User Interface Design Principles for Robotics in Agriculture: The Case of Telerobotic Navigation and Target Selection for Spraying

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ABSTRACT

Introducing semi-automatic teleoperation of an agricultural robotic system can enable improved performance overcoming the complexity that current autonomous robots face due to the dynamic and unstructured agriculture environment. This requires design of a human-robot interface. A user interface for a vineyard robotic sprayer was implemented including functions. The user interface incorporates several functions; robot navigation, target selection and spraying. Following examination of the user interface several usability limitations were identified.

Semi-automatic teleoperation implies that the user is not collocated with the robot, and therefore, when designing a user interface several principles must be considered aiming to improve the usability of user interface. In the case of an interface for semi-automatic teleoperation in agricultural robotics, such principles include: visibility, safety, simplicity, feedback, extensibility, and cognitive load reduction.

The contribution of this paper is to specify the design guidelines of a user interface for a human-robot cooperative, agricultural robot, in the case of vineyard spraying.

Future work will include other interaction styles such as post-WIMP interfaces, within the framework of the AgriRobot project. This research also proposes a methodology to evaluate the usability of the user interface and to examine the human factors (e.g., user awareness, user centered design, interaction styles, learnability) and human-robot interaction parameters (e.g., level of autonomy, interaction roles).

Keywords: Agricultural Robotics, Human-Robot Interaction, User interface design principles, Usability

1 INTRODUCTION

We consider robotics in agriculture to be a *field application domain*, since they have the relevant characteristics as identified by Murphy (2004): (a) the robots are subject to unpredictable environmental effects that possibly impair platform and perceptual capabilities, and (b) robots are primarily extensions of humans (intended to remove humans from dangerous environments or difficult situations). Therefore, as opposed to industrial robots which operate in controlled environments, agricultural robots must operate outdoors in a continuously changing physical environment and must often deal with several complexities: (a) the agricultural robot moves on unstructured and unpredictable terrain, (b) the agricultural robot must perform complicated agricultural tasks in an undefined and unstructured, and highly variable physical environment, i.e., detach a fruit crop of variable size, shape, colour, shading and at random unknown location, and (c) climate related conditions that are uncontrolled and volatile, i.e., wet muddy soil, strong winds, dust in the atmosphere, different light setting depending on the sun location or clouds, et cetera.

Agriculture is an obvious application area for robotics given the harsh working conditions (Isaacs 1986; Marchant 1998; Edan 1999; Hollingum 1999; Murakami et al. 2008; Edan et al. 2009). In addition, there is a need to tackle the observed shortage of labourers which are a bottleneck to the production (Alexandrou, Pelagia & Pitiris 2006; Murakami et al. 2008). Furthermore, given the world population growth, there is a need for intensive crop and livestock production to secure food availability (FAO 2009)

Pre-programmed, completely automatic operation of an agricultural robot in the field would be, of course, the option of choice when available. It is not always possible –and it might be a moving target: as agricultural robotics progresses, there will always be more complicated agricultural tasks and terrains to tackle. Even if agricultural robotics are technically feasible, by incorporating a human into the loop the robotic system can be simplified; this combined with increased performance and robustness resulting from the human-robot cooperation can lead to decreased costs and economic feasibility which is the current limiting factor for agriculture robotics commercial implementation (Pedersen et al. 2006).

Robotic teleoperation is a recent but known alternative (Sayers 1998; Salcudean 1998; Fong, Thorpe & Baur 2001; Hainsworth 2001; Monferrer & Bonyuet 2002; Kheddar et al. 2007; Peña, Aracil & Saltaren 2008; Jie, Xiangyu & Rosenman 2009; Wang et al. 2009; Lum et al. 2009; Mollet, Chellali & Brayda 2009). Its advantages include the combination of human know-how and alertness with robot accuracy, repeatability and power, the possibility to remove humans from locations where it is hazardous to be (i.e., spraying plants with chemicals; (Roberto et al. 2003), ease of use and improved performance (Fong, Thorpe & Baur 2001) . Yet, agricultural robotic teleoperation has a serious limitation: the farmer must be kept busy and alert, if in more comfortable circumstances, and it remains to be seen if the savings in efficiency, comfort and health are worth the cost and effort.

