Science for Peace and Security (2023)
Multi-Year Projects (MYPs)

Modular Remotely Operated Mine Detection System

BRbJmJDk

Applicant details

Data Retention ✓
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Application details

In the field above, please provide a short title for your project.

Note that this title should match the content of the field "Short Title" (cell E2) in the tab "Info" of the Excel file "SPS_MYP_Detailed_Budget", which can be downloaded at this link.

Before starting this application, I confirm I have read the latest version of the Multi-Year Project Handbook	✓
Is the application developed jointly by one or more applicants from **NATO** nations **and** one or more from **eligible NATO Partner countries**?	Yes
Are the applicants **affiliated** with a governmental, academic, or other non-profit institution?	Yes
Do any of the applicants hold other **ongoing Science for Peace and Security (SPS) grant** ?	No

Click on the green button "Check Eligibility" below before proceeding to the next tab

This is necessary to continue with the application.

Project Co-Directors

NATO country Project Director (NPD)

The primary co-director from an institution in a NATO country is referred to as the NATO Project Director (NPD). Kindly note that:

- NPD shall be **employed** by an institution in a NATO country;
- NPD shall be **resident** in the NATO country where their institution is located;
- NPD **must be a national of NATO or of an eligible NATO Partner country**.

First name of the NPD	Annika
Family name of the NPD	Raatz
Date of birth of the NPD	1971-05-02
Sex of the NPD	Woman
Title of the NPD	Prof. Dr.-Ing
Nationality of the NPD	Germany
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Mobile phone number of the NPD +4951176218242

Professional online profile of the NPD https://www.researchgate.net/profile/Annika-Raatz

Personal email of the NPD raatz@match.uni-hannover.de

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Current job title of the NPD Professor (Full)

Name of the NPD's institution Leibniz Universität Hannover

Country of the NPD's institution Germany

Mailing address of the NPD's institution

> Institute of Assembly Technology
>
> Produktionstechnisches Zentrum
> der Leibniz Universität Hannover / PZH
> An der Universität 2
> 30823 Garbsen

Relevant employment history of the NPD

	Start and end dates	Positions	Employers
1	Since 2013	Full Professorship of Assembly Technology (W3) and Head of Institute of Assembly Technology	Leibniz University Hannover
2	2005 – 2013	Head of the Department "Assembly and Production Automation" at IWF	TU Braunschweig
3	2003 – 2005	Deputy head of the Department "Production Automation and Machine Tools" at IWF,	TU Braunschweig
4	2002 – 2003	Team Leader of the Group "Handling and Assembly" at IWF	TU Braunschweig

Education of the NPD

	Start and end dates	Degrees	Universities

1	2006	Doctor of Engineering (Dr.-Ing., with distinction),	TU Braunschweig
2	1991 – 1997	Studies of Mechanical Engineering, Dipl.-Ing. (grade 1,3)	TU Braunschweig, Germany
3			

Honours of the NPD

	Dates	Award names
1	since 2020	Member of the National Academy of Science and Engineering (acatech)
2	since 2019	Member of the German Academic Association for Production Technology (WGP)
3	since 2016	Member of the Scientific Society for Assembly, Handling and Industrial Robotics (MHI)

Research focus and expertise of the NPD

> Prof. Raatz's research focuses on the investigation and optimization of (robot-assisted) assembly and handling processes, the development of machine concepts and system integration as well as the development of automated assembly and disassembly processes. In a large number of basic projects and collaborative projects, 20 scientific employees are now researching solutions for issues facing modern industry. Prof. Raatz is the spokesperson for the priority program 2100 "Soft Material Robotic Systems", in which new and innovative robots made of soft, pliable materials are being researched. She is also a member of the Scientific Society for Production Engineering, the Scientific Society for Assembly, Handling and Industrial Robotics and the German Academy of Science and Engineering.

Partner country Project Director (PPD)

The primary co-director from an institution in a NATO Partner country is referred to as the Partner country Project Director (PPD). Kindly note that:

- PPD shall be **employed** by an institution in a Partner country;
- PPD shall be **resident** in the Partner country where their institution is located;
- PPD **must be a national of a NATO or of an eligible NATO Partner country**.

First name of the PPD	Stefan
Family name of the PPD	Zaichenko
Date of birth of the PPD	1975-04-03
Sex of the PPD	Man

Title of the PPD	Prof
Nationality of the PPD	Ukraine
Telephone number of the PPD	+380442048227
Mobile phone number of the PPD	+380671653748
Professional online profile of the PPD	https://scholar.google.com/citations?user=-SonRQgAAAAJ&hl=ru
Personal email of the PPD	zstefv@gmail.com
Work email of the PPD	stefanzaichenko-iee@lll.kpi.ua
Current job title of the PPD	Professor
Name of the PPD's institution	Igor Sikorsky Kyiv Polytechnic Institute National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”
Country of the PPD's institution	Ukraine

Mailing address of the PPD's institution

> 37, Prospect Beresteiskyi (former Peremohy), Kyiv, Ukraine, 0305

Other current employment of the PPD

> Head of the International Office
> Educational and scientific institute of energy saving and energy management
> National Technical University of Ukraine
> “Igor Sikorsky Kyiv Polytechnic Institute”

Relevant employment history of the PPD

	Start and end dates	Positions	Employers
1	2008-2011	assistant	Igor Sikorsky Kyiv Polytechnic Institute National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”
2	2011-2015	associate professor	Igor Sikorsky Kyiv Polytechnic Institute National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”
3	2015-	professor	Igor Sikorsky Kyiv Polytechnic

			Institute National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”

Education of the PPD

	Start and end dates	Degrees	Universities
1	1992-1997	master	Kyiv National University of Construction and Architecture
2	1997-2001	PhD	Kyiv National University of Construction and Architecture
3	2008-2014	doctor	Igor Sikorsky Kyiv Polytechnic Institute National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”

Publications of the PPD

	Dates	Titles	Publications details
1	2017	Zaichenko S. et al. Development of a geomechatronic complex for the geotechnical monitoring of the contour of a mine working //East European Journal of Advanced Technologies. - 2017. - 3 (9). - OF. 19-25.	While receiving information under dangerous conditions, at which human presence is difficult or impossible, widely spread are the mobile robotic complexes. Particularly important information to determine the stressed-strained state of the underground workings is data on their geometry. Establishing the values of convergence of underground workings will make it possible to locate dangerous areas and decrease the number of emergency cases. In order to design an experimental sample, we developed basic approaches to create geomechatronic complexes, which define the main tasks, the scope of application, and

			quality criteria. The motion of the complex along an underground working is accompanied by a spatial change in the position of a distance sensor, which must be considered when establishing the actual values of the profile of a working. As parameters that take into account a change in the position, we proposed six components, three displacements and three Euler angles, which are registered by a microelectronic gyroscope that registers the distance traveled. The proposed algorithm is a cyclical structure, which successively performs data registration from different sensors that define its position, data conversion, and data recording to a memory card. Implementation of the devised algorithm allows us to determine the geometry of a profile of the working with an accuracy of 0.5 cm.
2	2018	Zaichenko S. et al. Investigation of the change in the strength properties of a soil mass by mechanical sensing //East European Journal of Advanced Technologies. - 2018. - . 3 (9). - OF. 19-26.	Determination of depth distribution of strength characteristics and comparison with analytically determined values allows obtaining data on the depth of various morphological horizons, the presence of voids and inclusions. The sensing process occurs due to soil strengthening, which was considered in the analysis of changes in the penetration force. The present stage of development of means for determining the soil properties is characterized by the application of mechatronic systems, which allow obtaining data with high accuracy, reliability and

				performance. In order to develop the experimental sample, the basic approaches to the creation of a geomechatronic complex for surface soil monitoring, which determine the main objectives, application scope, quality criteria were developed. The presence of geotechnical deviations in the soil mass is accompanied by changes in the penetration force, which was proposed to be measured by a strain gauge dynamometer with the recording of the rod penetration depth. The program algorithm used is a cyclic structure in which the data are logically recorded from the force sensor and the step of the rod, which determines its position. The implementation of the developed algorithm allows determining penetration forces and changes in the strength parameters of the soil mass with high accuracy (0.05 %), which makes it possible, by comparing with the analytically determined distribution, to reveal the position of geoanomalies.
3	2016		Shevchuk, S. P., Shevchuk, N. A., Vovk, O. O., and Zaichenko, S. V. (2016). Analytical study of rock cutting mechatron vibration system by flat auger tools. Scientific Bulletin of the National Mining University, (3), 29-34.	To create a mechatron model of vacuum tube vibration system for rock cutting by flat auger tools based on physical and mechanical properties of processed array and kinematic characteristics of the instrument. Methodology:. The analytical model of the fracture process of rock cutting by tool vibration considering plastic properties of the massif was developed. The main technological parameters of massif vibrating cutting with normal variations

were modelled: dependences of normal and tangential pressure in the zone of working body interaction with the medium, normal and shear stresses in the zone of destruction, rock characteristics of the medium, vibration parameter dependences on the characteristics of mechatronic system geometry of the contact area of flat chisel treated with medium. Findings:. The choice of the computational model of the vibration rock cutting with the normal to the direction of movement of the working body fluctuations was substantiated considering the processes arising from destruction: the occurrence of compressive and tensile stresses. The main stages and interconnection options in the simulation of vibration cutting were established. Originality:. Scientific novelty lies in the development of a method of analysis of contact interaction of roller working body molding machine with an array taking into account the changes in the stabilization process of physical and mechanical properties of the treated medium, the aim of which is to predict the required voltage and depth of the formed layer. Practical value:. The theoretical basis of rock cutting by flat auger tool taking into account the normal component of the vibration with regard to the movement direction allowing for the deformation of the rock mass and the contact interaction with the working body was established, that allows improving the technology of drilling wells by reducing the power consumption of the cutting process.

