MINEONT: A proposal for a core ontology in the aerial non-technical survey domain

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Abstract: Logical representation of knowledge enables reasoning based on formal logic, integration of heterogeneous data sources, augmentation of existing knowledge, and discovery of hidden knowledge that is hidden or unknown even to experienced professionals. Moreover, many high-performance software tools and services for logical reasoning are readily available in the academic community. Computational ontologies, or ontologies for short, are a comprehensive, formal, scalable, and adaptable methods for knowledge representation and automated reasoning. They have been successfully used in many diverse application domains, from medicine and natural sciences to engineering and applied sciences. However, the use of ontologies in the context of demining is novel and has not been exploited to the full advantage. In this context, a new core ontology called MINEONT (an acronym for "MINE-action ONTology") has been proposed. The MINEONT is written in the OWL-DL 2 formalism and allows an expressive and formal representation of concepts in mine action, high-level semantics, geospatial metadata, and information obtained through method of remote sensing, non-technical surveys, and other mine action survey types. The vocabulary of this ontology supports, among others, the following corpora: multisensory aerial and satellite imagery, derived indicators of mine presence and absence, contextual data, terrain analysis information, formalized knowledge of the humanitarian demining specialists in the form of declarations and procedures. The designed ontology has many advantages in describing data for non-technical surveys. However, it is also relevant for building a specialized recommender artificial intelligence (AI) expert system. Such an ontology-based decision support system (DSS) would integrate a large amount of collected data and facilitate interpretation and decision-making processes. In the paper, details about the Web Ontology Language (OWL) are given and its advantages for application in the aerial non-technical survey for humanitarian demining are explained. The MINEONT model is introduced and described in detail. The advantages of MINEONT compared to other existing methods in the aerial non-technical survey system are planned to be tested and demonstrated as part of scientific projects in which domestic and foreign partners, including CROMAC, will participate.

Keywords: aerial non-technical survey, ontology, knowledge database, machine learning, recommender system, secondary mine indicators, DSS, CROMAC

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1. Introduction

Mine action is a complex, multi-faceted process that combines humanitarian assistance and development studies aimed at eliminating landmines and reducing the social, economic, and environmental impact of landmines and explosive remnants of war (ERW). The goal of mine action is to identify and reduce the effects and risks of explosive hazards to a level where people are safe. Demining involves more than just removing landmines from the ground. It also includes effective actions aimed at protecting people from danger, helping victims become self-sufficient and active members of their communities, and creating opportunities for stability and sustainable development. Humanitarian demining, such as mine and ERW surveys, land release, mapping, marking, and clearance, is a specific group of activities and a type of mine action [1].

In our paper the mine action dataset is a high-level generic term that jointly describes all available digital documents relevant for detection of explosive objects in the context of non-technical survey and humanitarian demining.

The benefits of an Advanced Intelligence Decision Support System (AIDSS) using piloted helicopters and a decision support system (DSS) relying on multi-criteria fusion of data, information, experts' knowledge, and secondary (indirect) indicators of explosive threats and mine presence have already been presented and experimentally verified [2] [3]. However, existing document databases used for this purpose suffer from at least three sets of important drawbacks that have an adverse and far-reaching effect on their construction, utilization and proliferation:

1. Construction. Creation of an integrated mine action dataset is a large and complicated task involving many different specialists from various domains. Individual records must be first selected and approved by the demining specialists. Then the approved records must be manually acquired and processed.

2. Utilization. Since no dedicated tools for automated content retrieval and extraction of datafiles used in humanitarian demining exist, the construction of mine action databases must be carried out manually by scrutinizing all available records stored in different formats. This is a time-consuming process and requires experts highly trained in mine-scene interpretation.

3. Maintenance and propagation. Databases containing semi-structured or differently structured also difficult to maintain and upgrade with new content because the laborious and time-consuming steps in the construction phase have to be repeated. Repositories of non-technical survey inputs are proprietary and have different architectures. As a consequence, their reuse and integration are severely restricted.