2 HUMAN-ROBOT INTERACTION

Interaction is the process of working together to accomplish a certain goal (Goodrich & Schultz 2007). Human-Robot Interaction (HRI) is the field of study dedicated to understanding, designing and evaluating robotic systems for use by or with humans (Clarkson & Arkin 2007; Goodrich & Schultz 2007). Fong et al. (2001) defined HRI as "*the study of the humans, robots and the ways they influence each other*". It is a multi-disciplinary field in which researchers from areas of robotics, human factors, cognitive science, natural language, psychology, and human-computer interaction, are working together to understand and shape the interactions between humans and robots.

Goodrich and Schultz (2007) defined two categories of interaction, remote and proximate. Remote interaction refers to the situation where the human and the robot are separated spatially or even temporally (i.e., Opportunity Mars rover), while with proximate interaction the humans and the robots are collocated. In this paper we will focus on remote interaction with mobile robots, often referred to as teleoperation (Sayers 1998). By definition, HRI imply the need for a user interface – the communication media between the humans and robots.

Bechar and Edan (2003) provide empirical evidence for the advantage of human-robot collaboration in agriculture in target recognition tasks. According to their research, collaboration between human operators (HO) and robots increases detection by 4% when compared to a HO alone and by 14% when compared to a fully autonomous robot and decreases detection times (Ron Berenstein et al. 2010).

2.1 Human-Robot Interaction Awareness

The standard definition for HRI awareness is: *"Given one human and one robot working on a task together, HRI awareness is the understanding that the human has of the location, activities, status, and surroundings of the robot; and the knowledge that the robot has of the human's commands necessary to direct its activities and the constraints under which it must operate*" (Drury, Scholtz & Yanco 2003). Endsley defines Situation Awareness (SA) as "*the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*" (1988).

Given the above definitions, HRI awareness in the case of a farmer operating an agricultural robot should have the following two components:

- **Farmer-Agricultural Robot**: the understanding that the farmer has of the location, activities, status, and surroundings of the agricultural robot; and level of certainty regarding these data.
- **Agricultural Robot – Farmer**: the knowledge that the agricultural robot has of the farmers' commands necessary to direct its activities and any depicted constrains that may require a modified course of action or command non compliance.

A preliminary list of required information is listed (Table 1). This will help in setting initial principles/guidelines for designing a user interface (UI) for HRI for agricultural purposes.

Table 1. HRI awareness for agriculture cases

HRI Awareness	**Agricultural case description**
Location awareness	For a farmer location awareness is to have an understanding of where the robot is located at all times. We are interested in information as to where the robot is currently located or moving towards, where it has already been, where it yet remains to go.
Activity awareness	Farmers must have an understanding of what the robot is doing at their field, how it is progressing, if it needs their attention in order to complete its mission, and if it is doing what it is supposed to do when operating autonomously.
Status awareness	The farmer operator must have an understanding about the status of the robot. Information related to the robot's operational status (platform, computer system, cameras, sensors, and other parts), as well as information about speed, energy levels, and other task related status information (i.e. sprayer tank level).
Surroundings awareness	The farmer should be aware of what is around the robot while executing its tasks Are there other farmers or robots in the field? What are the weather conditions?
Overall mission awareness	We related the overall mission awareness to SA, and therefore it is the farmers' perception of all the above (location, activities, status, surroundings) and his/her comprehension of their meaning, that would assist him in making decisions related to future robot activities.

