Bridging Blockchain Technology and Humanitarian Demining: A Novel Concept for Decentralized Storage of Landmine and UXO Locations

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Abstract*. This paper presents a proposal to explore decentralized storage solutions and the potential of blockchain technologies, in particular, Filecoin network and Storage.NFT framework, for the secure and reliable storage of landmine locations and descriptive information for non-technical survey in humanitarian demining. The presented innovative approach offers numerous benefits such as decentralized and secure storage, tamper-proof data, trust, and transparent data access by implementing reliable blockchain technology in the field of demining. Scalability, transparency, reliability, integration with existing systems, legal compliance, and cost-effectiveness are issues that need to be further explored. Using blockchain technology to store information in minefield records can significantly improve the efficiency, accessibility, and safety of humanitarian demining operations.*

Keywords. Distributed Storage Networks, Filecoin Blockchain, Non-Fungible Tokens, Non-Technical Survey, Mine Action

1 Introduction

Humanitarian demining is a critical process in post-conflict areas that aims to remove landmines and explosive remnants of war and ultimately save lives (Dorn, 2019; Camacho-Sanchez, Yie-Pinedo & Galindo, 2023). The Non-Technical Survey (NTS) in demining involves the collection, analysis, and storage of minefield records, which can be critical to successful mine clearance operations (Bajić et al., 2021).

Advances in remote sensing technologies such as magnetic detectors, ground penetrating radars, and hyperspectral aerial images captured by Unmanned Aerial Vehicles (UAVs), aircraft, and satellites have greatly improved the efficiency and accuracy of humanitarian demining (Krtalić & Bajić, 2019). These cutting-edge technologies, together with the application of novel Artificial Intelligence (AI) and Deep Learning (DL) algorithms, have greatly improved identification of landmines and Unexploded Ordnance (UXO) with a high degree of certainty (Baur et al., 2020; Horvat et al., 2022; Osmankovic et al., 2022; Horvat et al., 2023).

However, sharing and managing the data generated by these sensor technologies and non-technical survey analysis remains a significant challenge, particularly when it comes to secure access, trustworthiness, and collaboration among a diverse group of stakeholders, including governments, nongovernmental organizations, and international organizations (Horvat et al., 2023).

To address these concerns, a novel blockchain-based concept was proposed for data management for non-technical survey in mine-action. Specifically, in the proposed concept minefield records documents with information on secondary indicators about Suspected Hazardous Area (SHA) are stored on the blockchain. This innovative solution could securely and reliably store geolocation, type, presence probability and other relevant description of suspected UXO in an expressive and semantically rich user-defined format. This approach, as a continuation of our previous work (Krtalić & Bajić, 2019; Bajić et al., 2021; Horvat et al., 2022; Horvat et al., 2023), could enable further processing of such data, including data mining, automated reasoning, and decision support in mine action. The core benefit of the proposed concept lies in its ability to utilize inherent properties of blockchain technology in a novel manner to provide a transparent, immutable, and decentralized system for managing important demining data. This not only increases the security and reliability of data storage, but also facilitates seamless collaboration between stakeholders, allowing for efficient execution of humanitarian demining operations.

The reminder of the paper is organized as follows; Section 2 presents the novel concept of decentralized management of mine records on blockchain, focusing on the Filecoin and NFT.Storage technologies for its implementation. Section 3 explains on a real-life example how these technologies can be applied to minefield records blockchain storage. The benefits of the presented concept are listed in Section 3.1 and Section 3.2 discusses potential areas for future research. Finally, Section 4 concludes the paper and reiterates the most important implications of the proposed concept.

2 The Concept of Decentralized Mine Action Data Management using Blockchain Technologies

Blockchain has revolutionized the way we think about data storage and management transaction (Iansiti & Lakhani, 2017). One of the key benefits of blockchain technology is its ability to provide an immutable and transparent ledger, which can secure transactions without relying on a central authority.

This decentralized approach provides several benefits, including decentralized control, distributed architecture and applications, data immutability, and network consensus to approve any transaction (Wang et al., 2019). By leveraging these inherent advantages, blockchain technology enables streamlined and secure data management for businesses across various industries.