The potential of ontology-based recommender systems in personalized document retrieval has already been well identified [4]. In this context, computer ontologies integrate all available document information and present a list of suggestions to the user. The recommendation process considers similarities calculated between ontologies of objects and users, which reflect the descriptive features existing in the system's knowledge database. The researchers have also shown that ontology-based methods enable the interoperability of heterogeneous knowledge representations and results from inaccurate recommendations [4]. The applicability of ontology-based recommender systems in real-life settings has been successfully demonstrated in practice (per example [5]).

However, to the best of our knowledge, the benefits of computer ontologies in the representation of expert knowledge for detection of explosive objects and the non-technical survey has not been recognized and used in practice.

The aforementioned problems motivate research into the tools and methods for improving annotation of documents produced in non-technical surveys. Formal knowledge representation and automated reasoning techniques can be successfully applied to impair deficiencies of existing mine record repositories and represent the best option for their upgrade. To address these issues, we propose MINEONT (MINE-action ONTology) for a formal and comprehensive description of information for detection of explosive objects in the context of non-technical survey and humanitarian demining. The proposal of the MINEONT follows our previous work on the ontology-based recommender expert system for non-technical survey in decision support system functions [6].

2. Construction of the MINEONT knowledge database

The first step in utilizing computer ontologies in any domain is the construction of the knowledge database with a specific model optimized for the selected domain. The construction of the intelligent expert system's knowledge database involves acquisition, processing and preparation of all data required to obtain an integrated understanding of the minefield. The construction process can be split in two phases: 1) data acquisition and 2) data processing.

As shown in Figure 1 the inputs for construction of a mine action knowledge database may be many: minefield records, mine accidents maps, reconstructed minefields, interviews, surveyors' reports, military maps, etc. These inputs are usually acquired in many different digital formats, frequently proprietary, as well as physical documents (e.g. hand-drawn or printed on paper). One of the strong points of the proposed expert system is that it can use any data documents that are available for decision support. This requires from the ontology model to a comprehensively describe all knowledge elements that may be used and in sufficiently expressive detail.

The data acquisition phase incorporates information from different sensors used to collect additional data such as matrix, line, multispectral, hyperspectral, radar, Lidar, magnetometer and others if available. Afterwards specialized software is used to manipulate this information and the developed maps may also be used to plan subsequent data collection operations. Traditionally this is done manually by highly trained data acquisition specialists.

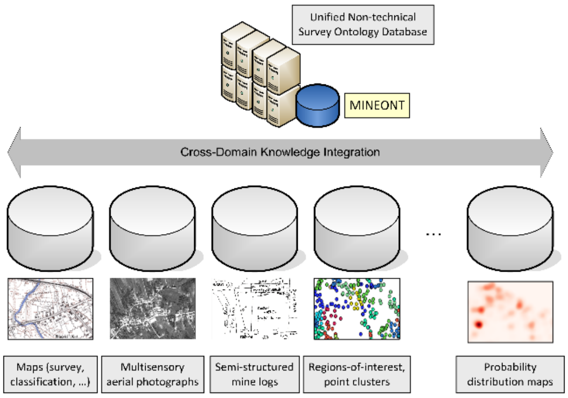

Figure 1. A schematic diagram of cross-domain knowledge integration of a diverse set of data inputs for construction of a unified Non-technical Survey Ontology Database.

Because of the different complex and diverse procedures involved in creating minefield records some of the documents are made available only in physical format such as handwritten reports, manually drawn maps etc. Such documentations must be first converted in an appropriate digital format to be included in the mine action dataset. This preparatory process, at the least, involves scanning and character recognition algorithms for image to text conversion (OCR) and conversion of data files between different digital formats. Additionally, the preparation of physical documents may include different image processing techniques such as image enhancement, edge finding and vectorization. Ideally these should be performed automatically because of the large volume of the traditional documentation that needs to be included in the dataset, multiple actions that must be performed in exact sequences, and the overall quality of the process that has to be ensured.

After the data acquisition phase has been finished, pre-processing and processing of data may begin. The pre-processing involves parametric geocoding of hyperspectral and multispectral images, conducting atmospheric correction on hyperspectral images providing the coverage of the field with images, the determination of the quality of images) and so-called "triage" which is manipulation and separation of images for further processing. This phase is also usually accomplished exclusively by small teams of skilled specialists. After the required data has been acquired and adequately processed, it can be stored in the ontology model of the integrated knowledge database.

