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Responsible development of autonomous robotics in agriculture

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[Standfirst]

Despite the promise of autonomous robots to contribute to agricultural sustainability, a number of social, legal, and ethical issues threaten adoption. To understand these challenges, we discuss how responsible innovation principles can be embedded into the user-centred design of autonomous robots and identify areas for further empirical research.

[Main]

Adding to the list of environmental challenges facing agriculture, COVID-19 and the demographics of age, migration and urbanisation poses a serious threat to the sustainability of farm businesses and food security[1]. In particular, farm businesses across the world are struggling to fill vacancies and provide safe working conditions for labourers.

Autonomous robots could help address these immediate challenges[2]. Whilst their physical manifestation comprises hardware, such as a vehicle combined with manipulators, their autonomy is derived from sophisticated algorithms routed in artificial intelligence. These algorithms fuse sensor data to enable control and real-time decision support. Autonomous robots perform tasks with a high degree of autonomy and may work collaboratively alongside human workers (so-called co-bots) or on their own[3]. Apart from isolated examples of these technologies being demonstrated on-farm, autonomous platforms with robotic mobility which fuse multiple technologies across a single fleet (e.g. crop forecasting, planting, harvesting, packing) are not yet fully implementable, and substantial barriers need to be overcome before they will be. However, there is already adoption of static robotic milking technologies in the dairy sector, and in-field deployment of tractor mounted robotic manipulators to remove weeds and protect crops from pests and diseases[2], for example.

26   We know, however, that the history of innovation in agriculture is littered with examples of failure

27   or slow adoption, and the legal, ethical, and social concerns associated with autonomous

28   agriculture are controversial[4,5]. Potential challenges, opportunities and consequences of

29   autonomous agriculture, illustrated in Figure 1, are interlinked and depend on how technologies

30   are designed and implemented. Many of these aspects have been discussed in the burgeoning

31   literature on the social and ethical impacts of digitalisation in agriculture[6,7.] For autonomous

32   robotics in farming, where empirical research remains limited, potential issues have largely been

33   identified by extrapolating views gathered from empirical research on smart farming technologies

34   in general, or from the use of autonomous robots in other workplaces. Here we identify examples

35   of where responsible innovation principles are being implemented and indicate where more needs

36   to be done.

37   Figure 1

38   **Responsible innovation in agriculture and beyond**

39   The most widely used framework for responsible innovation was proposed by Stilgoe and

40   colleagues[8] and involves four key components: *anticipating* the impacts of innovation; reflecting

41   on one's work and adapt accordingly (*reflexivity)*; *including* a wide range of stakeholders in the

42   design process; and *responding* to stakeholders' concerns, ideas and knowledge by constructing

43   appropriate institutional structures.

44   Guidance on responsible innovation – provided by funders such as Engineering and Physical

45   Sciences Research Council[9], InnovateUK[10], and the European Commission – encourages

46   companies to be cognisant of their responsibility and committed to RRI principles, by exploring

47   the challenges that could arise from innovation and acting on their findings in a transparent,

48   inclusive, and timely manner. Despite frequent calls for companies to conduct a transparent and

49   iterative process of responsible innovation, there is a lack of either a commitment to, or reporting

50   of, the steps taken in technology development in the agriculture industry.

51   In the following sections we discuss how the four key components mentioned above can be

52   operationalised to guide technology development in agriculture[11], outlining key research needs to

53   better understand how to operationalise the idea. Examples referenced in this paper and the

54 guidance from Stilgoe *et al.*[8] and Eastwood *et al.*[11] provide a good overview of techniques that can

55 be used to apply responsible innovation principles.

Anticipation

57 With the objective of minimising negative, unintended outcomes[8], 'anticipation' involves

58 identifying, predicting, and exploring the potential short- and long-term consequences of future

59 innovation across society and is therefore essential for the responsible development of autonomous

60 robots.

61 There has been little empirical anticipatory work for autonomous robots in farming that has

62 included a variety of stakeholders in the process, though a recent paper by Legun and Burch[12]

63 begins to describe a process of co-design in the context of robotic apple orchards in New Zealand.

64 Empirical studies have otherwise been limited to the narrow use of foresight exercises in the form

65 of technology use and acceptance surveys and farmer[13] or public opinion surveys[14] using online

66 questionnaires and short interviews. Foresight is also used to elucidate future benefits and

67 challenges associated with a technology in combination with other methods, such as the Delphi

68 technique (which relies on anonymous rounds of voting)[15]. Other anticipatory processes include

69 'horizon scanning' (scanning data sources to detect early developments[16]) and 'socio-literary

70 techniques' (using science fiction as a tool to encourage dialogue about technology futures[17],

71 possibly through 'Ag-Tech movie nights'[18]). A typical methodology in robotics and human-robotic

72 interaction are "Wizard of Oz" studies[19], where autonomy is "fake"; robots are usually remote-

73 controlled, anticipating the abilities they may have once fully implemented. Another useful

74 technique often employed are video studies[20], where participants are presented with recordings of

75 robot behaviour and assess it from a third person perspective.

