

Design and Preliminary Evaluation of FieldScout: A Modular Small-Scale Robot for Precision Management of Intercropping Systems

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Abstract. Intercropping fields require selective interventions within narrow cash-crop and service-crop arrangements, creating a need for customised robots that preserve beneficial vegetation while regulating crop competition. The objective of this study was to design and preliminarily evaluate a small-scale modular robot for precision operations in the Robotic Intercropping (RIC) project, with an architecture supporting later development towards swarm operation. FieldScout integrates a 3D-printed body, four encoder-equipped 24 V, 100 W hub motors, an industrial ESP32-S3 controller with isolated RS485, and a Jetson Nano computer with an STL27L two-dimensional LiDAR for navigation development. The control architecture separates local wheel actuation from network communication and navigation processing. A web interface provides manual driving, speed adjustment, status monitoring and diagnostic logs through an Internet-mediated command path. Local motion control incorporates bounded velocity commands, controlled reversals, command-expiry checks and latched fault handling. Analytical relationships link vehicle clearance and stopping response to crop protection, while simulation supports speed-limited row traversal and headland transitions using ground-truth target positions. Browser access supports the longer-term objective of farmer supervision from a mobile device while away from the field; live onboard video is identified as a necessary extension for visually informed remote driving. Preliminary evaluation examined mechanical functionality, field locomotion, embedded control and navigation-controller communication, complemented by analytical checks and CoppeliaSim controller development. The printed body remained functional during initial supervised field operation, the hub-wheel modules provided usable locomotion, and the control hardware supported these trials. Initial Jetson–ESP32 message exchange established a communication basis for navigation integration. These qualitative results demonstrate prototype integration feasibility under the encountered conditions. Quantified durability, communication reliability and localisation accuracy remain to be established, while SLAM and autonomous row following are under development. The resulting platform provides a configurable basis for investigating spatially selective service-crop management, with future work directed towards RTK-GNSS outdoor waypoint following, UWB indoor localisation, live-video supervision and coordinated multi-robot operation.

Keywords: agricultural robotics; intercropping; modular platform; LiDAR; web teleoperation; precision agriculture.

1 Introduction

Intercropping creates a spatially heterogeneous production environment in which different plant species are deliberately retained and managed together. Its benefits depend on species combinations, spatial arrangement and temporal complementarity (Li et al., 2020). This creates an engineering challenge: the intended management action must be spatially selective because vegetation between cash-crop rows may provide useful services while also competing for light, water and nutrients. Within the RIC project, crop arrangements and robotic operations are developed together to manage this balance (University of Copenhagen, 2025). A compact robot can support that approach when its footprint, sensing and intervention capabilities are matched to the crop system. The relevant design problem therefore extends from vehicle mobility to the interfaces through which observations, operator decisions and future tools can be coordinated. This study develops and preliminarily evaluates FieldScout as the mobile foundation for that workflow. The contribution comprises a modular mechanical platform, an embedded wheel-control layer, an accessible web interface and a separate computing path for LiDAR navigation. The evaluation addresses functional integration and early field use, while analytical clearance and timing relationships establish constraints for subsequent precision operation. The architecture is intended to support progressively greater autonomy and eventual fleet coordination after localisation, crop clearance and implement placement have been evaluated on an individual vehicle.

2 Agricultural requirements and platform concept

The target operation is selective management within intercropping systems, particularly the regulation of living mulch or service crops near cash-crop rows. The RIC task considered here concerns service-crop strips of approximately 25–30 cm, with interventions intended to reduce excessive above-ground biomass while retaining

a protective living cover. These dimensions define a task context, not a universal driving corridor or a measured clearance available to the present robot. A vehicle may need to travel beside a treated strip, straddle a suitable arrangement, or use an offset implement; the appropriate configuration depends on the complete plant and machine envelopes. The underlying agronomic decision is where, when and how strongly to intervene, because beneficial service crops can become competitors for light, water and nutrients. This co-design perspective (Ditzler and Driessen, 2022) supports a modular research vehicle on which mobility, sensing and intervention can be evaluated separately before they are combined into closed-loop crop management.

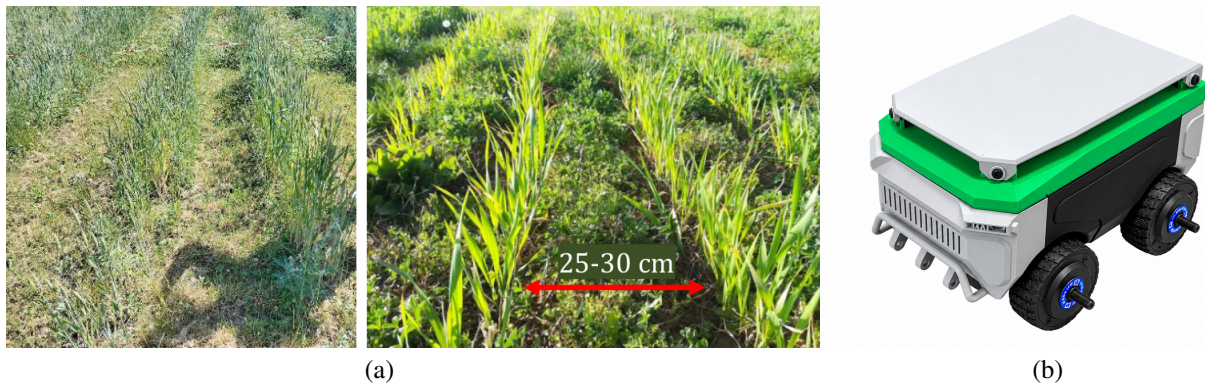


Figure 1: Robotic intercropping task context and FieldScout design: (a) representative intercropping conditions; (b) the FieldScout robot.

