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BRINGING ROBOTIC PLATFORMS FROM VEHICLE TESTING TO WARRIOR TRAINING

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ABSTRACT

In order to expedite the development of robotic target carriers which can be used to enhance military training, the modification of technology developed for passenger vehicle Automated Driver Assist Systems (ADAS) can be performed. This field uses robotic platforms to carry targets into the path of a moving vehicle for testing ADAS systems. Platforms which are built on the basis of customization can be modified to be resistant to small arms fire while carrying a mixture of hostile and friendly pseudo-soldiers during area-clearing and coordinated attack simulations. By starting with the technology already developed to perform path following and target carrying operations, the military can further develop training programs and equipment with a small amount of time and investment.

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1. INTRODUCTION

Robotic platforms are used by the automotive industry to move pedestrian mannequins (vulnerable road users) and vehicle targets in choreographed maneuvers. These platforms are used to evaluate the operation and reliability of various Automated Driver Assist Systems (ADAS), such as pedestrian detection and automated emergency braking. Most of these platforms have been designed only for ADAS testing and are expensive and inflexible. S-E-A's recent work creating a customizable low-profile robotic platform for carrying pedestrian targets provides an excellent use case for automotive technology transitioning to have use in military applications. This paper will describe the development and deployment of this nimble, low-cost platform for carrying pedestrian and other targets. Examples showing the platform in path-following (fully automated) mode and manual mode (remote control via joystick) will provide context. Other features such as the ability to trigger from external sources and platform return-to-home are discussed. This paper will also detail how non-GPS based sensing technologies can be used for path following, such as a camera-based system which could be used in GPS-denied areas such as tunnels and buildings. Finally, the paper will discuss the opportunity for a military-use platform which builds on the design and testing of the current platform, while adding capability such that combat or training exercises might be enhanced.

2. BACKGROUND

ADAS testing is a subset of automotive testing which deals with driver assistance systems designed to reduce the occurrences and severity of crashes. These systems can be active or passive, depending on the system. A passive system only provides alerts to the driver, while an active system can steer, brake, or otherwise act to avoid collision. To test active systems, the vehicle needs to be placed into a collision imminent scenario where it must respond or else risk hitting the object in question. This has created a market for soft targets that replicate cars, pedestrians, and bicyclists that can be struck without risking damage to the vehicle being tested, real cars, pedestrians, and bicyclists.

Figure 1: Guided Soft Target with Soft Car 360 Foam Car [1]

Figure 2: Child Pedestrian Target during Impact [2]

These soft targets are generally placed on some low-profile platform which is either robotic (Figure 1) or cable-driven (see Figure 2, cable system visible on ground). The development of these platforms has largely already been performed, and the military can take advantage of this work to develop robotic training tools. In the following sections, a new, low-cost platform which has been designed for ADAS testing is described. Modifications and adaptations required for military use are discussed which form the basis for transitioning this technology into the military and defense fields.

3. STRIDE PLATFORM

3.1. PHYSICAL FEATURES

The STRIDE (Small Test Robot for Individuals in Dangerous Environments) is a low-profile robotic platform originally designed for ADAS testing. The platform has been designed to carry pedestrian and bicyclist soft targets weighing up to 10 kg. It has been designed to be over-runnable by light vehicles (up to 1850 lbs. per tire), though a version capable of supporting heavy vehicles is being developed.

Figure 3: STRIDE Platform

The lid of the STRIDE, visible in Figure 3, has the minimum number of protrusions and mounting points, such that water/dust permeation is minimized, and the number of radar-reflective features is decreased. A plate in the center of the platform is made of highly magnetic stainless steel, for mounting horseshoe-shaped brackets capable of supporting the mannequin on the robot. The four silver points are magnetic attachment points suitable for use with stationary pedestrian dummies and bicyclist target tethers. Since the STRIDE is customizable, these attachment points can be varied depending on the targets of choice. For communications and GPS corrections, three antennas protrude through the lid. The large, black antenna is a 2.4 GHz wireless antenna to enable communications with other system components. Two gray antennas located on the back right and left corners of the platform are multi-constellation GPS antennas.