The issues are then: *how should the farmer guide and interact with the robot's operation? What is an appropriate interface, how should it be designed and how should its suitability and usability be measured?*

3 USER INTERFACE DESIGN PRINCIPLES FOR HRI

Based on the literature review, we grouped several design guidelines/principles/heuristics that apply both in Human-Computer Interaction and (adapted/applied) in Human-Robot Interaction, as presented in Table 2. The goal of this compilation is to provide a synthesis of design guidelines and discuss their adaptability to the special case of agricultural robotics HRI.

Table 2. Categorization of user interface design principles

Principle	Compilation (Source)
Visibility	• Make things visible (Norman 1988) • Minimize the use of multiple windows (Yanco, Drury & Scholtz 2004) • Visibility of system status (Nielsen 1994) • Sufficient information design (Clarkson & Arkin 2007) • Prioritize placement of information (Mohan Rajesh Elara et al. 2007)
Safety	• Implicitly switch interfaces and autonomy modes (Goodrich & Olsen 2003) • Manipulate the relationship between the robot and the world (Goodrich & Olsen 2003) • Provide robot help in deciding which level of autonomy is most useful. • Design for error (Norman 1988) • Provide help in choosing robot modality (Jill L. Drury et al. 2004) • Error prevention (Nielsen 1994) • User Control and freedom (Nielsen 1994) • Help users recognize, diagnose, and recover from errors (Nielsen 1994)
Simplicity	• Use natural mappings between controls and actions • Let the robot use natural human cues (Goodrich & Olsen 2003) • Match between system and real world (Nielsen 1994) • Let people manipulate presented information (Goodrich & Olsen 2003) • Consistency and standards (Nielsen 1994) • Aesthetic and minimalist design (Nielsen 1994) • Synthesis of system and interface • Use natural cues (Norman 1988) • Use efficient interaction language (Scholtz 2002) • Present the information in appropriate form (Scholtz 2002) • Appropriate information presentation (Clarkson & Arkin 2007)
Feedback	• Provide feedback to the user (Norman 1988) • Provide a map of where the robot has been (Yanco, Drury & Scholtz 2004) • Provide more spatial information about the robot in the environment (Yanco, Drury & Scholtz 2004) • Enhance HRI Awareness (Jill L. Drury et al. 2004) • Present the necessary information (Scholtz 2002)
Extensibility	• Provide an interface supporting multiple robots (Yanco, Drury & Scholtz 2004) • Provide an interface supporting multiple tasks (Yanco, Drury & Scholtz 2004) • Provide user interfaces that support multiple robots in a single display • Flexibility of interaction architecture (Clarkson & Arkin 2007) • Synthesis of system and interface (Clarkson & Arkin 2007) • User control and freedom (Nielsen 1994) • Flexibility and efficiency of use (Nielsen 1994) • Interaction architecture scalability (Scholtz 2002) • Support evolution of platforms (Scholtz 2002) • Increase efficiency (Jill L. Drury et al. 2004)
Cognitive load reduction	• Provide a good conceptual model and make things visible in order to reduce the gulfs of execution and evaluation (Norman 1988) • Manipulate the world instead of the robot (Goodrich & Olsen 2003) • Externalize memory (Goodrich & Olsen 2003) • Provide fused sensor information to lower the cognitive load on user (Yanco, Drury & Scholtz 2004) • Help people manage attention (Goodrich & Olsen 2003) • Lower cognitive load (Jill L. Drury et al. 2004) • Recognition rather than recall (Nielsen 1994)

3.1 The case of telerobotic navigation and target selection for spraying

The agricultural task selected to demonstrate this work is that of selectively spraying vineyards. Currently, farmers either use hand sprayers or tractor carrying sprayers (Figures 1 and 2, respectively). In both cases excessive pesticide is used, and, what is just as important, it is unhealthy for the farmer. Ongoing research (Berenstein, Edan & Ben-Halevi 2012; Berenstein &

Edan 2012a; Berenstein & Edan 2012b) aims to develop a human-robot cooperative sprayer. This current work focuses on development of a user interface suitable for targeted spraying, while simultaneously teleoperating the robot along the rows, so the farmer will be at a safe place away from hazardous materials during the spraying process. The motivation for selecting this agricultural task is twofold: (a) reduce the amount of pesticide used, and (b) reduce human exposure to pesticides.