76 One further method to consider is backcasting, which involves building an (ideal) future scenario,

77 and working backwards to identify the steps needed to get to that scenario. This is done in

78 anticipatory governance approaches, for example. A key area for future research will be to use

79 different anticipatory methods with diverse stakeholders specifically on the subject of autonomous

80 robots in agriculture. Those included in the process of anticipation should be those directly affected

81 by the adoption of robotics, including farmers, farm workers, and consumers of food produced in

82 that way. Including such a wide range of stakeholders will create a number of practical challenges

83   related to power inequality (farm managers v farm workers) and language barriers (migrant farm

84   workers) and these will need to be managed sensitively by trained facilitators.

Reflexivity

86   Reflexivity entails 'holding a mirror up to one's own activities, commitments and assumptions,

87   being aware of the limits of knowledge and being mindful that a particular framing of an issue may

88   not be universally held'[8]. Constant analysis and critique of one's work among peers is an embedded

89   practice of rigorous science. However, scientists and engineers typically carry out reflexivity and

90   other responsible innovation practices 'behind closed doors', in the lab, and do not recognise these

91   processes as 'reflexivity' in responsible innovation terms[21]. Opening these conversations up to the

92   public and acknowledging and listening to other actors can improve the quality of reflexivity.

93   Reflexivity in the realm of autonomous robots in agriculture has mostly come from the user-

94   centred design (UCD) process. Work to date in this space has recognised that robotic systems

95   interacting with humans need to undergo an iterative development approach[22], bringing together

96   subjective user experience with actual system logs. After including stakeholders and seeking their

97   information requirements and preferences for autonomous robots through surveys[23] , workshops[24],

98   and field experiments[25,26,27], designers have altered prototypes and design paths to ensure that the

99   robots work for the user. Yet, this is narrow reflexivity; it involves developers tweaking design

100   based on user feedback, rather than conducting a fundamental analysis of the assumptions and

101   values underlying the proposed solution or questioning if agricultural robotics is really the path we

102   want to take as society. We rarely carry out a deeper form of reflexivity, possibly missing

103   alternative solutions.

104   The development of and engagement with best practice guidelines, codes of conduct and

105   international standards is another form of reflexivity that can guide industry to conduct innovation

106   in a responsible manner, although it is not always clear whether they continue to serve the purpose

107   of reflexivity once adopted. In Australia, a code of practice for 'Agricultural Mobile Field

108   Machinery with Autonomous Functions' is currently under development to help guide safe

109   working procedures in the field; this code of practice is intended to hold some legal weight.

110   International standards for the use of autonomous robots such as ISO 10218 provide norms for

111   worker safety when collaborating with robots in a structured, industrial environment. In ISO

112   10218, safety aspects such as tactile and pressure sensors, safe maximum speed, proximity sensors,

113   human detection cameras, and emergency stop are described to ensure the safety of human-robot

114   collaboration. Other relevant international standards include: ISO 18497 (design principles for

115   safety with highly automated agricultural machines – operations of robots in-field are not covered)

116   ; ISO 17757 (for use of autonomous machinery in mining); and ISO/SAE DIS 21434, currently

117   under development (for cybersecurity in road vehicles). The agricultural industry can glean

118   insights from these standards, however there is a necessity to further develop agriculture specific

119   standards and codes of practice that account for human-robot collaboration in flexible,

120   unstructured environments such as in the field. Understanding how this might be done effectively,

121   bringing together relevant stakeholders, is an important future area for research.

122   **Inclusion**

123   Concepts of 'inclusion' are frequently limited to the 'consideration' of how stakeholders may be

124   impacted or react to innovation by a limited group of experts[28]. Genuine inclusion should involve

125   the participation of a full range of stakeholders through processes. If we do not pursue methods

126   for the substantive inclusion of a full range of actors, not just the 'usual suspects', and do not give

127   due attention to power inequalities between stakeholders throughout the participatory process, then

128   we risk reinforcing unequal participation under the guise of inclusivity. It may appear that

129   increased participation from the start is time-consuming and resource-intensive, but user-centred

130   design can prevent problems further down the line.

131   Within the development of autonomous robots in agriculture, inclusion has mostly taken the form

132   of consultation and sometimes collaboration, involving feedback from farmers and farm workers

133   on the technical side of robot development. Simulation experiments[29,30] and field-based

134   workshops[23] have allowed farmers and farm workers to test the usability of a technology.

