Localization of an Autonomous Personnel Carrying Vehicle in Indoor Environments

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ABSTRACT
There is an emerging need of intelligent vehicles on indoor environments such as university campuses, airports or shopping malls. These intelligent vehicles can help elderly, disabled, or people with heavy luggage. This paper describes an intelligent vehicle that can be used indoor as well as outdoor areas for this purpose. Finding the exact location for indoor robots is not an easy task, since Global Positioning System (GPS) is not available indoors. In this work onboard sensors such as motor encoder and steering-wheel encoder were used to obtain localization estimates. The errors are determined to be low even when the vehicle travels long distances.

CCS Concepts
• **Computing methodologies → Robotic planning**
• **Computer systems organization → Robotic autonomy**
• **Computer systems organization → Sensors and actuators**

Keywords
Driverless Vehicles; Autonomous; Obstacle Avoidance

1. INTRODUCTION
As of 2016 there is a high interest of developing autonomous vehicles on research community, as well as on various companies [1-7]. These efforts generated multiple successful autonomous vehicle prototypes on the roads worldwide. These self-driving, autonomous vehicles are expected to improve our life quality by reducing road accidents [2], traffic stress, and improving efficiency on roadways with cooperative driving [8].

Although the roadways take the biggest share of our transportation, there is a considerable need of intelligent transportation systems on indoor environments such as university campuses, shopping malls, and airports. In literature, only a few work deals with operating robots and transportation vehicles in public, crowded environments. The most successful implementation of robots working with people is the automated guided vehicles (AGVs). These vehicles are used for transportation of materials on factories [9-10]. Unfortunately, these systems run on predetermined paths, usually with an embedded wire on the floor. This kind of approach is not feasible for our everyday environments.

Figure 1. Transportation of people indoors.

Although, navigation of autonomous vehicles on outdoor areas is under consideration of multiple research projects, navigation within indoor areas such as buildings, tunnels are not very common. This environment requires strictly electric vehicle due to risks of hazardous internal combustion engine residue gasses. Additionally, having an autonomous vehicle inside a building poses additional problems. Firstly, GPS sensor which is one of the most relied on sensor for obtaining down to cm level accuracy on localization of autonomous vehicles, cannot be used inside buildings. Secondly, pedestrian traffic, and human behavior can cause additional problems.

This paper is focused on developing satisfactory localization techniques in indoor environments that can be used by an intelligent autonomous transporting vehicle to transport humans

ICMSCE '17, February 02-04, 2017, Kayseri, Turkey
© 2017 ACM. ISBN 978-1-4503-5207-9/17/02…$15.00
DOI: http://dx.doi.org/10.1145/3045714.3045719

and goods safely in known indoor and outdoor public areas (e.g. Fig.1).

The paper is organized as follows: Section II describes the system design of the proposed vehicle. The localization problem and our approach to solve it are presented in Section III. Experiments are presented in Section IV. Concluding remarks and future work are presented in Section V.

2. VEHICLE DESIGN

The main area of operation of the vehicle is indoors. Due to the hazards of combustion gases, we decided to choose an electric golf cart as the main vehicle. This vehicle has been upgraded with various actuators and sensors to enable automatic control, while leaving the vehicle drivable by a person, in case it is necessary.

There is a dSpace controller (MABX2), and Arduino control card, and a desktop computer on board the vehicle. MABX2 is responsible for control of vehicle main motor, brake motor and steering wheel motor as well as reading steering wheel encoder and motor encoder data. Arduino acts as a separate controller to read brake potentiometer, and emergency controller and apply emergency brake if necessary. The onboard desktop computer is responsible to read two LIDAR sensors, one USB camera, exchange information with a tablet pc, MABX2 and ground computer through modems and wi-fi. The system architecture is given on Figure 2.

Details of the system are given on [11]. The developed prototype human carrying system is shown in Figure 3. The vehicle can be controlled under remote control, or it can be put in to the automated mode. In the automated mode, the vehicle uses two on board LIDAR sensors to avoid any static or dynamic obstacles and drive to the defined way-points to the goal location. An algorithm based on potential-field method [12-14] was implemented to avoid obstacles during the journey.

3. LOCALIZATION

In order to successfully control the vehicle through complex environments, the vehicle location should be known. The techniques for localization are; odometry, GPS, inertial navigation and visual techniques.