Honours of the PPD

	Dates	Award names
1	2022	Gratitude of the Ministry of Education of Ukraine
2	2023	Gratitude of the Ministry of Education of Ukraine
3		

Research focus and expertise of the PPD

> The field of activity for 20 years was the study of the mechanics of contact interaction, complex electromechanical systems, and technical diagnostics of systems. The research is based on the consideration of the system as a whole, starting with the contact interaction of the working body with the environment. When constructing mathematical models of the contact interaction process, the properties of the medium that is deformed and the features of the distribution of contact pressures are taken into account. The rigid-plastic Coulomb-Mohr model was successfully used in the mathematical description of soils. Studies of the contact interaction of the probe with the ground made it possible to propose a system for searching for mines. The search is based on the study of changes in soil properties that occurred due to the installation of mines.
> A separate area of activity is the creation of various diagnostic and monitoring systems. These systems allow you to automatically determine the technical condition of an object in conditions of a minimum amount of information. An example is a system for determining the technical condition of an autonomous power source based on an internal combustion engine.

Other grants held by the PPD

	Date	Donor entity	Grant name	Short description	Results
1	2023	European Commission	Associating Ukrainian cities to the Climate-neutral and smart cities Mission (HORIZON-MISS-2023-CIT-02)	The Work Programme 2023 of the Climate-Neutral and Smart Cities Mission, in line with the provisions under the Implementation Plan of the Cities Mission, fosters the implementation of the Mission	Project results are expected to contribute to all of the following outcomes: Contribute to the implementation of EU policy and international commitments (European Green Deal[1], Global Approach to Research and

				through actions that will continue to provide a strong and direct support to cities that will commit to climate neutrality and enable them to roll out their climate action plans and achieve climate neutrality by 2030, in synergy with significant progress towards zero pollution. In turn, the cities benefitting from these actions will act as experimentation and innovation hubs for other cities to become climate-neutral by 2050.	Innovation[2]). Identify a core group of Ukrainian cities that would commit to a climate neutrality target, including in reconstruction efforts; Accelerate the systemic transition to climate-neutrality of Ukrainian cities by preparing local authorities to meet the overarching objectives of the European Green Deal; Increase the visibility of the EU and its cities as leaders and engage cities participating in the Cities Mission in twinning and teaming activities with collaboration-minded Ukrainian city partners.
2	2022	European Commission of the EU	Program to support Ukrainian scientific and pedagogical workers within the framework of international academic mobility under the legal regime of martial law	Study in the research project of the University of Juan Carlos, Madrid	Gaining experience in analytical research and international contacts

3	2019/2021	European Commission	Erasmus+	Staff Mobility For Training/The main objective of the mobility is to build up a network between two educational institutions, namely the Kütahya Dumlupınar University and the Institute of Energy Saving and Energy Management within Igor Sikorsky Kyiv Polytechnic Institute for the further science programs. Accumulation the skills and experience of using the latest students of microcontroller software and hardware.	Form a consortium for joint participation in science programs and development of new mechatronic systems and complexes with the participation of employees of both institutions, namely the Faculty of Engineering and the Institute of Energy Saving and Energy Management of the Kiev Polytechnic Institute. Igor Sikorsky.

Other Co-Director(s)

Please click on the "Add Co-Director" button and fill in all information for each co-director. Kindly note that:

- Project Co-Directors shall be **employed** by an institution in either a NATO or Partner country;
- Project Co-Directors shall be **resident** in the country where their institution is located;
- Project Co-Directors **must be nationals of NATO or eligible NATO Partner countries**;
- Project Co-Directors shall have their own budget allocation in the *SPS MYP Detailed Budget Excel spreadsheet*;
- An application shall have no more than one Co-Director per institution;
- The Co-Directors are responsible for the planning and progress of work performed at their institution, and all work together to ensure the success of the project.

Project Participants

The principal applicants, referred to as **project Co-Directors**, shall have their own budget allocated in the MYP application. An application shall have **no more than one Co-Director per institution.** The Co-Directors are responsible for the planning and progress of work performed at their institution, and all work together to ensure the success of the project.

Other project participants are not assigned their own budget and are not considered Co-Directors, for example students or post-doctoral researchers, further researchers at a given institute, etc.

Roles of Co-Directors and Participants

	Family name	First name	Affiliation	Position/Title	% Time	Task(s)
1	Zaichenko	Stefan	Igor Sikorsky Kyiv Polytechnic Institute	Professor/ Dr.-Ing.	25	designing and developing the mine detection system, making system and working on integration and testing
2	Raatz	Annika	Institute of Assembly Technology and Robotics	Professor/ Dr.-Ing.	5	management and coordination
3	Recker	Tobias	Institute of Assembly Technology and Robotics	Researcher/ PhD student	50	designing and developing mobile platform, system integration
4	Peresada	Sergiy	Igor Sikorsky Kyiv Polytechnic Institute	Professor/ Dr. Sci, (Tech),	25	Control system and electrical drive design
5	Kovbasa	Serhii	Igor Sikorsky Kyiv Polytechnic Institute	Chief of subdepartm ent/ Dr. Sci, (Tech),	25	Hardware and software design for implementat ion of electrical drive and control system
6	Nikonenko	Yevhen	Igor Sikorsky Kyiv	Assistant/Ph D	25	Simulations and

			Polytechnic Institute			experimental verification of control system and electrical drives
7	Vovk	Oksana	Igor Sikorsky Kyiv Polytechnic Institute	Director of the Scientific Institute, Professor / Dr.- Tech.	15	Local manager, mine detection system developing monitoring

End-User(s)

Depending on the nature of the project, end-users could be (but are not limited to):

- Government ministries;
- State organisations;
- Regional authorities within a participating country in the project submitted;
- Private, commercial and/or industrial companies, potentially interested in commercializing the results.

End-users should, as a minimum, advise the Co-Directors to ensure that the results will be of interest outside the laboratory. Deeper involvement is welcome although **end-users cannot receive NATO SPS funds**.
The end-user(s) should **be based in a NATO and/or eligible Partner country**.

End-User(s)

	Family name of the end-user	First name of the end-user	Title of the end-user	Job title of the end-user	Name of the end-user's institution	Full mailing address of the end-user's institution	Country of the end-user institution	Telephone of the end-user	Email of the end-user
1	Hubenko	Andrii	PhD in Public Administration	Director of the Mine Action Organization Department of the Interregional Centre	Interregional Centre humanitarian demining and rapid response of the State	63212, Kharkiv region, Vatutine village, Interregional Center for Human	Ukraine	+38(050)-992-992-9	mcgr.vozpmd@gmail.com

	humanitarian demining and rapid response of the State Emergency Service of Ukraine	Emergency Service of Ukraine	itarian Demining and Rapid Response of the State Emergency Service of Ukraine
2			
3			

End-user(s) commitments

Please upload in the box below any written commitments from end-users to their interest and participation in the project and use/development of the results.
For projects with governmental end-users, this will often take the form of letters of support describing the ministry or agency's interest in the results of the project.

Project Plan

Project title Modular Remotely Operated Mine Detection System with Sensorized Prodding

Primary key priority 3c) Mine and Unexploded Ordnance Detection and Clearance

Additional key priorities ✓ 3c) Mine and Unexploded Ordnance Detection and Clearance

Abstract

> A lot of mine detection in Ukraine is currently carried out using a technique known as prodding, where demining personnel manually probe the ground with rods. This ground penetrating method poses extremely high risks to the demining personnel, due to the close proximity to the mines. Furthermore, deep penetration of the ground requires substantial force, which reduces the sensitivity of human operators to detect unexploded ordnance (UXO). Therefore, this project aims to develop a modular remotely operated mine detection system, which uses electrically actuated prodders with force feedback to reliably detect potential mines in the ground.

