Technology, Peace and Security | Technologie, Frieden und Sicherheit

RESEARCH

Franz Kuntke

Resilient Smart Farming

Crisis-Capable Information and Communication Technologies for Agriculture

MOREMEDIA

Springer Vieweg

Technology, Peace and Security | Technologie, Frieden und Sicherheit

Series Editor

Christian Reuter, Darmstadt, Germany

Technology plays a major role in many questions of peace and security. This book series addresses questions on the intersection of technology (such as computer science, but also other technical disciplines) as well as peace and security studies. This includes questions of technical peace research, dual use, arms control, disarmament, non-proliferation, ICT for peace, misinformation as well as (resilient) technologies for emergencies, crises and disasters and questions of privacy or cybersecurity.

Technologie spielt in vielen Fragen von Frieden und Sicherheit eine wichtige Rolle. Diese Buchreihe befasst sich mit Fragen an der Schnittstelle von Technik (z. B. Informatik, aber auch andere technische Disziplinen) sowie Friedens- und Sicherheitsforschung. Dazu gehören Fragen der technischen Friedensforschung, Dual Use, Rüstungskontrolle, Abrüstung, Nonproliferation, IKT für den Frieden, Desinformation sowie (resiliente) Technologien für Notfälle, Krisen und Katastrophen und Fragen der Privatsphäre oder der Cyber-Sicherheit.

Franz Kuntke

Resilient Smart Farming

Crisis-Capable Information and Communication Technologies for Agriculture

Springer Vieweg

Franz Kuntke
Darmstadt, Germany

Approved dissertation, Department of Computer Science, Technical University of Darmstadt
First review: Prof. Dr. Dr. Christian Reuter
Second review: Prof. Dr. Jörg Dörr
Disputation on 06.12.2023

ISSN 3004-9318 ISSN 3004-9326 (electronic)
Technology, Peace and Security | Technologie, Frieden und Sicherheit
ISBN 978-3-658-44156-2 ISBN 978-3-658-44157-9 (eBook)
https://doi.org/10.1007/978-3-658-44157-9

Parts of this work were supported by funds of the German Government's Special Purpose Fund held at Landwirtschaftliche Rentenbank in the projects Geobox-I, Geobox-II, AgriRegio, by the German Federal Ministry for Education and Research (BMBF) in the project HyServ (01IS17030B), and by the LOEWE initiative (Hesse, Germany) within the emergenCITY centre.

This Springer Vieweg imprint is published by the registered company Springer Fachmedien Wiesbaden GmbH, part of Springer Nature.
The registered company address is: Abraham-Lincoln-Str. 46, 65189 Wiesbaden, Germany

Paper in this product is recyclable.

Foreword

For many years, it was assumed that the world market, along with globalization, would enable society to buy and received all kinds of products, such as food, at any time. The crises of recent years, such as COVID-19 with shortages of hygiene products or certain foods, e.g., rice, or Russia's war against Ukraine with shortages of food, grain, and energy supply, show that the general supply of food to the world's population is by no means guaranteed in the long term and that societies need to become resilient. The failure of digital infrastructures can also have an enormous impact on digitalized agriculture.

This dissertation by Franz Kuntke addresses the tension between digitalization and resilience from the perspective of business continuity in the agricultural domain. In this context, agriculture is regarded as an essential infrastructure for food security, which means that this sector is attributed a high criticality for society. As current research on the intersection of resilience and agriculture focuses mainly on the topics of climate change and social changes, the topic of resilient digitalization has received less attention.

The dissertation uses qualitative and quantitative methods to understand the extent to which the technologies currently used by farmers are at risk of failure. Furthermore, new software is designed and implemented that increases the resilience of these technologies due to a failed internet connections. Overall, the dissertation fulfills my expectations. This thesis looks at a highly relevant topic. It is characterized in particular by the innovative combination of human-computer interaction, distributed systems and resilience in the context of digital agriculture with empirical findings, as well as conceptual and technical approaches. As such, this dissertation is pioneering work in this field.

The studies included in this PhD thesis have been published as seven peer-reviewed papers. In addition to working on his dissertation and his 22 scientific publications, Franz was involved in project management of various projects of agricultural IT (e.g., AgriRegio or GeoBox), research-oriented teaching in our program-ming courses and our lecture series Secure Critical Infrastructures as well as in the management of our internal IT infrastructure, thus contributing to the future development of PEASEC.

