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Research Paper

Structured design of an automated monitoring tool for pest species

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Pests and diseases in agricultural systems cause severe production losses with associated economic impact. Integrated Pest Management (IPM) is a sustainable method to limit these losses. For improved implementation of IPM, fully automated monitoring tools are needed to provide instantaneous pest monitoring data and associated real time, user-friendly treatment advice for producers. The application of the Reflexive Interactive Design approach to design an automated pest monitoring tool including an automated pest detection sensor is described with Poultry Red Mite (PRM) as a model target. Three different concepts were designed for the automated mite detection sensor based on a combination of solutions to carry out the key functions. The functioning of the main solutions in the three concepts was tested with live mites to ensure that solutions aligned with the behaviour and biology of PRM *in vivo*. The best solutions were combined into two different prototypes, which were subsequently tested in the laboratory and on-farm. The most successful prototype of the automated mite detection sensor was situated under the bird's perch, had a through-beam sensor and was able to remove mites from the through-beam sensor area once recorded. Involvement of various multidisciplinary actors, users and varied user networks in the design process was vital for its rapid progress, the quality of the final product and the limited number of set-backs encountered. It is expected that this same design structure, with the addition of an evaluation step, is applicable to the design of automated monitoring tools for other pest species.

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Nomenclature

EGPIC	Electronic grain probe insect counter
EU	European Union
FAO	Food and Agricultural Organisation of the United Nations
HACCP	Hazard analysis and critical control points
ICOM	Block diagram representing a function in IDEF-0 with arrows indicating the Input, Control, Output and Mechanisms
IDEF	Integrated definition for function modelling
IPM	Integrated pest management
PRM	Poultry Red Mite, *Dermanyssus gallinae*
PTFE	Polytetrafluoretheen, brandname Teflon®
PVC	Polyvinyl chloride
RIO	Reflexive interactive design (In Dutch Reflexief Interactief Ontwerpen)
WHO	World Health Organization

1. Introduction

Pests and diseases in agricultural systems cause severe production losses both pre- and post-farm, with economic impacts that infiltrate multiple stakeholders along the supply chain (FAO, 2001; Oerke, 2006). The implementation of integrated pest management (IPM) is globally promoted by both the Food and Agricultural Organisation of the United Nations (FAO) and World Health Organization (WHO) to increase food security and public health (Bonnefoy, Kampen, & Sweeney, 2008; FAO, 2015; WHO, 2015), and is a requirement for European Union (EU) crop producers following the implementation of the Sustainable Use Directive (EU Directive 2009/128/EC). IPM is a multi-disciplinary approach that aims to control pests and diseases whilst minimising any negative environmental and economic effects associated with pest management activities (Narladkar, 2014). Monitoring of pest populations is a critical component of IPM programmes that can be used to inform treatment timings and evaluate applied treatments according to the eight general principles of IPM laid down in Directive 2009/128/EC. Continuous monitoring of pest species in IPM permits earlier detection of pests, and provides higher resolution insights into treatment effects and pest pre- and post-treatment population dynamics, than can be achieved through non-continuous monitoring methods. When effective control measures are applied quickly after pests exceed action thresholds, the spread of pests and consequent production losses can be minimised (Flint, 2012; Mul et al., 2009). Currently, however, monitoring of pests and diseases is typically time-consuming and often relies on visual observation of pest numbers (*in situ* or on/in traps) that can be affected by monitoring schedules and observer experience (Mul, unpublished results). Fully automated pest monitoring circumvents these issues by providing repeatable real-time data and subsequent decision-making support for a quick and targeted reaction to pests and diseases. When fully developed, automated monitoring devices can send data on pest numbers to a central computer that runs a model forecasting pest population growth and informs the user about the moment when the population is expected to exceed the economic threshold for treatment (Shuman, Coffelt, & Weaver, 1996; Shuman, Epsky, & Crompton, 2003).

Remote sensing and sensor-based methods, amongst others, are innovative tools currently being applied to automated monitoring of plant diseases (Martinelli et al., 2015; Polder, Van der Heijden, Van Doorn, & Baltissen, 2014). Automated monitoring of pests has also been developed for use in stored products, crops, in pastures and in buildings (Jianhua & Jingxue, 1992; Shuman et al., 1996; Trompen, 2003; Zhao, Mao, Zhou, Yuan, & Zhang, 2014). Nevertheless, no automated monitoring tools are currently available for invertebrate pests in animal husbandry systems, or for vertebrate pests such as mice and rats. Yet, these pests cause considerable production losses in this sector (FAO, 2001; Meerburg, Singleton, & Leirs, 2009; Meerburg, Singleton, & Kijlstra, 2009), which could be minimised through automated monitoring systems. Design of automated monitoring tools is potentially complex, though methods already exist to facilitate the design process (Canessa, 1989; Siers, 2004; Cross, 2008; Hemming, Van Henten, Van 't Ooster, Vanthoor, & Bakker, 2008). These methods aim to assist the methodical process by ensuring that developers "avoid jumping to conclusions, obtain a good overview of the stages in the designing process, reduce the chances for overlooking essential items, facilitate the taking of justifiable decisions, and to increase the chances on feasible design" (Siers, 2004). However, the aforementioned approaches focus on design aspects only, with little attention given to social structures and participation of actors and stakeholders to allow for field implementation of the solution. As a form of structured design, the Reflexive Interactive Design (in Dutch: Reflexief Interactief Ontwerpen or RIO) approach has been successfully used in the design of new concepts for husbandry systems for pigs, laying hens, broiler hens, goats, and dairy cows (Bos, 2010) and of semi structures in animal facilities (Van Weeghel, Bos, Spoelstra, & Groot Koerkamp, 2016), of which some have been further developed and realized by industry actors (e.g. Spoelstra, Groot Koerkamp, Bos, Elzen, & Leenstra, 2013). RIO as described by Bos, Groot Koerkamp, Gosselink, and Bokma (2009) is an interdisciplinary interactive method for structured design and consists of three stages: 1) "system and actor analysis", 2) "structured design" and 3) "anticipating niche and structural change".

The work presented in this paper is the first application of the RIO approach to the design of automated monitoring tools for pests. This approach could accelerate the development and adoption of fully automated pest monitoring in sectors where this has yet to be achieved, and support implementation of improved IPM as a result. In this paper we present a case study on the use of the RIO approach to design an automated monitoring tool for the Poultry Red Mite (PRM) *Dermanyssus gallinae*. PRM is the most significant pest of egg-laying hens in many areas of the globe (Sparagano, George, Harrington, & Giangaspero, 2014), and monitoring has been noted as key to IPM implementation to control pest species (Kogan, 1998; Van Lenteren & Woets, 1988), and PRM more specifically (Sparagano et al., 2014). Moreover, monitoring is one of the seven basic principles of the hazard analysis and critical control points (HACCP) method (Mayes, 1993, 1998; Sun & Ockerman, 2005), proven to reduce the risk of introduction and spread of PRM into poultry facilities (Mul & Koenraadt,