Problem and proposed solution

PDF MRO_Problem and Proposed... (65 KiB download)

Current status

The initial phase of post-conflict country reconstruction hinges on humanitarian demining, a pivotal undertaking that mandates the complete clearance of landmines throughout the designated area. This process necessitates the precise detection, location, and secure removal of each individual mine and unexploded ordnance (UXO), ensuring the targeted ground is rendered entirely free of these hazardous explosive remnants of war (ERW) [1].

As described in [2], no single mine detection technology can operate effectively against all mine types in all settings. Given the limitations of individual sensor technologies, major breakthroughs in mine detection capability are likely to occur only with the development of a multisensor system. The authors in [2] recommend a combination of at least two of the methods labeled as promising. The promising methods include nuclear quadrupole resonance, advanced prodders and acoustic/seismic detection.

Current advancements in landmine detection technology, encompassing advanced metal detectors [7], UAV/drones [5], nuclear methods [6] and Ground-Penetrating Radar (GPR) often coupled with deep learning techniques [3], represent significant progress yet face persistent challenges. High false positive rates, environmental sensitivities, and mainly the cost and complexity of the equipment continue to hinder efficiency and safety. These ongoing issues highlight a pressing need for innovative approaches that can synergize various detection methods, enhance accuracy, and simplify deployment in diverse environments.

In regions currently embroiled in conflict, such as Ukraine, the implementation of advanced demining systems holds immense potential for transformative impact. Economic stability in war-torn areas like Ukraine is intricately linked to the availability of usable land. Rapid and efficient demining becomes pivotal in unleashing the full economic potential of these territories. Early deployment of cutting-edge demining systems not only accelerates the process but also enhances the precision of mine detection, significantly expediting field clearance operations. Swift demining is crucial to mitigate the adverse effects of environmental and physical factors on temporarily occupied Ukrainian territories, reducing the likelihood of landmine repositioning and minimizing the risk of explosive incidents over time. The imperative is to develop cost-effective mine detection equipment capable of large-scale deployment and sustained high-speed operations to address the pressing needs of these conflict-affected regions.

Our team comprises experts with experience in the field of demining technology and mechatronics.

Participant's Contributions from Igor Sikorsky Kyiv Polytechnic Institute

Project Co-Directors Professor Stefan Zaichenko has over 20 years of experience in the study of contact interaction mechanics, complex electromechanical systems, and technical diagnostics. His work has been fundamental in understanding the contact interaction of probes with soil, utilizing the rigid-plastic Coulomb-Mohr model for accurate mathematical descriptions of ground properties. This research has led to innovative methods for detecting mines based on changes in soil properties and has applications in designing diagnostic and monitoring systems for various conditions.

The notable achievements include the development of a remote-controlled mine detector (penetrometer) [8] and significant contributions to the field through publications [9-11]. His pattern of research and innovation makes him an invaluable asset to our project, bringing expertise in mechanical probe technology and a holistic approach to system diagnostics and mine detection.

Participant's Contributions from match.

The Institute of Assembly Technology and Robotics (match) has gained extensive expertise in the field of mobile robots and systems over the years. The institute has designed and constructed a series of mobile robots equipped with various actuators and sensors tailored for specific applications. In an initial iteration [12], we combined a mobile manipulator with a commercially available roller board to create a tractor-trailer system, meant for transporting extra-long loads. Subsequently, in [13], the roller board was replaced by a second mobile manipulator developed in-house, significantly enhancing the handling capabilities of the system. To address localization errors between both robots, a hybrid position controller is employed, correcting the robot's target position based on force measurements from an attached force-torque sensor.

We then devised a motion planning strategy, detailed in [14] and [15], incorporating the robot's kinematics and the specific environmental conditions to determine the most efficient path through an environment. In conjunction with a decentralized tracking controller [16] the robots are able to maintain a desired formation while autonomously navigating in an environment with unknown obstacles. In [17], the mobile manipulator from [12] and [13] was equipped with a custom designed end effector capable of measuring an existing component contour and applying new material to the structure. In an ongoing project, this end effector is mounted on a newly developed heavy-duty robot with a lifting column, facilitating the transportation of a larger volume of material and expanding the working area. This task-optimized mobile robot aims to enable the printing of concrete building components on 1:1 scale in the future.

Collectively, our team has the necessary skills, experience, and innovative mindset to advance the state of mine detection.
[1] M. K. Habib, „Humanitarian Demining: Reality and the Challenge of Technology – The State of the Arts“, International Journal of Advanced Robotic Systems, Bd. 4, Nr. 2, S. 19, Juni 2007, doi: 10.5772/5699.
[2] Alternatives for Landmine Detection. RAND Corporation, 2003. doi: 10.7249/MR1608.
[3] P. Bestagini, F. Lombardi, M. Lualdi, F. Picetti, und S. Tubaro, „Landmine Detection Using Autoencoders on Multipolarization GPR Volumetric Data“, IEEE Trans. Geosci. Remote Sensing, Bd. 59, Nr. 1, S. 182–195, Jan. 2021, doi: 10.1109/TGRS.2020.2984951.
[4] A. Barnawi u. a., „A comprehensive review on landmine detection using deep learning techniques in 5G environment: open issues and challenges“, Neural Comput & Applic, Bd. 34, Nr. 24, S. 21657–21676, Dez. 2022, doi: 10.1007/s00521-022-07819-9.
[5] M. Schartel, K. Prakasan, P. Hugler, R. Burr, W. Mayer, und C. Waldschmidt, „A Multicopter-Based Focusing Method for Ground Penetrating Synthetic Aperture Radars“, in IGARSS 2018 - 2018 IEEE International Geoscience and Remote Sensing Symposium, Valencia: IEEE, Juli 2018, S. 5420–5423. doi: 10.1109/IGARSS.2018.8518905.
[6] P. Bestagini, F. Lombardi, M. Lualdi, F. Picetti, und S. Tubaro, „Landmine Detection Using Autoencoders on Multipolarization GPR Volumetric Data“, IEEE Trans. Geosci. Remote Sensing, Bd. 59, Nr. 1, S. 182–195, Jan. 2021, doi: 10.1109/TGRS.2020.2984951.
[7] R. J. Stanley, P. D. Gader, und K. C. Ho, „Feature and decision level sensor fusion of electromagnetic induction and ground penetrating radar sensors for landmine detection with hand-held units“, Information Fusion, Bd. 3, Nr. 3, S. 215–223, Sep. 2002, doi: 10.1016/S1566-2535(02)00071-4.
[8] S.V. Zaichenko, R.D. Kulysh, S.Y. Dokshina, S.V. Korol, «Mine detector» U.S. Patent UA140294U, July 18, 2019
[9] Zaichenko S. et al. Development of a geomechatronic complex for the geotechnical monitoring of the contour of a mine working //East European Journal of Advanced Technologies. - 2017. - 3 (9). - OF. 19-25.
[10] Zaichenko S. et al. Investigation of the change in the strength properties of a soil mass by mechanical sensing //East European Journal of Advanced Technologies. - 2018. - . 3 (9). - OF. 19-26.
[11] Shevchuk, S. P., Shevchuk, N. A., Vovk, O. O., and Zaichenko, S. V. (2016). Analytical study of rock cutting mechatron vibration system by flat auger tools. Scientific Bulletin of the National Mining University, (3), 29-34.
[12] Recker, T.; Matour, M.E.; Raatz, A.: A Simple And Modular Approach To Path Planning For Tractor-Trailer Robots Based On Modification Of Pre-Existing Trajectories. In: Herberger, D.; Hübner, M. (Eds.): Proceedings of the Conference on Production Systems and Logistics : CPSL 2021. Hannover : publish-Ing., 2021, S. 136-145. DOI: https://doi.org/10.15488/11241
[13] T. Recker, M. Heinrich and A. Raatz, "A Hybrid Control Approach on Handling Orientation Constraints and Tracking Errors in Formation Control for Multiple Nonholonomic Mobile Manipulators," 2021 20th International Conference on Advanced Robotics (ICAR), Ljubljana, Slovenia, 2021, pp. 891-896, doi: 10.1109/ICAR53236.2021.9659315.
[14] T. Recker, H. Lurz and A. Raatz, "Smooth Spline-based Trajectory Planning for Semi-Rigid Multi-Robot Formations," 2022 IEEE 18th International Conference on Automation Science and Engineering (CASE), Mexico City, Mexico, 2022, pp. 1417-1422, doi: 10.1109/CASE49997.2022.9926604.
[15] Recker, Tobias & Lurz, Henrik & Raatz, Annika. (2022). Smooth Spline-based Trajectory Planning for Semi-Rigid Multi-Robot Formations *. 1417-1422. 10.1109/CASE49997.2022.9926604.
[16] Tobias Recker, Malte Heinrich, Annika Raatz, A Comparison of Different Approaches for Formation Control of Nonholonomic Mobile Robots regarding Object Transport, Procedia CIRP, Volume 96, 2021, Pages 248-253, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2021.01.082.
[17] Lukas Lachmayer, Tobias Recker, Annika Raatz, Contour Tracking Control for Mobile Robots applicable to Large-scale Assembly and Additive Manufacturing in Construction, Procedia CIRP, Volume 106, 2022, Pages 108-113, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2022.02.163.