Figure 1: Spraying vineyards by hand inside a greenhouse

Figure 2: Spraying vineyards in the field with a tractor

Figure 3: Robotic sprayer (R. Berenstein et al. 2010)

We assume the farmer/operator is situated away from the vineyard, in a comfortable environment and is using a user interface to teleoperate the mobile robot (Figure 3). The goal is to navigate the robot within the vineyard and to select the targets to be sprayed.

Based on the above identified user interface design principles we aim to develop a user interface suitable for the case of vineyard robot sprayer. We analyze the principles using the following screen prototypes (Ben-Halevi 2011), illustrated in Figure 4 below.

Table 3: User interface screen prototypes

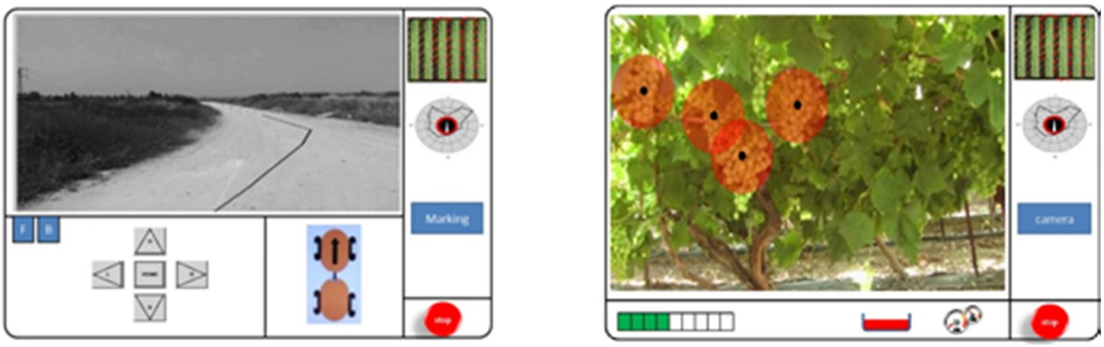

Table 4 Design principles and user interface prototype elements

Principle	User interface prototype elements
Visibility	System status (robot operation status, gas level status, speed), sprayer tank level status, radar, video
Safety	Emergency stop button, robot modality buttons (camera, marking)
Simplicity	Navigation buttons, spraying button, video feedback
Feedback	Video feedback (both navigation and targets selected), field map, radar, system status
Extensibility	Path planner algorithm, algorithm for automatic cluster detection, marking methods (i.e. touch screen)
Cognitive load reduction	Attention management (navigation and marking), fused information

4 CONCLUSION

This article examines the factors that determine the user interface design principles for teleoperating an agricultural robot to perform a selective spraying task. Agricultural robot teleoperation is demanding because the operator needs to guide a robot in a harsh and dynamic environment, executing a difficult dual-task (navigation and grape clusters marking).

The identified principles are: visibility, safety, simplicity, feedback, extensibility, and reduction of cognitive load. These principles were gathered based on the literature review of human-robot interaction and human-computer interaction usability design guidelines, principles and heuristics. Ongoing research aims to develop the user interface for the AgriRobot project and evaluate the user interface design principles.

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REFERENCES

Alexandrou, L, Pelagia, S & Pitiris, D 2006, *Agricultural Statistics* p. 155.

Bechar, A & Edan, Y 2003, 'Human-robot collaboration for improved target recognition of agricultural robots', *Industrial Robot: An international journal*, vol. 30, no. 5, pp. 432-436.