Small agricultural robots already have precedents in reconfigurable platforms and within-canopy phenotyping. MARS demonstrates the value of separating drive, frame, power, sensing and actuation modules (Xu and Li, 2022); TerraSentia provides an example of an ultra-compact 3D-printed robot developed with embedded control and agricultural sensing (Kayacan et al., 2018). More recent multi-season phenotyping work illustrates the level of agricultural validation that compact robots can eventually support (DeBruin et al., 2025). FieldScout combines a compact mobile base with accessible web operation and a separate interface for LiDAR navigation development. The research question is whether this mechanical and control architecture provides a functional basis for targeted intercropping operations and subsequent integration of precision tools. The staged development approach allows mobility and communication constraints to be identified before navigation and agronomic intervention are coupled. The platform concept places replaceable printed body elements around four hub-driven wheels and reserves attachment and electronics space for successive sensing and implement configurations. Figure 1 presents representative intercropping conditions in panel (a) alongside the FieldScout design rendering in panel (c), illustrating the agricultural context and the proposed platform configuration. Additive manufacturing permits rapid modification of mounting points and protective panels as crop arrangements, sensor placement and working tools evolve. However, stiffness, fastener retention, fatigue resistance and environmental durability require dedicated evaluation under representative operating conditions. Modularity is therefore expressed through accessible mechanical and electrical interfaces that support component replacement, reconfiguration and testing; standardised implement interchangeability and long-term outdoor durability remain subjects for further validation. The future agricultural workflow is to observe the strip, identify a management need, position the robot and tool, execute a bounded intervention, and retain a spatial record of the action. That sequence connects the robot to precision agriculture through farm-level decisions on service-crop suppression and the allocation of field operations. At the current stage, manual control supports inspection, repositioning and commissioning of the mobile base; autonomous agronomic decisions and tool actuation remain outside the reported evaluation. This distinction is consistent with co-design approaches that adapt robotics to diversified cropping systems instead of imposing the geometry and operating assumptions of monoculture machinery (Ditzler and Driessen, 2022).

3 Mechanical and electronic implementation

The mobility module comprises four ZLTECH 4-inch gearless BLDC hub motors, each rated at 24 V and 100 W and equipped with an encoder. Integrating the motor into the wheel reduces transmission components and facilitates a compact arrangement around replaceable printed body elements. The assembled prototype is shown in Figure 2. Independent wheel modules also permit mechanical replacement without redesigning the complete platform. The combined nominal motor rating is 400 W; usable payload, traction and operating time depend on the chassis, surface conditions and power system. The wheel product's nominal load specification consequently

does not define the vehicle's field payload.