A block is a fundamental component that plays a crucial role in ensuring the security, immutability, and decentralization of the blockchain network. It is a data structure that contains a set of transactions and additional information, which typically includes block header and transactions. A header contains metadata about the block, while transactions are actual data entries or operations that are being recorded on the blockchain. Blocks are connected in a chain, hence the name blockchain.

The size of the blocks is predefined. Once the block is filled, it is "closed" and connected to the previous block called Parent block, thus creating a chain. Each transaction that is written into the block has its own timestamp when it was added to the block. This property makes blockchain a secure information storage technology as it is almost impossible to change the timestamp. All blocks are written to all devices connected in the network, which means that if a change is to be made, it must be achieved by consensus, i.e., by unanimous decision of all related stakeholders. There are various open blockchain networks, one of them is Filecoin, it is primary decentralized, peer-to-peer storage network (Vyzovitis et al., 2020).

2.1 Filecoin Blockchain

Filecoin (FIL) is a decentralized storage network built on a blockchain-based market, designed to enable users to store and retrieve data in a secure, reliable, and efficient manner (Bauer, 2022a; Psaras & Dias, 2020). The Filecoin network's primary function is to provide storage services, relying on a native token as an incentive mechanism for storage providers (Benet & Greco, 2018). Its unique consensus mechanism, Proof-of-Replication (PoRep), and Proof-of-Spacetime (PoSt), ensures that the data is stored securely and can be retrieved when needed (Dai et al., 2020). In this regard, the Filecoin network trades storage like a commodity. Its role is to ensure the safe and reliable storage of data by involving various storage providers for this purpose. The Filecoin network thus acts as a marketplace for data storage, bringing together users who need storage with parties willing to provide storage capacity.

This storage network is built on peer-to-peer principle, using cryptography to provide security of files over longer periods. Users pay for their files to be stored on available storage providers, which guarantee safe storage over time (Bamakan et al., 2021). Filecoin facilitates open markets for available storages for storing and retrieving files that anyone can participate in, it is not controlled by single company, hence decentralization (Fisch et al., 2018).

Filecoin can also store Non-Fungible Tokens (NFT). NFT is type of a cryptocurrency, that originated from token standard of Ethereum. Each NFT is created unique and irreplaceable. They have distinctive source code and are bound with virtual/digital properties, called metadata, making it possible to individually distinguish between each other. These tokens can be any digital object. NFT is a type of cryptocurrency derived by Ethereum using smart contracts. Every NFT contains details of ownership, safe mechanisms, and metadata, which is the main difference between normal currency and NFTs. This feature comes from ERC-721 standard which implements application programming interface (API) inside smart contracts (Bauer, 2022b). It also offers trades with tokens between stakeholders, overview of an account, shows current owner of each token and list of available tokens on the network (Wang, Wang & Qin, 2021).

An overview of Filecoin architecture is shown in a diagram (Figure 1). The diagram explains user-system interaction, where users upload or download data through a client, which then interfaces with the NFT.Storage API. The NFT.Storage API is responsible for data storage. It stores metadata in a dedicated Metadata Database and the actual data in an InterPlanetary File System (IPFS) cluster. Then the data is pinned from the IPFS cluster to the Filecoin network. The final step of the process is the Filecoin network, which guarantees the storage of the data by different storage providers.

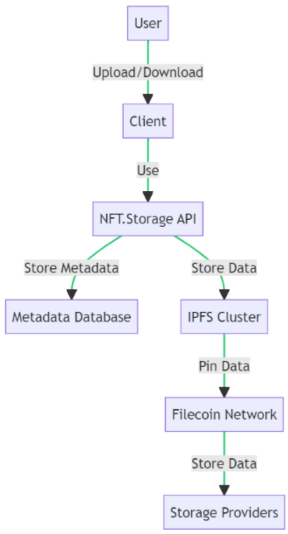

Figure 1. Simplified flowchart of the Filecoin and NFT.Storage network architecture.