Ben-Halevi, I 2011, *Human-robot cooperative interface for vineyard robot sprayer.* in final project report, Dept. of Industrial Engineering and Management, Ben-Gurion University of the Negev, Beer Sheva.

Berenstein, R & Edan, Y 2012a, *Evaluation of marking techniques for Human-Robot Selective Vineayrd Sprayer* in Intl. Conf. of Agricultural Engineering (CIGR-AgEng), Valencia, Spain.

Berenstein, R & Edan, Y 2012b, 'Robotic precision spraying methods', *ASABE Annual Intl. Meeting*, no. 1341054.

Berenstein, R, Edan, Y & Ben-Halevi, I 2012, *A remote interface for a human-robot cooperative vineyard sprayer* in Intl. Society of Precision Agriculture (ICPA), Indianapolis, Indiana.

Berenstein, R, Shahar, O, Shapiro, A & Edan, Y 2010, 'Grape clusters and foliage detection algorithms for autonomous selective vineyard sprayer', *Intelligent Service Robotics*, vol. 3, no. 4, pp. 233-243.

Berenstein, R, Shahar, OB, Shapiro, A & Edan, Y 2010, 'Grape clusters and foliage detection algorithms for autonomous selective vineyard sprayer', *Intelligent Service Robotics*, vol. 3, no. 4, pp. 233–243.

Clarkson, E & Arkin, RC 2007, 'Applying Heuristic Evaluation to Human-Robot Interaction Systems'.

Drury, JL, Scholtz, J & Yanco, HA 2003, 'Awareness in Human-Robot Interactions', in *IEEE Conference on Systems, Man and Cybernetics*, p. 6.

Edan, Y 1999, 'Food and Agriculture Robotics', in *Handbook of Industrial Robotics*, Second Edition edn, ed. SY Nof, John Wiley & Sons, Inc.

Edan, Y, Han, S, Kondo, N & Nof, SY 2009, 'Automation in Agriculture', in *Springer Handbook of Automation*, Springer Berlin Heidelberg, pp. 1095-1128.

Endsley, MR 1988, 'DESIGN AND EVALUATION FOR SITUATION AWARENESS ENHANCEMENT', *Human Factors and Ergonomics Society Annual Meeting Proceedings*, vol. 32, pp. 97-101.

FAO 2009, *The State of Food Insecurity in the World - Economic crises and lessons learned.*

Fong, T, Thorpe, C & Baur, C 2001, 'Advanced Interfaces for Vehicle Teleoperation: Collaborative Control, Sensor Fusion Displays, and Remote Driving Tools', *Autonomous Robots*, vol. 11, pp. 77-85.

Goodrich, MA & Olsen, DR, Jr. 2003, 'Seven principles of efficient human robot interaction', in *Systems, Man and Cybernetics, 2003. IEEE International Conference on*, pp. 3942-3948 vol.4.

Goodrich, MA & Schultz, AC 2007, 'Human-robot interaction: a survey', *Found. Trends Hum.-Comput. Interact.*, vol. 1, no. 3, pp. 203-275.

Hainsworth, DW 2001, 'Teleoperation User Interfaces for Mining Robotics', *Autonomous Robots*, vol. 11, no. 1, pp. 19-28.

Hollingum, J 1999, 'Robots in agriculture', *Industrial Robot: An International Journal of industrial and service robotics*, vol. 26, no. 6.

Isaacs, GW 1986, 'Robotic applications in agriculture', *Acta Horticulturae*, no. 187, pp. 123-128.

Jie, Z, Xiangyu, W & Rosenman, M 2009, 'Fusing multiple sensors information into mixed reality-based user interface for robot teleoperation', in *IEEE International Conference on Systems, Man and Cybernetics, 2009. SMC 2009.* , pp. 876-881.

Jill L. Drury, Holly A. Yanco, Dan Hestand & Scholtz, J 2004, 'Design guidelines for improved human-robot interaction', *CHI '04 extended abstracts on Human factors in computing systems*.

