

Pronto4™ Series 4 Safety Overview





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Background

Autonomous vehicle technology is immature and inherently dangerous, therefore the behavior of autonomous vehicles is often erratic and accidents may occur. Personnel, vehicles, and property in the vicinity of autonomous vehicles may be at risk. The safe operation of the system is highly dependant on the scenario of usage and the surrounding environment. *The safe operation of the system is ultimately the responsibility of system operators and site-specific safety protocols and procedures.*

Purpose

The Pronto4 system uses several methods to assist with the safety of those working with or around the vehicle. The E-stop connections provide an interface that kills the vehicle engine and applies the vehicle brake. An additional feature is Pause, which applies the vehicle brake and causes the current mission to pause until the signal is de-asserted. These signals can and should be used through both a local set of switches and through a radio link. The Alerts interface allows for a flashing warning light and audible alert to be active when the vehicle is enabled or in a run state.

Overview

The E-stop signals are +12V and active low. When a switch or a button interrupts the signal, the vehicle engine is killed and the vehicle brake is applied. Normally a switch is placed on the exterior and interior of the vehicle such that any person working on or around the vehicle can safely disable the vehicle at any time. A method to stop the vehicle through a radio link, such as an Operator Control Unit (OCU) E-Stop or Safety Direct, is strongly recommended as well.

The Pause signal is 3.3V and active low. When the signal is interrupted by a switch or button, the software on the Pronto4 system applies the vehicle brake and pauses the running mission script. Once this signal resumes, the vehicle will release the brake and continue the mission script. Normally a switch is placed in the interior of the vehicle such that a safety operator can pause the vehicle at any time. A method to pause the vehicle through a radio link, such as an Operator Control Unit (OCU) E-Stop or Safety Direct, is strongly recommended as well.

Safety alerts include two +12V signals and the user brake signal. The +12V (Enabled) signal is asserted when the vehicle is in Auto mode and is enabled in software. This signal is normally connected to a flashing light as a visual cue for humans. The +12V (Motor Power) signal is asserted when the vehicle is in Auto mode and enabled in software. This signal will de-assert when there is no power to the actuator motors. This signal is normally connected to an audible alert system. The User Brake signal is tied to the state of the vehicle brake. This is normally used to disable the audible alert when the vehicle brake is applied.



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Sample Safety Procedures

Safety is paramount on an unmanned ground vehicle. The following list outlines how an unmanned ground vehicle (UGV) operational area may be established and how operations in that area may be performed. This list should be adapted to the specific needs of the end user:

1. A safety briefing is performed prior to each operation.
2. Proper trailers and securing systems are used to move all UGVs to operational sites.
3. Road signs indicating “Caution: Unmanned Vehicles in Motion” are placed at entrances to the area where operations are underway.
4. Traffic cones are used to mark operational areas and entrances.
5. Traffic flags are used for traffic management.
6. All operational staff wear bright day glow safety vests.
7. Communications equipment for operational staff is available.
8. There are flashing amber lights on robotic and chase vehicles.
9. Radio E-stop systems are used that function identically to the DARPA units.
10. A following or chase vehicle is used and is required to have a human operator that is holding a “dead man” switch during the entire unmanned operation.
11. In most cases a safety operator can be used for precautionary purposes and has no impact on operations.
12. The majority of operations can be performed unmanned as desired in a very safe manner.

For simple operations and/or demonstrations, a safety operator can sit inside the vehicle for precautionary purposes. The safety operator may take control of the unmanned vehicle as needed by tapping on the brake and taking control of steering.

KEY POINT: Prior to exiting the vehicle, when it isn't performing unmanned operations, the safety operator should manually disconnect the transmission cable (easily done while sitting in the vehicle driver seat). This provides maximum disconnection of the Pronto4 system from the vehicle.

Equipment

Kairos Autonomi offers the following safety-related items for use with the Pronto4 system.

Safety Direct Handheld Controller, P/N: KA232-01 — designed by Kairos Autonomi specifically for use with the Pronto4 system, the Safety Direct provides two key controls to the Pronto4:

- It is a multi-level, wireless E-stop system for optionally unmanned and autonomous vehicles.
- It enables direct control of the vehicle from a remote location.

