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THE ROBOTIC SITE SHUTTLE - A FULLY AUTONOMOUS SOLUTION

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ABSTRACT

Lockheed Martin Missiles and Fire Control has developed a robotic site shuttle for use in structured areas, such as commercial railroad yards, port operations and storage/distribution industries. The purpose of the site shuttle is to provide an autonomous taxi service for personnel needing to move to various locations around the facilities. Many rail yards, ports and storage area are very large, so "taxi" transportation is vital to maintain efficiency and safety. The shuttle vehicles operate in complete autonomy: they have no steering wheel, accelerator or brake pedal. Personnel using the vehicles have only emergency stop buttons in the front and rear of the vehicles. Once implemented, the robotic shuttles will considerably reduce the costs of operation for the company. This need is consistent throughout the rail, port and storage/distribution industries, as all need to move personnel around their yards.

INTRODUCTION

Lockheed Martin Missiles and Fire Control (MFC) has been developing robotic platforms and autonomous capabilities since 1999. Our heritage is in unmanned ground vehicles and specifically in the medium to large class vehicles. Figure 1 provides an overview of MFC's robotics development.

A key to our approach has been to develop autonomy that is vehicle agnostic, able to be integrated on any ground vehicle. To that point, over the years, MFC has successfully integrated autonomous capabilities on numerous different vehicles. Figure 2 provides and overview of some of the vehicles on which we have applied autonomous capabilities.

In the past two years, MFC invested in the development of an autonomous site shuttle system. This two-year effort resulted in significant advancements in autonomy and permitted MFC to install, integrate and fully test the site shuttle system in a live, fully dynamic rail yard. The finalized system worked very well and is now available for future opportunities with additional rail yard, ports and depots, and can be leveraged to support site security missions.

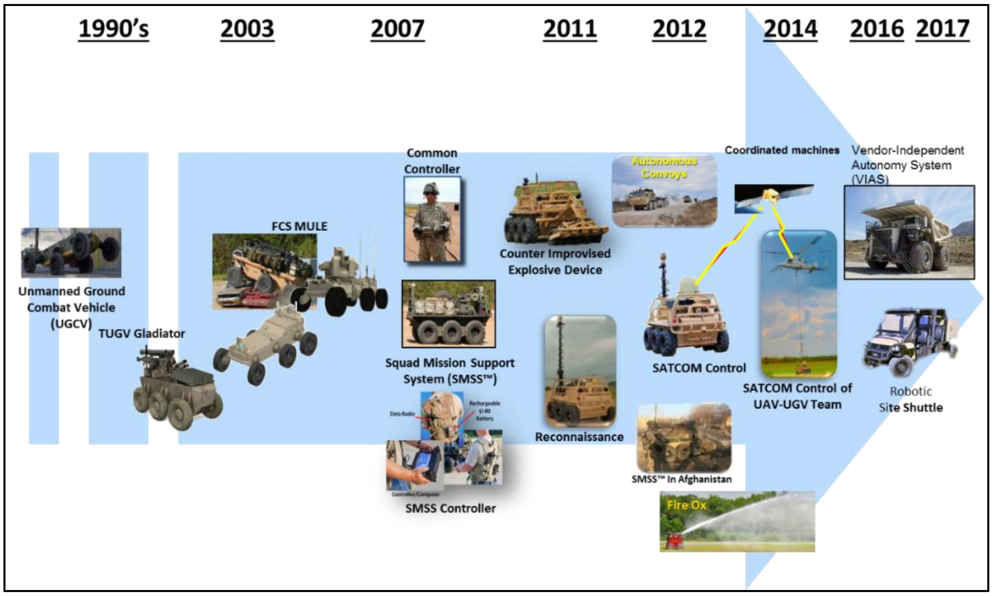

Figure 1: Lockheed Martin's Key Robotics Development

Figure 2: The Autonomy Is Agnostic and Has Been Applied on Numerous Vehicles

BACKGROUND

The heritage of the Site Shuttle was derived from MFC's Squad Mission Support System (SMSS™). The SMSS™ was developed to meet the needs of light and dismounted Infantry. Essentially, to unburden the Soldier and increase the time and distance that a small unit can operate from its larger parent unit. Figure 3 provides and overview of the SMSS™ and some of the variants and missions.

Figure 3: The SMSS™ Is Capable Of Varied Missions And Configurations.

The SMSS™ can carry 1500 pounds of gear and the extra ammunition, water, food, heavy weapons and anything else required for the squad to conduct a 72-hour mission. It can operate in all weather conditions and in both day and night operations. It has several modes of control: human-drivable, remote control, teleoperation, supervised autonomy, follower and SATCOM. Since 2008, the SMSS™ has participated in nine U.S. Army, British Army and UAE experiments and evaluations. One of the more notable experiments was teaming of the K-MAX helicopter with a reconnaissance variant of the SMSS™. In the experiment, 2014 at Fort Benning, the K-MAX autonomously lifted the SMSS™ by slingload, flew a prescribed route, approached a landing zone and autonomously released the SMSS™, upon touch down. The SMSS™ then, autonomously, conducted a resupply mission. Upon completion, it was ordered to move to another location and conduct a surveillance mission. Both the K-MAX and the SMSS™ received commands through SATCOM.

