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ScienceDirect

ICT Express 2 (2016) 53–56

www.elsevier.com/locate/icte

Low-complexity UWB-based collision avoidance system for automated guided vehicles☆

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Received 1 March 2016; received in revised form 29 April 2016; accepted 30 May 2016

Available online 11 June 2016

Abstract

This paper describes a low-complexity collision avoidance system for automated guided vehicles (AGVs) based on active ultra-wide band (UWB) modules. In particular, we consider an industrial warehouse where all the AGVs and target nodes (TNs) (e.g., people) are equipped with active UWB modules. A communication session between a pair of UWB modules permits the exchange of information and the estimation of the distance between them. The UWB module positioned on an AGV is connected to an on-board computer; whenever the UWB module on an AGV receives a message from a TN, it communicates all the received data to the on-board computer that can decide to stop the AGV if the range estimate is below a given threshold. This prevents undesired collisions between the AGV and the TN. In this paper, we present the experimental results of the proposed collision avoidance system obtained using the UWB modules, PulsON 410 ranging and communication modules (P410 RCMs), produced by Time Domain.

Keywords: Collision avoidance; Automated guided vehicles (AGVs); Ultra-wide band (UWB)

1. Introduction

This paper focuses on the application of an ultra-wide band (UWB) technology for collision avoidance within industrial buildings aimed at incrementing the safety in scenarios where Automated Guided Vehicles (AGVs) move. UWB signals are chosen owing to the fact that they represent a leading option for indoor communications and range estimations [1]. Their significant bandwidth guarantees considerably short duration pulses that result in an accurate estimation of the time of flight of the signals traveling between pairs of nodes, rendering the time-based range estimates particularly accurate [2].

Various collision avoidance techniques have been proposed in literature [3]. Such approaches rely on vision-based techniques [4] or on the radar [5]. In this paper, we consider a UWB-based collision avoidance system that allows the identification of target nodes (TNs) such as people because of the UWB-based range estimates. A key assumption is that the AGVs and TNs cooperate. We assume that each AGV and TN within the warehouse is equipped with a UWB module. The UWB module on each AGV is positioned on the top, front part of the AGV and is connected to the on-board computer that can then receive all the information acquired via the UWB channel. This allows the AGV to stop if the UWB communication between the AGV and a TN reveals that the latter is considerably close. The results presented in this paper are derived based on an experimental operation performed within an industrial warehouse, involving an AGV and a TN. The accuracy of the proposed approach is investigated considering the positions of several TNs and is aimed at exploiting the reliability of the considered collision avoidance system. The proposed collision avoidance system uses the UWB PulsON 410 ranging and communications modules (RCMs) by Time Domain, single-board radio nodes with an UWB antenna [6]. The key characteristics of the P410 RCMs is that they provide accurate estimates of the inter-node distances at update rates up to 150 Hz. A list of the

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Peer review under responsibility of The Korean Institute of Communications Information Sciences.

☆ This paper has been handled by Dr. Hyukjoon Lee.

http://dx.doi.org/10.1016/j.icte.2016.05.004

Fig. 1. Picture of the AGV in an industrial scenario.

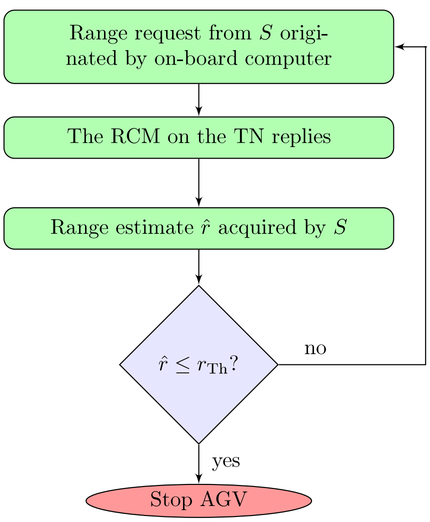

Fig. 2. Block diagram of the collision avoidance system architecture.

data structures that the C library provides can be found in the official Time Domain documentation [7].

