A semi-autonomous driverless geophysical survey system for efficient large-scale high-resolution archaeological prospection

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Abstract
This research and development project aims to evaluate the feasibility of conducting large-scale autonomous ground penetrating radar (GPR) surveys. An electric autonomous implement carrier was used to integrate a 22-channel GPR array. This innovative approach shows promise for advancing GPR survey capabilities in the future.

Keywords
autonomous prospection; efficiency; ground penetrating radar; 3D subsurface mapping

Introduction

Buried archaeological remains constitute our common invaluable cultural heritage. Industrial farming, erosion, construction, and infrastructure development threaten this heritage on a massive scale. Near-surface geophysical prospection methods are well suited to search for archaeological remains in open fields. Ground penetrating radar (GPR) measurements, magnetometry, or electromagnetic induction surveys make it possible to search for, map, and document structures hidden in the subsurface. Over the past decade, substantial advancements have been made concerning geophysical archaeological prospection methods by introducing efficient motorized multi-channel magnetometer and GPR array systems in combination with precise data positioning solutions into archaeological research and rescue archaeology (Trinks et al. 2018). The exemplary application of the developed systems at selected archaeological sites throughout Europe has resulted in numerous outstanding archaeological discoveries.

The application of large-scale geophysical surveys for archaeological purposes has advanced even further in Norway. Here, motorised large-scale GPR surveying has become an important tool for archaeological mapping in advance of large infrastructure development projects, with survey areas often exceeding 1 km^2 for individual projects (Nau et al. 2017). Under Norwegian geological and environmental conditions, GPR has shown significant advantages over other, often faster, and more affordable geophysical prospection methods, and has thus become the preferred method. However, considering the huge survey areas affected by infrastructure development projects, even motorised multi-channel GPR systems with a potential daily coverage rate of up to 5 ha remain time-consuming for the operator in the field.

The next logical step for further development and substantial improvement of this successful approach is the setup of semi-autonomous driverless survey systems, permitting even greater fieldwork efficiency, but foremost increased data quality and measurement accuracy through controlled, ultra-dense spatial sampling.

Fig. 1: Computer rendering of the AutoAgri ICS20E implement carrier to be used in the presented project. The MIRA HDR system will be mounted centrally between the wheels.

Automation of GPR surveys

Several autonomous or semi-autonomous geophysical survey systems have been presented over the past years. The development of unmanned aerial vehicles (UAV) equipped with geophysical sensors has advanced the most in the field of archaeological geophysics (Linck 2019; Schmidt et al. 2020), but also small autonomous unmanned ground vehicles equipped with a GPR system have been presented recently (Gibb et al. 2018; Verdonck 2021). Such systems have shown their potential to successfully map archaeological structures below the ground. However, an insufficient spatial resolution and a rather limited survey speed hinder their application within large survey projects.

The presented project aims to overcome these shortcomings and develop a semi-autonomous multichannel GPR system allowing for the efficient, large-scale mapping of arable land. Semi-autonomous in this context refers to a self-propelled system that, after being programmed or set (in terms of line spacing, the main direction of travel, speed), travels within a defined outline polygon, which may contain obstacles, following predominantly parallel tracks, stopping only in the case of exceptional occurrences (e.g. the appearance of moving or unexpected obstacles, failure of GPR data collection, loss of contact with the operator) and then awaits interaction from a nearby operator.

The planned system consists of an innovative autonomous implement carrier (ICS20E, AutoAgri) and the latest generation of a multichannel GPR (MIRA HDR, MALÅ / Guideline Geo). The implement carrier is a recently developed, electrical-powered, driverless vehicle intended mainly for agricultural purposes (Fig. 1). Integrated positioning and navigation systems, such as a dual-head RTK-GSNS and an inertial measurement unit as well as sensors for obstacle detection, allow for autonomous, highly accurate, and safe navigation and operation. The MIRA HDR system provides 22 individual GPR channels with a cross-line sampling distance of 6.5 cm and a swath-width of 148 cm. The HDR technology will allow for an increased penetration depth with a significant reduction of noise and higher survey speed.

The full integration of both components is the main aim of the project. Hardware integration will be solved by an adapted antenna carrier frame mounted to the 3-point hitch on the vehicle, while the power for the GPR system will be provided from the main vehicle battery. A battery

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capacity of 60 kWh should allow for 10-12 hours of continuous operation and data collection. A communication channel between the individual computers of the vehicle and the GPR will be set up, allowing for two-way communication between the systems, the channelling of position data and sharing of the internet connection. A custom-made software solution will function as the interface between the vehicle and the GPR unit, enabling the vehicle software to trigger the start and stop of GPR data acquisition based on its position within the survey area. Control functions will be implemented to check for the validity of incoming data and potential errors or system failures. An onboard Wi-Fi and 4G communications module as well as onboard cameras will at any time allow the operator to remotely access the system for manual inspection. Individually controllable wheels on the implement carrier allow for optimised survey patterns, with navigation accuracy in the range of 1–2 cm permitting for efficient and optimised GPR data coverage. Several iterative rounds of lab and field-testing are planned to optimise the system.

Outlook

The anticipated developments and improvements will lead to superior high-resolution subsurface images and thus more reliable archaeological data interpretations. The increased efficiency in data acquisition will permit the investigation of larger areas, for the benefit of archaeological scientists, cultural heritage managers, and society at large. The highly interdisciplinary project involves the fields of applied geophysics, robotics, geomatics, and archaeology. Close parallels can be seen regarding the latest developments in agricultural engineering and precision farming.

The project is partially funded by *Innovation Norway*, with substantial in-kind contributions made by the Norwegian Institute for Cultural Heritage Research (NIKU) and AutoAgri. Funding was secured in August 2022 and the project was started in September 2022. The production of the implement carrier and integration of the MIRA HDR array will be finished by the end of 2022. Subsequent development of the necessary software interface and lab testing of the system is planned for early 2023. The fully operational system is expected to be ready by mid-2023. We intend to present an overview of the ongoing development and the first results from field testing at the ICAP 2023.

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