Kheddar, A, Neo, E-S, Tadakuma, R & Yokoi, K 2007, 'Enhanced Teleoperation Through Virtual Reality Techniques', in *Advances in Telerobotics*, vol. 31, Springer Berlin / Heidelberg, pp. 139-159.

Lum, MJH, Rosen, J, Hawkeye, K, Friedman, DCW, Lendvay, TS, Wright, AS, Sinanan, MN & Hannaford, B 2009, 'Teleoperation in surgical robotics - network latency effects on surgical

performance', in *Engineering in Medicine and Biology Society, 2009. EMBC 2009. Annual International Conference of the IEEE*, pp. 6860-6863.
Marchant, J 1998, 'Agriculture - a challenge to robotic science', *Industrial Robot: An international journal*, vol. 25, no. 5, p. 2.
Mohan Rajesh Elara, Carlos A. Acosta Calderon, Changjiu Zhou, Pik Kong Yue & Hu, L 2007, 'Using Heuristic Evaluation for Human-Humanoid Robot Interaction in the Soccer Robotics Domain', *Second Workshop on Humanoid Soccer Robots at IEEE-RAS International Conference on Humanoid Robots*.
Mollet, N, Chellali, R & Brayda, L 2009, 'Virtual and Augmented Reality Tools for Teleoperation: Improving Distant Immersion and Perception', in *Transactions on Edutainment II*, vol. 5660, Springer Berlin / Heidelberg, pp. 135-159.
Monferrer, A & Bonyuet, D 2002, 'Cooperative robot teleoperation through virtual reality interfaces', in *Information Visualisation, 2002. Proceedings. Sixth International Conference on*, pp. 243-248.
Murakami, N, Ito, A, Will, JD, Steffen, M, Inoue, K, Kita, K & Miyaura, S 2008, 'Development of a teleoperation system for agricultural vehicles', *Computers and Electronics in Agriculture*, vol. 63, no. 1, pp. 81-88.
Murphy, RR 2004, 'Human-robot interaction in rescue robotics', *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 34, no. 2, pp. 138-153.
Nielsen, J 1994, 'Enhancing the explanatory power of usability heuristics', *Proceedings of the SIGCHI conference on Human factors in computing systems: celebrating interdependence*.
Norman, DA 1988, *The Psychology of everyday things*.
Pedersen, S, Fountas, S, Have, H & Blackmore, B 2006, 'Agricultural robots—system analysis and economic feasibility', *Precision Agriculture*, vol. 7, no. 4, pp. 295-308.
Peña, C, Aracil, R & Saltaren, R 2008, 'Teleoperation of a Robot Using a Haptic Device with Different Kinematics', in *Haptics: Perception, Devices and Scenarios*, vol. 5024, Springer Berlin / Heidelberg, pp. 181-186.
Roberto, O, Chen, Z, Bobby, B & Julie, AA 2003, *Interface Evaluation for Mobile Robot Teleoperation*.
Salcudean, S 1998, 'Control for teleoperation and haptic interfaces', in *Control Problems in Robotics and Automation*, vol. 230, Springer Berlin / Heidelberg, pp. 51-66.
Sayers, G 1998, *Remote Control Robotics*, Springer-Verlag, New York.
Scholtz, J 2002, 'Evaluation Methods for Human-System Performance of Intelligent Systems'.
Wang, C, Wang, F, Chen, L & Zhang, C 2009, 'A System Design for the Testing Platform of Robot Teleoperation with Enhanced Reality Based on Binocular Vision', in *Information Technology and Applications, 2009. IFITA '09. International Forum on*, pp. 565-569.
Yanco, HA, Drury, JL & Scholtz, J 2004, 'Beyond usability evaluation: analysis of human-robot interaction at a major robotics competition', *Hum.-Comput. Interact.*, vol. 19, no. 1, pp. 117-149.