As previously mentioned, Filecoin can store NFTs, which is accomplished through specialized service, NFT.Storage. By using this service, the storage of tokens on a decentralized network is simple and reliable for stakeholders, without the obligation of setting up and maintaining their own infrastructure.

2.2 NFT.Storage Framework

NFT.Storage is an open software framework that enables the creation and management NFTs representing digital assets and their storage on decentralized networks ("NFT.Storage Docs", 2023; Wyatt, 2022a; Wyatt, 2022b). NFTs are unique tokens representing ownership and provenance of digital assets, ensuring their uniqueness and traceability (Herian et al., 2021). By combining NFTs with decentralized storage networks, NFT.Storage provides a secure, verifiable, and tamper-proof storage solution for digital assets, with a goal to store all NFT data as public goods. As such, NFT.Storage presents and ideal choice for the implementation of the presented concept of storing demining documents as digital assets on the blockchain.

NFT data is stored using IPFS as a Uniform resource identifier (URI), e.g., „`ipfs://`…", making the connection between token and its data transaction ("Introducing NFT.Storage", 2021). Once the data is uploaded, stakeholder will receive IPFS hash which represents data that is to be stored, Content IDentifier (CID). This can be accessed through URLs, such as „`ipfs://<CID>`". As mentioned before, blockchain technology makes a copy on every node in the network, which is here used to store multiple copies of data on network. The most important copies are the ones on IPFS server (monitored by NFT.Storage) and on Filecoin. To access any of the data for certain NFT, all that is needed is to provide the CID. Data can be retrieved through IPFS gateway or directly from IPFS command line. This process is illustrated in Figure 2.

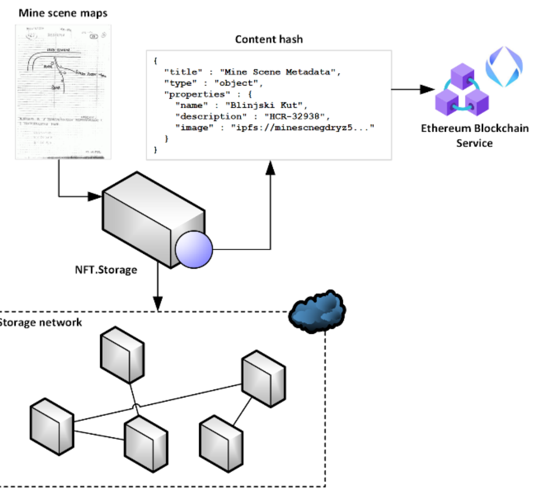

Figure 2. NFT.Storage architecture overview incorporating content addressing, provable storage and resilient retrieval features. Adapted from ("Introducing NFT.Storage", 2021).

3 Utilizing Filecoin and Storage.NFT for Minefield Records Storage

Minefield records are very important demining documents. As can be seen in Figure 3, such documents are hand-drawn and may be difficult to ready, yet they contain important information needed to determine the type, shape and location of secondary mine indicators. The maps contain various information written on this document – for instance when it was made, which mines were found in this are – that helps in describing Suspected Hazardous Area (SHA) (Bajić et al., 2011).

It is important to note that minefield records should be made available and easily accessible to interested stakeholders while ensuring the integrity of the information. For this reason, the use of the proposed concept is beneficial to both government agencies and the public.

In the proposed concept all pertaining information in the minefield records are stored as metadata in NFT, with NFT being the digital object of the scanned minefield record itself. To store this metadata and the demining document as NFT, there must exist function to create a file from uploaded image and append its metadata.