Impact

With the successful completion of the project, a new and safe method for mine detection will be available for introduction in field operations. It is expected that the usage of the system by personnel previously deployed for manual demining will reduce the risk and occurrence of heavy or lethal injuries drastically since the personnel can operate the mine detection system from a safe distance.
Due to the cost-effective approach, it is expected that the novel mine detection system will see widespread use through the Interregional Centre humanitarian demining and rapid response of the State Emergency Service of Ukraine.

Technology Readiness Level (TRL)

With the completion of the project, a TRL of 6 - technology demonstrated in a relevant environment is expected. At the beginning of the project, basic principles for mechanical mine detection are already known (TRL 1 - basic principles observed) and are used to formulate technology concepts for the mine detection system, the mine marking system and the mobile modular platform (TRL 2 - technology concept formulated). During the development of the final designs of these three components of the planned demining system, each concept will be experimentally proven, validated in a laboratory environment (TRL 3 - experimental proof of concept and 4 - technology validated in lab) and adjusted accordingly. After the integration of all components into a functioning prototype, validation and testing in a real-world environment (e.g. already cleared mine fields) takes place (TRL 5 - technology validated in relevant environment). The data generated in these trials will be used for further enhancement of the system so that a demonstration of the prototype in a controlled environment (TRL 6) is possible at the end of the project

Security relevance and real-world applications

Landmines and unexploded ordnance (UXO) pose a serious threat to the health and lives of civilians all over the world. Left behind during or after conflicts, mines and UXOs remain dangerous for years to come, preventing land usage and hinder social, psychological and economic recovery of the affected people.
Therefore, thorough demining becomes a vital humanitarian task in affected areas. Depending on the environmental conditions and other factors, manual detection and removal of mines can be necessary. Manual detection of mines, especially invasive detection is a highly dangerous task. Considering the quantity of mined areas in Ukraine alone (an estimated 30 % of the territory may be contaminated by mines) and the high risk with conventional methods, death and serious wounding of demining personnel will almost certainly occur.
This project aims to develop a cost-effective mobile modular mine detection system, which can be used by demining personnel to remotely and safely detect and mark mines for later removal. If successful, the mine detection system can save the lives of demining personnel, not only in Ukraine but potentially worldwide. Furthermore, reducing the risk of death and injury for demining personnel could increase willingness to participate in demining operations and therefore increase the pace of demining, potentially saving more lives.

Data exploitation plan

For the early stage development and testing of the prodding mechanism (Mine Detection System module), the European Soil Database will be used to assess the expected properties of the soil in the affected areas. The data will be used to estimate the forces needed for soil penetration and therefore to design the system with sufficient structural integrity and select adequate actuators and sensors. In the experimental testing phase, the soil data will be used to reproduce realistic soil conditions in the laboratory environment. During the experimental testing of the prodding mechanism, all sensor data will be collected and used later for the training of artificial neural networks or other AI-driven algorithms for anomaly detection.

In general, all relevant data collected during the project will be saved on the servers of both partner universities. At Leibniz University Hannover, all data is backed up daily on central backup servers and additionally archived on magnetic tapes after completion of the project. This ensures the long-term availability of all research data. Furthermore, research data relevant to the public or other researchers will be made available via the Research Data Repository of Leibniz University. Through this repository, the data will be assigned a DOI and will be accessible via open-access indefinitely.

Work-plan

List of work packages

WP1- Management and Coordination
WP2- Mine Detection System(MDS)
WP2.1 - MDS Prodding Mechanism - Invasive method
WP2.2 - MDS Complementary Mechanism - Non-invasive method
WP3 - Remotely Controlled Modular Mobile Platform (MMP)
WP3.1 -MMP Conceptualization and Hardware

WP3.2 - MMP Remote Control and Data Transmission
WP4 - Mine marking mechanism
WP5 - Integration, Testing and Enhancement

Institute of Assembly Technology and Robotics (match) -WP1,WP3,WP4,WP5
Igor Sikorsky Kyiv Polytechnic Institute (KPI) - WP2,WP4,WP5

WP1 - Management and Coordination (Months 1-24)

Objectives
This work package addresses the critical aspects of managing and coordinating the project, ensuring its effective execution, seamless collaboration among team members, and successful achievement of objectives. The primary focus lies in establishing robust project management methodologies and communication strategies to optimize efficiency, foster innovation, and mitigate potential challenges.

Activities and methodologies
Develop a communication plan to ensure all participants are informed and engaged.
Schedule regular project status meetings for team alignment and timely updates.
Use collaborative tools for project tracking
Project documentation and establishment of knowledge base
Conduct risk assessment sessions to proactively identify and address potential issues.

Risks and Mitigation:
Risk: Inadequate communication leading to misalignment among participants.
Mitigation: Implement the communication plan with scheduled updates and ensure adherence to it across all teams.
Risk: Inefficient tracking of project progress.
Mitigation: Utilize collaborative tools for real-time project tracking and assign team members to update tasks regularly.
Risk: Loss of critical project knowledge due to poor documentation.
Mitigation: Establish a centralized knowledge base that is regularly updated and backed up.

Milestones and deliverables:
M1: Initial Project Coordination Review (Month 6)
An interim evaluation of the project management and coordination effectiveness, including a review of communication and risk management strategies.
D1.1-WP1: Project Management Plan.
A plan outlining the project management and coordination strategies.
D1.2-WP1: Initial Coordination Review Report
A report assessing the effectiveness of the project at the early stage of the project.
M2: Mid-Project Review of Management Processes (Month 15)
In-depth review and adjustment of management strategies based on the project's progress and initial technical and financial reports.
D2-WP1: Mid-Project Management Report
A detailed report evaluating the project at the project's midpoint.
M3: Pre-Final Review of Project Coordination (Month 19)
Evaluation of management processes in preparation for the final stages of the project.
D3-WP1: Pre-Final Coordination Review Report
An assessment report of the project processes leading up to the final phase of the project.
M4: Comprehensive Project Closure Review (Month 24)
Final evaluation of the project management and coordination, including lessons learned and final project documentation.
D4-WP1: Final Project Management and Coordination Report
The final comprehensive report summarizing the project activities throughout the project lifecycle.

WP.2 Mine Detection System (Months 1 - 19)

Landmines pose a significant threat to human lives and impede socio-economic development worldwide. Thus, within this working package, we aim to develop a double-check approach that seeks to improve a cost-effective system with the precision and reliability of mine detection technologies.
To increase safety two methods will be developed:

1. An invasive method, which will determine the existence of possible landmines by penetrating the soil (WP2.1).
2. A non-invasive method as a redundant system to decrease the probability of false positives and negatives with a strong inclination towards zero false negatives concerning the potential dangers of undetected mines (WP2.2).

WP2.1 Prodding Mechanism - Invasive method (Months 1-15):

Objectives
In WP2.1, our primary objective is to develop an advanced, modular probing mechanism tailored for precise and efficient landmine detection. This initiative is driven by the urgent need to enhance safety in demining operations. The focus is on conceptualizing multiple designs for a prodding mechanism that aligns seamlessly with our mobile platform, ensuring adaptability across varied terrains. Through a collaborative approach, involving feedback from demining experts, we aim to create and test prototypes using both industrial-ready and custom-designed control systems. This process includes thorough testing for usability and effectiveness, selection of optimal sensor technologies based on expert insights, and rigorous experimental investigation of soil interactions. Our goal is to refine these designs iteratively, informed by testing feedback, to achieve a highly functional and accurate prodding mechanism. A schematic sketch to illustrate the system is shown in Fig. 1.

