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An Analysis of Automated Guided Vehicle Standards to Inform the Development of Mobile Orchard Robots

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Abstract: This paper aims to leverage knowledge and experience, gained from the well-established Automated Guided Vehicle (AGV) industry, to highlight key hazards and solutions that may be considered in the risk assessment and risk reduction of large autonomous mobile service robots in orchards. There are notable differences between orchard environments and the warehouses or factories, where AGVs operate, including the presence of uncontrolled growth, exposure to the weather as well as the slope, softness, cluttered and undulating nature of terrain in orchards. However, there are also many similarities in the technologies used, the basic navigation tasks that have to be performed and the nature of the hazards that arise. This paper discusses these similarities and differences in relation to key parts of AGV standards, EN 1525:1997 and ANSI/ITSDF B56.5-2012.

Keywords: Orchard Robotics, Autonomous Mobile Robots, Agriculture, Automated Guided Vehicles, Standards.

1. INTRODUCTION

Mechanization in orchards using autonomous mobile robots has the potential to reduce the use of pesticides and improve the efficiency of fresh fruit production, by performing tasks such as weeding, targeted spraying, harvesting and transport. It is an area that is developing, with a number of research groups producing working prototype systems (Li et al., 2009, Mousazadeh, 2013, Shalal et al., 2013). One of the barriers to commercialization will be adequately performing risk assessment and risk reduction. The magnitude of this task is compounded by the novelty of the technology. The authors feel that it is best to have an open discussion in the community about risk assessment and risk reduction for the mutual benefit of developers and eventual end-users alike.

Previous work in risk assessment and risk reduction for orchard robots includes a risk assessment and design of the Safety Related Parts of the Control System (SRP/CS) for an autonomous tractor (Griepentrog et al., 2009). However, this work found it necessary for the autonomous tractor to be supervised. The goal of this paper is to consider unsupervised autonomous vehicles and not to do a full risk assessment but to analyse the past work put into standards, in order to inform a more robust risk assessment in the future.

This paper aims to contribute “information for risk assessment”, which is a precursor of risk assessment according to machine safety standard ISO12100:2010, clause 5.2 (ISO, 2010). Specifically, this paper analyzes experience and, in particular, standards of “similar machinery”, which is how ISO12100:2010 refers to prior art in analogous applications. The similar machinery considered in this paper is the Automated Guided Vehicle (AGV).

AGVs are industrial mobile robots, which can have various configurations and are typically used in factories or warehouses. AGVs are a useful reference point for mobile robots in orchards because they use many of the same technologies that are used in state of the art mobile robots, the basic navigation task is similar in different industries and the AGV industry has established standards, which have evolved from widespread commercial use. AGVs have been in use for over 60 years (Vis, 2004) with over a thousand vehicles commissioned annually in recent years (MHI, 2014). The technologies used for navigation of AGVs this century have included triangulation with 2D laser scanning of reflective beacons, 2D laser scanning of natural features- including simultaneous localization and mapping- and camera based systems, such as those used by Seegrid (Moravec, 2008, Trebilcock, 2011). Similar technologies have been used in recent research in orchard mobile robots (Barawid et al., 2007, Hansen et al., 2011, Bergerman et al., 2012).

The basic task of navigation along pre-planned paths in a low-risk manner is common to AGVs and mobile orchard robots. The fundamental goal of reducing the risk of causing harm to people is the same. The impact and crushing hazards due to collisions, may occur in similar ways. Hence, in developing mobile orchard robots, it seems prudent to learn from the experience of the AGV industry.

One of the key accessible sources of knowledge of the AGV industry is its standards. The key standard in the AGV industry is ANSI/ITSDF B56.5-2012 (ITSDF, 2012). There have been other AGV standards but these have waning relevance. With the adoption of the Machinery Directive, EN 1525:1997, another AGV standard, became outdated with

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many references to obsolete standards (BSI, 1997). ISO 3691-4 was drafted and intended to replace EN 1525:1997; however, this standard was not completed and its development has been restarted as a new project.

In this paper, key hazards, tests, exceptions and solutions from EN 1525:1997 and, in particular, ANSI/ITSDF B56.5-2012 are highlighted and discussed in relation to the development of autonomous mobile service robots for orchard environments. This analysis leads to suggestions for methods to develop safer orchard service robots and the identification of open areas for future research, which will be important for the development of safer collision avoidance systems.

