A decentralized method for making sensor measurements tamper-proof to support open science applications

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Abstract

Open science has become a synonym for modern, digital and inclusive science. Inclusion does not stop at open access. Inclusion also requires transparency through open datasets and the right and ability to take part in the knowledge creation process. This implies new challenges for digital libraries. Citizens should be able to contribute data in a curatable form to advance science. At the same time, this data should be verifiable and attributable to its owner. Our research project focuses on securing and attributing incoming data streams from sensors. Our contribution is twofold. First, we analyze the promises of open science measurement data and point out how Blockchain technology changed the circumstances for data measurement in science projects using sensors. Second, we present an open hardware project capable of securing the integrity of data directly from the source using cryptographic methods. By using inexpensive modular components and open source software, we lower the barrier for participation in open science projects. We show how time series of measurement values using sensors, e.g., temperature, current, and vibration measurements, can be verifiably and immutably stored. The approach we propose enables time series data to be stored in a tamper-proof manner and securely timestamped on a blockchain to prevent any subsequent modification.

CCS CONCEPTS
- Information systems → Distributed storage

KEYWORDS
Open Science, Blockchain, Data Storage, Sensor Data
1 Introduction

Traditionally, the workflow of research scientist has typically consisted of the following steps: (1) researching literature, (2) formulating hypothesis, (3) performing measurements, (4) evaluating data, and (5) publishing the results. If the fifth step is repeatedly unsuccessful, scientists in today’s research environment cannot pursue a successful career. In part due to this pressure to successfully publish, there are regular occurrences of scientists only reporting positive experimental outcomes, or pruning their data – i.e., attempting to manipulate steps 3 and 4 of the research cycle – in order to publish more successfully [5, 6]. In contrast to traditional science, which has typically been performed behind closed doors, today’s open-science movement has encouraged and facilitated the publishing of measurements (Goal A of open science). In particular, Goal A has introduced new challenges for digital libraries.

Performing research according to open science principles [12] provides at least two significant advantages. First, retrospective data pruning or manipulation can become detectable, and second, other researchers may be able to obtain additional results and reuse datasets for new purposes without the time-consuming measurement step. Another component of the open-science movement is a blurring of the barrier between scientists and citizens by enabling an inclusion of any interested community in so-called ‘citizen science projects’ (Goal B of open science).

Currently, there is no agreement among scientists on any standardized procedures for reviewing openly available datasets in a way that could be analogous to today’s literature-assessment process. Methods for researching and reviewing scientific literature by combining content-based assessments and bibliometric
measures are well established for traditional publications. While bibliometric measures could also be applied to datasets when these are citable, a content-based assessment based on the raw data hardly seems possible. In contrast to the authenticity of physical analytes which can be assayed using forensic methods, digital datasets are of a fundamentally different nature and their quality and integrity cannot be assessed by other researchers post creation.

In contrast, digital measurements of real-world phenomena are a snapshot of a state at a particular time, which is as accurate as the capturing technology at that given moment. After the information is digitized, there is no way to capture additional information that could be used by future technology to evaluate the authenticity of the data. Therefore, scientists could benefit from a method to ensure the trustworthiness of sensor data immediately as it is generated by a measurement device (challenge I).

Regarding challenge I, the law of large numbers suggests that if the same experiments are repeated over and again, the average results will be close to the expected outcome. Thus, by distributing the measurements in a citizen science fashion (goal B) to different parties’ errors due to measurement equipment malfunction, and even fraudulent intentions (as long as they do not collude) will average out. Systematic data manipulation becomes more difficult, since multiple independent players would need to be corrupt.

The trustworthiness of data measurements concerns the following aspects: (1) well-defined error estimates, (2) accurate meta-data, (3) high redundancy, (4) adequate sampling rate, (5) confirmation of all currently known physical laws. At the same time, researchers would benefit from a method to guarantee the immutability and durability of time-series research data (challenge II). We suggest that challenge II could be addressed by a technical solution that enables data to be protected against subsequent manipulation through cryptographic hashing and blockchain technology (BT), including decentralized trusted timestamping using blockchain [8]. The tamper-proof nature of BT could be used to, for the first time, ensure the permanent immutability of time-series data in the digital era.

