

A LOW COST, MODULAR ROBOTICS TOOL CARRIER FOR PRECISION AGRICULTURE RESEARCH

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ABSTRACT

Current research within agricultural crop production focus on using autonomous robot technology to optimize the production efficiency, enhance sustainability and minimize tedious, monotonous and wearing tasks. But progress is slow partly because of the lack of flexible and low cost robotic platforms suitable for research within precision agriculture.

This paper presents Armadillo, a \$50k field robotic tool carrier with a modular design which makes the robot configurable and adaptable to a wide range of precision agriculture research projects. Armadillo weighs around 425 kg and consists of two 18x80 cm footprint track modules each with an integrated 3.5 kW electric motor, gear and motor controller. The track modules are mounted on the side of an exchangeable tool platform which allows an adjustable width and

clearing height of the robot. The 48 V lithium power pack lasts 10 hours of operation.

Armadillos industrial grade Linux based FroboBox computer runs the FroboMind architecture which is based on the Robot Operating System (ROS) by Willow Garage. FroboMind is a novel generic architecture that has been implemented and successfully tested on different field robots. It has been developed for research within precision agriculture and the design is highly modular in order to optimize with respect to extensibility, scalability, short development time and code reuse. All FroboMind software components used for the Armadillo robot are released as open-source.

A prototype of Armadillo has been developed and tested as part of ongoing research projects within sustainable and organic weeding in row crops and orchards. Based on the experiences obtained, the first public version of Armadillo has been constructed and delivered to the University of Hohenheim, Germany. Current activities focus on further improving the Armadillo hardware and software and application to new research projects.

Keywords: Field Robot, Precision Agriculture, FroboMind, ROS

INTRODUCTION

Research in agricultural field robots for crop production has intensified significantly in recent years. Farmers are experiencing an increasingly competitive market and it has become much harder to find qualified and reliable labor at reasonable wages. At the same time there are growing concerns about the environmental impacts of crop production among politicians and consumers (Godfray *et al.*, 2010) (Nature, 2010) who demand more sustainable production methods and more organic products.

Current research focus on using autonomous robots to optimize the production efficiency (Pedersen *et al.*, 2005) (Blackmore *et al.*, 2005), enhance sustainability (Chaui and Sørensen, 2008) (Sørensen *et al.*, 2005) and minimize tedious, monotonous and wearing tasks. But many research projects with a great potential reaches only the stage of testing using computer simulations, since the task of performing practical tests in the field using a robot platform is very resource demanding.

For indoor applications, there are generic robotic platforms available like the Personal Robot 2 (PR2) developed by Willow Garage, allowing researchers to carry out practical experiments. But there is apparently no equivalent product in field robotics. A number of field robots have been developed by various research groups and companies during the past decades like the Autonomous Mechanisation System (AMS) (Blackmore *et al.*, 2004), HortiBot (Jørgensen *et al.*, 2007) Weeding Robot (Bakker *et al.*, 2010) and BoniRob (Ruckelshausen *et al.*, 2009). However, they are typically built with a specific project or purpose in mind and their design limits the possibility of using them for other purposes.

It is hypothesized that introducing a generic field robot platform suitable for research within biological production with a high degree of modularity and flexibility will significantly reduce the time and resources needed for performing practical development and research experiments in the field.

The aim of this project is to have a prototype of a generic and modular field robot platform with a flexible interface to allow easy implementation in various agricultural research projects. The robot platform and related documentation will be made available to interested research groups and other stakeholders. The project is aiming at a price tag of \$50k for the robot platform which makes the robot easily obtainable for many applications.

MATERIALS AND METHODS

Functional design

It turned out to be quite difficult to design a functional robot platform that can support various intelligent agricultural implements for monitoring and light manipulation tasks. During the project a list of requirements was drafted based on recommendations by researchers in this domain:

- Good driving abilities in rugged terrain as well as in cultivated land such as fields with row crops and orchards.
- Support for intelligent implements designed for data acquisition and light manipulation tasks.
- Configurable width and clearance height to allow application to various structured agricultural and horticultural environments.
- Minimized vibration while driving to improve the output from navigation- and implement sensors.
- Simple and modular design and construction to ease the task of repair as well as modifications and extensions of the robot.
- Low cost

Both wheels and tracks were considered for the propulsion and steering of the platform. Steered wheels allow precise control of the vehicle and have a low weight. They run smoothly over the terrain with limited skidding and thus make only little damage to the the soil. However four wheels are required due to platform stability, and full omni rotation (Jørgensen and Maagaard 2008) is thus required on all wheels in order to allow a flexible steering including turning the robot about its geometric center. This requires individual steering and propulsion of each wheel, and feedback from both the steering and propulsion are required as well. This is a technically complicated and expensive solution which fits poorly with the aim of this project. Instead a tracked solution was chosen for the robot. Tracks skid while turning and are therefore somewhat harder on the soil. But it is a simple and reliable solution and makes the robot very maneuverable in all kinds of terrain.