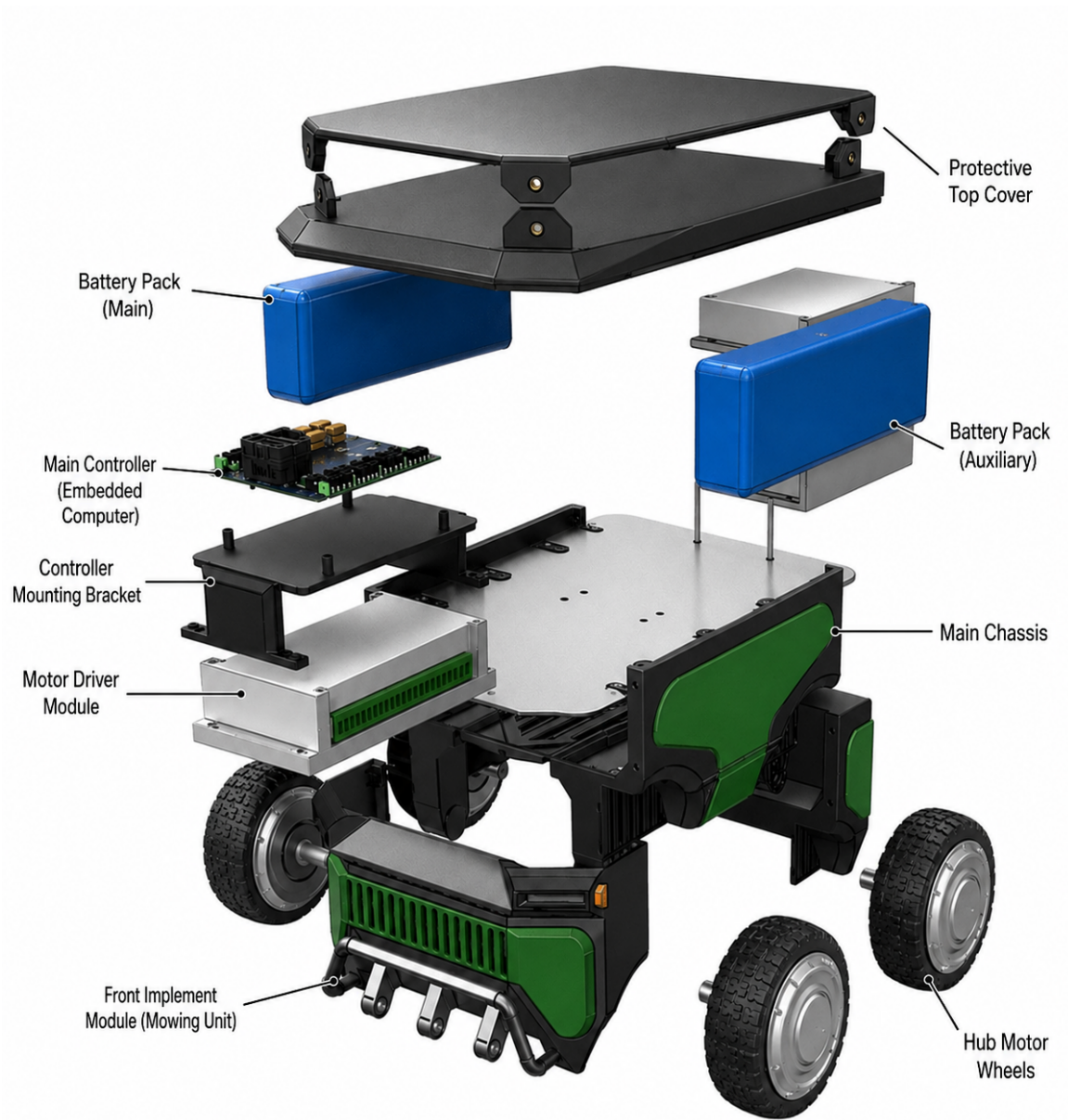


Figure 2: Assembled FieldScout prototype with four hub-driven wheels and printed body elements.



(a) Hub wheel



(b) ZLTECH servo drive



(c) ESP32-S3



(d) Jetson Nano Lite



(e) STL27L

Figure 3: Principal hardware components: (a) encoder hub wheel; (b) ZLTECH ZLAC8030L single-channel servo-drive module; (c) ESP32-S3 industrial controller; (d) Jetson Nano Lite development kit; (e) STL27L LiDAR.

Table 1: Platform hardware and subsystem functions.

Subsystem	Component or configuration	Function
Traction	Four ZLTECH 24 V, 100 W encoder hub wheels	Skid-steered locomotion
Drive interface	Four wheel channels; software assumes two dual-channel Modbus nodes	Velocity command distribution
Embedded control	Waveshare ESP32-S3-ETH-8DI-8RO	Web exchange and isolated RS485 motor control
Navigation computing	Original JETSON-NANO-LITE-DEV	LiDAR processing and navigation development
Laser sensing	STL27L, 360° planar LiDAR, UART	Environmental range measurement
Mechanical structure	Replaceable 3D-printed body elements	Enclosure and component mounting

The electronic components in Figure 3 are organised by function in Table 1. The ESP32-S3 board provides Wi-Fi, digital inputs, relay outputs and an isolated RS485 interface for local motor communication. Navigation processing is assigned to the original Jetson Nano Lite kit, supplied through a regulated 5 V branch, while the STL27L provides planar range data over UART. Separating these functions permits changes to perception software without replacing the motion controller. Inertial sensing is reserved as an extension for pose estimation; it is not included in the evaluated sensor configuration.

4 System architecture and power distribution

The architecture separates operator communication, local motion control and navigation processing (Figure 4). During manual operation, the browser exchanges commands with a hosted relay service, and the ESP32-S3 retrieves them through outbound HTTPS over Wi-Fi. Valid commands are converted to wheel targets and transmitted over the local Modbus RTU motor bus. Outbound polling permits the robot to communicate through conventional routed Internet connections without requiring an inbound connection to its controller. Local scheduling and command validation remain within the robot, so motor updates do not depend on the browser executing a continuous real-time control loop.

