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OMNI-DIRECTIONAL AUTONOMOUS GUIDED VEHICLE (AGV) WITH WIRELESS NAVIGATION

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ABSTRACT

Automatic guided vehicles (AGV) have made big inroads in the automation of assembly plants and warehouse operations. There are thousands of AGV units in operation at OEM supplier and service facilities worldwide in virtually every major manufacturing and distribution sector. Although today's AGV systems can be reconfigured and adapted to meet changes in operation and need, their adaptability is often limited because of inadequacies in current systems. This paper describes a wireless navigated (WN) omni-directional (OD) autonomous guided vehicle (AGV) that incorporates three technical innovations that address the shortfalls. The AGV features consist of: 1) A newly developed integrated wireless navigation technology to allow rapid rerouting of navigation pathways; 2) Omnidirectional wheels to move independently in different directions; 3) Modular space frame construction to conveniently resize and reshape the AGV platform. It includes an overview of the AGVs technical features and how the flexibility and agility can be adapted to fit military and commercial application. The AGV is being evaluated as a mobile work station platform and a precise material handling robot.

INTRODUCTION

An autonomous robotics vehicle (ARV) can be programmed to maneuver to a geographical designated location using a global positioning system (GPS), unless GPS signals are degraded and/or not available. Factors rendering GPS ineffective are numerous and hence GPS guided navigation would fail when GPS signal suffer from multipath and blockage. An ultra-wideband (UWB) local positioning system (LPS) has been proposed for complementing the GPS in many scenarios including operating indoors, under foliage, etc. This project adapts the UWB LPS for an ARV to track and follow another object such as person or vehicle. The developed UWB tracking system fuses UWB localization and an inertial measurement unit (IMU) sensor reference to reliably pinpoint the object location relative to the ARV. Several useful techniques including self-calibration trilateration, quaternion kinematics and sensor fusion were utilized to enhance robustness of results. An experimental demonstration of an R-Gator autonomously follow a lead person in an indoor environment culminates and highlights the project. **Figure 1** shows a version of the wireless navigated omni-directional autonomous guided vehicle developed by Omnico AGV to demonstrate flexible and agile operation.

Figure 1: An Omnico AGV developed for flexible and agile operation

SCALABLE OMNI-DIRECTIONALVEHICLE (ODV)

Omnidirectional mobile platform

A mobile robot should also be agile in its mobility [11]. On hard surfaces where slips are negligible, OmnicO autonomous guided vehicles (AGVs) (see **Figure 2**) have been fitted with Mecanum wheels, to provide instant movement in any direction without changing orientation. They have a zero turning radius, allowing it to simultaneously rotate while following a defined path. The vehicle operates in confined space and orientates easily to line up with plant operations. This proficiency speeds up material handling, assembly processes and thus saving cost for users. Current AGVs use Ackermann steering mechanisms which are inherently difficult to maneuver in confined space and limited in movement

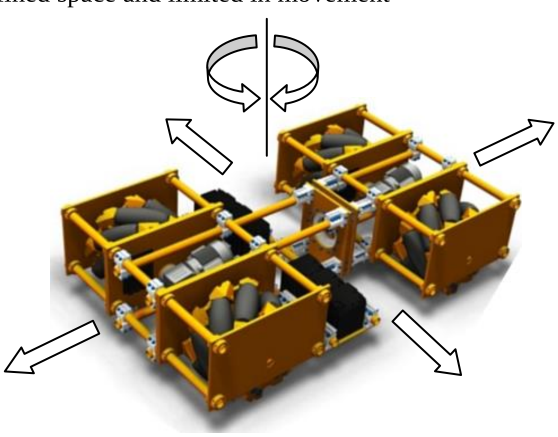

Figure 2: An omnidirectional AGV fitted with Mecanum wheel is able to move independently in different directions to provides agile mobility for speedy maneuvers.