The three-point hitch for attaching implements to agricultural tractors, which have been widely used since 1926, were seriously considered for this project. But given the limited footprint and low weight of the platform this could create

balancing problems when using heavy or manipulating implements, and it would also limit the flexibility of the platform.

Instead a more modular design was chosen as depicted in Fig.1. The implement is carried by two identical (however mirrored) track modules. Each track module includes motor controller, electric motor and transmission, and is controlled by a robot computer integrated in the implement. Power for the track modules are supplied by the implement as well. This allows different power sources like a battery pack, electrical generator or even sustainable energy sources like fuel cells etc. depending on the requirements of the implement. The width between the tracks and clearance height are determined by the geometry of the implement which facilitates adaptation to many different tasks within biological production.

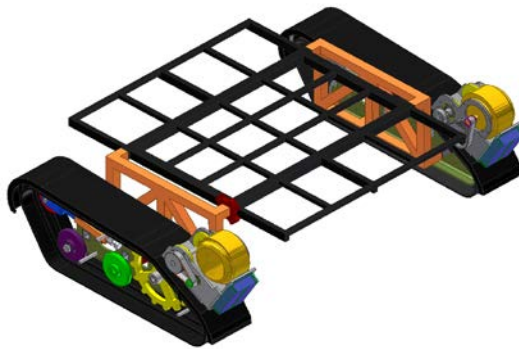


Fig. 1. Two track modules and an exchangeable implement module in between.

Robot computer

The purpose of the robot computer is to run the necessary software for interfacing to the robot platform and sensors, sensor information processing, mission planning and execution, navigation, implement control, user interface, network communication etc. A list of requirements for the robot computer was drafted:

- Rugged, waterproof and to the extent possible vibration proof casing.
- Provide common interfaces to sensors and actuators (RSxxx/USB/Ethernet /CAN)
- Provide a wireless cloud around the robot for remote monitoring, control and logging
- Optional internet uplink through a 3g modem

RESULTS

During this work two versions of the Armadillo robot were constructed and tested in the field. A FroboBox robot computer was constructed and the FroboMind architecture for field robot control was designed and implemented in ROS.

Armadillo

The first Armadillo robot prototype was built in the Spring 2011 as a joint project between The University of Southern Denmark, Aarhus University and the company Lynex.



Fig. 2. Left: The Armadillo frame, tracks, and motors assembled. Right: The Armadillo driving in a maize field.

The two track modules on the Armadillo depicted in Fig.2 have a footprint of 18x80 cm each. In this implement prototype configuration the robot width were 150 cm measured between the center of the two tracks.

Each track module is powered by a 3.5 kW brushless DC motor. With a 27:1 gear ratio, which gives a top speed of 7.4 km/h and an expected 25% loss in the powertrain. One track module can deliver 1 kN continuous thrust and up to 1.7 kN thrust in 30 second bursts.

The Armadillo carries an exchangeable 48V 100Ah battery back weighing 150 kg. Battery packs are based on four 12 Volt Absorption Glass Mat (AGM) technology sealed batteries supporting a 50% discharge. A worst case calculation gives the Armadillo minimum 40 minutes operating time at maximum continuous power. In normal operating conditions, where a vehicle with two track modules have to overcome a dynamic friction of 500N, an effective operating time of 2.6 hours can be expected. With additional battery packs ready and charged, the vehicle can be operational as long as desired. A battery pack can be fully recharged in 4.5 hours.

Armadillo Scout

The second Armadillo robot named Armadillo Scout was built in the Winter 2012 by the University of Southern Denmark and the company Lynex in collaboration with the University of Hohenheim.



Fig. 3. Image of the Armadillo Scout robot at Hohenheim University.

The most significant changes from Armadillo to Armadillo Scout is the housing, a redesign of the track modules and the new battery technology. The Armadillo Scout weighs around 425 kg in its full configuration depicted in Fig.3. The footprint and dimensions are the same as on the Armadillo.

In order to obtain a higher degree of modularity, the entire powertrain was mounted directly on the track module, and the transmission was placed closer to the propulsion wheel. With this design the width and height of the frame can easily be adapted to different operations.