WEB MANUAL CONTROL

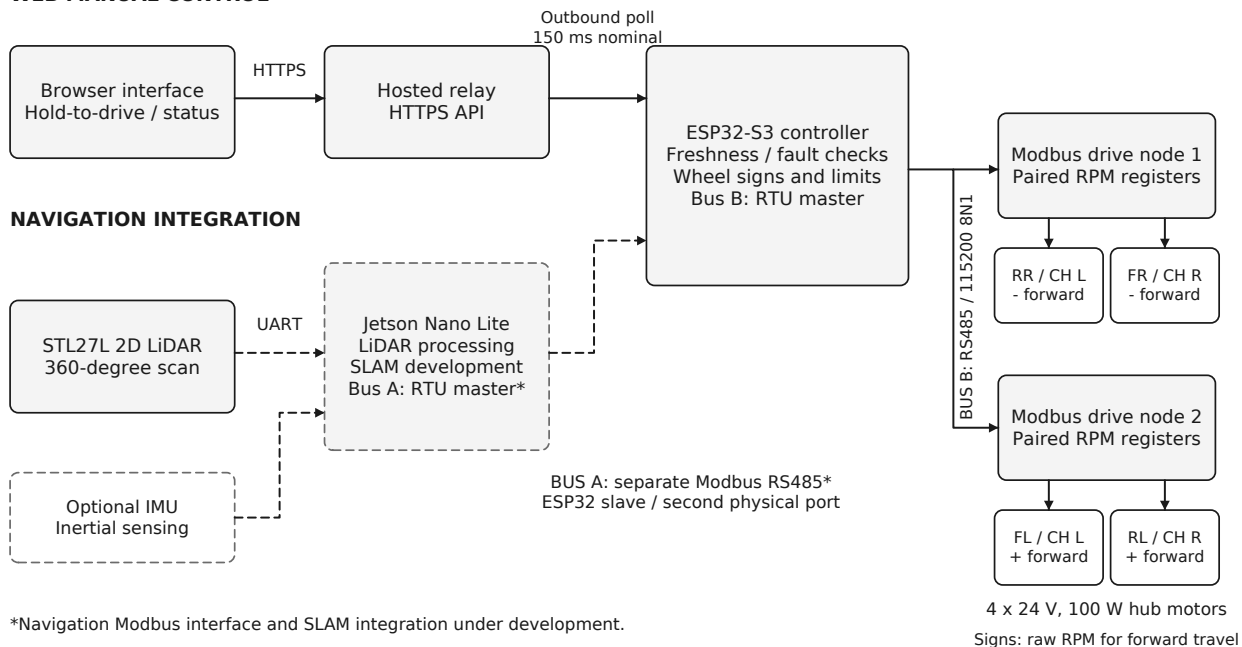


Figure 4: FieldScout control architecture. Solid paths denote the implemented web and motor-control interfaces; dashed paths denote navigation and sensing interfaces under development. Drive nodes represent the paired wheel-command register groups assumed by the control software.

The motor-control implementation assumes two dual-channel Modbus nodes, each addressed directly through paired signed RPM registers. The first node corresponds to the rear-right and front-right wheel commands; the second corresponds to the front-left and rear-left commands. Both wheels on each side receive a common velocity target, producing four-wheel skid steering. This command structure separates wheel mapping from higher-level motion requests and exposes a compact interface for manual and future autonomous operation. Diagnostic acknowledgement is handled locally, allowing a failed transaction to affect motion permission without requiring the network service to interpret motor-bus responses. Navigation is assigned to the Jetson Nano so that scan processing, pose estimation and planning can evolve independently of wheel control. The integration design uses a separate RS485 link between the Jetson and ESP32, with the ESP32 acting as slave on the navigation bus and master on the motor bus. This arrangement avoids competing masters on one bus and establishes a boundary at which motion requests, validity periods and operating modes can be checked. Preliminary controller-to-controller message exchange has been achieved, while the navigation register map and SLAM-to-motion integration remain under development. Manual and autonomous requests will require explicit authority selection at this boundary. Power distribution is based on a 24 V-class traction supply and independently regulated electronics. The supplementary power schematic defines the intended protected branches, including a regulated 5 V input for the original Jetson Nano. The protection design places isolation and overcurrent protection upstream of the drive branches and reserves a hardwired traction-disconnect path. Maintaining electronics power during traction isolation supports diagnosis and controlled recovery. Final protection settings depend on full-charge battery voltage, peak motor demand, regenerative energy and cable ratings; the schematic expresses the distribution concept rather than a certified stop circuit. This separation of traction energy from information processing is relevant to serviceability as well as later integration of autonomous control.

5 Web-based manual control and embedded execution

The browser interface provides hold-to-drive controls, keyboard operation, adjustable speed, connection indicators, application logs and a three-dimensional motion display (Figure 5). It supports commissioning, field inspection and supervised repositioning through a common interface on network-connected devices. The interface avoids a dedicated handheld controller and provides a basis for retaining the same operator workflow as autonomous functions are introduced. Its current feedback consists of command state and application information. The displayed pose and trail are derived from motion commands, so they support interpretation of requested movement rather than independent observation of vehicle position.

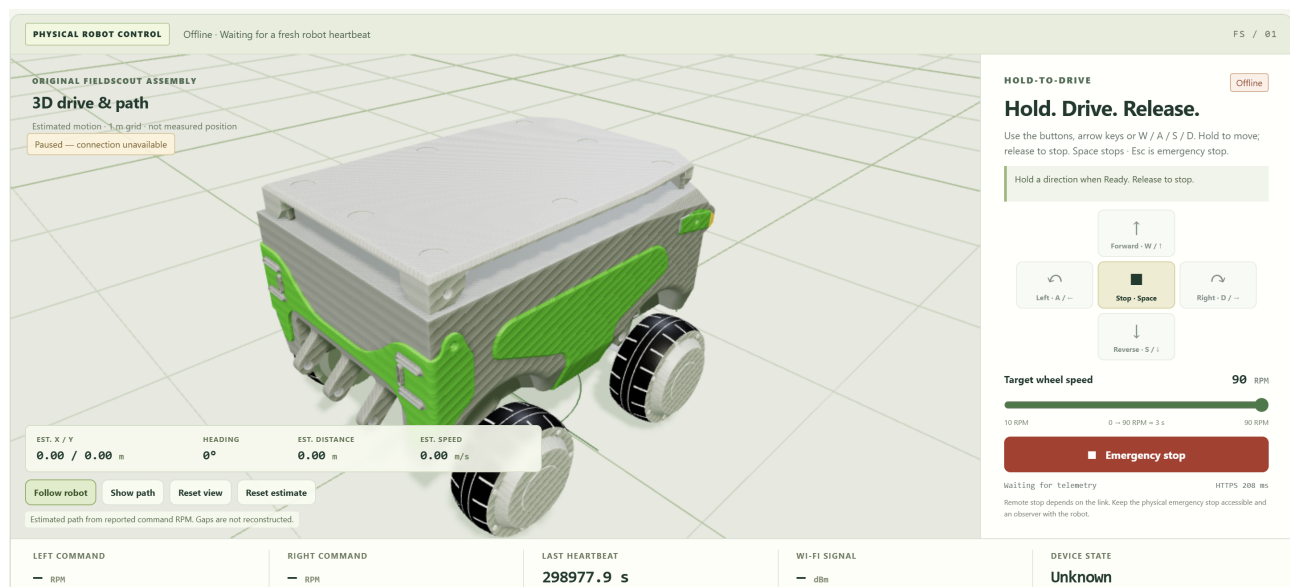


Figure 5: FieldScout web-based manual-control interface, showing driving controls, speed selection, status information, logs and the command-derived motion display. The interface is shown without an active robot connection.