2. Scenario and notations

In this section, we describe the scenario and introduce the performance metrics for evaluating the experimental results shown in Section 3. The considered environment is a warehouse and the collision avoidance system involves an AGV and a TN, each equipped with an RCM. In Fig. 1, a picture of the considered AGV is shown; the front side (without the forks) and the back side (with the forks) are highlighted. The RCM on the TN is not connected to a host because it is carried as a UWB module that needs to be perceived by the AGV. The RCM on the AGV, denoted as S, is connected to the on-board computer that originates all the range requests and receives all the data acquired by the RCM. The AGV can then be stopped in case of a potentially hazardous situation, namely, if a TN is exceedingly close to the AGV. The block diagram in Fig. 2 outlines the system architecture.

The performance of the proposed system is evaluated considering the positions of the various TNs, as shown in Fig. 3 and they are denoted as $\{\mathrm{TN}_i\}_{i=1}^{22}$. In all the cases, the height of the TNs coincides with the height of the module, S, that is

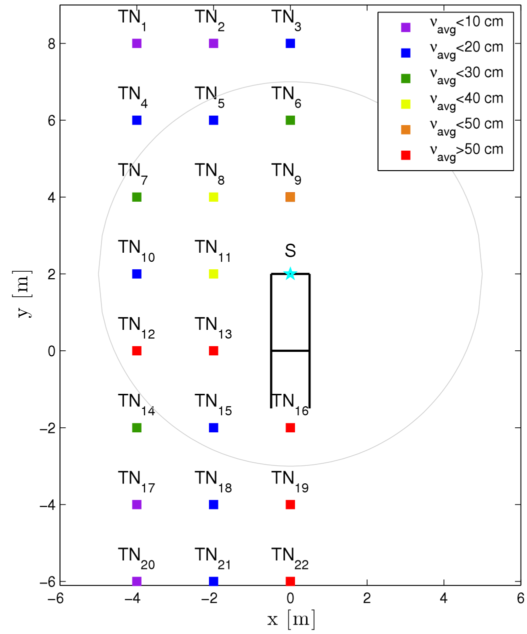

Fig. 3. The LGV (black rectangle) and its forks (black lines) are depicted together with the node, S (cyan star). The TN positions are also shown (colored squares). The colors are associated with the values of the average range error, ν_{avg}. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

placed on the top of the AGV. In order to simplify the notation, as all the RCMs lie on the same plane and their coordinates are denoted as vectors of length, 2, considering only the x and y components. The coordinates of S in the considered coordinate system can be expressed as,

$$\underline{s} = [s_{\mathrm{x}}, s_{\mathrm{y}}] \tag{1}$$

where $s_{\mathrm{x}} = 0$ m and $s_{\mathrm{y}} = 2$ m. The true positions of the TNs are denoted by $\{\underline{u}_i = [x_i, y_i]\}_{i=1}^{22}$. The actual distances between S and the ith TN can be expressed as:

$$r_i = \|\underline{s} - \underline{u}_i\| \quad \forall i \in \{1, \ldots, 22\}. \tag{2}$$

For each TN position, N range estimates from S are considered, denoted as $\{\hat{r}_i^{(j)}\}_{j=1}^{N}$. The range error relative to TN_i in the jth range estimate can then be defined as:

$$\nu_i^{(j)} = |r_i - \hat{r}_i^{(j)}| \quad j \in \{1, \ldots, N\}. \tag{3}$$

When considering the ith TN, the average range error, ν_{avg}, and the maximum range error, $\nu_{\max}$, are:

$$\nu_{\mathrm{avg}}(i) \triangleq \frac{1}{N} \sum_{j=1}^{N} \nu_i^{(j)} \qquad \nu_{\max}(i) \triangleq \max_{j \in \{1,\ldots,N\}} \nu_i^{(j)}. \tag{4}$$

As per the definitions in (4), the standard deviation of the range error relative to TN_i can be defined as:

$$\sigma_\nu(i) \triangleq \sqrt{\frac{1}{N-1} \sum_{j=1}^{N} \left(\nu_i^{(j)} - \nu_{\mathrm{avg}}(i)\right)^2}. \tag{5}$$