STRIDE is powered by a single onboard 24V battery. This battery slides into the rear of the platform, and unlike other platforms being used in the automotive industry, does not require tools to remove. An onboard 12V backup battery provides enough power to keep critical components powered during a hot swap of the 24V battery. By hot swapping, the amount of run time can be increased without needing to reset the system's components. An image of the 24V battery is shown in Figure 4. The battery can be charged either within the STRIDE platform or by using the provided External Charger (Figure 5).

Figure 4: 24V battery, two pictured

Figure 5: External Charger

For the STRIDE platform to receive GPS corrections messages and to house some larger components, a Vehicle Control Station is another key component of the system. The Vehicle Control Station (Figure 6) is housed in a Pelican case and has an onboard 12V battery, several communications control boards, a wireless node, a receiver for the E-stop, and in some cases, a GPS base station. By housing these components outside of the STRIDE chassis, the size and complexity of the STRIDE is reduced.

Figure 6: Vehicle Control Station

In ADAS testing of automotive vehicles, it is often important to be able to perform an emergency stop of the platform in the case of an undesired motion in either the robotic system or the vehicle being tested. While many platforms require complicated control systems and corresponding support vehicles to make them mobile, the STRIDE instead uses a wireless E-stop transmitter. This transmitter is capable of being clipped to a belt or otherwise carried such that the test conductor can move freely and participate in testing operations. To prevent signal overlap between the Wi-Fi communications with the robot and the E-stop signal, the E-stop system operates in the 900 MHz frequency band.

Figure 7: Wireless E-stop

Speed capability is an important aspect of performing automotive tests, as the motions of child and adult pedestrians must be capable of being replicated, as well as bicyclists. The STRIDE is capable of a top speed of 20 kph (12.4 mph) and accelerations up to 0.2g. With four independently driven motors, the STRIDE can spin in place.

Another capability of the platform is integration with a Subject Vehicle Box. For automotive testing applications, this box is connected to a GPS IMU in the vehicle being tested. By publishing the speed and position data of the vehicle being tested to the STRIDE network via this box, special triggers are enabled. These generally are used to suspend all operation of the robot until the specific speed or position criteria has been met, then continue with the remainder of the test. This allows the pedestrian or bicyclist target to hold until some criteria are met such that the timing and overlap is desirable to test the safety features of the vehicle.

Figure 8: Subject Vehicle Box

3.2. SOFTWARE FEATURES

While the hardware features of robotic platforms are important, the software features and programmability are also important in determining the operation and ease of use of the system. Like many other robotic systems, the core backbone of the STRIDE system is Robotic Operating System (ROS) programming. The ROS environment provides branches for different components of software to reside and topics to publish common information to. Underneath the ROS layer, Python scripting defines most of the other operations being performed on the robot. Scripts control everything from what the current robot states are and whether motion is enabled, to what happens if no heartbeat is detected from certain components.

The STRIDE code is open-sourced and available via GitHub. This enables two key features: community-sourced upgrades and customization. If a STRIDE user or even a hobbyist were interested in developing new functionality or behavior of the robotic system, the code which they develop can be reviewed for safety and applicability, but then be added to the current repository for many other users to have access to.

Customization is different in that user-specific needs can be addressed by changing the underlying system software to modify behavior or functionality. This customization need not be shared back with the larger community but could be if desired. By allowing the user to change the behavior of the platform, the STRIDE design and programming team can write basic software which need not be capable of performing every scenario, but rather has the backbone necessary to do what is needed.

4. GUI

The STRIDE control is performed using a Graphical User Interface (GUI) which is hosted on the onboard computer. The GUI allows a user to connect to the robot, perform manual driving, record and follow paths, and download test data.

4.1. CONNECTING TO ROBOT

When the user joins the wireless network, which has been established using a powerful wireless modem mounted to a 360-degree antenna, they are able to connect to the robot's web-port and access the mobile GUI using a browser. This can be performed on any device with a Wi-Fi connection, which includes modern cell phones, tablets, and laptops. Figure 9 shows the initial state of the GUI on the left and the state of the GUI once connected to the robot on the right.

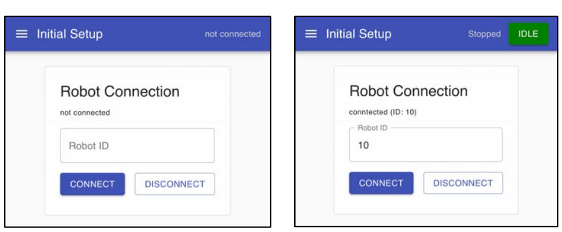

Figure 9: Robot GUI

Once a connection to the robot has been made, the other menus within the GUI may be accessed. The Robot Status page details the robot's current battery voltage, robot temperature, GPS status, motor controller statuses, and other information that can be helpful for troubleshooting.