Modular Space Frame Construction

Additionally, the frame for the OmnicO AGV has been constructed with modular space frame components and proven technology capable of high rigidity and strength (see **Figure 3**). The flexible framing provides ease of resizing and configuration. Current AGVs are constructed around a fixed frame chassis which is inherently inflexible for modification of shape and size.

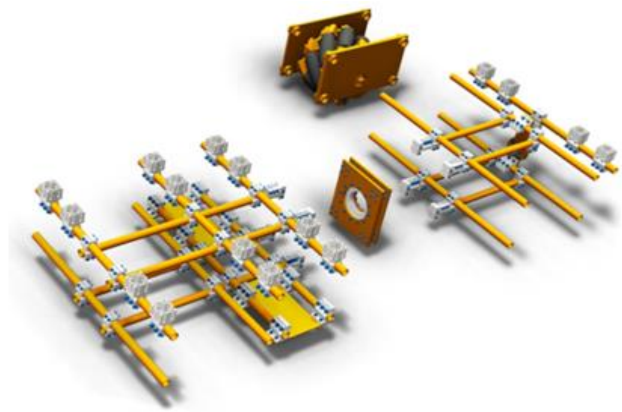

Figure 3: Flexible space frame construction conveniently allows resize and reshape of an AGV platform.

AUTONOMOUS AND SEMI_AUTONOMOUS OPERATIONS

OmnicO AGV is equipped with five different navigation systems including computer stereo vision, GPS, UWB, IMU and dead reckoning sensing devices, integrated by a sensor fusion decision scheme. The fusion software will automatically select which navigation system will best perform the task at hand.

The AGV incorporates autonomous and semi-autonomous controls for accomplishing tasks in the face of uncertain and unexpected variations in ground vehicle operations. A common example is the navigation and guidance control systems that will determine the best route while avoiding obstacles in its path.

Example of Computer Vision Guidance

Replacing humans with machinery is difficult, especially when the tasks to be performed are highly complex and mission sensitive, and accountability is critical. An ongoing effort is the evaluation development of a computer vision weapon loader, for robotic manipulation of a missile or bomb with precision and speed. The robotic system will be a semi-autonomous machine that will handle the task of reloading the missile onto the launcher of a fighter aircraft

(**Figure 4**). Stereo computer vision is used to autonomously recognize desired locations and load and secure payload onto aircraft wings. The omni-directional capability allows holonomic movement for adjusting and attaching payload. The semi-autonomous operation with a human-in-the-loop control interface will accomplish the reloading in a minimum of time with a minimum of manpower.

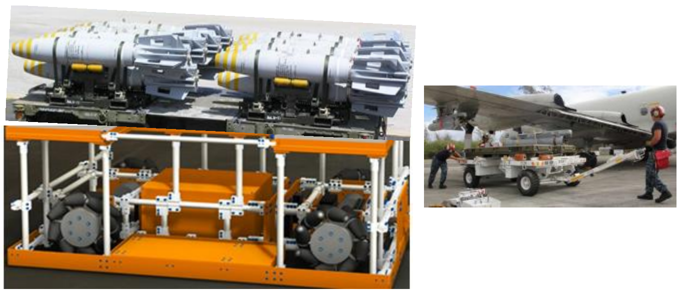

Figure 4: OmnicO AGV weapon loader (on-going development)

Example of Wireless Omni-directional Walk-On AGV Workstation

The omnidirectional AGVs provide a broad range of tasks, from simple tasks like building up components and assemblies on a moving platform to pulling carts. The AGV with mecanum wheels main advantage over other utility vehicles is its zero degree turning radiuses, which allows it to turn in any direction from a fixed point. This allows the AGV to operate in confined spaces by eliminating additional space required to accommodate the large turning radius of the vehicle. The chassis construction is made up of modular components and tubing allowing for adjustable space frame type construction. **Figure 5** shows a prototype OmnicO AGV with an attached walk-on platform allowing the technician to reach the axle center ergonomically and ride with the AGV to complete work. When work is required at the axle ends, (safety will not allow a technician to work between moving vehicles) the mecanum wheels can rotate the moving AGV to place the axle ends into the work cell adjacent to the moving line, then rotate the AGV 180° to deliver the opposite axle end to the technician. This is a total flexible manufacturing feature that is presently not available.