Network handling and motor execution are separated in firmware through protected shared state. The nominal service-poll interval is 150 ms, while the local motor scheduler targets 40 ms updates. Unchanged targets are refreshed after a 250 ms threshold on the next motor-service cycle. These are scheduling settings, with realised timing dependent on network exchange and bus transactions. The motor bus operates at 115200 baud, 8N1, using Modbus function 0x10 to write paired signed 16-bit targets beginning at register 0x2088. Opposing

wheel orientations are accommodated by negative raw RPM for the right-side node and positive RPM for the left-side node during forward motion. Reply validation checks node identity, content and CRC. The recorded acknowledgement confirms command acceptance at the protocol level and does not constitute measured wheel-speed feedback. Motion commands are limited to 90 RPM. Normal software ramps limit acceleration and deceleration to 30 and 45 RPM s^{-1} , respectively; reversal first requests zero and applies a 300 ms dwell. Driver ramps are configured separately to 900 ms acceleration and 800 ms deceleration. Releasing the drive control requests zero without the normal software ramp. Command validation checks authorisation, sequence and age, caps received validity at 1000 ms, and counts HTTP transaction time against that interval. The robot starts disarmed, rejects stale commands and latches emergency or drive faults until explicit reset. These mechanisms provide bounded command handling during supervised operation; physical stop performance also depends on the bus, drive response and traction-disconnect system.

6 Remote farmer supervision and visual feedback

Remote access addresses an operational requirement that extends beyond commissioning. A farmer may need to inspect robot status while working in another field, attending to other farm operations or travelling away from the farm. A browser-based interface can maintain access through a phone, tablet or computer when both the robot and the operator have network connectivity. Within RIC, this capability is relevant to repeated, spatially selective service-crop interventions, for which the operator may need to review progress or respond to an interruption without remaining beside the vehicle throughout an operation. FieldScout therefore treats web access as a common supervisory interface for the present manually controlled platform and its future autonomous functions. Off-site driving and mobile usability have not yet been evaluated.

REMOTE SUPERVISION AND LOCAL MOTION CONTROL

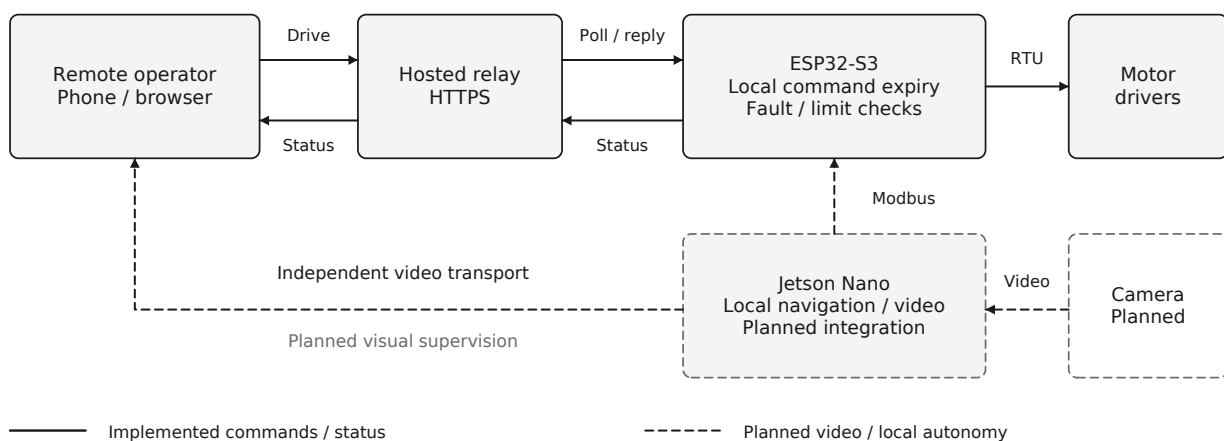


Figure 6: Remote-supervision architecture. The implemented command and status path is separated from the planned onboard camera stream and local autonomous-navigation path. Local command expiry remains independent of video transport.

Effective remote intervention requires visual information about the crop corridor, nearby obstacles and the working area. Graphical command indicators cannot reveal an unexpected obstruction, plant contact or wheel slip. Research on agricultural-machine supervision demonstrates that camera views should be selected according to the operator's task and the surrounding information required for decisions (Edet and Mann, 2020). A live onboard video stream to the farmer's mobile device is therefore a necessary extension for visually informed manual driving beyond direct sight of the robot. A forward view would support route inspection, while a future implement view could support assessment of crop clearance and treatment execution. These views would complement the current command-derived display by showing the physical scene.

The proposed extension in Figure 6 uses an onboard camera and video processing on the navigation computer, with video transport separated from the command relay. This permits stream rate and image quality to be managed without altering the local motor interface. Video availability alone is insufficient: the operator must also be able to judge whether the displayed scene is current. Measurements of wireless agricultural video transmission demonstrate the relevance of end-to-end delay (Green et al., 2021), while field network experiments show that communication capability must be evaluated against the demands of the robotic application (Zhivkov et al., 2023). Integration should therefore expose image age and loss of video, and evaluate delay variation, interruptions and

recovery under representative coverage conditions. The intended progression is from local manual operation to visually informed remote intervention and, ultimately, supervisory control of locally autonomous tasks. In the latter mode, the farmer would assign or review bounded operations while the robot performs short-horizon motion control onboard. This reduces dependence on continuous remote steering and provides a practical basis for future supervision of several units. Video loss or stale control data must inhibit continued manual driving beyond sight, and reconnection must not automatically restore motion. These requirements guide the next integration stage; the present implementation establishes the browser command and status path, with live-video feedback and remote-driving validation remaining future work.