In many studies, the vehicle localization data is obtained with GPS sensor. For an indoor vehicle, relying on GPS is not an option due the fact that the GPS data is not reliable or not existing due the inability to access satellite data.

Another approach on localization is to use vehicle tire rotation as well as steering wheel. This approach is called odometry.

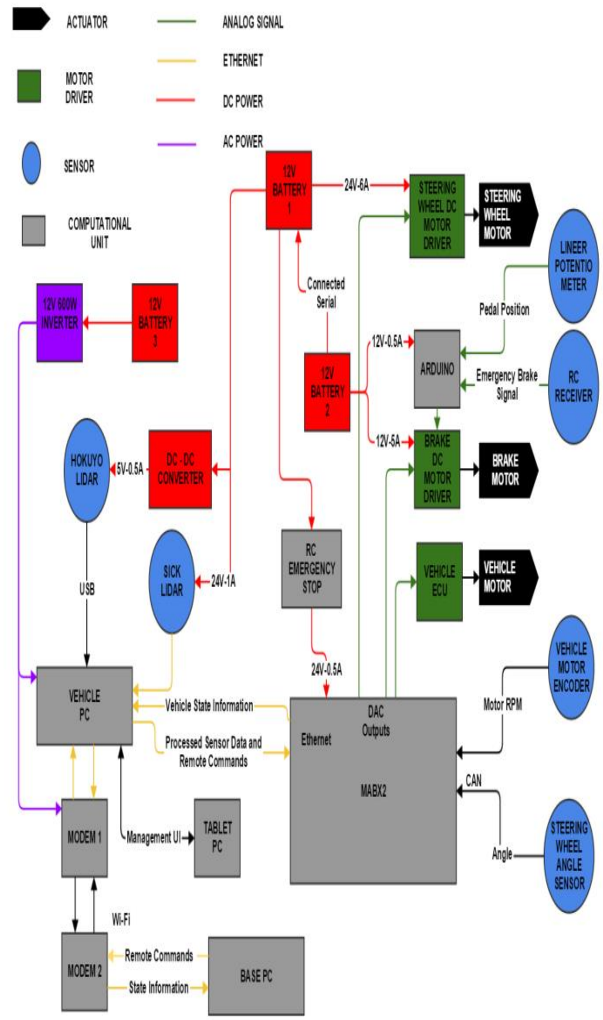

Figure 2. System Elements and Connections.

Figure 3. Developed autonomous transport vehicle

Figure 4. An indoor environment that the proposed system can be useful

In recent years, another option has emerged. This approach uses inertial navigation system (INS), which relies on inertial sensory techniques to estimate vehicle position. In this approach Micro Electro Mechanical systems (MEMS) based micro sensors involving accelerometers, gyros, and magnetometer are combined in a package, and a microprocessor fuses the data through a filter to calculate the vehicle position. If Global Navigation Satellite System (GNSS) data is available, the estimated of INS can be updated or calibrated. This approach is called as GNSS/INS integration, and it proposes even smaller errors. Xsens MTI-G-700, proposes accuracy of 2 meters depending on GNSS availability and placement of the antenna [15]. Although GNSS based techniques are simple, easy to implement and proposes small localization errors, it is not applicable to our environment due to the fact that the indoor environment does not have GNSS reception.

3.1 Odometry

In indoor environment, one of the most serious problems is localization. Consider a 2D vehicle as shown in Figure 5. As long as there is no wheel slip, the ***x*** and ***y*** positions of the vehicle can be calculated through kinematic equations.

Let us call, forward velocity as u_1, Steering angle as φ, heading of the vehicle as θ. The distance between the front and the rear axles is given as *l*. The velocity of the vehicle along x, y axes and angular velocity around z axis can be calculated using Equation 1.