Figure 5: OmnicO AGV with payload and walk-on work platform.

NAVIGATION & GUIDANCE STRATEGY

Additionally, the AGV can be equipped with a wireless navigation and guidance system that allows rapid rerouting for the mobile platform. Below is a description describing how ultra-wide band (UWB) RF work on a mobile ground vechile platform

UWB Localization

To be really flexible in operations, an unmanned ground vehicle (UGV) must necessarily be equipped with a navigation and guidance system that can be readily programmable. A new wireless navigation system that combines global positioning system (GPS), inertial measurement and dead reckoning technologies with a next generation ultra-wideband (UWB) radio ranging system, has been recently developed and tested [1]-[7]. The fusion of sensors relies on self-calibration trilateration, quaternion kinematics and special filtering to ensure robustness of localization results. The relatively low cost integrated navigation means that unlimited 'virtual' paths can be wireless routed via program to guide AGVs indoor, outdoor, and mixed environments.

Figure 6 illustrates a constellation configuration of UWB local positioning system (LPS) for guiding an omni-directional vehicle that can be used for an indoor environment. The LPS works just like a GPS except that the UWB LPS satellites are Smart Tracking Transceivers (STT), shown in **Figure 7**, under direct local control of the users. **Figure 8** shows the UWB LPS installed on a vehicle for tracking a moving object equipped with an STT. The STT units, available from Dataspeed Inc. [21] have multiple communication interfaces, with the fixed STT's communicating using Ethernet. The vehicle mounted STT communicates with the vehicle controller using either an Ethernet or CAN connection.

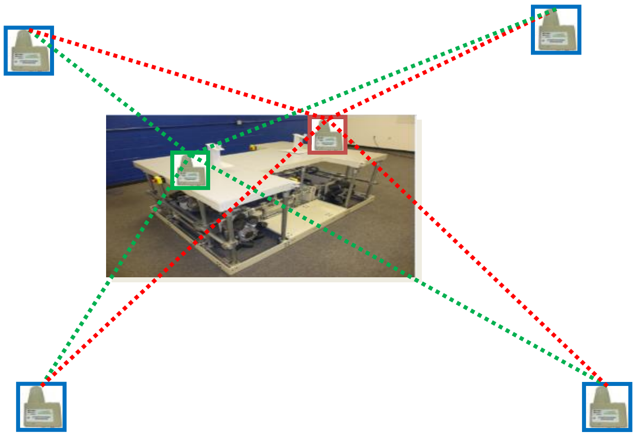

Figure 6: UWB LPS in a constellation configuration for accurate positioning.

Figure 7 : Smart Tracking Transceiver

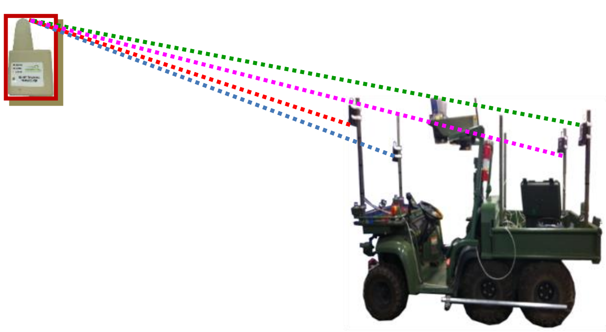

Figure 8: Mobile UWB LPS in a radiating configuration for tracking objects.