4.2. MANUAL CONTROL

The Manual Control page allows the user to control the robot manually. Control of the robot is performed using a virtual joystick located on this page. When the user moves their finger forward, the robot moves forward at a rate and velocity corresponding to the user's interaction with the GUI. Likewise, when the user returns their finger to the center of the joystick, the robot slows down. In this way, manual control of the robot is easily and simply enabled. To perform pure rotation and pure straight-line motion of the robot, Move and Spin buttons located on the Manual Control tab offer a different input option. This is especially helpful when driving the robot along a straight line or when a pure rotation is important for the path being followed.

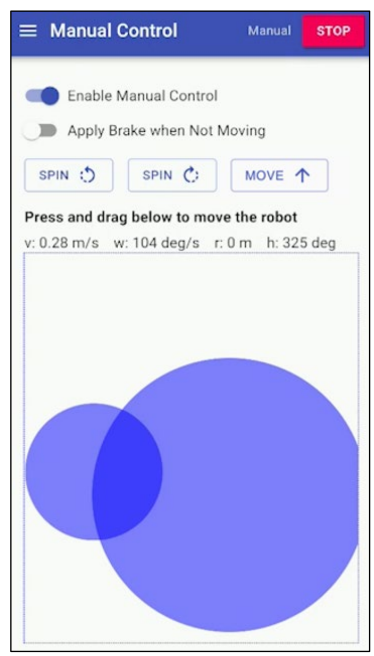

Figure 10: Robot GUI – Manual Control

4.3. PATH FOLLOWING

Most testing is performed in an automated way, instead of manually driving the STRIDE along the desired path. Automated tests use path following and user scripting to repeatably follow the same profile. Both of these components are necessary to enable automated operation.

Path following, as it sounds, requires that a path be recorded. Rather than creating a path using a complicated map-overlay methodology, the desired path is traced by the robot. Using the Path page of the GUI, the robot is placed into “Record” mode, and then it is driven along the desired path by the user in manual mode. When recording a path, the latitude and longitude of the robot are recorded via the output from the onboard GPS IMU, therefore, it is important during the recording process that the GPS status be Real Time Kinematic (RTK) Integer. The GPS status is displayed on the Manual Control page when the robot is in record mode. This is shown in Figure 11. Also in Figure 11, a helpful feature for recording straight lines appears when in record mode. The toggle bar within the virtual joystick allows the user to select the first and last point of a motion and allow the onboard computer to generate a straight line between these two points.

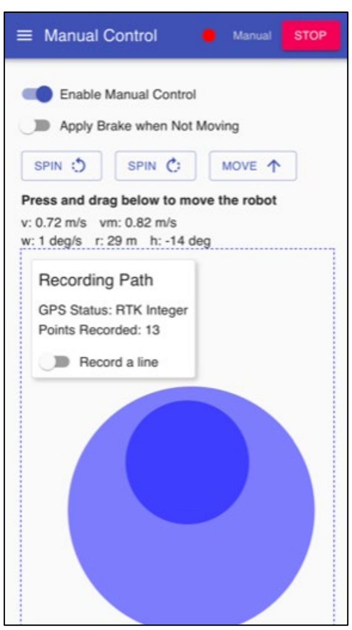

Figure 11: Recording a Path

After the path has been recorded, the user can generate a script which details the behavior of the robot along the path. This script file is written in Python and can use any of the pre-written function building blocks, or custom written functions. Examples of function building blocks are “sleep,” which simply rests the robot for a user defined amount of time, or "move until index,” which allows the user to input a speed, acceleration, and index to define motion up to that point. The pre-written building blocks can be used to write the script in whatever order the user requires, repeated within the same script, and organized to generate the desired platform motion along the path. Figure 12 shows an example script for motion along a path shown in Figure 13 where the robot moves to an index, spins in place, waits for a minute, and then proceeds more slowly to the end of the path.

```
rc = RobotCommander()

rc.move_until_index(3, 1.96, 30) # move until index 30 at a speed of 3 m/s and acceleration 0.2g
rc.decel_to_stop_at_index(35) # slow down and stop at index 35
rc.sleep(1) # pause for 1 s
rc.rotate_until_heading(0.1, 48) # rotate 180 degrees from current position of -132 deg
rc.rotate_until_heading(0.1, -135) # rotate the rest of the way around
rc.sleep(60) #pause for 60s
rc.move_until_end_of_path(2, 0.98) # move until end of path at speed of 2 m/s and acceleration 0.1g
```