1.1 Determination of the Limits of Machinery

We present here a brief "determination of the limits of machinery", as defined in ISO12100:2010 (ISO, 2010). This is provided for context and is not intended to be full and final documentation, as is required for a formal risk assessment.

The machinery considered in this paper is a relatively large mobile platform, designed to navigate autonomously through orchards. The largest version of the autonomous platform will have overall dimensions in the order of 2.5 metres wide and 3.5 metres long. The top speed of the autonomous platform will be in the order of 2.8 ms^{-1}. The platform will have 3 or more wheels, of which 1 or more will be steered and 1 or more will be driven. Although the navigation control system performs environment based localisation and obstacle detection, it is likely to use sensors that individually are not certified with a Performance Level or Safety Integrity Level, which give measures of the probability of failing to perform safety functions.

The autonomous platform may operate in a variety of horticulture environments such as kiwifruit orchards with a pergola structure and apple orchards with a tree wall structure. The autonomous platform will traverse all rows of an orchard block and will drive between orchard blocks, using predefined maps. It is expected that some orchards will have relatively steep terrain that could be muddy. The terrain is also expected to be undulating and littered with decaying branches and fruit. It is a requirement for operation that the orchard must be recently mown; although, even so, it is expected that weeds will be relatively high in patches.

The autonomous platform will only operate autonomously in relatively fine weather; it will not be deployed in rain, snow or fog. An operator will be available either on hand or remotely to manually recover the vehicle, when it is in a low certainty or fault condition.

The autonomous platform can pick up bins using a lifting mechanism and tines that face in the opposite direction to the main direction of travel. The operation of picking up bins is in the scope of this paper, as it relates to driving towards the bin, creating an area of low clearance.

The autonomous platform will carry harvesting and spraying equipment. However, only the safety of the moving platform itself is considered in this paper.

1.2 Paper Outline

Section 2 discusses various requirements from EN 1525:1997 and ANSI/ITSDF B56.5-2012, the relevance of those requirements to autonomous orchard vehicles and possible solutions to reduce the risk of the relevant hazards. Section 3 discusses some of the weaknesses and some elements that are missing from AGV standards. Conclusions and a road map for future work follows.

2. STANDARDS ANALYSIS

As discussed in section 1, ANSI/ITSDF B56.5-2012 (ITSDF, 2012) is the only current and up to date AGV standard. EN 1525:1997 (BSI, 1997) captures many of the same ideas as ANSI/ITSDF B56.5-2012 but is more stringent in some ways, including the stipulation of required architectures for different systems; however, it is less focused on general object detection and avoidance, compared to ANSI/ITSDF B56.5-2012. Otherwise, there is considerable overlap and agreement between these AGV standards.

In recent years standards for various forms of robots have been developed. ISO 10218-1:2011 (ISO, 2011) provides safety requirements for industrial robots, such as robots arms and manipulators, and so might be relevant to the equipment carried on an autonomous mobile orchard robot; however, it does not relate directly to the safety of the mobile platform itself, which is the subject of this paper. ISO 13482:2014 (ISO, 2014) provides safety requirements for personal care robots, including mobile robots; however, this standard is developed for smaller robots working closer to people, whereas this paper is concerned with larger robots that should generally maintain a separation from people during standard operation.

There are other ongoing efforts to develop standards for robots, including mobile and agricultural robots (ISO, 2015a). However, EN 1525:1997 and ANSI/ITSDF B56.5-2012 are considered here because they seem to be the most relevant of the established standards and they have evolved from many years of practice and experience. This paper primarily provides an analysis and discussion of EN 1525:1997 and, in particular, ANSI/ITSDF B56.5-2012. The analysis that follows is intended to highlight hazards and possible solutions for a formal risk assessment and risk reduction process.

2.1 Access Control

ANSI/ITSDF B56.5-2012 (ITSDF, 2012) has been developed for unrestricted areas. However, where possible, restricting access to the working area of an autonomous vehicle is an effective measure to reduce the risk of harm to people. This may be achievable in an orchard because access is already restricted at times, such as during spraying. However, signs and procedures would likely not provide sufficient risk reduction in themselves, in which case other layers of protection should be considered. Where possible, high fences and locked gates could provide a higher level of access control and protection. However, such measures may not always be practical and can be circumvented.