Much of the autonomous capability and sensors from the SMSS™ were transferred to the Site Shuttle, as the foundation for developing the capability to operate in a live, dynamic rail yard.

THE NEED

The type of railyard that the Site Shuttle was integrated into is known as a Hump/Classification yard. A hump/classification yard has four specific areas. The first is the receiving yard, where trains are held for the hump/classification process. Next comes the hump, which is literally a constructed hill, over which freight cars are shoved by yard locomotives, and then gravity is used to propel the cars to various sorting tracks. The cars are uncoupled from one another, at the top of the hump by the conductor of the train. Once uncoupled, each car rolls down from the top of the hump, powered by gravity, and are directed, through computer controlled switches, to the appropriate track to join an outbound train. Figure 4 provides an overview of a hump/classification yard.

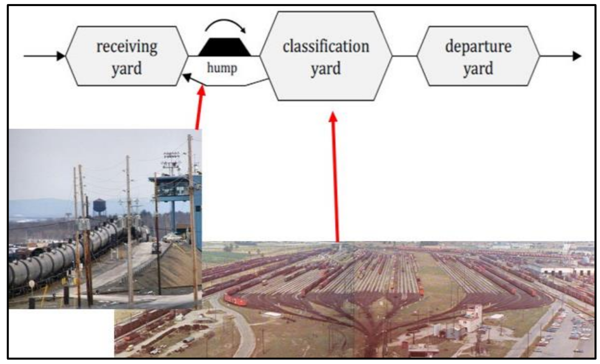

Figure 4: The design of a hump/classification railyard.

As previously mentioned, the uncoupling of individual cars is done by hand, by the conductor. Figure 5 provides a view of a conductor manually decoupling cars. At the start of the operation, the conductor is with the engineer in the pushing locomotive. Many trains are mile long or longer. Thus, to get the conductor to the hump, railroads

Figure 5: The conductor decoupling cars at the hump.

employ SUVs and vans, driven by either union employees of the railroad, or by outside contractors. This transportation effort operates twenty-four hours a day, seven days a week; employing three shifts of drivers. This adds considerable cost to the railroad's operations, when salaries, health coverage and retirement costs are considered. Additionally, drivers have a fair amount of down time between crew transport requirements, making it somewhat inefficient. To counter this operating cost, the railroad decided to try the use of robotic shuttles, believing they would significantly reduce operational costs and improve safety.

THE SOLUTION

To counter this operating cost, the railroad decided to use robotic shuttles, believing they would significantly reduce operational costs and improve safety. To that end MFC conducted an initial demonstration for the railroad's executive leadership in 2016. The demonstration was successful and MFC was awarded a contract to install a Site Shuttle system in one of the railroad's hump/classification yards for a pilot demonstration. If successful, the railroad would purchase several more systems for installation at their other railyards.

MFC quickly developed the Site Shuttle system for installation in the selected railyard. To meet the needs of the particular railyard, the Site Shuttle system consisted of two robotic site shuttles, two call boxes, one master control unit and 5 specified destinations. Figure 6 provides a view of the system.

Figure 6: The Site Shuttle System

THE ROBOTIC SHUTTLES

To meet the reliability, space and service support the railroad wanted, MFC chose the John Deere four-passenger, 855D S4 Gator. The Gators are diesel powered to meet the type fuel used in the rail yard.

The Site Shuttle vehicles are completely autonomous. At the mandate of the railroad, there is no steering wheel, or brake or accelerator pedals. For safety, there are two emergency stops (E-Stops) located in the cabin. One on the front dash and the second is mounted directly behind the front seats for access by personnel riding in the back seat. The vehicles possess obstacle detection and avoidance for safety and efficiency. However, unlike the SMSS™, which will immediately direct itself around an obstacle, the Site Shuttle will come to a halt and wait to see if the obstacle will move away. If after a set amount of time (seconds), the obstacle has not moved, the Site Shuttle will attempt to find a way around the obstacle. This procedure was implemented both for added safety and to accommodate the normal railyard traffic of maintenance and utility trucks moving through the yard. Speed of the vehicles ranges from 3 to 15 mph, to accommodate tight spaced areas and long runs on wider roads. To accommodate crew baggage, tools and other equipment, a special metal box was installed instead of the standard box bed. The metal box also

Figure 7: The Site Shuttle exterior and interior.

contains an extra 40 gallons of fuel to meet the railroads desire to only refuel the vehicles once a week. At the railroad's request, cameras were installed in both interior and exterior locations. Reason: to record acts of vandalism or accidents, so that evidence would be available. Figure 7 shows the Site Shuttle vehicle.