Figure 12: Example Script for Motion along path shown in Figure 13

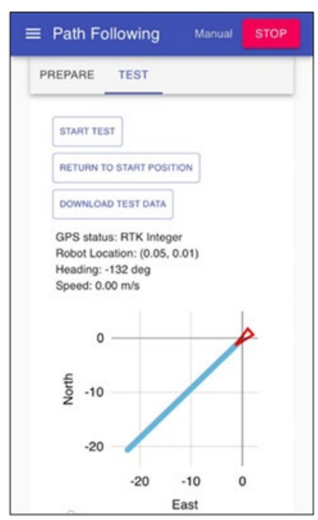

Figure 13: Example path

With both the path file and a script file ready, tests in automated mode can be performed. On the Path Following page, these two files can be uploaded. An image of the robot's location with respect to the path is displayed, and it updates live as the robot moves. From this page, an automated test can be started, monitored, and data can be downloaded at the end of the test. Data includes information about the robot location, speed, GPS status, and more. Additionally, the robot can be returned along the path to the initial start position in order to be ready for the next test to begin. This "return-to-home" functionality is timesaving as it resets the position precisely for the next test.

5. GPS-DENIED FUNCTIONALITY

Currently, the STRIDE platform has a Global Navigation Satellite System (GNSS) receiver coupled with RTK positioning to achieve centimeter level accuracy during path following. This approach was specifically chosen because the intended application was ADAS testing and validation. However, for indoor target-carrying this method would not be applicable. There is an option to use an Inertial Measurement Unit (IMU) for navigation and path following by Dead Reckoning, which is a method of estimating the subject's current position based on previously known positions using wheel odometry and/or IMU data. A typical Inertial Navigation System (INS) fuses data from GNSS and IMU, as standalone IMU data is prone to drifts that accumulate over time which makes this option not viable for indoor target-carrying systems that do not receive data from GNSS. Adding a simpler line-following capability to the STRIDE platform is another option but would require environmental setup and layout changes for different use cases which makes it difficult to be used indoors without prior mapping of the environment. For such applications, the intended solution is that STRIDE can localize and navigate itself without prior mapping using Simultaneous Localization And Mapping (SLAM), see [3], [4], and [5], techniques with which the system can build a map of the environment that it is operating in and know its location in that map simultaneously. This would require hardware additions of camera and/or Light Detection And Ranging (LiDAR) for Visual and/or LiDAR SLAM, as described in [6], [7], and [8]. This method is already being used in many indoor and outdoor applications where GNSS data may or may not be available such as robotic vacuum cleaners and lawn mowers to traverse an area efficiently. However, this method also comes with challenges such as loop closure which is similar to drift of IMU data over time. This can be overcome using landmark detection to identify previously visited places and by fusing data from other sensors like an IMU and wheel encoders to minimize localization errors. This SLAM methodology therefore overcomes the drawbacks of a standalone IMU or wheel odometry localization solution.

6. MILITARY APPLICATIONS

In order to expedite development of robotic target-carrying systems, the military can look to robotic systems designed for ADAS testing. Much of the development work has already been performed for these systems, such that a functional baseline can be built upon and developed for military needs. It is expected that robotic platforms would have specific applications within the military training space. Specifically, the STRIDE can be used to hold "hostiles," move along a specified path, and be used for practical training for how to clear and secure an outdoor area. The ability of the STRIDE to follow a predefined path enables the same training course to be used for many soldiers and their relative success at clearing the area can be compared. Instead of conveyor systems which move targets around an area, the motions of which can become predictable, the STRIDE's motion profile can be differentiated each time a soldier may interact with it, and there are no strings or pulleys giving away the motion.