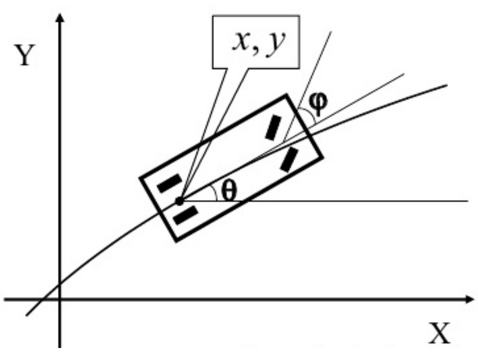

Figure 5. Calculation of position of the vehicle.

$$\begin{Bmatrix} x \\ y \\ \theta \end{Bmatrix} = \begin{Bmatrix} u_1 \cos\theta \\ u_1 \sin\theta \\ \dfrac{u_1}{l} \tan\varphi \end{Bmatrix} \quad (1)$$

The non-holonomic constraint is given as;

$$x \sin\theta - y \cos\theta = 0 \quad (2)$$

On the vehicle, an encoder is used as main sensor for localization calculations. The rotational speed of the motor shaft is obtained accurately from encoder. This information is used together with angle information from steering wheel and constant wheel circumference value, to calculate the vehicle position.

To implement the odometry functionality, a localization subsystem is included in main simulink model (Figure 6) on MABX. It receives wheel angle information from steering wheel control subsystem, using "from" and "go to" blocks. Wheel speed is received from encoder in wheel block, using encoder block of dSpace RTI and making conversion. Forward velocity is calculated from motor speed and fed to kinematics block with steering wheel angle. Position is calculated in kinematics block using the Equations 1 and 2.

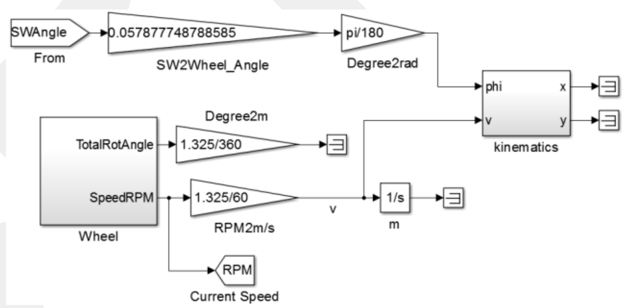

Figure 6. Vehicle localization model.

4. EXPERIMENTS

Various experiments were performed to test the autonomous vehicle and its functions. Figure 7 shows the autonomous operation experiment, where the vehicle moved from start position to a goal position while autonomously avoiding obstacles.

Figure 7. Vehicle autonomous operation experiment.

The localization of the vehicle has been obtained due to the method proposed in Section 3 (Figure 8).

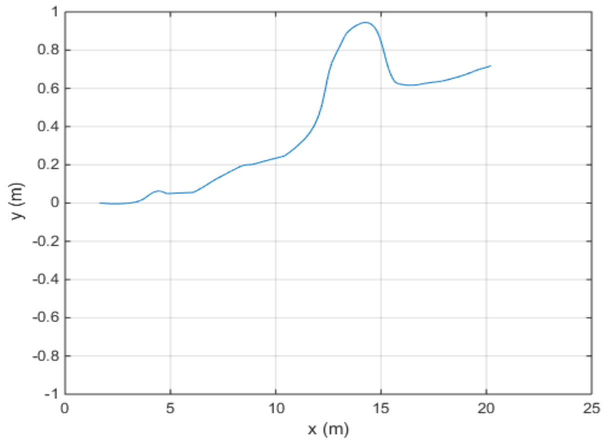

Figure 8. Vehicle position data.

The localization due to odometry has a cumulative error. What we observed through experiments is that error caused by tire slip is very small because of the flat surface and slow moving speed of the vehicle. But on long distances, the real position and calculated position may differ slightly.

5. CONCLUSION

There is a need of autonomous people and package carriers in indoor environments. In this study, the localization approach of an electric autonomous vehicle has been proposed. The approach is based on localization due to odometry.

As a future work, to overcome the problem of cumulative localization error, a GNNS/INS sensor will be included to the system to provide occasional localization updates. One other alternative will be to use computer vision. Square fiducial markers, which is used to determine camera pose fast and robustly, will be placed at some locations on the environment.

6. ACKNOWLEDGMENTS

This research work was supported in part by the Scientific and Technological Research Council of Turkey under Grant 115E345.

7. REFERENCES

[1] O.Khatib, "Real-time Obstacle Avoidance for Manipulators and Mobile Robots," International Journal of Robotics Research, Vol. 5, No. 1, pp. 90-98, 1986

[2] M. Buehler, K. Lagnemma, K., S. Singh, *The 2005 DARPA Grand Challenge: The Great Robot Race*. Springer Tracts in Advanced Robotics, 3540734287, 2007, Springer.

