Inventory of smart farming technologies – focus of commercial and research products

Spyros Fountas[a], Frits van Evert[b], Athanasios Balafoutis[c], Vasileios Psiroukis[a], Michael Koutsiaras[a], Konstantinos Grivakis[a], Pieter Blok[b], Chris van Dijk[b], Sandra Wolters[b], Sakura Tomita[b], Herman Berghuijs[b]

[a] *Agricultural University of Athens, Athens, Greece, sfountas@aua.gr, vassilispsiroukis@gmail.com, michaelgkoutsiaras@gmail.com, di.grivakis@gmail.com*

[b] *Wageningen Research, Wageningen, The Netherlands, frits.vanevert@wur.nl; pieter.blok@wur.nl; chris.vandijk@wur.nl; sandra.wolters@wur.nl; sakura.tomita@wur.nl; herman.berghuijs@wur.nl*

[c] *Center for Research and Technology Hellas, CERTH, a.balafoutis@certh.gr*

Abstract: *The application of Smart Farming Technologies (SFTs) for farm management and decision making will bring many benefits, including more efficient use of inputs and a reduced impact on the environment. The aim of this work was to create an inventory of SFTs. An inventory of SFTs that are available commercially was created by surveying manufacturers, providers of equipment and services, and agricultural consultants, as well as SFTs that can be expected to become available commercially by examining applied research projects. Finally, a systematic literature review was carried out, which inventory SFTs that are in the early stages of research development. In total more than 1000 SFTs were identified and analyzed. Each SFT was described in terms of where it can be applied, what benefits it is expected to bring, and how readily it might be expected to be adopted. The comparison indicated that the majority of commercially available SFTs lead to higher productivity and profitability, sometimes with reduced emissions as a side-effect. There are few SFTs that directly improve sustainability (e.g. biodiversity, soil compaction). Scientific research on SFTs often focuses on sensing technologies, but relatively little on action. This seems to indicate that there is a knowledge gap between measuring the status of crop and soils on the one hand, and using that information to make practical decisions in farming on the other hand. Commercially available SFTs often target larger farms, while SFTs investigated in applied research projects are applicable on smaller farms, as well as larger farms.*

Keywords: *smart farming technologies, management information systems, precision agriculture, variable rate technologies, technology readiness level*

Introduction

Farming faces several challenges, amongst which are the need to reduce the use of pesticides, fertilizers and energy, to decrease adverse effects on the environment, to achieve safe and transparent agri-food chains, and to implement the Greening of the Common Agricultural Policy (CAP) of the EU. New opportunities are emerging in farming, as a result of rapid development of communication networks (mobile telephony, high speed connections and narrow band, short and long range) and availability of a wide range of new sensors. In an agricultural context, these technologies help capture and transmit geo-localized real-time information at low cost. Once gathered, processed and analyzed, these data can help to measure the state of the agro-environment (e.g. soil, crop and climate) and when combined with agro-climatic and economic models, forecasts and advices for better tactical decisions and management of technical interventions can be given. Precision agriculture has a major significance for future cropping systems.

Precision agriculture is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. Multiyear crop characteristics are tied to topological terrain attributes. Precision agriculture was largely made possible by the emergence of widely available GNSS technology. This has resulted in the possibilities for farmers and researchers to geo-reference many agronomic variables.

Attention for precision agriculture and smart farming technology is growing rapidly. It is therefore necessary to gain more insight in the types of SFTs that are being developed or have been developed. There have been several overviews of the current status of SFT development. Previous research includes a survey about adoption rates of proposed technologies, the CropLife/Purdue Precision Ag Survey developed at Purdue University, where it was based on retail crop input dealers (in the US) regarding their use of precision agriculture services. Moreover, multiple reviews have been done on farm management information systems (FMIS). Fountas et al (2015) have reviewed the state of the art in FMIS from both an academic and commercial perspective. Lewis (1998) provided information on the evolution of FMIS and Kaloxylos et al. (2012), (Kitchen, 2008) and (Kuhlmann & Brodersen, 2001) took an outlook on FMIS in the future. These efforts have contributed to an increased understanding of previous, current and possibly future developments in SFT.

The underlying concept for Smart Farming Technology (SFT) is precision agriculture. The Smart-AKIS project (www.smart-akis.eu) was set out to investigate the role of SFT in the development of future agriculture and try to close the research and innovation divide in the SFT sector. Smart farming technology can help achieve higher production outputs with fewer costs in compliance with agricultural environmental standards. Smart-AKIS aims to provide an extensive overview of SFTs. Although some progress has already been made to synthesize current knowledge on smart farming, many important questions remain. The objective of this study was to collect research projects and papers related to SFTs and commercial products and try to find the main trends towards this direction.

Materials and methods

A systematic review was conducted to provide more insight in current SFT development, based on scientific journals, EU-funded projects, national projects, and markets. A distinction was made between SFTs from scientific articles, scientific projects and marketed products. Web-search resulted in a large amount of relevant research projects. A library query containing a collection of keywords has resulted in a large amount of articles that have been carefully progressed through manual filtering. Both sources of research publications entered into a designed and developed database via an online survey in the Smart-AKIS project website. There was no weighting the quality of the paper based on pre-determined parameters, as the purpose was also to compare them with the commercial products, where each category has no specified weights to be comparable.