Franz Kuntke has proven that he is capable of independent scientific work. Thus, in December 2023, his dissertation was accepted by the Department of Computer Science at the Technical University of Darmstadt for the degree of Dr.-Ing.—as the fifth PhD thesis in our research group PEASEC. I would like to see a further focus on topics of such high importance. Franz, thank you for your contribution and for allowing me to ac-company you on your way to your PhD. I wish you all the best and every success for the future.

Prof. Dr. Dr. Christian Reuter
Professor for Science and Technology
for Peace and Security (PEASEC)
and Dean of the Department
of Computer Science at Technical
University of Darmstadt
Darmstadt, Germany

Acknowledgements

At the beginning, I would like to express my sincere gratitude to the many individuals who have contributed to the success of this dissertation. Without their support and assistance, this work would not be possible. Firstly, I wish to thank my doctoral supervisor, *Prof. Dr. Dr. Christian Reuter,* for his trust, guidance, and unwavering commitment to address my questions and concerns. Furthermore, I thank my coexaminer *Prof. Dr.-Ing. Jörg Dörr,* as well as *Prof. Dr. Felix Wolfv Prof. Dr.-Ing. Matthias Hollick,* and *Prof. Dr. Zsolt István* who kindly join the doctoral committee.

Additionally, I wish to express my appreciation for the whole team of *Science and Technology for Peace and Security (PEASEC)* at the Department of Computer Science at the *Technical University of Darmstadt*. The exchange of ideas and insights with colleagues has enriched my understanding of various topics and provided valuable perspectives on potential solutions or projects. Here, I would like to thank *Sebastian Linsner* as a particularly important collaborator, especially during the initial two years of my PhD position. Moreover, I wish to thank many other colleagues who have provided insightful conversations, sometimes offering new ideas or perspectives on various topics. Here, I would like to single out *Philipp Kühn, Jasmin Haunschild, Dr. Thea Riebe,* and *Dr. Marc-André Kaufhold* for many valuable discussions throughout the research process, especially during the final phase of my PhD studies. I would also like to thank the former student assistants who provided invaluable support in software development, research, and even careful proofreading of various publications: *Anel Muhamedagic, Franziska Bujara, Sabrina Neuhäusel, Laura Utz, Alexander Praus,* and *Julian Marcel Schindel*.

I would also like to thank all the co-authors of the published papers, in addition to those mentioned above, in particular: *Enno Steinbrink, Jonas Franken, Daniel Eberz-Eder* and *Dr. Lars Baumgärtner* for their valuable contributions to the conducted research. Parts of this work were also supported by funds of the German Government's Special Purpose Fund held at Landwirtschaftliche Rentenbank in the projects Geobox-I, Geobox-II, AgriRegio, by the German Federal Ministry for Education and Research (BMBF) in the project HyServ (01IS17030B), and by the LOEWE initiative (Hesse, Germany) within the emergenCITY centre.

Finally, my deepest thanks go to my family and friends who have supported me throughout this journey. In particular, I would like to thank my girlfriend *Lena Cibulski,* who supported me during these difficult times marked by the pandemic, remote work, and doctoral studies.

どうもありがとうございます

(Domo arigato gozaimasu)
Thank you very much.

Franz Kuntke

Abstract

Like many sectors, agriculture is experiencing a continuous digitalization, i.e. an increase in data-driven technologies used. In contrast to companies of other critical infrastructures—e.g. energy or telecommunication—a typical farm is comparatively small and often run as a family business. Accordingly, the demands on farming technology, its implementation, and regulations are different in many terms. Furthermore, the circumstances that influence crisis risks and crisis management are different in agriculture—and as digitalization introduces new potential risks, this process should be reviewed critically. Currently, the most advanced approaches for agriculture are typically referred to as smart farming and agriculture 4.0, which incorporate more precise cultivation with less manual effort. But such new agriculture technology developments usually lack an assessment about its impact on the sector's resilience and dependencies on other infrastructures. The research domains of crisis informatics and information technology security (IT security) mostly focuses on other topics, apart from agriculture. The resilience research in agriculture itself is currently intensifying, however, this line of research focuses more on problems resulting from the climate crisis and social change. For these reasons it remains unclear, how digitalization impacts the resilience of food production and food safety. Therefore, it is not well researched which technological developments may lead to undesired effects in the future. How modern systems should be designed to allow for both, positive impacts on efficiency, and prevention of negative effects in terms of reduced resilience capacities, is also not answered by current literature. The aim of the present work is to close this research gap at the intersection of agriculture, digitalization, and resilience.