The handheld transmitter controls independent pause and stop relays, and provides visual and audible feedback that includes a display for providing safety status from the Pronto4, as well as the state of the relays and communication link, including power on, pause relay, stop relay and battery charging. The use of this E-stop system is based upon independent, line-of-sight. For direct vehicle control, two joysticks enable remote control of the vehicle during tele-operation. The transmitter can be used up to two (2) miles away from the vehicle mounted receiver. With multiple channels to choose from in one of 3 bands (868 MHz, 900MHz, and 2.4 GHz), multiple e-stop systems can be used simultaneously.



Figure 1: Safety Direct Handheld Controller

Integrated Roof Rack, P/N: KA249-01 or P/N: KA249-03 — these roof racks include navigation, communication, and safety equipment for operating an unmanned vehicle, as well as all associated cabling and mounting equipment for attaching to any vehicle.

The following components are integrated in the roof racks:

- **Augmented GPS Subsystem** — a rugged, self-contained GPS receiver and antenna designed for harsh tracking environments and precision path following. It includes standard support for Satellite-Based Augmentation System (SBAS) corrections provided by WAAS, EGNOS, and MSAS systems. Use of SBAS correction data provides increased positioning accuracy without additional cost or equipment. This subsystem comes with a mounting kit.
- **Single-band Network Radio, included with P/N: KA249-01** — a rugged, 2.4 GHz, wireless transmitter-receiver that forms a fused or point-to-point network when used in conjunction with other radios. This system also includes open system IEEE 802.11 a/b/g standards for increased connectivity.
- **Dual Band Radio Data Link, included with P/N: KA249-03** — a rugged, 900 MHz and 2.4 GHz wireless transmitter-receiver that forms a fused or point-to-point network when used in conjunction with other radios. This system also includes open system IEEE 802.11 a/b/g standards for increased connectivity.
- **Cameras with Mount and Pigtail** — two low lux cameras (mono, color) are mounted so one faces forward and one faces backward. Both cameras include an adjustable mount.
- **Warning Light and Audible Alarm Subsystem** — this subsystem provides a flashing safety light and audible alarm that indicates when a vehicle is operating in an unmanned mode.



Figure 2: Warning Light and Audible Alarm

Hardwired, External E-stop Subsystem, P/N: KA213-01 — this system allows the user to place E-stop buttons on the exterior of the vehicle. Weather resistant pushbutton stops are mounted on the vehicles' two front corners and back bumper, thus allowing the vehicle to be shutdown from any side. When a human presses one of the buttons, the E-stop is actuated, the engine stops running and the vehicle brakes are applied. In addition, a flashing light output can be enabled when the vehicle is armed and capable of unmanned operations, and an audible output can be actuated when the vehicle is performing unmanned operations.



Figure 3: Hardwired E-stop buttons place on the exterior of an unmanned vehicle

Operation

When an E-stop is actuated (hardwired pushbutton or wireless), the engine stops running and the vehicle brakes are applied. The E-stop system can bring the vehicle to a controlled stop on command to assist with the safety of vehicles, personnel and property in the vicinity and it does not interfere with the manual drive mode of the vehicle when properly configured. The steering actuator is easily back-drivable, allowing a human operator to steer the vehicle. Throttle and brakes are unaffected.

The following is a list of safety features and conditions that are designed in as part of the Pronto4. Additionally, hardware lines run through the system and vehicle for E-stop. All system errors can be classified in one of those three modes, defined as:

States:

E-Stop

This mode is a hardware only mode. There is no computer control of this mode or ability of the computer to exit this mode. It must be cleared by physically accessing the vehicle.