Activities and methodologies

1. Conceptualize multiple mechanical parts of prodding mechanism designs and align them with the mobile platform's conceptualization. Create multiple concepts of prodding mechanisms and present these to demining experts for feedback.
   Possible designs include a mechanism with two prodders or a rake-style mechanism that would penetrate the ground at several locations at once. A single penetration mechanism with two prodders would reduce the complexity of the system, but at the same time increase the detection time, compared to a rake or matrix-style mechanism. However, penetrating the ground on multiple locations at once requires much higher forces and therefore increases the load on the equipment and drive costs for actuators and sensors.
   Different concepts will be developed and then presented to demining experts with field expertise. Using the feedback from the experts, two concepts are chosen and laboratory prototypes are designed and manufactured. In the initial testing phase, different abilities of the respective systems are evaluated.
2. Design and create laboratory prototypes of control systems using industrial-ready equipment. Perform initial testing to evaluate their usability and the effectiveness of the detection processes.
   To provide a fast project start-up, at the first stage overall drive system and main control system will be designed and manufactured using standard industry-ready equipment, such as electrical drives (including electrical motors, power electronics, sensors), programmable logic controllers, DSP control boards or powerful computers, control software, etc..
   The equipment can be powered by standard grid voltage, which ensures a fast laboratory set-up in order to investigate the most critical points in this project: The requirements for the prodding drive performances and the collection and processing of force-position curves for different soil conditions. The fast laboratory setup with industrial components comes with high equipment costs and does not account for protection from environmental conditions and vibrations of the used components. The interaction between separate components and a reliable power supply of the initial equipment would be challenging on the mobile platform.
3. Design and implementation of a custom control system and electromechanical drive and interfacing these components with the prodding mechanism.
   This activity is intended to mitigate the disadvantages of the initial system based on commercially available equipment. The main idea is to design specialized hardware which combines an electrical drive for the prodding subsystem together with the main control system and force-position curve processing unit, using a powerful digital signal processor, for example TMS320F28378S from Texas Instruments. By this, the prodding drive system and main controller will provide fast interaction and better reliability under harsh mission conditions.

The hardware design will aim at a compact size for the integration into an IP67 case and the powering from an on-board battery system. Overall system cost will be reduced through a modular design. Main challenges in this activity are the long time for the development and the necessity of intensive experimental testing. The obtained results can be easily extended on other electrical drives, including the marking subsystem.

4. Execution of comprehensive testing and iterative design refinement of prototypes.
   Following the development of laboratory prototypes, we will conduct comprehensive system testing to assess their performance, focusing particularly on soil interaction to inform the final design of the prodding mechanism. This phase includes experimental analysis and expert feedback to identify the most promising designs. Based on these insights, we will construct refined prototypes, selecting optimal and effective sensor technology. The iterative process of refining these designs based on initial testing results is critical to enhancing the functionality and accuracy of the system, ensuring it meets the practical and technical demands of demining operations.

Risks and Mitigation:
Risk: Initial designs may not meet operational requirements or receive negative expert feedback.
Mitigation: Engage in iterative design and continuous expert consultation to refine the mechanism.
Risk: Prototypes may not perform adequately during initial testing.
Mitigation: Plan for multiple rounds of prototyping and testing, incorporating feedback loops from each testing phase.
Risk: Control system integration challenges.
Mitigation: Develop and test the control system in parallel with the mechanical design to ensure seamless integration.

Milestones and Deliverables:
M1: Detailed Design Conceptualization and Expert Consultation (Month 6)
Completion of multiple poking mechanism designs and alignment with the mobile platform. Presentation and feedback of CAD model designs and initial control system from demining experts.
D1-WP2.1: Prototype Designs and Expert Feedback
Completed designs of multiple probing mechanism prototype with control system, incorporating alignment with the mobile platform's specifications. Additionally, a summary of feedback and suggested improvements from demining experts.
M2: System Integration and Comprehensive Testing (Month 15)
Integration of a selected control system and electromechanical drive into the prodding mechanism. Comprehensive testing of the integrated system and initial experimental soil interaction investigations.
D2-WP2.1: Functional Laboratory Prototypes
Constructed laboratory prototypes of the prodding mechanism, complete with industrial-ready and custom control systems. This deliverable also includes results from the initial usability and effectiveness testing.
D3-WP2.1: Final Prodding Mechanism with Integrated Control System
The finalized prodding mechanism integrated with the selected control system and electromechanical drive, ready for comprehensive testing. A preliminary report on the soil interaction studies should accompany the prototype, providing initial insights into the system's detection capabilities.

WP.2.2 Complementary Mechanism - Non-invasive method (Months 10-19):

Objectives:
The invasive method in WP2.1 aims to enhance mine detection accuracy by directly interacting with the soil to detect anomalies in comparison with non-invasive detection methods. However, this approach inherently carries a high probability of false positives. To mitigate this, we will utilize a complementary non-invasive detection system in WP2.2. This system will use existing advanced sensors, and potentially machine learning algorithms, to reduce false positives and refine the accuracy of the overall detection system. The goal is to seamlessly integrate this non-invasive method with the invasive approach to create a robust, double-check mechanism for mine identification.

Activities and methodologies:

1. Conduct a comprehensive literature review and select optimal non-invasive technologies.
   Research and evaluate existing non-invasive mine detection methods like for example ground penetrating radar with optimized machine learning algorithms. Select the optimal non-invasive technologies by identifying the most promising and cost-effective non-invasive technologies suitable for integration with the invasive system developed in WP2.1.

2. Design and prototype development.
   Conceptualize and design a non-invasive detection system that is modular and can be integrated with the invasive poking mechanism and modular mobile platform. Build a prototype of the non-invasive system using the selected technologies. Ensure that the design allows for easy integration and modularity with the existing system.
3. Machine learning algorithm development (if applicable).
   If machine learning is identified as a viable approach to enhance the detection capabilities of the combined mine detection system, develop and train algorithms specifically tailored for landmine detection challenges. Select the optimal approach to the complementary method's control system.
4. System integration and testing.
   Integrate the non-invasive system with the invasive mechanism and conduct rigorous testing to validate the efficacy and accuracy of the combined system under mission-like conditions using landmine mockups.

Risks and Mitigation:
Risk: Technological Incompatibility:
Mitigation: Prioritize technologies with proven compatibility records with existing systems. Initiate early-stage integration testing and maintain open communication channels between development teams to ensure compatibility throughout the design process.
Risk: Prototyping Exceeding Budget Constraints:
Mitigation: Monitor budget allocation closely during the prototyping phase. Opt for iterative prototyping to test components individually before full-scale integration to manage costs effectively.

Milestones and Deliverables:
M2: Prototype Development and Preliminary Integration (Month 15)
Development of a modular non-invasive detection system prototype using the chosen technologies, and initial integration efforts with the invasive system.
D1-WP2.2: Literature Review and Technology Selection Report
A report documenting the outcomes of the literature review, including the rationale behind the chosen non-invasive technologies.
D2-WP2.2: Non-invasive Detection Prototype and Integration Report
First prototype, initial integration efforts with the invasive system, and preliminary testing results.
M3: Final Integration and Comprehensive System Testing (Month 19)
Integration of the non-invasive system with the invasive mechanism and completion of testing to confirm system efficacy and accuracy.
D3-WP2.2: Integrated Detection System and Testing Report
A final report detailing the non-invasive system with the invasive mechanism, including results from system testing and any machine learning algorithm development and training, if applicable.

WP3 Remotely Controlled Modular Mobile Platform (Months 1 - 19)

WP3.1 MMP Conceptualization and Hardware (Months 1-15)

Objectives:
Finding and neutralizing landmines and another ERW is one of the main goals of current and future mine action and yet this process relies highly on manual labor to a significant extent, especially in Ukraine. Therefore, our approach relies on a remote-controlled solution to minimize the operational risks of the deminers on site and at the same time maximize mission efficiency in terms of time and costs.
Unlike many existing approaches, the entire system will be designed as a modular platform to allow maintenance and replacement of parts, but also to allow customization by the deminers working on site. Special challenges, like heavy vegetation, often arise on site and in practice, which require rapid adaptations to the mobile system. All components used are therefore industrially available parts for the active components of the system and simple semi-finished components that are screwed or welded together to form the structural shell.
The design process involves a meticulous evaluation of kinematics suitable for navigating challenging terrains. Factors such as the type of wheels, the implementation of active steering, or a tank-like steering mechanism will be systematically assessed. Through this comprehensive approach, our modular platform will not only accommodate the landmine detection

system effectively but also ensure a high degree of flexibility and efficiency in a variety of operational scenarios. Special consideration is given to the design for work in areas with slopes of up to 15° and obstacles that have to be maneuvered around to make the system effective in a wide range of possible mission scenarios. The entire system is designed in consultation with the end users ensuring that the system can be transported by car and loaded, deployed and operated by a maximum of two operators.
As a key requirement for every device used in mine detection, the mobile platform will be designed to withstand explosions of anti personnel blast mines and fragmentation mines with limited and repairable damage to its structural components and mine detection systems thanks to a robust design and the shielding of fragile components.

Activities and methodologies:
Definition of system parameters: In consultation with the end users and in mutual exchange with WP2, the framing parameters for the system are defined in terms of size, weight, power and possible payload.
Concept for interfacing the components: Definition of interfaces of the two mine detection mechanisms from WP2 with the mobile platform including mounting and actuation.
Design and development of the mobile platform: Construction of the platform based on the frame parameters using bolted/welded aluminium and steel semi-finished products. Construction of the drive mechanism using industrial components. When building the platform, assembly-specific adjustments are made to ensure the maintainability and modularity of the concept. Detailed assembly and maintenance plans are developed with a focus on long-term use and mission-specific adjustments of the system.
Extensive testing of the platform: In addition to experiments on drive system performance (power and maneuverability) in the field, the simple setup and maintenance of the overall system are also tested with input from the end users.