The battery technology was changed from AGM to Lithium iron phosphate (LiFePO₄) battery (LFP) technology which lowers the total weight of the batteries with $\frac{1}{3}$ to approximately 100 kg. The capacity was increased with 60% from 100 Ah on the AGM to 160 Ah on the LFP. The total weight reduction on the robot when using LFP batteries is 50 kg. However lithium ion batteries are more expensive than AGM batteries of similar capacity and they require individual charging circuits. The LFP technology has some advantages compared to the widely used lithium cobalt oxide (LiCoO₂) technology. LiFePO₄ is non-toxic and cheaper than LiCoO₂, and LFP is less susceptible to overheating and fire.

The power consumption of the Armadillo Scout has been measured at a speed of 0.3 m/s in dry loose soil. When navigating the robot uses 520 W and when weeding mechanically it uses 625 W. The approximate operating time at this speed is 10 hours assuming 70% battery efficiency. The possibility of powering the Armadillo Scout with photovoltaic energy has been investigated and it was concluded that a feasible solution would be to use solar modules at a stationary charging station (Dühning 2012).

Besides FroboMind a second software framework called MobotWare, (Beck *et al.*, 2010) has been implemented on the Armadillo Scout (Griepentrog *et al.*, 2012). The implementation enables the Armadillo Scout to perform the same tasks as the the AMS robot.

FroboBox

A generic field robot computer platform named FroboBox was developed for the Armadillo. The current FroboBox version (Fig.4,5) is based on a VersaLogic Mamba Single Board Computer with an Advantech PCM3680 2-port CAN module attached to the PC/104 interface.

The computer is shielded from the environment in a rugged Ingress Protection (IP) 66 aluminium enclosure which also contains an automotive grade ATX supply and a wireless router with a 3g modem option.

The connectors for interfacing to sensors and actuators follow the the industrial connector standard M12 defined by IEC 61076-2-101. The current FroboBox base software installation is Ubuntu 11.10 (Oneiric), can4linux and ROS Fuerte.

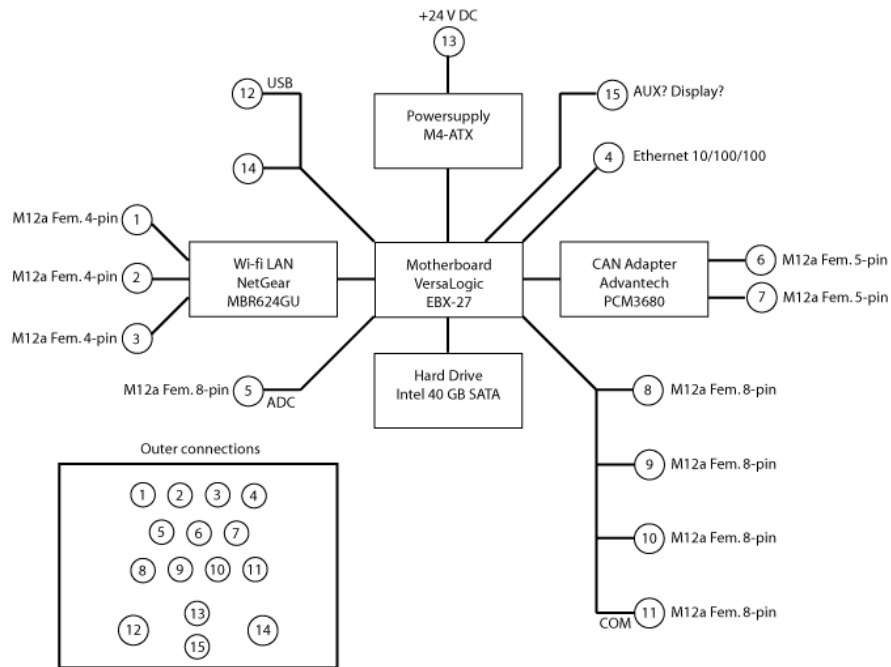


Fig. 4. Wire diagram of the FroboBox.



Fig. 5. The assembled FroboBox.

FroboMind

During the development of the Armadillo robot it became apparent that in order to provide true modularity and flexibility, a modular architecture for the robot software was needed as well, and FroboMind was therefore developed alongside the Armadillo robot.

FroboMind (Jensen *et al.*, 2012) is a conceptual architecture for a robot control system designed for field robotics research. The FroboMind architecture has been implemented in ROS (Robot Operating System), a meta-operating system developed by Willow Garage that provide libraries and tools to help software developers create robot applications (Quigley *et al.*, 2009).

