Article

Localisation and Sensor Privacy Using the Extended Information Filter and Secure Weighted Aggregation

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Abstract: Distributed state estimation and localisation methods have become increasingly popular with the rise of ubiquitous computing, and have led naturally to an increased concern regarding data and estimation privacy. Traditional distributed sensor navigation methods involve the leakage of sensor information or navigator location during localisation protocols and fail to preserve participants' data privacy. Existing secure methods fail to address sensor and navigator privacy in some common model-based non-linear measurement localisation methods forfeiting broad applicability. We define a novel, cryptographically secure, weighted aggregation scheme which we apply to the Extended Kalman Filter with range-sensor measurements, and show that navigator location, sensor locations and sensor measurements can remain private during navigation. The requirements and cryptographic proof are given for the weighted aggregation scheme, and simulations of the private filter are used to evaluate the accuracy and performance of the method. Our approach defines a novel, computationally plausible, and private model-based localisation filter with direct application to environments where nodes may not be fully trusted, and data is considered sensitive.

Keywords: Extended Kalman Filter; Secure Localisation; Private Aggregation

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1. Introduction

Introduce localisation, filtering and the need for privacy.

Examples of environments where privacy is relevant and concrete examples where lack of privacy could have large costs

Public key cryptography applicability to distributed systems; difference to symmetric schemes. Homomorphic encryption power and use case.

Explain the additional difficulties with achieving privacy in distributed environments (malicious subsets etc). AO and pWSAO.

Differential privacy concerned with hiding individuals in a group but results in noisy results. Also often requires a trusted aggregator, although aggregation methods exist.

Application of partially Homomorphic encryption. Control examples include Alexandru and Farokhi papers, mostly applicable due to distributed aggregation step.

Estimation examples include Filters with a sensor hierarchy and linear models, localisation methods which hide sensor information in a model-free environment but either pay in security or require additional rounds of communication.

Additionally encoding for signal processing is an issue. Typically unlimited scalar multiplications and additions using a scheme that allows it over integers does not work on encoded real numbers. Google bignum adds power but risks overflow and leaks exponents, Farokhi leaks no information but allows only a single multiplication (extendable to more but each further limits the real number size and increases risk of overflow).

Describe Navigator scenario and our contributions

Section Summary

2. Problem Statement

Restate the scenario but more formally.

Exact security guarantees we aim for

Rough computational capabilities expected by parties

Fixed sensor subsets of which only whole subsets can be used at once

3. Existing Literature

Details and differences to private localisation methods, aggregation methods, and encoding methods

Model-free localisation examples can include polygon thing, WSN examples which protect against adversaries but don't preserve individual information. Importantly model-based filtering and localisation provides accurate estimates and these are not applicable there.

Estimation examples can include Aristov paper (which requires linear model, and a hierarchy of sensors)

Alexandru weighted aggregation requires redistributing keys at every timestep resulting in a costly operations, and a complicated communication protocol.

Encoding of signal processing values for use in encrypted processing should consist of google bignum library and Farokhi qnm encoding

4. Preliminaries

4.1. Integer Encoding for Real Numbers

4.2. Paillier Encryption Scheme

4.3. Joye-Libert Privacy-Preserving Aggregation

4.4. Extended Information Filter

5. Private Partially Homomorphic Aggregation

6. Requirements for Measurement Model

7. Localisation Measurement Modification

8. Private Localisation with Privacy-Preserving Sensors

9. Results

10. Conclusion

<Rest is template>

11. How to Use this Template

The template details the sections that can be used in a manuscript. Note that the order and names of article sections may differ from the requirements of the journal (e.g., the positioning of the

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12. Introduction

The introduction should briefly place the study in a broad context and highlight why it is important. It should define the purpose of the work and its significance. The current state of the research field should be reviewed carefully and key publications cited. Please highlight controversial and diverging hypotheses when necessary. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the introduction comprehensible to scientists outside your particular field of research. Citing a journal paper [1]. And now citing a book reference [2]. Please use the command [1] for the following MDPI journals, which use author-date citation: Administrative Sciences, Arts, Econometrics, Economies, Genealogy, Humanities, IJFS, JRFM, Languages, Laws, Religions, Risks, Social Sciences.

13. Results

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

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13.1. Subsection

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Bulleted lists look like this:

- First bullet
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- Third bullet

Numbered lists can be added as follows:

1. First item
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13.2. Figures, Tables and Schemes

All figures and tables should be cited in the main text as Figure 1, Table 1, etc.

Figure 1. This is a figure, Schemes follow the same formatting. If there are multiple panels, they should be listed as: (**a**) Description of what is contained in the first panel. (**b**) Description of what is contained in the second panel. Figures should be placed in the main text near to the first time they are cited. A caption on a single line should be centered.

Text

Text

Table 1. This is a table caption. Tables should be placed in the main text near to the first time they are cited.

Title 1	**Title 2**	**Title 3**
entry 1	data	data
entry 2	data	data

Text
Text

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This is an example of an equation:

$$a + b = c \tag{1}$$

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Theorem 1. *Example text of a theorem.*

The text continues here. Proofs must be formatted as follows:

Proof of Theorem 1. Text of the proof. Note that the phrase 'of Theorem 1' is optional if it is clear which theorem is being referred to. □

The text continues here.

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Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

15. Materials and Methods

Materials and Methods should be described with sufficient details to allow others to replicate and build on published results. Please note that publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

Research manuscripts reporting large datasets that are deposited in a publicly available database should specify where the data have been deposited and provide the relevant accession numbers. If the accession numbers have not yet been obtained at the time of submission, please state that they will be provided during review. They must be provided prior to publication.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

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This section is not mandatory, but can be added to the manuscript if the discussion is unusually long or complex.

17. Patents

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Abbreviations

The following abbreviations are used in this manuscript:

MDPI	Multidisciplinary Digital Publishing Institute
DOAJ	Directory of open access journals
TLA	Three letter acronym
LD	linear dichroism

Appendix A

Appendix A.1

The appendix is an optional section that can contain details and data supplemental to the main text. For example, explanations of experimental details that would disrupt the flow of the main text, but nonetheless remain crucial to understanding and reproducing the research shown; figures of replicates for experiments of which representative data is shown in the main text can be added here if brief, or as Supplementary data. Mathematical proofs of results not central to the paper can be added as an appendix.

Appendix B

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References

1. Author1, T. The title of the cited article. *Journal Abbreviation* **2008**, *10*, 142–149.
2. Author2, L. The title of the cited contribution. In *The Book Title*; Editor1, F., Editor2, A., Eds.; Publishing House: City, Country, 2007; pp. 32–58.

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