To answer the question to what extent current technologies used by farmers are at risk of failure, the dissertation first presents a snapshot of the resilience state of agricultural companies and the technologies used. This involves interviews with stakeholders, mainly farmers, as well as surveying security issues of the Long Range Wide Area Network (LoRaWAN) protocol, a transmission technology especially useful for agricultural Internet of Things. Which desires of farmers exist regarding software focusing on aspects of business continuity and secured operations, is another open question. This dissertation aims to also answer this question with empirical methods, mainly focus groups and usability tests. Then the rise of Internet of Things in agriculture raises another question, whether such technologies acquired for smart farming could also have benefits for resilience against internet-connection-lost situations. This question is answered by empirical evaluation of LoRaWAN range characteristics in agricultural landscapes, as well as artifact generation for resilient communication channels on top of LoRaWAN transmission devices.

Several findings are derived from the conducted research: There is a lack of understanding of how strong the used tools in agriculture depend on Information and Communications Technology, and many tools require a working internet connection. Moreover, information technology employed by agricultural enterprises presents security concerns similar to those encountered in other domains. Based on these findings, developments, and evaluations of new software approaches are presented: Derived design criteria and own system designs that allow for modern data-driven business operations, including Internet of Things integration based on LoRaWAN. The developed solutions show an increase in resilience capacities by enhancing the communication possibilities in crisis situations. The detected low absorption capacities against communication infrastructure outages shows room for improvement. To improve agricultural information technologies' resilience, software engineers could use the concepts and designs of this dissertation for their product development, like a modular offline- capable farm management storage that allows an exchange of small data in an autarkic manner via commodity LoRaWAN hardware. But also technology advisors and farmers benefit from the technological analyses and suggestions embedded in this work, like using multiple LoRaWAN gateways with an overlapping coverage to mitigate security vulnerabilities.

List Of Own Publications

In sum, 23 publications have been published in the context of the authors work.
The following 7 publications are published as chapters in part II of this thesis:

1. Kuntke, F., Linsner, S., Steinbrink, E., Franken, J., & Reuter, C. (2022). Resilience in Agriculture: Communication and Energy Infrastructure Dependencies of German Farmers. *International Journal of Disaster Risk Science*, *13*(2), 214–229. https://doi.org/10.1007/s13753-022-00404-7
2. Linsner, S., Kuntke, F., Steinbrink, E., Franken, J., & Reuter, C. (2021). The Role of Privacy in Digitalization—Analysing the German Farmers' Perspective. *Proceedings on Privacy Enhancing Technologies (PoPETs)*, *2021*(3). https://doi.org/10.2478/popets-2021-0050
3. Kuntke, F., Romanenko, V., Linsner, S., Steinbrink, E., & Reuter, C. (2022). LoRaWAN security issues and mitigation options by the example of agricultural IoT scenarios. *Transactions on Emerging Telecommunications Technologies*, 1–20. https://doi.org/10.1002/ett.4452
4. Kuntke, F., Kaufhold, M.-A., Linsner, S., & Reuter, C. (2023). GeoBox: Design and Evaluation of a Tool for Resilient and Decentralized Data Management in Agriculture. *Behaviour & Information Technology*. https://doi.org/10.1080/0144929X.2023.2185747
5. Kuntke, F., Bektas, M., Buhleier, L., Pohl, E., Schiller, R., & Reuter, C. (2023). How Would Emergency Communication Based on LoRaWAN Perform? Empirical Findings of Signal Propagation in Rural Areas. *Proceedings of Information Systems for Crisis Response and Management (ISCRAM)*, 1–8. https://idl.iscram.org/files/kuntke/2023/2586_Kuntke_etal2023.pdf

6. Kuntke, F., Sinn, M., & Reuter, C. (2021). Reliable Data Transmission using Low Power Wide Area Networks (LPWAN) for Agricultural Applications. *Proceedings of the 16th International Conference on Availability, Reliability and Security (ARES 2021)*, 1–9. https://doi.org/10.1145/3465481.3469191
7. Kuntke, F., Baumgärtner, L., & Reuter, C. (2023). Rural Communication in Outage Scenarios: Disruption-Tolerant Networking via LoRaWAN Setups. *Proceedings of Information Systems for Crisis Response and Management (ISCRAM)*, 1–13. https://idl.iscram.org/files/kuntke/2023/2581_Kuntke_etal2023.pdf