Base Radio Calibration

The UWB localization algorithm tracks the 2-D position of a target radio from a set of base station radios. The algorithm is easily scaled to accommodate any number of base and target radios. There must be at least 3 radios (R_1, R_2 and R_3) to form a "foundation" of the base radio configuration. The coordinates of any more base radios ($R_4, \ldots, R_n$) are then defined in terms of these three foundation radios, as seen in **Figure 9**.

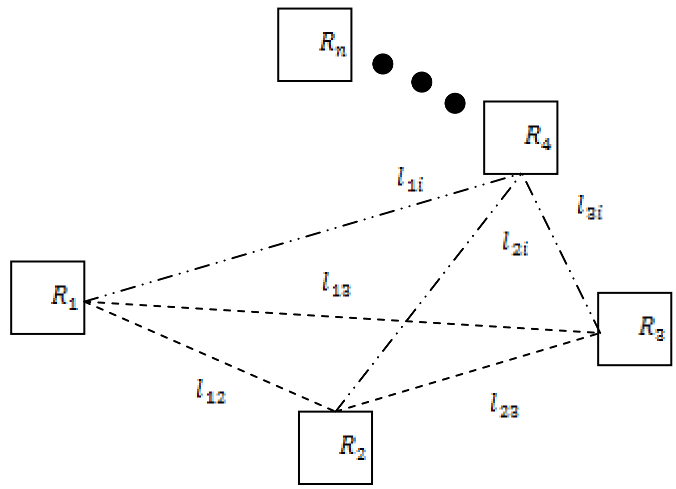

Figure 9: Base Radio Configuration.

The coordinates of R_1 are defined to be the origin of the radio coordinate frame, and the line from R_1 to R_2 is arbitrarily defined as its x axis. Based on these two definitions, the coordinates of the foundation radios can be computed by a set of trilateration algorithm tuned by rule-based dynamic filtering [1]-[10].

To compute the coordinates of the base radios from (1) and (2), the distances between each foundation radio (l_{12}, l_{13} and l_{23}) and the distances from each additional base radio to each foundation radio (l_{1i}, l_{2i} and l_{3i}) need to be measured. This is accomplished by running a calibration routine that acquires these measurements from the radios.

However, in order to provide the greatest flexibility in the configuration of the base radios, the 3-D locations of the base radios are necessary to compute. Running the calibration only computes the 2-D coordinates of the base radio configuration relative to the plane that is formed by the three foundation radios.

To compute the coordinates relative to a level plane, the heights of each base radio are measured and provided a priori. With the height information, a rotation matrix can be constructed to project the radio plane coordinates into level coordinates. After projecting all base radio coordinates, the z coordinates of the radios can be set to the height measurements to complete the 3-D calibration.

When the calibration is complete, the 3-D coordinates of all n base radios are computed. These coordinates are relative to a coordinate frame centered at R_1, whose x axis lies along the line between R_1 and R_2, and is oriented level with the ground. The calibration process is outlined in the flowchart in **Figure 10**.

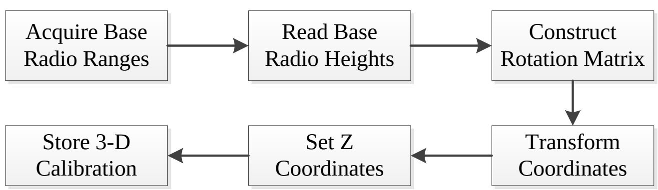

Figure 10: UWB calibration procedure.

Localization Algorithm

Experiments have shown that explicit 3-D localization of a target is very noisy when the base radios do not have much variance in their heights. Also, imposing geometric constraints on how the base radios have to be mounted is a problem when implementing a field-ready system. Therefore, a much more robust 2-D tracking algorithm is used instead, which handles base station configurations with any height distribution (even all coplanar).

A flowchart of the algorithm is shown in **Figure 11**. The algorithm has three main modes of operation, which are discussed in more detail in the following sections:

- **Implicit 2-D Triangulation:**
  Using a prior localization estimate, a pair of base radios can be selected to yield a geometrically optimal triangle to solve to update the localization estimate. The solution is inherently multi-valued, and the prior estimate is also used to choose the "obvious" solution.