7 Simulation controller and analytical checks

A CoppeliaSim development framework implements four-wheel motion control and reference-trajectory generation for row traversal and headland transitions. Two robot-controller instances use the same control formulation with corresponding trajectory generators, allowing the architecture to be extended to multi-robot studies. The controller reads a target's position in the robot frame directly from the simulator and calculates distance $d = \sqrt{x_t^2 + y_t^2}$ and bearing $\alpha = \text{atan2}(y_t, x_t)$. Proportional distance and heading terms are limited by speed and acceleration bounds, with lower translational limits near turns. Rotation-only behaviour uses hysteresis, entering at an absolute bearing of 50° and leaving below 20° . The target's ground-truth coordinates remove the perception and localisation problem from this control exercise; successful use of the scripts therefore cannot establish LiDAR navigation accuracy in a field. For nominal wheel radius r and effective track b , the commanded left and right wheel angular speeds are

$$\omega_L = \frac{v - b\dot{\psi}/2}{r}, \quad \omega_R = \frac{v + b\dot{\psi}/2}{r}, \quad n_{L,R} = \frac{60\omega_{L,R}}{2\pi}. \quad (1)$$

Both wheels on each side receive the same target. This differential-drive approximation is convenient for command generation, while a four-wheel skid-steered vehicle must accommodate lateral tyre slip during turning. The simulation configuration uses $r = 0.0535$ m, $b = 0.2321$ m and a 0.2000 m wheelbase. These are simulation settings, not independently measured physical dimensions. The controller formulation is analysed here as a development method; dynamic performance and tracking-error distributions are outside the present evaluation.

Table 2: Embedded and simulation control parameters. Values denote configuration settings and acceptance thresholds.

Quantity	Value	Interpretation
ESP32 speed limit	90rpm	Absolute command cap
Local motor scheduling target	40 ms	Nominal, not a hard deadline
Command validity cap	1000 ms	Upper bound in received-command handling
Simulation forward speed limit	0.40 m s^{-1}	Normal controller saturation
Simulation corner speed limit	0.15 m s^{-1}	Reduced speed above 35° bearing
Reference row / connector speed	$0.20/0.04 \text{ m s}^{-1}$	Moving-target generator settings
Normal / corner arrival radius	0.10 / 0.13 m	Controller acceptance thresholds
Waypoint handover	0.16 m; 0.05 m s^{-1}	Position and speed conditions held 0.75 s

As summarised in Table 2, the controller applies distinct limits for row traversal and turns. The row generator uses alternating 30 m traversals separated by 0.5 m connectors, slows the first 0.70 m of a row to 0.08 m s^{-1} , and inserts 3 s pauses between segments. A second instance offsets a trajectory but introduces no inter-robot communication, task allocation or collision avoidance. Thus, the scripts support reproducible controller development for individual vehicles and potential future multi-agent studies, without constituting a swarm demonstration. These 0.10–0.16 m acceptance thresholds are commissioning settings, not evidence of centimetre-level trajectory or tool-placement accuracy. The ideal no-slip straight-line speed follows $v = 2\pi rn/60$. At the firmware cap of 90 RPM and the simulation radius, it is 0.504 m s^{-1} ; at 30 RPM it is 0.168 m s^{-1} . These are calculated conversion values, not field measurements. A robot travelling at 0.504 m s^{-1} could cover approximately 0.504 m during a one-second stale-command interval before braking is considered. The calculation motivates lower commissioning speeds and local supervision; it does not predict a tested stopping distance. Precision field use requires measurement of wheel slip, timing, braking and tool position under the intended crop and soil conditions.

8 Preliminary evaluation and results

The preliminary evaluation examined the functional integrity of the printed body, basic field locomotion, web-command execution and message exchange between the navigation and motor controllers. Software inspection and analytical calculations complemented the supervised field observations by establishing the implemented control logic and its nominal operating bounds. The study was exploratory, with emphasis on integration feasibility before autonomous navigation and agricultural tool operation are combined. The qualitative outcomes are summarised in Table 3; they provide a basis for selecting the next validation tasks without assigning statistical reliability or positioning accuracy to the prototype.

Table 3: Preliminary evaluation outcomes and engineering interpretation.

Evaluation item	Outcome	Interpretation
Printed body	Remained functional during initial supervised field operation	Adequate for the encountered conditions; extended durability testing required
Hub-wheel mobility	Supported usable field locomotion	Basic mobility established; terrain-dependent slip and traction to be quantified
Electronic integration	Embedded control hardware supported the preliminary trials	Functional integration established; endurance not quantified
Web and motor control	Command validation, acknowledged writes and latched fault handling implemented	Defined local control behaviour; physical stop response to be measured
Jetson–ESP32 interface	Initial messages exchanged successfully	Communication basis established for navigation integration
LiDAR navigation	Sensor and computing architecture established; SLAM under development	Platform ready for navigation development and independent accuracy testing
Simulation controller	Speed-limited target and row-transition logic formulated	Development support for motion control; field localisation not evaluated