In this paper, we make the following contributions: We enumerate the challenges to ensure the trustworthiness of time series of measurement-data (challenge I). Moreover, we present a simple and inexpensive open hardware solution that can be used by citizens to measure physical properties, such as temperature, electric current, and vibration, and an open source software that guarantees the immutability of the measured values using Bitcoin’s blockchain (challenge II).

The remaining paper is structured as follows. In Section 2, we review related work. In Section 3, we describe our experimental setup, before enumerating challenges and discussing future steps in Section 4.
2 Combining citizen science and blockchain technology

The BT underlying cryptocurrencies, such as Bitcoin [11], offers a bulk of characteristics, for example, decentralization, immutability, and decentralized trusted timestamping [14, 17], which make it unique and have enabled both research and industry to develop new solutions for a variety of use cases [3].

BT has found rapid adoption to support not only financial and industry application, but also academia [9]. Several use cases have been proposed to support scientists and academics, such as managing academic reputation [15], protecting the intellectual property of academic manuscripts submitted for peer review [7], or tracking the individual contributions in collaborative research projects [13]. In this paper, we propose using blockchain technology as a foundation to create a secure and reliable method to perform citizen science projects. To achieve this aim, we also propose to integrate the previously proposed concept of decentralized trusted timestamping [8].

A blockchain can be defined as a decentralized database without a central authority in charge of managing the data stored on it [1]. All data stored on a blockchain are by design immutable. We use this tamper-proof characteristic of blockchains to ensure that each measurement value recorded by a sensor can be made immutable to subsequent manipulation or deletion, as well as traceable to its owner. With this contribution, we hope to further support the viability of citizen science projects and today’s open science movement by making data and entire datasets more trustworthy.

The validity or accuracy of collected measurement data can, of course, never be automatically guaranteed. However, in the case of citizen science projects, the effort to manipulate a significant number of sensors in a decentralized network would not justify the cost-benefit factor and is additionally very unlikely. The easiest methods of manipulation in crowd-sourced data collection experiments would be to adjust data after it has been measured and aggregated, which we prevent with our approach.

We do not propose to store all raw measurement data directly on a blockchain, instead, we only store hashes of the data, which is more efficient in the ways of performance, cost, and scalability to prove that the data existed in a certain format at a certain time, thus increasing transparency and trustworthiness.

Once a hash has been stored on a blockchain it can always be proved that the data (for example, sensor measurement values) were not manipulated after they were collected [4]. From a technical point of view, there is much literature that explains blockchain technology, how it works and its strengths and weaknesses in different stress tests and use cases [14, 16, 17]. Thus, we only described the special features of the technology that we exploit for our use case. The idea is to use open source software and hardware in combination with BT, which we
Figure 2: Open hardware prototype consisting of basic and testing module to demonstrate commonly used sensors and their simple integration into our proposed system.
implemented in an example measurement device set-up that we will present in the next section. The benefits in combining open science experiments with BT are the creation of a reliable trustworthy infrastructure for building digital libraries consisting of measurement data with superior data security and integrity.

3 Bootstrapping Citizen Science Projects

Combining BT with citizen science to capture time series of sensor data, practically means building an interface between the physical world and a particular blockchain. In general, this would require advanced skills in electrical engineering and blockchain programming. To lower this entrance barrier, we developed a simple and inexpensive open hardware prototype that captures vibration, electric current, and temperature measurements. Our step-by-step instructions can also guide people with a limited knowledge of single board computers and blockchain technology through this process. Upon completion of our tutorial, the modular design of the open hardware allows for easy customization to specific project needs.

For our basic module, we used a Raspberry Pi model 3, a general-purpose input/output board and an initial set of three sensors (cf. Table 1). To test the sensors of the model, we designed a testing module - a rotor with a battery power supply. The rotor from the testing module consumes power and generates vibrations, which generates signals that we can measure with the sensors from the basic module. Detailed instructions on the building process are available from the project’s GitHub repository:

https://github.com/FellowsFreiesWissen/Blockchain_Pi

Figure 2 displays the first instance of our open hardware project (basic and testing module). The components of our hardware setup are very affordable (cf. list of components, Table 1), and sums only to approximately 71 euros. The building time for the hardware is approximately one hour.