3. The MINEONT model

The MINEONT is designed to − as stated previously − provide a formal and comprehensive, yet simple and manageable, description of a minefield containing different UXOs. The MINEONT model has necessary and sufficient expressiveness and decidability and can be used in inferences and SPARQL queries [7]. This ability enables the MINEONT to be used together with an AI mine action expert system in order to discover hidden knowledge and generate expert recommendations.

All documents required to describe a minefield chart and listed in the previous section must be structured and formally described at the sufficient level of semantic expressiveness to be included in the ontology's model. In this process properties and functional dependencies of all categories of mine action documents will shape the ontology's structure. Some knowledge elements will form individual concepts while others will be encapsulated as functional or data relationships between different concepts. Further, data categories in documentation will be transferred to concepts' data attributes.

The MINEONT model showing the structure of the ontology concepts, functional properties and data attributes is in Figure 2. The model is written in the OWL 2 DL XML-based annotation language [8].

The top concept in the MINEONT ontology is MinefieldChart which is directly subsumed by owl:Thing class. An instance of MinefieldRecord is related to one or more instances of MinefieldDrawing, OrientationPointList and UXOList classes with their respective object relationships:

$$MinefieldRecord \equiv \exists_{\geq 1} MinefieldDrawing \sqcap OrientationPointList \sqcap UXOList$$

Each UXO in MinefieldChart is represented in the knowledge database (KB) ABox as exactly one instance of UXO concept. This concept can have a labeled name, description, and quantity.

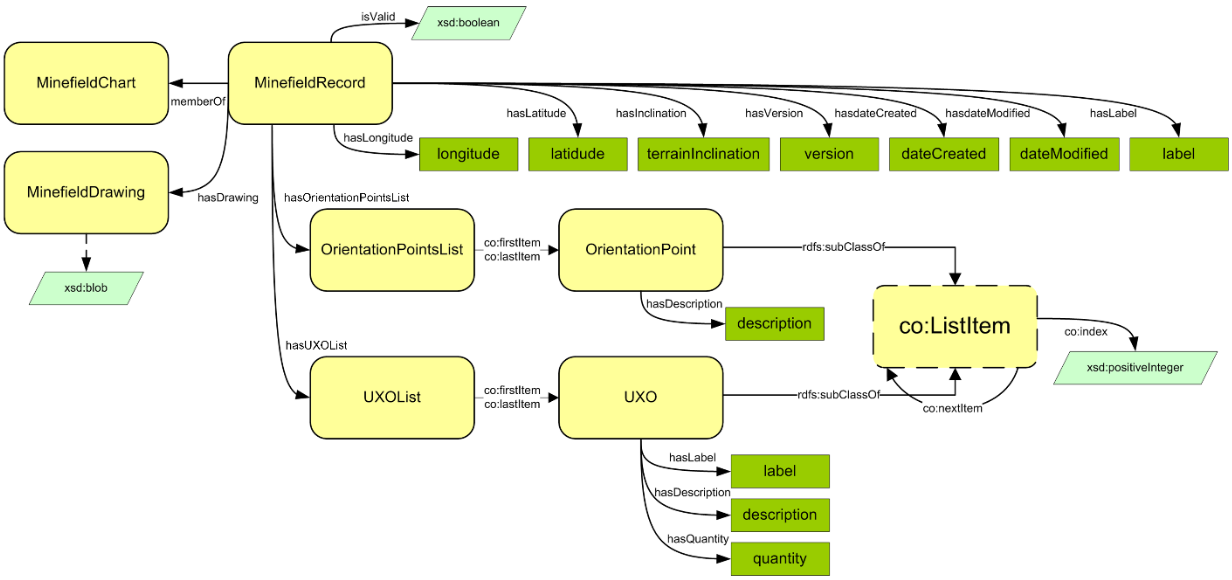

Figure 2. The concepts and relations in the MINEONT model defined in OWL 2 DL. Data properties (owl:DataProperty) are indicated with dashed lines while class inheritance (rdfs:subClassOf) and object properties (owl:ObjectProperty) are denoted with solid lines. External ontology concepts have dashed borders.