OPERATIONAL DESCRIPTION

The Site Shuttle system operates with an on-call procedure. When not being used, the shuttle vehicles autonomously drive into a special garage built for them and park themselves. The vehicles "sleep" until called. When the diagnostic system detects the batteries getting low, it automatically starts the engine to recharge them. When called by a crewman, the vehicle "wakes up", conducts a self-diagnostic and then cautiously proceeds out of the garage, watching for oncoming traffic.

The shuttle selection process is as follows: when the call box signal is received the shuttle that is idle and has the shortest travel distance and time is selected. If they are both in the garage at the same time, the same vehicle will likely always leave first. However, if a shuttle is active then the shuttle in the garage would be called. In the future, we will introduce a balancing feature to prevent the same vehicle from always being selected.

The site shuttles travel on pre-designated routes, for safety. For additional safety, jersey barriers lined one portion of the route, to prevent tractor-trailer, intermodal operations from entering the shuttle travel lanes.

For the crewmen, there are two call boxes located at strategic locations in the railyard. Operation is simple, the crewman opens the weather protectant cover, pushes the appropriate number on a key pad and then pushes ENTER. The box unit then transmits a signal, over the radio communications network, which is received by one of the vehicles. The vehicle wakes up and proceeds to the call box from which it received the request. Upon arrival, the vehicle conducts a three-point turn and positions itself for the return trip. It lets the crewman know it is safe to approach and board by sounding the vehicle horn once. The crewman opens the door, enters, buckles his seatbelt and then pushes the appropriate button on the key pad mounted on the dashboard, to select his destination. He then pushes ENTER. The vehicle then sounds the horn three times to notify the crewman that it is about to depart. The shuttle then travels the designated route at three to fifteen miles an hour, dependent on the road width and closeness to an operating train.

Upon arrival, the shuttle pulls into the designated parking area and stops. It then sounds the horn once, letting the crewmen know it is safe to exit the vehicle. The vehicle will remain in this spot for a designated period (set by the railroad), if not called to another call box, and then will conduct a three-point turn and return to the garage.

To accomplish the precision navigation accuracy required to operate in the railyard environment, navigation was enhanced by the use of Real Time Kinematic (RTK) receiver. Which enhances the precision of position data derived from satellite-based positioning systems. Figure 8 illustrates the system operation.

Figure 8: The Site Shuttle Operation.

OPERATIONAL BENEFITS

The Site Shuttle system provides several benefits. It is able to operate 24 hours a day, seven days a week. It permits all weather operation; however, severe conditions will impede its operation, just as it will humans operating in those environments. It will provide significant cost savings through the reduction of salaries, health care and retirement pensions. It provides increased safety, as the vehicles will not fall asleep or be distracted from driving. It provides timely response. Once called, the vehicles immediately respond. The system will mitigate hacking, spoofing and take-overs by using anti-tamper processes and AES-256 SHA-512 Suite B Encryption Algorithms.

CHALLENGES OVERCOME

In conducting the development, integration and testing of the system, we were faced with several challenges which we overcame.

One of the greatest challenges was conducting safe operations in a very dynamic and dangerous environment. The trains operating in the yard cannot stop instantly, even though they were limited to 10 miles per hour. Additionally, the yard had active truck and personnel traffic, which was not predictable. To mitigate some of these issues, the railroad installed jersey barriers on the pathways that traveled by the tractor-trailer, intermodal operation near the hump. That prevented the intermeshing of the shuttles with the tractor-trailers. Special signage was posted throughout the yard warning of autonomous vehicles operating in the area.

Another major challenge was solving the issue of GPS-Denied condition when the vehicles were parked in the special garage. Ultimately, we found a solution and it worked very well.

Another challenge was navigating through a narrow, steep sided culvert crossing and a very narrow passage under a bridge. The problem with the bridge was exacerbated by the passage of train cars, because the side overhang of the cars can be as much as two feet. That was solved by significant constriction of the “electronic fence”, forcing the vehicle to maintain an exact path, with no deviation.

A final challenge was to keep the system affordable. This was done by using low cost components and streamlining the architecture. Figure 9 illustrates some of the challenges.

Figure 9: The Site Shuttle Challenges.

SUMMARY

Lockheed Martin successfully developed, integrated and tested the robotic Site Shuttle in a fully operational and stressful environment. It was very challenging, but an open dialogue with the railroad personnel, careful planning, advanced designs and extremely qualified personnel succeeded in overcoming the challenges. Additionally, the vehicle agnostic design of our autonomy significantly facilitated the successful development of the robotic Site Shuttle.

Lockheed Martin continues to leverage internal and government investment to continue to improve state of the art and expand applications to other industries.

We are also pursuing opportunities to expand applications and provide greater efficiency and safety in additional railroads, ports, depots, automated resupply, site security and reconnaissance.