* be known
- *Are there still anomalies in recent data? Are they just existent during specific periods, or did they completely vanish? What is the immediate cause of the endurance of the anomaly?*

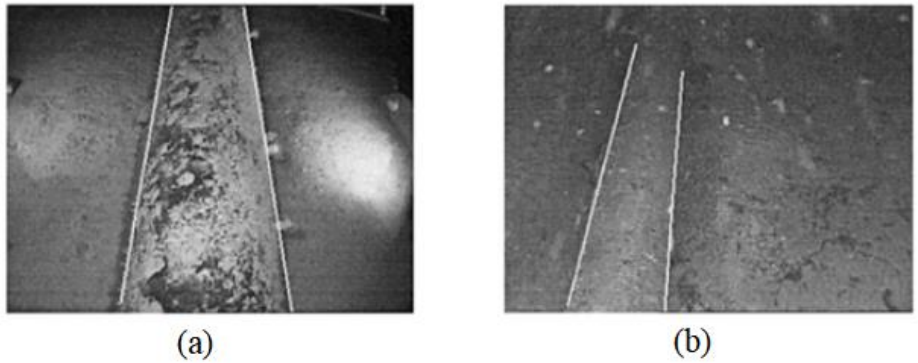


Fig. 3. (a) Visual inspection of underwater pipeline, images taken by autonomous underwater vehicle: Possible material degradation or biological growth?; (b) 3D scan over the underwater pipeline

Expanding Anomalies

- Insignificant anomaly may grow to affect various regions of the inspected structure (i.e., growing rupture on pipeline surface material, or biological growth).
- The purpose is to identify the onset of the anomaly as fast as feasible while maintaining a low false alarm rate.

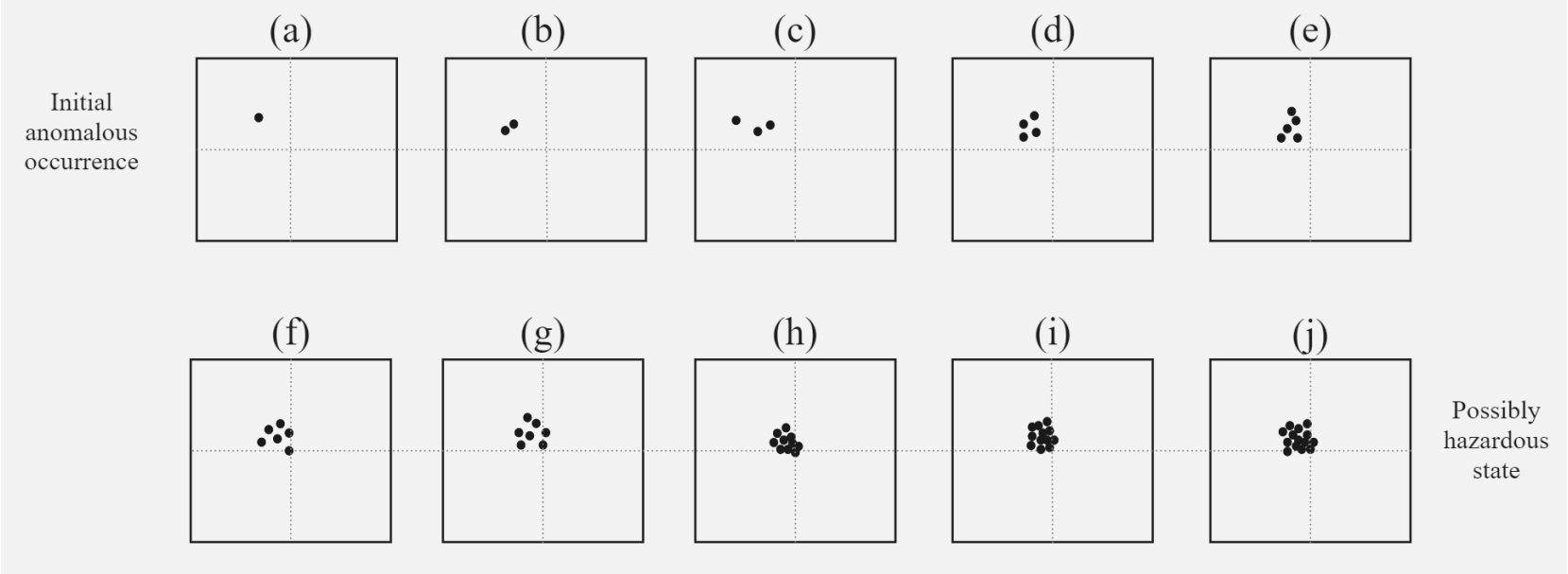


Fig. 4. Anomalies that expand over time

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Describing Anomalies by Temporal Change

Anomaly Type	**Frequent / Recurring**	**Disappearing and Reappearing**	**Expanding**
Point	Frequently occurring point anomaly.	Disappearing and reappearing point anomaly may be a sign of pervasive environmental phenomena.	Point anomaly may evolve into a collective anomaly of larger size and impact.
Collective	Frequently occurring collection of anomalies with similar properties (i.e., geospatial context).	Disappearing and reappearing collective anomaly may be a sign of pervasive environmental phenomena.	Collective anomalies may evolve into a more intrusive anomalous occurrence of larger size and impact.
Contextual	Anomalous depending on the context due to a potential risk of being misinterpreted as normal and left unexposed or a frequent anomaly collection obscuring more intrusive processes.	Context (i.e., geospatial, seasonal, weather) aids in determining the anomalousness of the disappearing/reappearing phenomena and finding the causes of their persistence.	Anomalous depending on the context.

Conclusion

- Observing and categorizing anomalies according to their temporal changes adds context to our understanding of how anomalies relate to one another and evolve in a normal and predictable data environment.

Image is property of BRU21, available at https://www.ntnu.edu/bru21

significance and criticality of anomalous occurrences

deduce the underlying causes of anomalous occurrences

focus on more pertinent data from the vast collections of sensor measurements

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Future Work

- construct a framework for detecting anomalous change in real-time by identifying practical time-series anomaly detection methods

- simulate streaming data and analyze images collected by the UAS during visual inspection of an underwater pipeline to validate the proposed temporal categorization of anomalies

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