The following 16 papers are not included in the thesis, although their findings are supplementary to it:

8. Schmid, D., Kuntke, F., Bauer, M., & Baumgärtner, L. (2023). BPoL: A Disruption-Tolerant LoRa Network for Disaster Communication. *2023 IEEE Global Humanitarian Technology Conference (GHTC)*, 440–447. https://doi.org/10.1109/GHTC56179.2023.10354717
9. Höchst, J., Baumgärtner, L., Kuntke, F., Penning, A., Sterz, A., Sommer, M., & Freisleben, B. (2023). Mobile Device-to-Device Communication for Crisis Scenarios Using Low-Cost LoRa Modems. In H. J. Scholl, E. E. Holdeman, & F. K. Boersma (Eds.), *Disaster Management and Information Technology* (pp. 235–268, Vol. 40). Springer International Publishing. https://doi.org/10.1007/978-3-031-20939-0_12
10. Kuntke, F., Eberz-Eder, D., Trapp, M., & Reuter, C. (2023). RSF-Lab'23: Konzepte und Anwendungen zur resilienten digitalen Landwirtschaft. *INFORMATIK 2023: 53. Jahrestagung der Gesellschaft für Informatik—Informatik für Gesellschaft (Workshop-Beiträge)*, 1–7. https://doi.org/10.18420/inf2023_156
11. Orlov, D., Kuntke, F., & Reuter, C. (2023). Optimierte Messenger-Applikation zur Notfallkommunikation via LoRaWAN-DTN. *INFORMATIK 2023: 53. Jahrestagung der Gesellschaft für Informatik—Informatik für Gesellschaft (Workshop-Beiträge)*, 1–6. https://doi.org/10.18420/inf2023_160
12. Guntrum, L., Güldenring, B., Kuntke, F., & Reuter, C. (2022). Using Digitally Mediated Methods in Sensitive Contexts: A Threat Analysis and Critical Reflection on Security, Privacy, and Ethical Concerns in the Case of Afghanistan. *Zeitschrift für Friedens- und Konfliktforschung (ZeFKo)*, *11*(2), 95–128. https://doi.org/10.1007/s42597-022-00088-2

13. Eberz-Eder, D., Kuntke, F., Brill, G., Bernardi, A., Reuter, C., Wied, C., Nuderscher, P., & Reuter, C. (2023). Prototypische Entwicklungen zur Umsetzung des Resilient Smart Farming (RSF) mittels Edge Computing. *43. GIL-Jahrestagung: Informatik in der Land-, Forst- und Ernährungswirtschaft*. https://dl.gi.de/handle/20.500.12116/40264
14. Linsner, S., Steinbrink, E., Kuntke, F., Franken, J., & Reuter, C. (2022). Supporting Users in Data Disclosure Scenarios in Agriculture through Transparency. *Behaviour & Information Technology (BIT)*, *41*(10), 2137–2159. https://doi.org/10.1080/0144929X.2022.2068070
15. Reuter, C., Kuntke, F., Trapp, M., Wied, C., Brill, G., Müller, G., Steinbrink, E., Franken, J., Eberz-Eder, D., & Schneider, W. (2022). AgriRegio: Infrastruktur zur Förderung von digitaler Resilienz und Klimaresilienz im ländlichen Raum am Beispiel der Pilotregion Nahe-Donnersberg. In D. Demmler, D. Krupka, & H. Federrath (Eds.), INFORMATIK 2022: 52. *Jahrestagung der Gesellschaft für Informatik—Informatik für Gesellschaft (Workshop-Beiträge), Lecture Notes in Informatics (LNI)* (pp. 961–972). Gesellschaft für Informatik e. V. https://doi.org/10.18420/inf2022_81
16. Reuter, C., Eberz-Eder, D., Kuntke, F., & Trapp, M. (2022). RSF-Lab'22: Resilient Smart Farming Laboratory: Für eine widerstandsfähige und intelligente Landwirtschaft. In D. Demmler, D. Krupka, & H. Federrath (Eds.), *INFORMATIK 2022: 52. Jahrestagung der Gesellschaft für Informatik—Informatik für Gesellschaft (Workshop-Beiträge), Lecture Notes in Informatics (LNI)* (pp. 931–934). Gesellschaft für Informatik e. V. https://doi.org/10.18420/inf2022_78
17. Eberz-Eder, D., Kuntke, F., & Reuter, C. (2022). Sensibilität für Resilient Smart Farming (RSF) und seine Bedeutung in Krisenzeiten. *42. GIL-Jahrestagung: Informatik in der Land-, Forst- und Ernährungswirtschaft*. https://dl.gi.de/handle/20.500.12116/38375
18. Kuntke, F., Sinn, M., Linsner, S., & Reuter, C. (2021). Low Power Wide Area Networks (LPWAN) für krisentaugliche Datenübertragung in landwirtschaftlichen Betrieben. In A. Meyer-Aurich, M. Gandorfer, C. Hoffmann, C. Weltzien, S. D. Bellingrath-Kimura, & H. Floto (Eds.), *41. GIL-Jahrestagung: Informatik in der Land-, Forst- und Ernährungswirtschaft* (pp. 193–198). Gesellschaft für Informatik. https://dl.gi.de/handle/20.500.12116/35671
19. Eberz-Eder, D., Kuntke, F., Schneider, W., & Reuter, C. (2021). Technologische Umsetzung des Resilient Smart Farming (RSF) durch den Einsatz von Edge-Computing. *41. GIL-Jahrestagung: Informatik in der Land-, Forst- und Ernährungswirtschaft*, 79–84. https://dl.gi.de/handle/20.500.12116/35651