In a second step, we implemented an open source software, which captures the incoming data-stream from the sensors, partitions the stream into data-chunks, timestamps each chunk, and finally stores the chunks. The software and installation manual, as well as links to these initial open science datasets, are available from our GitHub repository. To install the software, the Raspberry Pi needs to be connected to a computer. During operation the hardware needs power and an internet connection. The software reads the data-stream from the sensors and appends it to an internal buffer. After a user-defined time, or when the data volume size exceeds a chunk size of about 256 kB, a new chunk is created. A hash of this data chunk is calculated and uploaded to the trusted timestamping service OriginStamp\(^1\) which stores it on Bitcoin’s blockchain [10].

\(^1\)www.originstamp.org
Table 1: Hardware components and prices

| Type                        | Price approx. in EUR |
|-----------------------------|----------------------|
| Raspberry Pi 3              | 30                   |
| Case                        | 10                   |
| GPIO Breakout and Wires     | 8                    |
| Vibration sensor SW-420     | 1                    |
| Current sensor WCS1800      | 7                    |
| Temperature sensor DHT11    | 5                    |
| DC Engine (optional)        | 5                    |
| Battery pack (optional)     | 5                    |
| **Total**                   | **71**               |

Therefore, a personally owned API key is required. That key can be used to identify the creator of the dataset, thus signing the data itself is not required. Beginning from the second chunk, a reference to the previous chunk is included in the hash.

However, the hash is useless without the data. Many services exist to upload data to a central server. However, this central resource might fail or get compromised. We therefore use the Interplanetary Filesystem (IPFS) to be independent of a central authority for storage. IPFS itself is organized in blocks and the block-address is the hash of the file content, which we already used to generate the timestamp. Therefore, we installed IPFS on the Raspberry to upload the data chunk by chunk.

For long-time archival, we plan to copy the finalized measurement timeseries from IPFS to the long-time archival platform Zenodo.

4 Discussion and Future Challenges

In section 3, we demonstrated how to guarantee the immutability of time series of measurement values with inexpensive hardware (challenge II). While this line of research has many open questions when the data volume of the incoming data stream of sensor data increases, a first step has been completed. We argued before (Section 1) that a highly distributed network of citizens performing measure reduces the chance for intentional data fabrication or malicious device tampering. One model use case, such as temperature recording for climate research has easy achievable requirements, with regards to the 5 requirements for trustworthy data (challenge I). The instruction of the participants and the development

\[\text{www.zenodo.org}\]
of algorithms to automatically detect measurement time series that do not fulfil the requirements requires extra effort. Especially the collection of meta data, for instance the location of the experiment is hard to verify automatically, even though first approaches for verifying location exist [2]. Proof-of location is based on token incentivized, community driven data. People witness their mutual locations supported by hardware IDs from network cards and Bluetooth controllers to provide evidence that a certain device was at a certain point.

Moreover, for many use-cases the required error rate is too low, the sampling rate too high or the overall complexity of the experiment is too high so that citizens must be replaced by a smaller number or institutions that have the capabilities to perform the experiments. While the same methods can be applied to ensure the immutability and durability as outlined before, the chances for tampering and unintentional mistakes during measurement remains. While trusted timestamping can guarantee that data has at least a certain age this does not prevent one from recording data without timestamping it, manipulate the data thereafter pretend that the manipulated data is current. This is different from the physical world, where the age of an object can be determined using forensic methods. As a result, we currently are unaware of any data-driven approach to ensure the trustworthiness of an individual data source. Thus, if only one, or a few data sources exist the classical author reputation is the only method to estimate the data quality.

5 Conclusion

Measurement values and data streams from sensors are not immune to manipulation or retrospective selective pruning. The ability to securely prove that data was not manipulated or omitted is especially important for both open science and citizen science projects. In this paper, we proposed a method for independently and securely verifying the time of creation of sensor data, as well as tracing it to its rightful owner. By storing the data in a decentralized manner on the Interplanetary Filesystem and by relying on a blockchain-backed solution for storing tamper-proof and decentralized trusted timestamps associated with discrete chunks of measurement values, we showed how sensor data can be made securely verifiable. Our exemplary Raspberry Pi prototype demonstrates how our proposed modifications can be easily implemented into commonly used hardware sensors, such as temperature, electric current, and vibration detection sensors. We argue that enabling any researcher or interested citizen to verifiably trace the integrity of measurement values and their time of origin can significantly strengthen the open science movement and can increase the trustworthiness of citizen science projects.
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