The aim of FroboMind is to standardize robot software development among different field robotics research platforms and optimize the robot software in terms of:

- Modularity and code reuse in order to decrease the time spent on software development, debugging and testing.
- Extensibility and scalability, It must accommodate implementations from small student projects to advanced research.
- Support for intelligent implement control.

Royalty-free open standards and open-source software has been a paramount requirement for the FroboMind architecture as this enables free use and sharing of software among researchers and students as well as companies and other external partners working within the domain.

FroboMind is based on an intuitive decomposition of a simple decision making agent (Fig. 6). The robot perceives the surrounding environment through its sensors and feedback from the robot platform and implement systems, and combines the perception with shared and a' priori knowledge. The robot mission planner continuously monitors this accumulated knowledge as well as any user interaction, and selects on this basis the optimal behaviour which leads towards the fulfillment of the mission. The active behaviour continuously monitors the available knowledge and update action plans accordingly. Actions are then executed with respect to time and state.

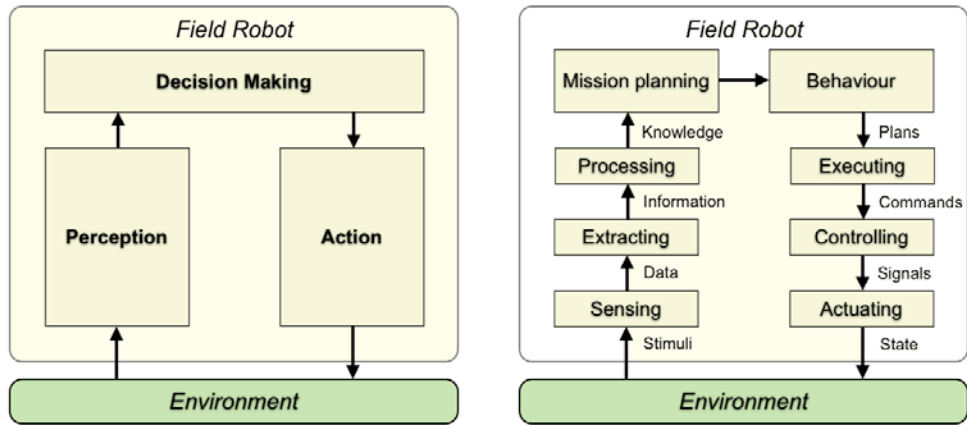


Fig. 6. Simple decision making agent and decomposition hereof.

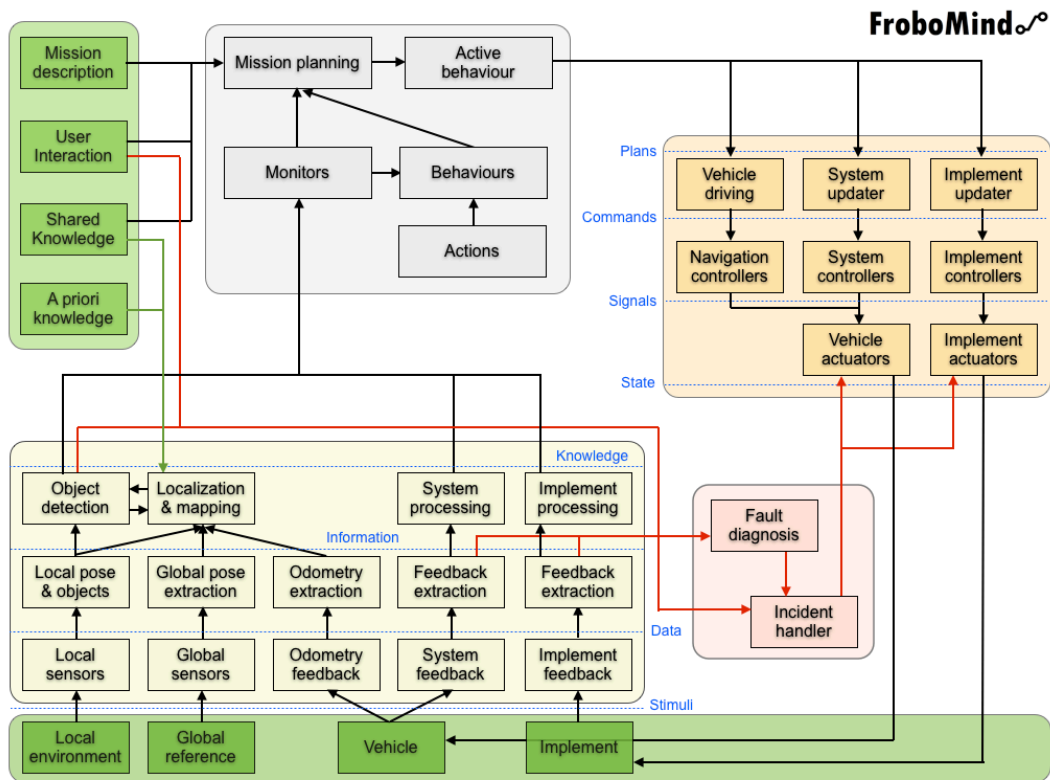


Fig. 7. FroboMind conceptual architecture.