20. Kuntke, F., Reuter, C., Schneider, W., Eberz, D., & Bernardi, A. (2020). Die GeoBox-Vision: Resiliente Interaktion und Kooperation in der Landwirtschaft durch dezentrale Systeme. In C. Hansen, A. Nürnberger, & B. Preim (Eds.), *Mensch und Computer 2020—Workshopband* (pp. 1–6). Gesellschaft für Informatik e.V. https://doi.org/10.18420/muc2020-ws117-407
21. Höchst, J., Baumgärtner, L., Kuntke, F., Penning, A., Sterz, A., & Freisleben, B. (2020). LoRa-based Device-to-Device Smartphone Communication for Crisis Scenarios. *Proceedings of Information Systems for Crisis Response and Management (ISCRAM)*, 996–1011. http://idl.iscram.org/files/jonashochst/2020/2291_JonasHochst_etal2020.pdf
22. Linsner, S., Kuntke, F., Schmidbauer-Wolf, G. M., & Reuter, C. (2019). Blockchain in Agriculture 4.0—An Empirical Study on Farmers Expectations towards Distributed Services based on Distributed Ledger Technology. In F. Alt, A. Bulling, & T. Döring (Eds.), *Mensch und Computer 2019* (pp. 103–113). ACM. https://doi.org/10.1145/3340764.3340799
23. Kalle, T., Kaufhold, M.-A., Kuntke, F., Reuter, C., Rizk, A., & Steinmetz, R. (2019). Resilience in Security and Crises through Adaptions and Transitions. In C. Draude, M. Lange, & B. Sick (Eds.), *INFORMATIK 2019: 50 Jahre Gesellschaft für Informatik—Informatik für Gesellschaft (Workshop-Beiträge), Lecture Notes in Informatics (LNI)* (pp. 571–584). Gesellschaft für Informatik e. V. https://doi.org/10.18420/inf2019_ws60

Contents

Acronyms

ABP	Activation By Personalization
ADR	adjusting adaptive data rate
AES	Advanced Encryption Standard
AFR	autonomous field robot
AI	artificial intelligence
AS	application server
BP7	Bundle Protocol Version 7
CSCW	Computer-Supported Cooperative Work
DoS	Denial-of-Service
DSR	design science research
DTN	disruption-tolerant networking
ED	end device
FMIS	Farm Management Information System
GPS	Global Positioning System
GW	gateway
HCI	Human-Computer Interaction
ICT	Information and Communications Technology
IETF	Internet Engineering Task Force
IoT	Internet of Things
IT	information technology
ITU	International Telecommunication Union
JS	join server
LoRaWAN	Long Range Wide Area Network
LoS	line of sight
LPWAN	Low Power Wide Area Network
MANET	Mobile Ad Hoc Network

MIC	message integrity code
NAS	network-attached storage
NS	network server
OTAA	Over-The-Air Activation
OSI	Open Systems Interconnection
PWA	Progressive Web App
RQ	research question
RSSI	received signal strength indicator
SLR	Systematic Literature Review
SME	small and medium-sized farms and enterprises
SNR	Signal-to-Noise-Ratio
SUS	System Usability Scale
UAV	unmanned aerial vehicle
UI	User Interface
WSN	Wireless Sensor Network

List of Figures

List of Tables