The printed body remained functional under the conditions encountered in initial field operation, and the hub-wheel modules provided sufficient locomotion for these trials. This supports the use of additive manufacturing during development of a customised agricultural platform, where mounting positions, protective panels and tool configurations may change as the cropping system and robot are refined together. The result is particularly relevant to modularity because a functioning base permits subsequent configurations to be examined without reconstructing the entire vehicle. Long-term suitability will depend on print material, wall geometry, fastener retention and environmental exposure. The present observations establish initial functionality rather than fatigue life, weathering resistance or an all-terrain operating envelope. The industrial-format embedded hardware operated successfully during the preliminary trials and supported the separation of web interaction from wheel actuation. Local validation of commands, protocol acknowledgements and fault latching provide explicit mechanisms for commissioning and diagnosis. Initial Jetson–ESP32 message exchange further demonstrated that the navigation computer and embedded controller could exchange information across the intended subsystem boundary. This is a useful integration result because navigation software can subsequently be developed while retaining a consistent low-level motion interface. It does not yet establish the timing distribution or loss tolerance of the complete navigation-control loop.

The principal limitations concern measurement depth and autonomy maturity. The preliminary evaluation did not quantify operating life, wheel slip, stopping distance, localisation error or agricultural treatment performance. Similarly, encoder-equipped motors provide a basis for future odometry, but the current web telemetry reports acknowledged command values rather than independently measured displacement. SLAM, autonomous row following and crop-relative tool placement remain under development. Subsequent evaluation must therefore connect measured vehicle trajectories and communication timing to the crop-clearance and intervention requirements before ultra-precision performance can be established.

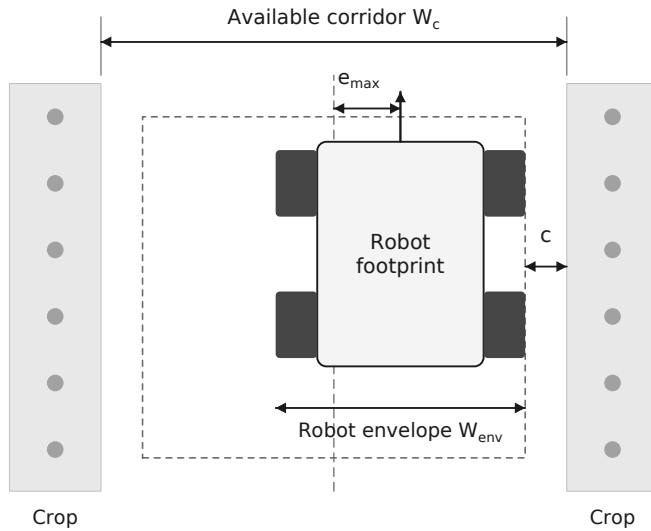
9 Engineering implications for narrow-strip operation

Intercropping compatibility must be assessed using the complete vehicle and implement envelope. Wheel track measures the spacing between wheel centres and omits tyre width, body overhang, connectors and moving-tool excursions. For a simplified straight corridor, a necessary geometric condition is

$$W_{\text{corridor}} \geq W_{\text{envelope}} + 2(e_{\text{max}} + c), \quad (2)$$

where $e_{\max}$ is a selected lateral tracking-error allowance and c is a clearance reserve on each side. The condition in Figure 7 is not sufficient for safety or crop protection because vegetation can move, rows can curve and implement motion can enlarge the swept area. It is nevertheless a useful first screen for matching a robot configuration to a field layout. Using an illustrative $e_{\max} = 20$ mm and $c = 10$ mm requires 60 mm beyond the physical envelope. A 250 mm corridor would then admit at most a 190 mm envelope, and a 300 mm corridor at most 240 mm. These examples are engineering scenarios, not measured RIC navigation accuracy or certified crop clearances.

CROP CLEARANCE IS AN ENVELOPE CONSTRAINT



$$W_c \geq W_{\text{env}} + 2(e_{\max} + c)$$

W_c : free width between crop edges

W_{env} : body, wheels and tool excursions

$e_{\max}$: bounded lateral tracking error

c : crop-protection clearance

Dashed envelope includes lateral error.

Treatment reach needs its own constraint.

Headlands require a turning envelope.

Conceptual corridor geometry for configuration-specific clearance design.

Figure 7: Geometric screening of a narrow strip. The body-and-tool envelope, tracking allowance and crop-clearance reserve must all fit within the available corridor. Track width alone cannot demonstrate compatibility. The schematic defines a design constraint rather than the measured dimensions or achieved accuracy of FieldScout.

The consequence is that a 25–30 cm service-crop strip cannot automatically be designated a travel lane for this robot. Where the complete base is wider than the usable lane, the solution is not simply to improve localisation: the route, wheel placement or tool arrangement must change. An offset implement may reach a service-crop band while the base travels on a wider access lane, whereas a straddling configuration would require adequate clearance above and beside protected plants. These choices should be made jointly with the crop layout and then checked over the full growth stage range. The complete assembled envelope must be measured for each tool configuration and assessed against the available corridor throughout the operating growth stages.