The FroboMind conceptual architecture Fig. 7 represents an expansion of the decomposition indicated by the grouping of components in the perception, decision making and action layers as well as the data flow through the layers marked by the dashed lines.

In order not to clutter the overview it is assumed that any component has access to data accessible by its predecessor, and therefore multiple connections to successors are shown only when relevant to the understanding of the architecture. Data available for all components have not been included in the overview.

Internal fault diagnosis and incident handling are organized as a separate Incident layer to ensure maximum simplicity and clarity in these components and hence minimize potential software errors, which in turn ensures a high level of reliability.

ROS implementation

The implementation of the FroboMind architecture in ROS follows the structured division of ROS in stacks, packages and nodes. FroboMind is published as a single ROS stack, and the layers in the architecture are implemented as ROS packages each containing ROS nodes for the components within that layer. Below is a list of the packages:

Perception

fmSensors	Stimuli → Data
fmExtractors	Data → Information
fmProcessors	Information → Knowledge

Decision Making

fmMissions	Knowledge → Behaviour → Plans
fmBehaviours	Library of behaviours
fmMonitors	Library of monitors
fmActions	Library of actions

Action

fmExecuters	Plans → Commands
fmControllers	Commands → Signals
fmActuators	Signals → State

Abstraction layers and interfaces

fmIncident	Fault diagnosis and incident handling
fmCore	ROS
fmMsgs	ROS inter-node communication messages
fmCSP	Computer Support Packages
fmPSP	Platform Support Packages
fmKinematics	Vehicle kinematics
fmHMI	Human Machine Interface
fmSim	Simulation

Tests and applications

The Armadillo platforms have been exposed to a series of field experiments to test the design and the various components such as mechanical construction, transmission, power supply, the electrical system, robot computer and software

architecture. In addition the platforms have been utilized in different research projects:

- Armadillo has been utilized as a platform for autonomous navigation and collecting images of weed in a maize field (Fig. 8).
- Armadillo Scout is currently being used as autonomous platform for data collection and tree mapping in orchards (Jaeger-Hansen *et al.*, 2012) as well as 3d-mapping of a field using a laser range scanner.
- A mechanical weeder for the Armadillo Scout is currently being designed.
- The Armadillo platform is currently used in an innovation project focusing on the use of mobile robots for humanitarian demining (Jensen *et al.*, 2012)



Fig. 8. Armadillo collecting images of weed in a maize field at dusk

DISCUSSION

The practical tests of the Armadillo platforms in the field have given rise to various design considerations and issues which should be optimized during the further development:

- The powertrain on the Armadillo Scout is not properly protected against dirt and soil during driving in the field. On grassland this is not a major problem, but in dry loose soil and sand, the dirt can easily reach the chain, track drive and motor. An efficient protective shielding is therefore needed for the next prototype.
- The total weight has a great influence on the robot's maximum operating time and the weight should be minimized wherever possible.
- The Lithium ion battery technology was introduced on the Armadillo Scout primarily due to weight considerations. The experiences so far, however, shows that even though AGM technology will add significantly to the robot weight. AGM technology is a better solution in many applications due to simplicity and price.

CONCLUSION

This paper presents the initial results from the design and development of a generic and modular field robot platform for use in agricultural research projects. A prototype of the robot, the Armadillo, has been constructed, and the first performance tests have been carried out in the field while being utilized in research experiments. All FroboMind software components used for the Armadillo robot has been released as open-source for others to build upon.

Based on the Armadillo prototype, a new and improved Armadillo Scout was constructed in collaboration with the University of Hohenheim, Germany who is currently implementing the robot in their research projects.

There is still room for improvements with respect to mechanical reliability of the drivetrain and optimizing the modularity and flexibility, and the FroboMind architecture still need some work as well. But the preliminary field tests of the Armadillo prototypes have demonstrated that the overall design concept is an innovative and functional solution.

Current activities focus on further development of the Armadillo platform as well as application to other research projects. A third prototype is expected to be ready during the summer 2012, and a FroboMind scripting interface for high level mission tasks like navigation and implement control are currently being developed.

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