Although not already mentioned, the capability to equip the STRIDE with a sensor for detecting if a mannequin is mounted on it or not has already been developed. Using technology similar to this, when soldiers successfully strike the hostile mannequin and knock it off the platform, the robot would automatically stop motion and end the test. This can be used to evaluate the performance of several soldiers along the same course based on criteria such as takedown time and location.

6.1. ROUGH TERRAIN

Several customizations would likely be needed for military applications. The current STRIDE model, since it is designed for automotive testing, has been optimized for operation on smooth asphalt surfaces and is as low-profile as possible. For outdoor use on terrain that is not paved, expected obstacles might include deep sand, mud, underbrush, and grasslands. The current STRIDE design would be modified for an all-terrain version with significantly increased ground clearance. It is expected that a STRIDE would be built to mount and dismount obstacles up to and including a 4-inch curb.

One method of accomplishing all-terrain capability would be to use the current driven-wheel as the power sprocket with some track-based wheel system. Current high-drive construction equipment such as Caterpillar track-type tractors use a similar design.

Figure 14: Caterpillar D6 Track-Type Tractor [9]

The drive wheels, now power sprockets, would be housed in the current chassis location. Additional hardware might be added for mud-shedding and other dirt intrusion considerations. Shown in blue in Figure 15, a suspension-type arrangement would be used to maintain tension in the track. By increasing the amount of ground contact (and decreasing the corresponding ground pressure) via the track system, sinking into deep sand could be minimized. This high-drive design would also provide more tractive-area for getting over terrain-based obstacles. Note that the wheelbase would be increased as well in the final design for better stability.

Figure 15: High-drive Track Design Concept

Another conceptual design, shown in Figure 16, would include a set of six wheels (blue) rather than the current four-wheel design. The wheels themselves would be larger and have more tractive power due to material and tread changes. A soft, large travel suspension would keep each tire in contact with the ground, even over bumpy terrain (shown as a spring in Figure 16). The chassis would no longer overhang the wheels such that obstacles would be encountered first by the wheels, aiding obstacle climbing. In order to provide motive force to the wheels, the motor and gearbox itself (orange) might move up and down with the wheels. The wheelbase and trackwidth of the robot would both be increased to something on the order of 0.8 m and 1 m respectively.

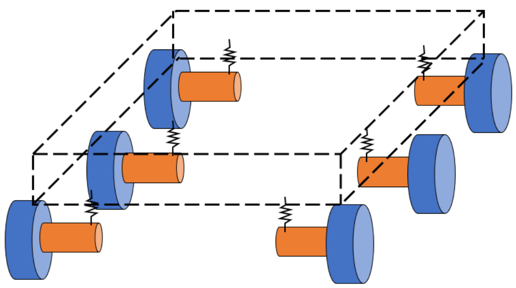

Figure 16: Conceptual 6-wheel Design

In any all-terrain configuration option, the STRIDE would not be over-runnable by passenger vehicles, but could be made resistant to small arms fire, except for the antennae which may require some different form of protection. Battery capacity would also need to be increased greatly.

The STRIDE could also be modified to carry targets in indoor situations. For indoor use, the STRIDE would have the GPS antennas removed but would have other sensors as described previously. The ground clearance would be less than an outdoor unit, but still large enough that the STRIDE could go over small obstacles. The overall dimensions of the unit are already small enough that it can pass through doorways.

6.2. CONTROL STRATEGY

The control strategy of the STRIDE could be adapted to allow "squads" of STRIDEs to move in coordinated ways while carrying various target mannequins, simulating a squad of soldiers attacking in a coordinated effort or obscuring the access to some other primary target. The Subject Vehicle Box, previously discussed, can be modified to have different triggering mechanisms and be used as a virtual "trip-wire" to start platform motion, with positions varying throughout the different training exercises.

It is expected that a purpose-built military version might have specified security protocols, such as password protected access and underlying programming that is not publicly available. Both these modifications, in addition to other security layers, can be implemented to ensure the safe operation of the robotic system.

7. CONCLUSION

The use of mobile robotic platforms in non-military applications is becoming increasingly common. These robots often have new technologies or applications which can be used for military purposes. Modifying and building on existing work in these areas creates opportunities for military and government groups to realize faster and less-expensive product development while picking and choosing technologies which will be most helpful to current work. By building on the backbone of the STRIDE platform to create a robust military training tool, target training and hostile identification and takeout scenarios will be advanced.

8. REFERENCES

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