Speed and timing create an additional spatial budget. For a latency τ and an ideal constant braking deceleration a , a simple level-ground estimate is

$$d_{\text{stop}} = v\tau + \frac{v^2}{2a}. \quad (3)$$

Here the first term is travel before braking and the second is braking travel; neither term includes slope, tyre slip or a failed actuator. The one-second command-validity cap therefore cannot be interpreted as a one-second guaranteed stop. Field commissioning must measure the full delay and motion response, including driver ramp behaviour and the hardwired stop path. Motor reversal dwell, bus acknowledgements and command expiry provide useful software mechanisms, but only an independently measured trajectory can determine whether their combined behaviour is compatible with a crop-protection clearance. Potential capacity must likewise be expressed as a task-dependent quantity. For working width w , mean productive speed v and field efficiency η , the ideal single-robot area rate is $C = wv\eta$. Neither w nor η has been established by the present evaluation, so no hectare-per-hour capacity is reported. Replication into a fleet would introduce shared headlands, intervention delays, charging and recovery, and would not generally multiply useful capacity linearly. This turns future swarm research into an operational question about completed, verified crop treatment rather than simply the number of mobile bases deployed.

10 Discussion and development towards autonomous operation

FieldScout provides a configurable experimental base for small, spatially selective operations in the RIC programme. Its agricultural relevance arises from the relationship between robot configuration and crop-management decisions: service crops must be regulated at appropriate locations and times while useful vegetation and cash crops are retained. Modular construction supports this process by allowing the mobility, sensing and future intervention modules to be refined separately. Comparable modular platforms illustrate the value of accessible subsystem interfaces (Xu and Li, 2022), while compact field robots demonstrate the potential of additive manufacture and embedded control for agricultural sensing (Kayacan et al., 2018). FieldScout contributes an implementation centred on web-accessible operation and a separate navigation-computing interface, with preliminary field observations supporting continued integration.

Small size alone does not ensure low disturbance or agronomic benefit. Soil stress depends on machine loading, tyre contact, moisture and traffic frequency (Keller et al., 2019); skid steering additionally introduces lateral wheel motion during turns. The platform must therefore be evaluated with its intended implement, surface conditions and crop arrangement. The clearance relation in Figure 7 makes the dependence on the complete vehicle envelope explicit. If the available lane cannot accommodate the base and its operating margins, the field route or implement arrangement must change. Improved localisation cannot resolve a geometric incompatibility. The relevant agricultural outcome is effective treatment with acceptable crop injury and soil disturbance, assessed at the level of the complete operation. LiDAR navigation is the principal autonomy-development task. The STL27L provides planar range observations, while the Jetson Nano supplies a computing environment for scan processing, map representation and pose estimation. Agricultural SLAM research identifies changing vegetation, repeated geometry and unstructured terrain as central challenges (Ding et al., 2022; Tiozzo Fasiolo et al., 2023). In intercropping, similar rows may create ambiguous scan matches, moving leaves may violate static-map assumptions, and low vegetation may provide weak features at the scan plane. Orchard navigation research demonstrates the importance of independent accuracy assessment (Blok et al., 2019), but its structural conditions cannot be assumed for low service-crop strips. Wheel odometry and inertial measurements are candidate complements to LiDAR, subject to calibration, synchronisation and evaluation of their actual contribution to pose continuity.

RTK-GNSS is planned for outdoor absolute localisation and waypoint following, while UWB is intended for indoor localisation and commissioning where satellite positioning is unavailable. These sources address different operating conditions and should first be evaluated individually before fusion. The navigation interface must communicate motion requests together with their validity and operating mode, while the embedded controller retains authority over local command execution. The web interface provides a complementary supervisory layer. Live video will be required for remote visual assessment, whereas locally autonomous control should handle immediate motion decisions. This division supports the farmer's ability to supervise work while away from the field without making the Internet connection part of the robot's inner motion-control loop. The next evaluation stage should relate independent trajectory measurements to crop-clearance and tool-placement requirements. Cross-track and heading errors should be reported with speed, surface condition and crop geometry, including percentile and maximum deviations as well as average error. Communication trials should measure command age, loss and recovery, and mechanical trials should document operating hours, material configuration and component condition. Stop behaviour should be measured under representative network and drive faults. Once these engineering requirements are established, agricultural trials can examine service-crop suppression, residual height, treatment coverage and cash-crop injury. Multi-season compact-robot studies provide a useful precedent for linking platform development to sustained agricultural measurements (DeBruin et al., 2025).

Swarm operation is a subsequent research objective. Replication of the mobile base creates the need for task allocation, collision-free use of headlands, access to charging or service areas and recovery from an interrupted unit. Multi-agent planning is therefore an additional layer beyond individual vehicle control (Botteghi et al., 2020). The repeated CoppeliaSim controller instances provide a starting point for that development, while the separation of supervisory, navigation and wheel-control interfaces offers a consistent structure for future units. Fleet evaluation should compare completed crop treatment, operator workload and recovery time with single-robot operation; the number of deployed vehicles alone is insufficient to establish useful field capacity.

11 Conclusions

FieldScout integrates a printed modular body, four hub-driven wheels, an ESP32-S3 motor controller, web-based manual operation and a separate Jetson Nano–LiDAR subsystem for robotic intercropping research. Initial supervised field operation established the functional feasibility of the body, wheel modules and embedded

hardware under the encountered conditions. Preliminary Jetson–ESP32 exchange established a communication basis for subsequent navigation integration. The browser interface supports accessible supervision, with live onboard video required for future visually informed remote driving. Quantified durability, localisation accuracy and crop-relative intervention remain to be evaluated. The next development stages comprise SLAM, RTK-GNSS outdoor waypoint following, UWB indoor localisation and independently measured vehicle and tool placement. Coordinated multi-robot operation will build on validation of the individual platform.

Acknowledgement. This work was developed within the Robotic Intercropping project, supported by the Novo Nordisk Foundation and involving the University of Copenhagen, Wageningen University, the Technical University of Denmark and the University of Southern Denmark.

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