- **Explicit 2-D Trilateration:**
  Using range measurements from three base radios, the 2-D location of the target has a closed form solution based solely on the stored coordinates of the base radios and the range measurements.

- **Automatic target height calibration:**
  It is assumed that the height of a target radio does not change significantly over a short period of time, but an estimate of the height is necessary. This mode solves triangulation solutions from all possible combinations of base radios, and iteratively adjusts the height estimate until the solutions are in agreement. This process is run periodically to keep the height estimate up to date.

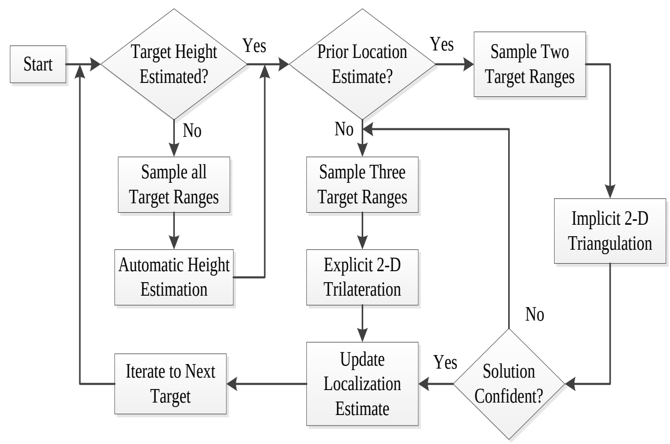

Figure 11: Flowchart of the localization algorithm

Sensor Fusion

Information from a 3 axis accelerometer, gyro and magnetometer is fused with the UWB position estimate using a Kalman filter algorithm to provide a cleaner estimate. **Figure 12** shows a block diagram of the estimation/filtering approach [12]-[19].

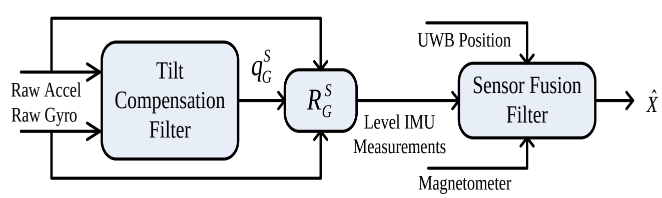

Figure 12: Navigation estimation/filtering approach.

The tilt compensation filter is used to estimate the pose of the sensor by generating a quaternion representing the rotation from the sensor frame to the ground frame. Using the estimate q_G^S, the raw accelerometer and gyro measurements are transformed into the ground reference frame. These tilt-corrected measurements are then used by the sensor fusion filter to be fused with the UWB position estimate to produce a better vehicle state estimate $\hat{X}$.

Quaternion Definitions

For this purpose, quaternions have proven to be the most useful and robust method to represent the orientation of the sensors.3-D rotations can be described from several transformation (**Figure 13**) including

- Euler angles: A set of 3 orthogonal body axes and 3 rotation angles about those axes
- Rotation or Direction Cosine Matrices: 3x3 orthogonal matrices
- Quaternions: angle-axis, an axis vector, and a rotation angle around that axis

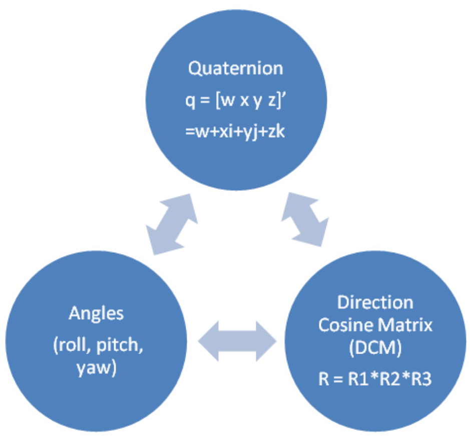

Figure 13: 3D kinematic transformations

In order to use quaternions in state space models, the following definitions are needed [12]-[19]. A quaternion is defined as a 4-D vector consisting of a real component and 3 independent imaginary components. A quaternion describing a rotation from reference frame A to another reference frame B is written as:

$$q_A^B = w + x\hat{\imath} + y\hat{\jmath} + z\hat{k} \qquad (1)$$

where the real component can be conceptually related to the amount of rotation, and the vector $[x \quad y \quad z]$represents the axis of rotation. The rotation described by q_A^B can also be represented by an equivalent rotation matrix, defined in terms of the quaternion components:

$$R_A^B = \begin{bmatrix} w^2+x^2+y^2-z^2 & 2(xy-wz) & 2(xz+wy) \\ 2(xy+wz) & w^2+y^2-x^2-z^2 & 2(yz-wx) \\ 2(xz-wy) & 2(yz+wx) & w^2+z^2-x^2-y^2 \end{bmatrix} \qquad (2)$$

The time derivative of a quaternion is defined as:

$$\dot{q}_A^B = \frac{1}{2} q_A^B \Omega \qquad (3)$$

where $\Omega = 0 + \dot{\rho}\hat{\imath} + \dot{\theta}\hat{\jmath} + \dot{\psi}\hat{k}$are the roll, pitch and yaw rotation rates represented in quaternion form. (2) can be expanded into a system of differential equations:

$$\begin{cases} \dot{w} = -\frac{1}{2}\left(x\dot{\rho} + y\dot{\theta} + z\dot{\psi}\right) \\ \dot{x} = \frac{1}{2}\left(w\dot{\rho} + y\dot{\psi} - z\dot{\theta}\right) \\ \dot{y} = \frac{1}{2}\left(w\dot{\theta} + z\dot{\rho} - x\dot{\psi}\right) \\ \dot{z} = \frac{1}{2}\left(w\dot{\psi} + x\dot{\theta} - y\dot{\rho}\right) \end{cases} \qquad (4)$$

The quaternion dynamics model can be visualized graphically, as shown in **Figure 14**.

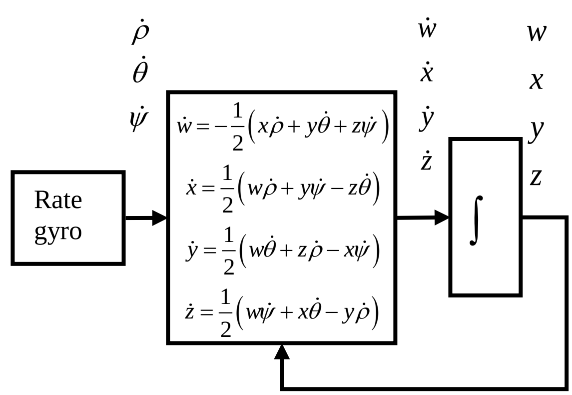

Figure 14: Quaternion kinematics model

Guided Trajectory Planning

Using a robust adaptive Kalman estimated pose $\hat{X}$, the omnidirectional vehicle can be controlled b a specified trajectory using a Predictive Linear Quadratic Tracker (PLQT) algorithm.

CONCLUSIONS

OmnicO AGV has the three technical innovations described in this paper that address gaps in the marketplace: 1) Speeding up the placement of material (Omnidirectional capability), 2) Speeding up the reconfiguration of the AGV (Modular Frame System) or 3) Rapid reconfiguration of the path (Navigation System). These innovations will lead to cost savings for the customer: The innovative AGV will enable entrance into manufacturing plants that desire highly mobile, reconfigurable, cost effective AGV platforms. AGVs provide a broad range of tasks, from simple tasks like building up components and assemblies on a moving workstation platform to autonomous pulling carts to semi-autonomous precision loader.

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