Risks and mitigation:
Risk: Initial platform designs may not meet operational requirements like manoeuvrability or framing limitations like weight and size.
Mitigation: Iterations of adjustments and remedial solutions to ensure usability like in the case of excessive weight the division into smaller parts that can be assembled on site.
Risk: No suitable and available industrial components.
Mitigation: If there are no industrially available components for parts of the platform, custom-made parts should be manufactured that still meet the requirements of simple and inexpensive assembly and maintenance.

Milestones and Deliverables:
M1: Conceptualizing the foundational design of the mobile platform, incorporating feedback from end users and the KPI through collaborative engagement with WP2. (Month 6)
D1-WP3.1: Mobile platform design specifications and a limitations assessment
M2: Successful completion of the assembled mobile platform prototype, demonstrating key functionalities and performance benchmarks as outlined in the project timeline (Month 15)
D2-WP3.1: Prototype of the modular mobile platform (Month 15)

WP3.2 MMP Remote Control and Data Transmission (Months 9-19)

Objectives:
This working package aims at expanding the mobile modular platform by incorporating the necessary remote control and data transmission capabilities. The primary goal is to create a versatile and cost-effective system that ensures the safety and continuous operation of the platform during demining missions. This WP starts nine months after the start of WP3.1 and the general project. The primary objective is to enable the real-time control of the system while keeping a safe distance between the operators and the mine detection system. For navigation purposes, the system should be equipped with a rotatable camera which, in an elevated position on the platform, should provide the operators with an all-round view during operation. On the one hand, it is important that the camera has a high resolution in order to detect possible, non-buried landmines and, on the other hand, that the cameras are readily available for replacement in the event of unintentional explosions or other equipment failures. Interfacing should use standardized communication interfaces to allow the use of mission specific cameras. In special weather, visibility and vegetation conditions, for example, a thermal imaging camera could provide additional information.
A simple user input device, for example, based on available open-source drone or remote-controlled car controllers, should

be used as the input device for controlling the mine detection system. This would also allow smartphones to be integrated as a display element. This should avoid the need for customized and special solutions and ensure the simple replacement of control systems. In addition, further features can be easily integrated into the overall system. While the user input for the integration of the basic control system is still being tested using a wired computer, this will be replaced by a wireless control system as soon as the control system functions sufficiently well. The MMP prototype will then be used for initial trials in controlled environments to evaluate functionality, adaptability, and reliability under mission like conditions.

Activities and methodologies:
Definition of demining-mission relevant requirements and specifications for the remote control and data transmission of the modular mobile platform.
Conceptualization of the whole system based on the requirements and specifications in close consultation with the end users and in accordance with the needs of the mine detection mechanisms regarding control and data transmission. The modular composition of the individual parts is also a key focus here. This allows simple interfaces to be implemented and individual parts to be interchangeable.
Realization of the control unit for the whole system including the platform and mine detection mechanisms. First tests will be conducted to prove the sufficient computational power of the system and the operability of the single components.
Interfacing of the user input device and tests and improvements of the whole system.

Risks and mitigation:
Risk: There is a risk that no suitable electric drive system can be realized that would allow practical use of the system under the real conditions of sometimes more rural and remote regions.
Mitigation: In this case, a suitable solution should be developed in consultation with the end users, which could, for example, be cable-bound or use generators based on available fossil fuels.
Risk: The control of the entire system could be highly complex and therefore pose challenges for end users.
Mitigation: The control of the entire system will be designed to be as simple as possible. Should there nevertheless be usability problems, attempts will be made to integrate and automate functions in order to reduce the total number of components to be controlled.

Milestones and Deliverables:
M3: Tested and optimized platform design including remote control capabilities (Month 19)
D3-WP3.2: A mobile platform optimized through extensive testing, including instructions on how to set up and maintain it (Month 19)

WP4 Mine marking mechanism (Months 12 - 19)
Objectives
WP4 aims to create a cost-efficient and seamlessly integrated mine marking mechanism within the modular mobile platform developed in WP3. The marking of possible discovered mines but also the marking of surveyed areas and safe areas is an important part of demining missions in the context of land release efforts. The mechanism for marking will be carried out in close consultation with the end users and in compliance with international standards for humanitarian demining. The mechanism will not only accurately mark detected mines and cleared zones but also be designed for easy maintenance and replacement. A key goal is to develop a marking method that enables subsequent mine destruction efficiently. Emphasizing possible eco-friendliness, material savings, and high accuracy, we are exploring lightweight solutions like fluorescent marker paint systems to reduce the device's overall weight.

Activities and methodologies

1. Development of detailed technical specifications.
   The first step is to establish a comprehensive set of technical requirements for the mine marking mechanism. This involves determining exact weight limitations, environmental impact assessments, and precise accuracy metrics necessary for effective marking. We will also define the technical constraints and integration requirements for compatibility with the mobile platform developed in WP3.
2. Advanced conceptual and detailed design phase.
   We will engage in an intensive design process that includes the creation of intricate electrical and kinematic schematics. This phase will see the use of sophisticated CAD tools for structural calculations. The design will specifically

focus on creating a mechanism that can apply markers at a sufficient speed without compromising the accuracy or increasing the weight significantly.

3. Prototype development, integration, and field testing.
   The construction of a physical prototype will involve selecting materials and components that align with our usability, eco-friendly and efficiency goals. Post-construction, this prototype will be integrated with the mobile platform's control system. The integration process will be followed by field testing under various simulated conditions to ensure robust functionality. These tests will assess the speed of marker application, the durability of the markers in different environmental conditions, and the ease of integrating or replacing the mechanism in the field.

Risks and Mitigation:
Risk: Design Incompatibility with Mobile Platform
Mitigation: Regular coordination with the Mobile Platform developers to ensure design compatibility and ease of integration.

Milestones and Deliverables:
M2: Development of Prototype (Month 15)
Completion of the mine marking mechanism prototype, integrating it with the mobile platform developed in WP3, and conducting preliminary tests to assess its functionality.
D1-WP4: Integrated Mine Marking Prototype (Month 15)
A developed prototype of the mine marking mechanism with the mobile platform integration.
M3: Final Testing and Deployment Readiness (Month 19)
Completion of extensive testing, final adjustments, and validation of the mine marking mechanism, ensuring it is ready.
D2-WP4: Operational Mine Marking System (Month 19)
This prototype includes initial test results demonstrating its functionality. This system of the mine marking mechanism, is tested, adjusted, and validated.

WP5 Integration, Testing and Enhancement (Months 18- 24)

Objectives
In order to efficiently utilize the strengths of the respective project partners, the individual components of the system are developed in the respective institutes in Ukraine and Germany. Despite the close cooperation and regular exchange, intensive testing of the overall system is still required at the end under conditions that are similar to the later place of use. In a first step, the individual components of the system are combined at the interfaces provided for this purpose. There will still have to be adjustments, which can be accomplished most efficiently in a joint effort. The entire system will then be evaluated in extensive tests. The most important aspects besides the reliable detection of landmines and other ERW are the usability of the system and its maneuverability. The knowledge gained should be documented directly on site and used to improve the system. Thanks to the modular design and the exclusive use of industry-available products in the modular mobile platform, changes can still be made to fundamental parts of the system. Final tests will then be carried out on the finished system in the presence of the end users. All of these tests will take place under different boundary conditions (e.g. temperature, visibility, weather) and in different terrains. For test purposes, the mine replicas are used under conditions that comply with international guidelines for comparable testing of mine detection systems.

Activities and methodologies
Integration of all components to one functioning system using the predefined interfaces.
Testing of functionality and interoperability of the components.
Collection of additional data for the further refinement of the detection algorithms.
Design and function enhancements through system adaptations between the single components.
Presentation of the system to the end users and final testing under realistic conditions using landmine mock ups and debris placed and buried in different terrains and under different conditions.

Risks and Mitigation:
Risk: Components may face challenges in integration due to compatibility issues.
Mitigation: Regular communication with the project team and stakeholders will help identify and address potential compatibility issues during earlier project phases.
Risk: Hardware Issues -Functionality testing may reveal hardware limitations or malfunctions.
Mitigation: Conduct comprehensive pre-testing of individual hardware components to identify any existing issues before

integration. Address and rectify these issues before moving to functionality testing.
Risk: User Acceptance- End users may have expectations that the system fails to meet.
Mitigation: Involve end users in the development process from the early stages to gather their input and expectations. Conduct regular user feedback sessions to ensure ongoing alignment with user needs.