The order of UXOs in the sequence is defined as in a linked list. In this scheme the first sequence member in the list is attached to a UXOList individual using co:firstItem object relation. The second member in the list is linked to the first with co:nextItem object relation and so on, until, eventually, the last member is denoted using co:lastItem object relation. Thus the sequence can be easily traversed by following all UXO individuals in the chained list. Each list item has its index that uniquely identifies it.

In accordance with the most important ontology designing objectives the MINEONT reuses an existing ontology Collections Ontology (prefix "co") for formal representation of collections [9]. The Collections Ontology is an OWL 2 DL ontology developed for creating sets, bags and lists of resources, and for inferring collection properties even in the presence of incomplete information. Although RDF data can be used to define collections and containers to group resources as one entity, this important feature has not been included in OWL and even in OWL 2 DL specifications. The Collections Ontology has been created to address this issue [9].

In the MINEONT model one MinefieldRecord is divided into one or more sequences of UXOs which contain a particular explosive device. Sequences have their index and can be numbered. Likewise, the MinefieldRecord can have at least one OrientationPoint. UXOs and OrientationPoints are hierarchically organized into sequences. Sequence is a type of List from the Collections Ontology [9]. The co:List cannot be empty, i.e. data property co:index of the class co:ListItem is a positive integer. Therefore, at least one instance of UXO and OrientationPoint classes must exist in ABox.

4. Conclusion

The MINEONT ontology presented in this paper enables a formal, consistent, systematic, and expressive model of minefield records. The ontology enables DL-based reasoning about the aggregated content and document metadata.

The MINONT model enables formal representation of high-level semantics of minefield charts. It facilitates knowledge reuse, interoperability and formalization of UXO information that are superior to the contemporary methods for interpretation of mine-scene information. The MINONT model was intentionally made simple and compact as to be easier to use by experts and in software tools. However, even more expressive model may be created later incorporating additional mine-scene information.

In the future, we intend to develop a decision support system utilizing the MINEONT model [6] [10]. Such DSS would be built around an intelligent expert system supporting ontological reasoning and packaged as a computer workstation that can be deployed in remote areas. The envisioned system could be used even by personnel not proficient in mine-scene interpretation with minimum training required. We hope that the presented MINONT is a step toward this larger goal.

References

[1] Humanitarian Demining, Geneva International Centre for, (2016). A Guide to Developing National Mine Action Standards," Global CWD Repository, 1317. Available: 01-April-2022, https://commons.lib.jmu.edu/cisr-globalcwd/1317

[2] Bajić, M. (2010). The advanced intelligence decision support system for the assessment of mine suspected areas. Journal of ERW and Mine Action, James Madison University, 14.3.

[3] Krtalić, A., & Bajić, M. (2019). Development of the TIRAMISU advanced intelligence decision support system. European Journal of Remote Sensing, 52(1), 40-55.

[4] Ruotsalo, Tuukka. (2010). Methods and applications for ontology-based recommender systems.

[5] Juszczyszyn, Krzysztof, Przemysław Kazienko, Katarzyna Musiał (2010). Personalized ontology-based recommender systems for multimedia objects. In Agent and Multi-agent Technology for Internet and Enterprise Systems (pp. 275-292). Springer, Berlin, Heidelberg.

[6] Bajić, M., Gold, H., Horvat, M., Krtalić, A., Laura, D., & Muštra, M. (2021). The novel paradigm for a decision support system of the aerial non-technical survey. Book of papers of 17th International Symposium MINE ACTION 2021.

[7] Pérez, J., Arenas, M., & Gutierrez, C. (2009). Semantics and complexity of SPARQL. ACM Transactions on Database Systems (TODS), 34(3), pp. 1-45.

[8] Glimm, Birte, et al. (2014). HermiT: an OWL 2 reasoner. Journal of Automated Reasoning, 53(3), pp. 245-269.

[9] Ciccarese, P., & Peroni, S. (2014). The Collections Ontology: creating and handling collections in OWL 2 DL frameworks. Semantic Web, 5(6), pp. 515-529.

[10] Krtalić, A., & Bajić, M. (2019). Development of the TIRAMISU advanced intelligence decision support system. European Journal of Remote Sensing, 52(1), 40-55.