System power plant is shut down as fast as possible
Brake is applied at pre-set level (100% or close)
Power is removed from throttle servo
Power is removed from steering servo after delay
Power is maintained for brake servo



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- Pause This is a software mode where the computer ceases driving operations.
System is brought to a software-controlled stop
Throttle is brought to zero
Steering angle is maintained

- Run Control is returned to the primary computer after 5 seconds
Brake is released and restored to operation
Throttle is increased as desired

Transitions:

- Exit E-Stop Condition causing E-Stop must be cleared
Must reset at vehicle
Always goes into Pause mode

- Exit Pause Always goes to Run mode
May be cleared remotely
Pause switch must be cleared
Local Pause has highest precedence

The following are safety functions the Pronto4 system can execute. The user can enable, disable or alter these safety functions based on test parameters. Establishing these functions should be done prior to expected usage.

Tele-operation Mode, Manned:

- Loss of communications for more than 2 seconds in a 1 minute period
Vehicle enters Pause mode
- Loss of primary system power
Vehicle enters E-stop mode
- Radio E-stop
Vehicle enters E-stop mode
- E-Stop switch activation
Vehicle enters E-stop mode
- Actuation of software watchdog
Vehicle enters E-stop
- Pause switch selected
Vehicle enters Pause mode
- Operator motion enable (Deadman) released & Operator Steering not active
Pause mode entered
- Run selected
Vehicle enters run if all conditions met
- Brake press



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- Throttle forced to zero
- Brake release
 - Throttle control restored
- Pause mode must be manually cleared
- Throttle limit switch actuated
 - Vehicle enters E-Stop mode
- Vehicle E-stop times
 - Radio command
 - <100 ms
 - Local E-stop actuation
 - <10 ms
 - Brake flight time from 0 to 100%
 - 1 second
- Vehicle pause times
 - Radio command
 - <300 ms
 - Local pause switch command
 - <300 ms
 - Software pause command
 - <1 sec
- Brake actuated
 - Throttle brought to zero
- Collision Pending (development)
 - Brake is applied fully
 - Throttle is brought to zero
 - Proximity system detection
 - Forward trajectory greater than speed adjusted stopping distance
 - Turn to the right if GPS path following on straight road
 - Vehicle enters Pause mode
- Collision occurred (development)
 - Vehicle enters E-stop mode
 - High shock values

Tele-operation Mode, Unmanned:

Same as in tele-operation mode, except brake press is ignored

Semi-autonomous Mode, Manned:

Same as in tele-operation mode, except Pause mode must be manually cleared

Vehicle enters Pause

Greater than settable error from waypoint following

High speed error

Speed above max > 3 seconds



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Steering error
Steering desired delta > 3 seconds
Vehicle enter E-stop
Braking error
Velocity to zero > 5 seconds

Semi-Autonomous Mode, Unmanned:

Same as in semi-autonomous mode, except brake press is ignored

Throttle servo has non-powered return to zero
Throttle servo has user settable E-stop above hard setpoint

MIL-STD-882 Safety Analysis

The Pronto4 system has successfully completed the U.S. MIL-STD-882D, Revision 1, Safety Assessment Analysis. This standard provides guidance and criteria to assess the level of risk with operating the system. This analysis has been performed by examination of the system design and analyzing the possible failures that can occur and the resultant vehicle action. This determines the hazard.

The MIL-STD-882D, Revision 1, safety analysis is for the base version of the Pronto4 system which does not include any sensors other than GPS. There are no sensors to detect and avoid obstacles or humans. This is the least safe configuration since it has no redundant sensors, no redundant actuators, and no ability to detect or avoid obstacles or human pedestrians.

However, in general the more sensors the system has the safer it is, both through redundancy of systems and through the ability of the system to self detect and avoid obstacles, the largest hazard to any autonomous vehicle.

This analysis has been based on the Pronto4 system in its third generation (Pronto 4 Series 3) and has several years of customer use in more than 70 systems. This use has resulted in thousands of hours of recorded use, an ostensible standard for determining reliability.

Since this analysis was created, Kairos Autonomi has developed the Pronto4 Series 4. The Series 4 is a mechanical repackaging of the Series 3 that uses the same underlying technology, but provides components in a more modular package. There are more than 300 of these systems in use by customers in several countries. Kairos Autonomi is the highest volume manufacturer of robotic appliqué kits in the world.