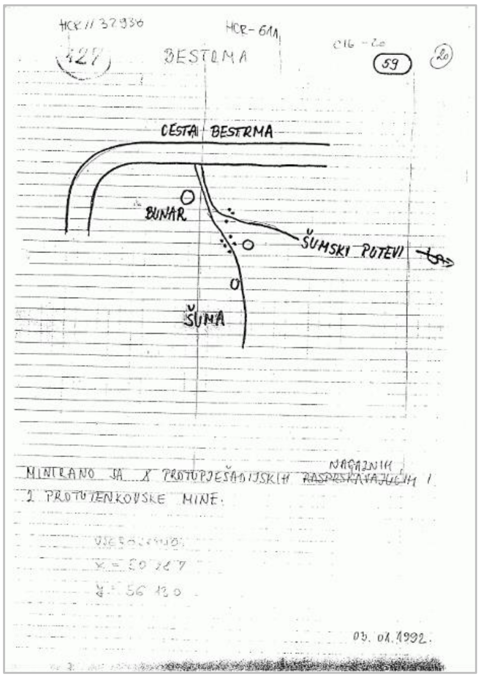

Figure 3. A real-life example of a typical hand-drawn minefield record document (kindly provided by the Croatian Mine Action Centre – HCR) that is stored on blockchain as NFT.

Figure 4 shows a source code for creating a new NFT and storing it in FIL. The code imports `NFTStorage` class from `NFT.Storage` package, that takes users' API key and uses it to store and connect NFT to its rightful owner.

```
async function storeNFT(imagePath, name,
description, DocType, Iink, GKZona, GKE, GKN,
UNSektor, OznakaUN, Oznaka, Zupanija, Opcina,
Naselje, VojskalD, Date, POM, PPM, Ostala,
Provjere, TipPolja) {
// load the file from disk
    const image = await fileFromPath(imagePath)

// create a new NFTStorage client using our API
key
    const nftstorage = new NFTStorage({token:
NFT_STORAGE_KEY })

// call client.store, passing image & metadata
    return nftstorage.store({image, name,
description,DocType, Iink, GKZona, GKE, GKN,
UNSektor, OznakaUN, Oznaka, Zupanija, Opcina,
Naselje, VojskalD, Date, POM, PPM, Ostala,
Provjere, TipPolja
    })
}
```

Figure 4. The usage of `storeNFT()` function.

The `main` function calls `storeNFT` function and passes attributes for the metadata processing. Also, as Figure 4 shows, from given parameter `imagePath`, program calls `fileFromPath` function which then returns object of class `File`. This is crucial because functions that are called after can work with objects of type File or Blob. After this function call has successfully finished, the program will try to execute function `store` from `NFTStorage` class object. The `store` function takes the metadata, passed in JSON format according to theERC-1155 standard, and creates a new NFT data file. Then the function returns the address IPFS URL from which the user can access the NFT data file and retrieve the metadata.

In Figure 5 is an example of how to call this code and provide all the required parameters and what the outcome will be. Every argument written behind the `upload.mjs` is a document data for NFT's metadata.

```
node upload.mjs 32938.gif 'dd32938' 'Deminig
document no 32938' 'DeminingDocument' '32938' '5'
'611360' '5028700' 'None' '0' '59' 'SM' 'Sunja'
'Bestrma' 'None' '03/01/1992' '2' '8' '0' 'False'
'Mix'
```

Figure 5. Example of `upload.mjs` file call.

In Figure 5 can be seen how all the necessary parameters are provided when `upload.mjs` is called. In this certain example it is import that user provides all the parameters because otherwise the program will return error and ask the user to provide new, complete data. This will return a token, which has two elements, `ipnft` and `url`. `Ipnft` is used in URL, and this URL is IPFS URL from which the user can access metadata. It is crucial to enclose all parameters intended to be stored as strings within quotation marks. This practice enables parsers to accurately identify the beginning and ending of each parameter, ensuring proper data processing. An example of JSON metadata for creating NFT with a minefield record is shown in Figure 6.

There are certain components of metadata that cannot be changed such as the CID and contract address, but other information in metadata can be changed. The metadata may be changed in case if new field of information is needed or a more precise location coordinates are defined. Figure 7 shows TypeScript code of how this can be done using Metaplex service ("Metaplex Docs", 2023; Camacho-Sanchez, Yie-Pinedo & Galindo, 2023; Peterfay, 2022).