Milestones and Deliverables:
M3: Fully Assembled and integrated mine detection system (Month 19)
D1-WP5: The fully assembled mine detection system incorporating two mine detection systems and a marking mechanism mounted and interfaced with a remotely operated mobile platform (Month 19)
M4: Completion of the integration, testing and enhancement process with the involvement of the end users.
D2-WP5: The optimized and functioning mine detection system.

Sustainability and role of end-user(s)

If successful, our project, "Modular Remotely Operated Mine Detection System", will transition into a phase of implementation and real-world application, guided significantly by the involvement of our end-user, the Interregional Centre humanitarian demining and rapid response of the State Emergency Service of Ukraine. Their commitment to the project extends beyond interest; they will actively participate in monitoring progress, assessing relevance, and providing valuable advice based on their practical experience in demining operations.
Post-Project Implementation
Upon project completion, the Modular Remotely Operated Mine Detection System will be introduced to the Interregional Centre humanitarian demining and rapid response of the State Emergency Service of Ukraine. The system is designed for operational use in real condition, enabling professional sappers to conduct mine detection remotely, thereby enhancing safety and efficiency. The end-users will play a critical role in field-testing the system, offering feedback for further refinement.
Next Steps
The immediate steps post-development involve testing with the Interregional Centre humanitarian demining and rapid response of the State Emergency Service of Ukraine, ensuring that the system meets the real-world demands of mine detection. Their insights and hands-on experience will guide necessary adjustments, tailoring the system for optimal performance in varied conditions.
End-User Guidance and Long-Term Adoption
The Interregional Centre humanitarian demining and rapid response of the State Emergency Service of Ukraine sappers, currently engaged in mine detection, will provide continuous consultation throughout the project. This collaboration ensures that the system is not only technically sound but also practical and user-friendly. Post-project, our goal is to fully equip and train their personnel, ensuring the system's long-term adoption and sustained use in their regular operations. This collaboration model exemplifies a sustainable approach, where the end-user's direct involvement ensures that the project results in a practical, field-ready solution, aligning closely with the actual needs and conditions of humanitarian demining.

Risks and mitigation strategies

	Risk description	Likelihood (High, Medium, Low)	Impact (High, Medium, Low)	Mitigating action
1	Delays in project timelines due to unforeseen technical challenges	High	Medium	Implement a proactive project management approach with contingency planning, and regularly update stakeholders on progress.

2	Inadequate funding or budget overruns	Low	Medium	Maintain a clear and detailed budget, seek additional funding sources, and implement cost control measures.
3	Loss of key project participants	Medium	High	Establish robust contingency plans, including identifying potential replacements and ensuring knowledge transfer, while fostering a collaborative environment that can accommodate changes in team composition.
4	Mine Detection System does not fulfill functionality	Low	High	Conceptualization of multiple approaches for mine detection, change of concept, if chosen concept fails
5	Mine Marking System does not achieve functionality	Low	Medium	Consideration of different approaches for Mine Marking, Virtual/Digital Marking of detected mines via GPS, odometry or other positioning system

Communication Plan

> The communication plan is divided into three areas: communication within the project among the project partners, communication with the scientific community and communication with the general public and society.
> Communication among the project partners will mainly take place in digital form. To ensure coordinated project implementation, there will be regular meetings (jour fixe), which will be held via video conference. The latest results and findings will be shared so that there is always a uniform level of knowledge among the project partners. In addition, physical exchanges between the project partners are also planned during the project period. Depending on the respective situation in Ukraine, bilateral exchanges are planned in principle. This means that both scientists from Ukraine will conduct research in Germany together with the project partners and German scientists will conduct research in Kyiv, if this is possible. These exchanges are planned in the second half of the project in order to carry out the integration of the two subsystems Mine Detection System and Mobile Modular Platform, for the joint development of the Mine Marking System and for the final integration, evaluation and demonstration.
> For communication with the scientific community, the project results are regularly published in established formats (conferences, journals, magazine articles). In particular, the presentation and discussion of results at relevant specialist

conferences continues to be a direct and discourse-intensive form of communication, from which the project can only benefit.
Communication with the public will take place both via digital media (YouTube, institute website, etc.) and via the public relations work of the partner universities. Both project partners will regularly produce videos in which the current status of the project is explained at a generally understandable level. These videos will be shared via the existing YouTube channel of the Institute of Assembly Technology and Industrial Robotics and the channel form Igor Sikorsky Kyiv Polytechnic Institute such as KPImedia, IEE MEDIA, the websites of the universities and other social media sites. We are planning to get an assistant from the university's publishing department to create high quality content.
At the University of Hanover, already established publicity-generating events like the “Nacht, die Wissen schafft” (Night of Science, open doors) will be used to spread awareness of the project and the underlying problematic of demining. And at the Igor Sikorsky Kyiv Polytechnic Institute we are also planning to present the project at open doors events.

Criteria for success

	Criterion	Relative weight (in %)
1	Completion of the project within the allocated budget and timeline	15
2	Successful testing and validation of mine detection system (module)	20
3	Successful testing and validation of mobile modular platform (module)	20
4	Tested and validated Design for Mine Marking System	10
5	Successful testing and validation of fully integrated Modular Remotely Operated Mine Detection System	25
6	Publication of research findings during the project running time	10
	Total	100

Related Projects / Duplication

In the field of demining, numerous innovative efforts are underway, ranging from advanced robotics to groundbreaking research. Our proposal for the "Modular Remotely Operated Mine Detection System" exists within this dynamic landscape. To ensure our project's distinctiveness and avoid duplication, we have reviewed related initiatives, categorized into three main groups:
1. Advanced Robotics and Autonomous Vehicles:
This category includes projects that leverage robotics and autonomous systems for demining and related tasks. Projects like the TALON Tracked Military Robot [1], Digital Vanguard-S ROV [2], and Bomb-detecting Husky [3] represent the forefront of using autonomous vehicles in challenging environments. Similarly, aunav.NEO HD [4] and Minerva [5] focus on robotic solutions for demining and area clearance. While these projects illustrate the technological advancements in the field, our

proposal distinguishes itself through its unique integration of invasive and non-invasive detection methods within a modular framework and the strong focus on cost efficiency for widespread use in Ukraine.

2. Innovative Demining Solutions:

Innovative approaches like the Mine Kafon Airborne Demining System [6] and Demine Robotics [7] showcase the application of novel technologies in demining. The findmine initiative and the R-Bot UGV [8] further contribute to this landscape with their focus on landmine detection and clearance. Our project complements these solutions by offering a system that not only detects mines but also marks them efficiently, adding an essential layer to the demining process.

3. Research and Development in Demining:

Research-oriented projects such as the Landmines Detection Using Low-Cost Multisensory Mobile Robot [9], and the Mine Hunter Vehicle (MHV) [10] demonstrate a commitment to evolving demining technologies. Our project aligns with these research efforts, particularly in its application of a multidisciplinary approach combining mechanical, electronic, and potentially AI-driven techniques.

Our Proposal's Uniqueness:

While there is some overlap in the broader themes of robotics and technology application, our proposal stands out in its approach to combining different detection methods within a single, adaptable system. We aim to make a solution that will be safe to use and practical as a field-applicable system. Our focus on modularity, cost-effectiveness, and adaptability differentiates our project, ensuring it adds value to the field without duplicating existing efforts. Our system will be specially tailored to the needs of humanitarian demining in Ukraine by being easy to transport, set up, use and maintain through its modularity and the use of interchangeable commercially available components and standard interfaces.