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Scalable Manufacturing

The Pronto4 system can be ordered and delivered using a variable build standard. The build standard ranges from best commercial practices to MIL-STD-810E/F environmental compliance. The standard commercial system uses un-gasketed, robust end caps on all aluminum extrusions with plastic circular connectors. Internal components are secured for shock and vibration levels found in commercial vehicles. Increasing the build standard replaces dust end caps with precision-gasketed versions and MIL-C-38999 circular connectors. Internal components are cocooned for specified shock and vibration profiles of the vehicle platform. PVC cabling can be Teflon based as required. ATR and other rack mount options are available as required. Standard surface finish is black anodized. Alternate finishes and colors are available to assist with NBC and other survivability requirements. Labeling meets MIL-STD-130C requirements.

12 or 24 vdc Power

The Pronto4 system runs from a single 12 vdc power source (24 vdc is optional with a converter). Power draw is nominally 5 amps while not driving or running actuators, under 20 amps running actuators without the engine running and under 10 amps running actuators and the engine. The power module contains a secondary battery with a high-speed $<25 \mu\text{s}$ isolation switch. A simple connection is made to the main vehicle battery with 6 AWG cabling from the power module. All battery charging occurs from the main battery. The Pronto4 is quickly isolated (and thus protected) from the main vehicle power when main battery voltage drops below nominal levels, such as vehicle start, winch operation or other high draw main vehicle applications occur. 12 vdc is most common on vehicles, but other voltages are available.

Safety-related Documentation

Operation manuals are provided with Pronto4 units. These manuals include general safety information, detailed procedures for preparing, operating, and securing unmanned vehicles, and checklists corresponding to the procedures. End users may adapt these procedures and checklists, as appropriate.

The operation of unmanned vehicles is inherently dangerous. Kairos Autonomi cannot control how the end user operates the system, nor can Kairos establish or enforce the safety procedures and protocols end users may put in place. As such, Kairos requires the following waiver to be signed by all entities, except the federal government, that purchase the Pronto4.



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ASSUMPTION OF RISK, WAIVER AND RELEASE, AND INDEMNITY AGREEMENT

This Assumption of Risk, Waiver and Release, and Indemnity Agreement (the “Agreement”) is made as of this ____ day of _____, 2014, by and between [Name(s) of customer(s)] (“Purchaser”), and Kairos Autonomi (together with its agents, employees, parent corporation, affiliates, predecessors, successors and assigns, “Kairos Autonomi”).

Purchaser wishes to purchase, and has requested that Kairos Autonomi sell to Purchaser, [accurately/precisely describe the goods being purchased], as evidenced by the [Title of Purchase Agreement], entered into between Purchaser and Kairos Autonomi on [Date] (“Purchase Agreement”), which is attached as Exhibit A hereto, incorporated herein, and made a part hereof. As a condition precedent to executing the Purchase Agreement, and as part of the consideration thereof, Kairos Autonomi has required that Purchaser execute and deliver this Agreement to Kairos Autonomi.

INHERENT RISKS: Autonomous vehicle technology is immature and inherently dangerous, and the behavior of autonomous vehicles is, therefore, often erratic and accidents may occur. Persons, vehicles, and property in the vicinity of autonomous vehicles may be at risk.

ASSUMPTION OF RISKS: Purchaser knows, acknowledges, represents and agrees that autonomous vehicle technology involves inherent and other risks, some of which are described above. Purchaser acknowledges and represents that it has received from Kairos Autonomi the [add titles of all instruction/training manuals, etc.], and that Purchaser has read, understands and will follow all written and oral instructions and warnings, make reasonable and prudent decisions, and operate any or all products purchased from Kairos Autonomi in a reasonable and prudent manner. Purchaser acknowledges and represents that Purchaser is solely responsible for determining Purchaser’s suitability to possess and/or operate any or all products purchased from Kairos Autonomi. Purchaser acknowledges and represents that the safe operation of any or all products supplied by Kairos Autonomi is highly dependent on the circumstances and scenario of usage, and the surrounding environment, none of which is within the knowledge or control of Kairos Autonomi, and all of which are within the knowledge and control of Purchaser. Purchaser acknowledges, represents and agrees that the safe operation of any or all products supplied by Kairos Autonomi is highly dependent on site-specific safety protocols and procedures and is, therefore, the sole responsibility of Purchaser. Purchaser agrees, acknowledges and represents that Purchaser voluntarily purchases and takes possession of any and all products supplied by Kairos Autonomi subject to and despite all risks, known and unknown. **Purchaser assumes all inherent and other risks and accepts responsibility and liability for any and all property damages and loss, and for any personal injury, illness, disability, emotional distress, and/or death that may result, whether described above or not.**