Metaplex is an open framework and high-level application protocol designed for creating, minting and deploying NFTs ("Metaplex Docs", 2023; Camacho-Sanchez, Yie-Pinedo & Galindo, 2023; Peterfay, 2022). It consists of a set of tools and smart contracts that provide NFT developers with a comprehensive set of services that simplifies the process of creating and deploying NFTs.

```
{
    "Date": "03/01/1992",
    "DocType": "DeminingDocument",
    "GKE": "611360",
    "GKN": "5028700",
    "GKZona": "5",
    "Iink": "32938",
    "Naselje": "Bestrma",
    "Opcina": "Sunja",
    "Ostala": "0",
    "Oznaka": "59",
    "OznakaUN": "0",
    "POM": "2",
    "PPM": "8",
    "Provjere": "False",
    "TipPolja": "Mix",
    "UNSektor": "None",
    "VojskalD": "None",
    "Zupanija": "SM",
    "description": "Deminig document no 32938",
    "image": {
        "/":
"bafybeictkpxa4siq4yk7e5aakih5uzmhayob3ou2z3rcysu
jistrxcx4vu"
    },
    "metadata.json": {
        "/":
"bafkreigdqt2ic6piktw56kb6oxwgyceyiyhw7kq44vwrtzr
ccm2cwr4nim"
    },
    "name": "dd32938",
    "type": "nft"
}
```


Figure 6. An example of JSON configuration file for storing minefield metadata.

For the code provided in Figure 7, user is required to create JSON for metadata, which will be uploaded by `NFTClient` object which has a method `uploadMetadata`. After this is successfully executed, the URI of the uploaded JSON metadata will be linked to NFT and new, updated metadata will be added.

```
const NEW_METADATA = {
    description: 'New description!',
    attributes: [
        {trait_type: 'GKN', value: '5028701'},
        {trait_type: 'GKZone', value: '4'},
        {trait_type: 'GKE', value: '611361'}
    ]
};

async function uploadMetadata(imgUri: string,
description: string, attributes: {trait_type:
string, value: string}[]) {
    const { uri } = await METAPLEX
        .nfts()
        .uploadMetadata({
            name: "My new name",
            description: description,
            image: imgUri,
            attributes: attributes
        });
    return uri;
}

async function updateNft(nft:Nft|Sft,
metadataUri: string, newName: string) {
    await METAPLEX
        .nfts()
        .update({
            name: newName,
            nftOrSft: nft,
            uri: metadataUri
        });
}
```

Figure 7. Upload of new minefield metadata using Metaplex open framework.

NFT and its minefield metadata can be deleted from user's account, but despite this the nodes in the IPFS storage network can still contain a copy of this data indefinitely. This is why anything that is stored on blockchain is considered permanent. To delete an NFT from blockchain, it is important to provide correct CID. An example of this function is shown in Figure 8.

```
async function deleteNFT(cid) {
const nftstorage = new NFTStorage({ token:
NFT_STORAGE_KEY })
    res = await nftstorage.delete(cid)
}
```

Figure 8. The usage of `deleteNFT()` function.

The UML use case diagram in Figure 9 shows the three basic operations of the proposed concept for the NFT blockchain-based mine record storage service: creation, updating, and deletion of NFTs enabled by interactions between the user, the Metaplex framework, and the Filecoin network.

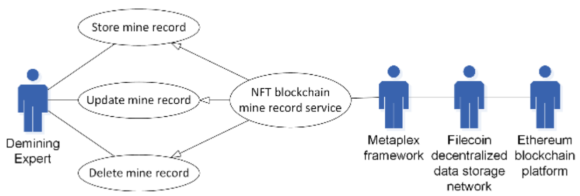

Figure 9. UML use-case diagram representing the interactions between the demining expert and the proposed system for NFT blockchain-based mine record storage service using Metaplex and Filecoin for the creation, updating, and deletion of NFTs containing minefield records.

3.1 Benefits of the Proposed Concept

The integration of Filecoin and Storage.NFT for minefield record storage in humanitarian demining provides several advantages including: (*i*) decentralized and secure storage, (*ii*) immutability, and (*iii*) transparency and transparent data access.

First, concerning decentralized and secure storage, the Filecoin network is important for guaranteeing data redundancy and distributed storage. This reduces the risk of data loss significantly while also offering enhanced protection against unauthorized access (Benet & Greco, 2017).