135   Researchers have used task scenarios, observations, and participant feedback to feed into prototype

136   development. The social sciences have developed a number of participatory methods that allow

137   substantive inclusion, such as citizen juries and deliberative workshops, and a greater selection of

138   these should be brought to bear for inclusion surrounding autonomous agriculture[31].

139   Stakeholders identified in the PAS 440 Responsible Innovation framework developed for

140   InnovateUK[10] include co-developers; markets, customers, end-users; regulators and standards

141 bodies; NGOs representing civil society stakeholders and individual citizens likely to be affected.

142 Beyond the 'usual suspects', it is important to engage with 'harder to reach' stakeholders. Schillo

143 and Robinson[28] discuss the importance of engaging with historically marginalized groups. In the

144 case of autonomous agriculture, this could involve small farmers (who may be pushed out of the

145 industry by larger farmers with more capacity to adopt and adapt), organic farmers (whose farming

146 strategy may be more difficult to align with autonomous robots focussed on precision

147 fertilisation[32]), as well as farm workers (who could lose jobs as they are replaced by robots). Blok[33]

148 argues that stakeholder inclusion and participation can typically become reductive as it focuses on

149 the cognitive approach to understanding the perspectives of stakeholders in a self-serving

150 'immunization strategy', where the goal is to convince others, prevent criticism and portray the

151 company as having good intentions. We should ultimately ensure that we are undertaking

152 substantive, rather than tokenistic inclusion.

153 The involvement of stakeholders should not be restricted to the exploration of consequences in

154 terms of economic opportunity or technology acceptance, but include wider implications and

155 society's 'grand challenges'. To date there are limited examples of this work; Pfeiffer *et al.*[14]

156 explored public's opinions of digital farming technology through surveys and spontaneous

157 associations; Kester *et al.*[13] surveyed farmer's views of the future of automation on topics such as

158 perceived value, applications and expectations; and Baxter *et al.*[26] asked fruit pickers questions

159 regarding the impact of autonomous robots on their job security.

160 **Responsiveness**

161 Identifying potential consequences, reflecting on underlying assumptions, values, and problem-

162 solving processes, and including stakeholders in the innovation process can only lead to

163 responsible innovation if newly gained insights are enacted upon. Actors should be reactive to new

164 knowledge and ensure development is iterative. This could be in the form of adapting R&D

165 projects or early design prototypes based on information feedback from stakeholders. Other actions

166 that result from new information could include adjusting business models, altering control or

167 access to software, amending workers contracts and working conditions[3], or refraining from

168 developing a certain robot altogether if it is not desired by society.

169 Responsiveness is also important within institutional structures, which should respond promptly
170 to new information, in policy, law, and regulatory environment. Regulation can restrict innovation
171 (e.g. GM crops in Europe), efficiency, and competitive advantage, however legal structures will
172 be important to ensure protection for users of autonomous robots and for clarifying the liability
173 framework. Hence, regulation can act as both a barrier to and an enabler of adoption. Basu *et al.*[5]
174 describe the current legal frameworks, regulations and standards that are relevant to the
175 development of autonomous robots in agriculture, as well as the gaps in areas such as data
176 protection law, ethics of robot autonomy and artificial intelligence. Similarly to how the European
177 Union embedded 'Privacy by Design' into its General Data Protection Regulation, others are
178 calling for 'Equality by Design' in artificial intelligence (AI) regulation to safeguard against bias
179 and discrimination that may inadvertently be engrained in technology and machine learning[34].
180 There are examples of "technological redlining" as well as technological limitations of
181 measurement such as unequal object detection or lower quality heart rate measurement for those
182 with darker skin[34]. A lack of transparency with algorithms, machine learning and AI – the "black
183 box" problem – can lead to bias and discrimination issues within machine learning to become
184 further entrenched and replicated. Regulatory oversight of "Equality by Design"[34] is key to ensure
185 that programmers address any bias and discrimination that may be produced in algorithms,
186 ultimately ensuring that technology treats users fairly.

187 **Conclusion**

188 Addressing the social, legal, and ethical implications of autonomous robots is arguably a greater
189 challenge than the development of the technology itself. More research is needed to ensure that
190 anticipation, reflexivity, and inclusion efforts are turned into responsive action on the ground. As
191 highlighted in this paper, most empirical work for the development of autonomous agriculture has
192 been focused on the technical aspects of robot operation with some level of inclusion and
193 reflexivity to ensure improvement of technical performance. Little published work has gone
194 beyond this to use methods that allow for substantive inclusion and deeper reflexivity on the
195 subject. Yet, if society decides that autonomous robotics for farming is the way to go, then
196 practising responsible innovation in their development is vitally important to prevent future
197 controversy, implementation delays, and negative consequences. Ultimately, the success or failure

198   of autonomous robots in agriculture will not rest on the limits of our technical enterprise, but on

199   our ability to include society and maturity to listen, learn, and respond.