WAIVER AND RELEASE: Purchaser, on behalf of itself and its agents, employees, parent corporations, subsidiaries, affiliates, predecessors, successors and assigns, agrees forever to waive, release, and discharge Kairos Autonomi from, and agrees not to sue Kairos Autonomi for, any and all liability and/or claims that may exist or arise by reason of any property damage or loss, personal injury, emotional distress, illness, disability, and/or death, relating in any way to Purchaser’s purchase, possession, or operation of any or all products supplied by Kairos Autonomi. This waiver and release is for, and shall extend to, any type of claim, including, but not limited to, breach of contract, fraud, negligence, tort, or any other type of legal liability or claim, to the fullest extent permitted by law.



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INDEMNITY: Purchaser, on behalf of itself and its agents, employees, parent corporations, subsidiaries, affiliates, predecessors, successors and assigns, agrees to defend, hold harmless and indemnify Kairos Autonomi, on an ongoing and continuous basis, of, from, for and against all claims, causes of action, liability, loss, damage, costs and expenses, including attorney’s fees and all other sums which Kairos Autonomi incurs, pays or is required or becomes obligated to pay, as a result of or on account of any claim, cause of action, liability or loss relating in any way to Purchaser’s purchase, possession, or operation of any or all products supplied by Kairos Autonomi. This obligation to defend, indemnify and hold harmless is for, and shall extend to, any type of claim, including, but not limited to, breach of contract, fraud, negligence, tort, or any other type of legal liability or claim advanced, instituted or brought by any person or entity, to the fullest extent permitted by law.

ADDITIONAL PROVISIONS: This Agreement shall be governed by and construed in accordance with the Laws of the State of Utah without giving effect to any choice of law or conflict of law provision or rule that would result in the application of the laws of any jurisdiction other than the State of Utah. Purchaser consents to jurisdiction in Utah, and any dispute, controversy or claim arising out of, relating to or in connection with this Agreement shall be entered into only in Utah. In any dispute or litigation arising under or relating to this Agreement, the prevailing party shall be entitled to reasonable attorney’s fees and costs as damages. This Agreement, including the Purchase Agreement incorporated herein, is the entire agreement and understanding of, by and between the parties pertaining to the subject matter expressed herein. There are no independent, collateral, different, additional or other understandings or agreements, oral or written, that shall have any effect whatsoever on this Agreement. All of the terms and provisions of this Agreement are contractual and not a mere recital. Any portion of this Agreement deemed unlawful or unenforceable is severable and shall be stricken without effect on the enforceability of the remaining provisions. No provision of this Agreement may be waived unless it is done so in writing and signed by all the parties hereto. This Agreement may be modified or amended only by a written agreement executed by all the parties hereto. This Agreement may be executed in one or more counterparts, each of which shall be original but all of which, together, shall be deemed to constitute a single document.

This Agreement was first carefully read in its entirety by the undersigned parties and their attorneys, and this Agreement is understood and known to be a full and final agreement in consideration of the Purchase Agreement. This Agreement was signed and executed voluntarily by the undersigned after being fully advised by legal counsel of their choice, or with the opportunity to receive advice from legal counsel of their choice.

Dated: _____

[Purchaser Company]

 By: _____
 Its: _____

Dated: _____

Kairos Autonomi

 By: _____
 Its: _____