Second, data immutability and tamper resistance are also very important features of the proposed approach. Blockchain technology ensures that once data is added to the blockchain, it cannot be altered or deleted. This provides a reliable and tamper-proof record of landmine and UXO locations enhancing trust in the data. By using Storage.NFT, minefield records are represented as unique NFTs, ensuring their authenticity and provenance, and preventing unauthorized changes (Herian et al., 2021).

The third advantage is transparency and transparent access to data. The decentralized nature of the blockchain allows all stakeholders involved to access the same data set, which promotes transparency and facilitates collaboration in demining efforts. The blockchain-based nature of Filecoin and Storage.NFT allows for transparent and verifiable data access, which facilitates collaboration and trust between various demining stakeholders such as Mine Action Centers (MACs), companies conducting the demining and the public.

One of the major drawbacks of adding digital documents to the blockchain is that uploads to the blockchain are not real-time. Since consensus must first be reached, the allowable wait time is 48 hours. This is more of a disadvantage for the Blockchain than for demining and uploading demining documents, as demining occurs after the end of hostilities and the non-technical aspect of demining (i.e., collecting the data) requires more time.

In addition, since Filecoin is based on the Etherum blockchain network, there are certain file size limits. For each upload, the user is only allowed to upload a total of 31 GiB. This is still a lot of space, but every user should be aware of this limitation.

Furthermore, for future use, instead of just the demining documents, there should be an option to also save the edge points of polygons after multiple analysis of all the collected data from the suspected threat area. Moreover, to make uploading demining documents easier, there should be a web page with user friendly GUI, where end user could input all necessary metadata and image, and after successful upload get JSON with this metadata. Also, a possibility for delete and update options for NFTs which will call functions described in this chapter.

3.2 Future Research

Considering future work, several challenges need to be addressed when implementing blockchain technologies for minefield record storage in humanitarian demining.

Primarily, these include data validation and verification, scalability, integration with existing mine action systems and databases, legal and regulatory compliance (i.e., GDPR and other potential legal issues related to the use of decentralized storage networks in humanitarian demining), and cost effectiveness. Developing a mechanism to validate and verify the landmine and UXO data entered into the blockchain may involve processing and cross-referencing sensor data from multiple sources, correlating the information with existing databases, or using artificial intelligence algorithms to identify potential discrepancies.

Furthermore, in terms of scalability it is necessary to assess the blockchain network's ability, such as the Filecoin, to efficiently store and retrieve large volumes of minefield records and ensure seamless integration with existing humanitarian demining tools.

Thirdly, to fully realize the potential of the blockchain in humanitarian demining efforts, future research should focus on developing a proof-of-concept system, conducting comprehensive performance evaluations, assessing security, exploring interoperability, and evaluating usability. A proof-of-concept implementation will demonstrate the feasibility of integrating blockchain based NFTs for minefield records storage, retrieval, and management. A performance evaluation will determine the suitability of the proposed storage solution for humanitarian demining, while the security analysis will ensure the protection of minefield records and the safety of demining personnel. Interoperability with other decentralized technologies, such as distributed ledger systems, can improve collaboration and data sharing among demining stakeholders.

Finally, evaluation of user experience and usability will facilitate adoption and integration into existing workflows and allow researchers to further explore the potential of blockchain-based storage solutions to improve the efficiency, security, and reliability of minefield record storage in humanitarian demining operations.

4 Conclusion

This paper proposes a novel concept of using blockchain technologies and NFTs for secure and reliable storage of minefield records in humanitarian demining operations. The technical feasibility of the proposed concept has been explained and demonstrated on a real-world example using existing blockchain technologies: Filecoin blockchain platform and Storage.NFT framework.

Other advantages of this approach, such as decentralized and secure storage, tamper-proof data, incentives for storage providers, and transparent data access, were considered. Challenges such as scalability, integration with existing systems, legal and regulatory compliance, and cost-effectiveness should be considered in future research.

The use of blockchain technologies for distributed storage of minefield records on the Internet has the potential to significantly improve the accessibility, efficiency, and security of humanitarian demining operations and should be fully explored in the future.

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