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Ethics declaration

Competing interests

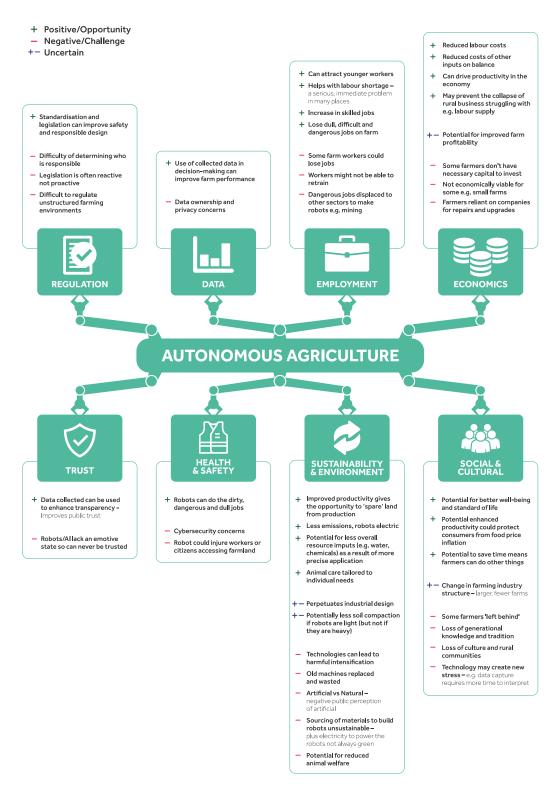215   The authors declare no competing interests.

Legend:
+ Positive/Opportunity
− Negative/Challenge
+− Uncertain

REGULATION
+ Standardisation and legislation can improve safety and responsible design
− Difficulty of determining who is responsible
− Legislation is often reactive not proactive
− Difficult to regulate unstructured farming environments

DATA
+ Use of collected data in decision-making can improve farm performance
− Data ownership and privacy concerns

EMPLOYMENT
+ Can attract younger workers
+ Helps with labour shortage – a serious, immediate problem in many places
+ Increase in skilled jobs
+ Lose dull, difficult and dangerous jobs on farm
− Some farm workers could lose jobs
− Workers might not be able to retrain
− Dangerous jobs displaced to other sectors to make robots e.g. mining

ECONOMICS
+ Reduced labour costs
+ Reduced costs of other inputs on balance
+ Can drive productivity in the economy
+ May prevent the collapse of rural business struggling with e.g. labour supply
+− Potential for improved farm profitability
− Some farmers don't have necessary capital to invest
− Not economically viable for some e.g. small farms
− Farmers reliant on companies for repairs and upgrades

AUTONOMOUS AGRICULTURE

TRUST
+ Data collected can be used to enhance transparency – improves public trust
− Robots/AI lack an emotive state so can never be trusted

HEALTH & SAFETY
+ Robots can do the dirty, dangerous and dull jobs
− Cybersecurity concerns
− Robot could injure workers or citizens accessing farmland

SUSTAINABILITY & ENVIRONMENT
+ Improved productivity gives the opportunity to 'spare' land from production
+ Less emissions, robots electric
+ Potential for less overall resource inputs (e.g. water, chemicals) as a result of more precise application
+ Animal care tailored to individual needs
+− Perpetuates industrial design
+− Potentially less soil compaction if robots are light (but not if they are heavy)
− Technologies can lead to harmful intensification
− Old machines replaced and wasted
− Artificial vs Natural – negative public perception of artificial
− Sourcing of materials to build robots unsustainable – plus electricity to power the robots not always green
− Potential for reduced animal welfare

SOCIAL & CULTURAL
+ Potential for better well-being and standard of life
+ Potential enhanced productivity could protect consumers from food price inflation
+ Potential to save time means farmers can do other things
+− Change in farming industry structure – larger, fewer farms
− Some farmers 'left behind'
− Loss of generational knowledge and tradition
− Loss of culture and rural communities
− Technology may create new stress – e.g. data capture requires more time to interpret

216
217 **Figure 1: Overview of challenges, opportunities, and potential consequences of autonomous**
218 **agriculture.** The signs +, - and +- indicate positive, negative and uncertain consequences,
219 respectively. Positive consequences denote opportunities to be harnessed, whereas negative
220 consequences denote challenges to be overcome concerning the operationalization, adoption
221 and/or deployment of innovations (see Sparrow and Howard[4] and Basu et al.[5] for more detail).

9

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