[1] TALON Tracked Military Robot https://www.army-technology.com/projects/talon-tracked-military-robot/?cf-view
[2] Digital Vanguard-S ROV https://www.scopex.fr/en/products/digital-vanguard-low-profile-robot/
[3] Bomb-detecting Husky to remove killer landmines https://clearpathrobotics.com/coimbra-autonomous-demining-husky/
[4] aunav.NEO HD https://aunav.com/product/aunav-neo/
[5] Minerva https://www.idscorporation.com/pf/minerva/
[6] Mine Kafon Airborne Demining System https://minekafon.org/
[7] Demining Robots http://www.natospsdeminingrobots.com/
[8] R-Bot UGV https://www.gichd.org/publications-resources/equipment-catalogue/r-bot-ugv-332/#overview
[9] Landmines Detection Using Low-Cost Multisensory Mobile Robot https://www.researchgate.net/publication/288749281_Landmines_Detection_Using_Low-Cost_Multisensory_Mobile_Robot
[10] Mine Hunter Vehicle (MHV) Development of a Mine Detection Robot Mine Hunter Vehicle (MHV), Controlled Metal Detector and Multi-functional Hydraulic Manipulator

List of abbreviations

WP - Work package
MMP - Mobile Modular Platform
MMS - Mine Marking System
MDS -Mine Detection System
UXO - unexploded ordnance
ERW - explosive remnants of war
IED - improvised explosive devices
ROV - remotely operated vehicle
SPS - Science for Peace and Security
MYP - Multi-Year Project

If needed, please add in the box below any picture or table relevant to the project plan

Schedule

Project duration in months 24

Project schedule

PDF	MRO_Schedule.pdf (92 KiB download)

Milestones overview

	Event	Description	Expected number of months after kick-off meeting (e.g. 0 for Kick-off, 6 for Milestone1..)
1	Kick-off	Project kick-off meeting	0
2	Milestone 1 - REQUIRED	First Technical and Financial Reports	6
3	Milestone 2 - REQUIRED	Second Financial and Technical Reports	15
4	Milestone 3 - REQUIRED	Third Financial and Technical Reports	19
5	Milestone 4 - OPTIONAL	Fourth Financial and Technical Reports	0
6	Final Report - REQUIRED	Final Financial and Technical Reports	24

Budget

SPS MYP Detailed Budget Excel Workbook

XLSX	MRO_SPS_MYP_Detailed_Budg... (304 KiB download)

Budget summary by item - NATO SPS funding requested (in EUR)

Budget category	Milestone 1	Milestone 2	Milestone 3	Milestone 4 - OPTIONAL	Final milestone
	Total M1 €135,775.00	Total M2 €66,115.00	Total M3 €32,750.00	Total M4	Total MF €30,565.00

1	Equipment	€77,300.00	€13,600.00	€400.00	0	0
2	Training	0	0	0	0	0
3	Communication and Publications	€1,500.00	€1,500.00	€2,000.00	0	€4,500.00
4	Travel	€1,600.00	€5,600.00	€10,600.00	0	€4,500.00
5	Consumables	€30,100.00	€3,000.00	€1,400.00	0	0
6	Other	0	€2,000.00	0	0	0
7	Stipends	€5,400.00	€10,600.00	€5,100.00	0	€5,000.00
8	Co-financing of personnel	€19,875.00	€29,815.00	€13,250.00	0	€16,565.00
		Total M1 €135,775.00	Total M2 €66,115.00	Total M3 €32,750.00	Total M4	Total MF €30,565.00

Project Budget - Funding requested from NATO SPS in EUR €265,205.00

Equipment

> Major equipment:
>
> **1. Industrial components for electrical drives 12000€**
> Equipment includes power converters, electric motors, sensors, actuators, power sources, controllers, software for programming and others. This equipment is intended to provide activity number three in WP2.1 (creation of laboratory set-up for primary investigations of critical points). Some components also can be used in a final version of the mine detection system.
> **2. Altium Designer (schematic and PCB development) 11000€**
> Altium Designer is a CAD software for schematic and printed circuit board development. The software will be crucial for WP2.1 (hardware development of combined electrical drive and control system)..
> **3. Matlab, Simulink, Toolboxes (Control algorithm simulation and testing) 5500€**
> Matlab and Matlab Simulink is the worldwide standard software for simulation. Simulations provide performance investigation and possible problem detection in the system design stage. As far as the mine detection unit is a complex dynamic system with several drives - simulations are a mandatory tool. The design procedure of the control system for electrical drives also requires intensive simulation. Signal processing and curve fitting toolboxes of Matlab are necessary in this project for poking process analysis.
> **4. Complementary Mechanism detection component 4000€**
> This advanced piece of equipment is pivotal for enhancing precision and efficiency. The component will be equipped with sophisticated sensor technology its integration will significantly improve the overall effectiveness of the mine detection and will help to reduce false positive signals from the prodding detection system, thereby increasing the safety and speed of demining operations.

Training

> -

Travel

> Travelling to project meetings and at the beginning of the work for two participants from Ukraine to Germany.
> To travel up to four weeks for one person from Ukraine to Germany for system components integration.
> Travel from Germany to Ukraine for final testing and validation of complete system 4 weeks stay (if possible).
> Also travel to national and international conferences after 15 months of project, 19 months and the end of the project.

Co-financing of personnel

> In the co-financing plan seven researchers are included.
> This will include Co-Directors from NATO country Project Director (NPD) Annika Raatz with 5%, Partner country Project Director (PPD) Stefan Zaichenko with 25% and local manager from Igor Sikorsky Kyiv Polytechnic Institute Oksana Vovk with 15%.
> And 4 researchers who will have 25%: Tobias Recker from Institute of Assembly Technology and Robotics and Sergiy Peresad, Serhii Kovbasa, Yevhen Nikonenko from Igor Sikorsky Kyiv Polytechnic Institute. The participant characteristic is written below.
>
> **Tobias Recker** has been a researcher at the Institute of Assembly Technology and Robotics for several years and has extensive expertise in the areas of mobile robotics, kinematics and control. He is currently researching methods for formation control and automated path planning for multiple non-holonomic mobile robotic platforms. Mr. Recker also successfully designed and built multiple mobile robotic platforms in the past and oversaw the manufacturing of four new platforms with a net worth of 600.000 €. In Conclusion, Mr. Recker is ideally qualified and experienced to carry out the challenging work program.
> **Sergiy Peresad** received the Diploma of electrical engineering from the Donetsk Polytechnic Institute, Donetsk, Ukraine, and the Candidate of Technical Sciences degree and Doctor of Sciences in control and automation from the Kiev Polytechnic Institute, Kiev, Ukraine, in 1983 and 2007. Since 1977, he has been with the National technical university of Ukraine "Igor Sikorsky Kyiv polytechnic institute", where he is currently a Professor of control and automation of the department of Electromechanical Systems Automation and Electrical Drives. He has been a Visiting Professor with the University of Illinois, Urbana, USA, University of Rome Tor Vergata, Rome, Italy, and University of Bologna, Bologna, Italy. He is the author of more than 300 scientific publications and a co-author of the volumes: Theory and Control of Electrical Drives and Control of Electromechanical Systems and three monographs. During 2002 – 2008 he served as an Associate Editor of the IEEE Transactions on control systems technology. His research interests include nonlinear and adaptive control of electromechanical systems based on ac motors, control of power converters.
> **Serhii Kovbasa** received the Diploma of electromechanical engineering from National technical university of Ukraine "Igor Sikorsky Kyiv polytechnic institute" in 1999, Ph.D. degree in electrical engineering in 2004 and Doctor of science degree in electrical engineering in 2020. In 2002 he became an Assistant Professor in the Department of electromechanical systems automation and electrical drives. Since 2008, he became an Associate Professor and from 2022 he is a chef of the same department. He was also a Visiting Professor in THM, Germany. IEEE member, has over 25 years of theoretical and practical experience in the field of research and development of control systems for electrical drives and power electronics. His field of interests cover control algorithm design, digital signal processing, control systems hardware and software development, implementation and experimental verification.
> **Yevhen Nikonenko** received the B.S., M.S. (both with Honors) and Ph.D. degrees in electrical engineering and automation from National technical university of Ukraine "Igor Sikorsky Kyiv polytechnic institute" in 2017, 2019 and 2023. He is currently an Assistant Professor with the department of Electromechanical Systems Automation and Electrical Drives. He was also a Visiting Ph.D. Student with THM, Germany, University of Warwick, UK. His main research interests include nonlinear and adaptive control of electric drives, power converters and active hybrid energy storage systems for electric vehicles.

Non-NATO funding

At the Institute of Assembly Technology and Robotics, the researcher Tobias Recker will partially be financed by core funding of the federal state of Lower Saxony.
The international mobility program Erasmus+ will cover exchange students who will work on the project.
And DAAD scholarships will allow research from Ukraine to work in the German institution for system modular integration.

Budget summary by Item - Non-NATO funding contribution (in EUR)

	Budget Category	Amount
1	Salaries	€39,905.00
2	Equipment	0
3	Other	0
	Total Overall Amount	€39,905.00

How do you want to share the financial rules of the NPD's Institution? Link to a website

Financial Rules https://www.uni-hannover.de/en/studium/finanzierung-foerderung

How did you learn about SPS? Word of mouth

From whom? University colleague

SPS MYP Acceptance of Funds

PDF MRO_SPS_MYP_Acceptance of... (150 KiB download)

SPS MYP Agreement for Joint Research

PDF MRO_SPS_MYP_Agreement for... (827 KiB download)

Brief overview of participating institutions

PDF MRO_Brief_overview_of_par... (11 KiB download)

Log in to natosps.grantplatform.com to see complete application attachments.

PDF

Name of the end user

The Interregional Centre humanitarian demining and rapid response of the State Emergency Service of Ukraine

MRO_End-user_... 3.4 MiB

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Short description of the attachment

Figure 1 Concept of the prodding mechanism and modular mobile platform

MRO_Figure 1 C... 76 KiB

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MRO_Work plan ... 404 KiB