[3] S. Thrun, M. Montemerlo, H. Dahlkamp, D. Stavens, A. Aron, J. Diebel, P. Fong, J. Gale, M. Halpenny, G. Hoffmann, K. Lau, C. Oakley, M. Palatucci, V. Pratt, P. Stang, S. Strohband, C. Dupont, L.E. Jendrossek, C. Koelen, C. Markey, C. Rummel, J. van Niekerk, E. Jensen, P. Alessandrini, G. Bradski, B. Davies, S. Ettinger, A. Kaehler, A. Nefian, and P. Mahoney, "Winning the darpa grand challenge," Journal of Field Robotics, 2006, accepted for publication.

[4] Urmson, C., Anhalt, J., Bagnell, D., Baker, C., Bittner, R., Clark, M. N., Dolan, J., Duggins, D., Galatali, T., Geyer, C., Gittleman, M., Harbaugh, S., Hebert, M., Howard, T. M., Kolski, S., Kelly, A., Likhachev, M., McNaughton, M., Miller, N., Peterson, K., Pilnick, B., Rajkumar, R., Rybski, P., Salesky, B., Seo, Y.-W., Singh, S., Snider, J., Stentz, A., Whittaker, W. "., Wolkowicki, Z., Ziglar, J., Bae, H., Brown, T., Demitrish, D., Litkouhi, B., Nickolaou, J., Sadekar, V., Zhang, W., Struble, J., Taylor, M., Darms, M. and Ferguson, D. (2008), Autonomous driving in urban environments: Boss and the Urban Challenge. J. Field Robotics, 25: 425–466. doi: 10.1002/rob.20255

[5] A. Broggi, P. Medici, et al., "Development of the control system for the Vislab intercontinental autonomous challenge," in Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on, 2010, pp. 635–640.

[6] Wuthishuwong, C., Silawatchananai, C., Parnichkun, M. 2008. "Navigation of an Intelligent Vehicle by using Stand-alone GPS, Compass and Laser Range Finder". Proceedings of the 2008 IEEE International Conference on Robotics and Biomimetics.

[7] Z.J. Chong, B. Qin, T. Bandyopadhyay, T. Wongpiromsarn, E.S. Rankin, M.H. Ang, E. Frazzoli, D. Rus, D. Hsu, K.H. Low,. "Autonomous Personal Vehicle for the First- and Last-Mile Transportation Services". IEEE 5th International Conference on Cybernetics and Intelligent Systems, 2011.

[8] L. Güvenç, İ. M. C. Uygan, K. Kahraman, R. Karaahmetoğlu, İ. Altay, M. Şentürk, M. T. Emirler, A. E. H. Karcı, B. A. Güvenç, E. Altuğ, M. C. Turan, Ö. Ş. Taş, E. Bozkurt, Ü. Özgüner, K. Redmill, A. Kurt, B. Efendioğlu, "Cooperative Adaptive Cruise Control Implementation of Team Mekar at the Grand Cooperative Driving Challenge", IEEE Transactions on Intelligent Transportation Systems, Vol. 13, No. 3, pp. 1062 – 1074, September 2012.

[9] Mart ńez-Barber á, H., Herrero-Pérez, D. 2010. "Autonomous navigation of an automated guided vehicle in industrial environments", Robotics and Computer-Integrated Manufacturing, Volume 26, Issue 4, 296-311.

[10] Ji, M., Xia, J. 2010. "Analysis of vehicle requirements in a general automated guided vehicle system based transportation system", Computers & Industrial Engineering, 59, 544–551.

[11] Ş. Y. Gelbal, E. Altuğ, F. Keçeci, "Design and HIL Setup of an Autonomous Vehicle for Crowded Environments", 2016 IEEE International Conference on Advanced Intelligent Mechatronics, in Banff, Alberta, Canada, July 12–15, 2016.

[12] Wilschut, T. (2011). An Obstacle Avoidance Algorithm for a Mobile Robot Based upon the Potential Field Method, Ph.D. thesis, Eindhoven University of Technology.

[13] Koren, Y. and Borenstein, J. (1991). Potential Field Methods and Their Inherent Limitations for Mobile Robot Navigation, IEEE Conference on Robotics and Automation, pp.1398–1404.

[14] Hellstrom, T. (2011). Robot Navigation with Potential Fields, Umea University Department of Computing Science.

[15] MTi User Manual, Xsens, 27 February 2015.