For the retrival of projects, an active search was carried out for EU-Funded projects. Horizon 2020, FP7 and ICT-AGRI programmes were collected from the CORDIS website of the European Commission. A selection query was used in order to select relevant articles from the Horizon 2020 and FP7 collection. In this selection relevant keywords have been used to identify SFT related projects.

['%sensor%, '%automat%', '%decision-support%', '%dss%', '%database%', '%ict%', '%autonom%', '%robot%', '%gps%','%gnss%', '%information system%', '%image analysis%', '%image processing%', '%precision agriculture%', '%smart farming%', '%precision farming%', '%agricult%', '%crop%', '%arabl%', '%farm%', '%vineyard%', '%orchard%', '%horticult%' '%vegetabl%']

where, the '%' helps to also get words from which the keywords is a part. This selection was supplemented by projects from the ERA-NET ICT-AGRI projects. These projects have been selected through a manual selection procedure. After selection for both sources of research projects 201 projects were entered in the survey.

For the retrieval of articles, the Scopus Elsevier database was used to collect scientific articles. A library query was developed to search articles that might describe SFTs. The query consisted of two parts: a first part that aimed to select all articles related to technology, and a second part that aimed to select all articles related to arable farming. The two parts of the query were joined with an "AND" clause. The selection of keywords was supplemented by considerations on the scope of relevant time and subject related settings. A copy of part of the query is written below as it was used to select articles by formulation of keywords:

[sensor, decision-support, dss, database, ict , automat, autonom* ,robot*, gps, gnss ,information system, image analysis, image processing, precision agriculture, smart farming, precision farming, agriculture, crop, arable, farm, vineyard, orchard, horticulture or vege]*

here keywords ending with " * " could have different endings (e.g. automat* could mean automatic or automated etc).

Results were limited by year, document type (article), subject type (agriculture) and language (English). For our purpose we have collected papers only from 2010 and later, in order to focus on recent SFTs that are likely of interest to modern farmers. Ten key papers considered relevant for our subject were used to verify the results of the query. When these 10 papers were included in the query result, this increased confidence that we had formulated an appropriate query.

The Scopus query has resulted in 11090 selected articles that are expected to be holding information on smart farming technology. The selection was followed by a manual sorting procedure. From these papers there were many that were not relevant to Smart-AKIS project or could only include the keywords but they were from domains outside agriculture. Therefore, a manual selection procedure was used to select only the articles that are relevant for our project, namely, articles describing a technology that can (or could be) used by a farmer in his or her daily farming practice. The manual selection of articles was done in two rounds. In the first round, we focused on the question *"Is this a relevant SFT?"*. The abstract of each scientific article was read to select the most related ones to SFT. Some important decisions on the relevance of articles were made in considerations between all partners. It was decided that some restrictions would reduce the scope of the articles to a level that would better represent SFT. Anything related to water or fish farming, post-harvest procedures and plant breeding and genetics was removed from our list of selected articles. Anything related to storage, processing, distributing and marketing was also not included in our selection. In the second round, we attempted to locate the full paper and evaluate in more detail the applicability of the SFT. As a result, there were 11090 articles selected. The first selection round filtered out articles that were not directly related to SFT in the field, reducing the amount of papers to +/- 1337 papers. The second selection round has been done to select SFTs that are of practical relevance and in a practical phase of development. A final selection of 718 articles was loaded in a database. This data was supplemented with the 201 EU projects.

For the collection of commercial products, a Call was announced through the project newsletter, as well through the network of Smart Farming Technology companies through the European Association of Agricultural Machinery companies that was partner in the Smart-AKIS project. In total 164 products were entered into the database and used for the comparative analysis of this study.

Results

The total amount of survey entries at the time of analyzing the data was 1103, where 164 were product entries and the remaining research papers and projects. Firstly, the most important results related to the types of SFTs are presented. Then, the results present the actual application of SFTs. Table 1 shows the results for the question about the type of SFT that is being or has been developed

Table 1 Types of SFT

	Type of SFT	Scientific articles	Research projects	products

1	Recording or mapping technology	35	224	77
2	Reacting or variable rate technology	10	66	59
3	Guidance or Controlled Traffic Farming technology	7	21	43
4	Farm Management Information System application or App	50	95	64
5	Robotic system or smart machine	16	67	44

Similarly to the entries of the research projects most product entries are about SFTs that are being developed for recording or mapping of relevant variables. However, there are also many efforts directed at the development of information systems in the form of system applications or apps. Slightly fewer entries were about SFTs that are involved in guidance or controlled traffic farming technology or robotic systems. Overall, entries were spread quite evenly over the different types of SFT that we have classified between.

In Table 2 information is summarised on the different relevant field operations that SFTs could be used for. Many products that were presented can be used for fertilisation, pest- and disease control and pesticide application related operations. On the contrary very few SFTs are about post-harvest storage, similarly to the SFTs found in research. In comparison to research SFTs there are many more SFTs involved in sowing technology.

Table 2 Field operations

Field operation in which the SFT is used	Scientific articles (Yes)	Research projects (Yes)	Products (Yes)
Tillage	17	12	55
Sowing	4	14	59
Transplanting	2	12	46
Fertilization	64	31	93
Pesticide application	31	15	92
Weed control	48	12	66
Pest and disease control	43	20	81
Irrigation	60	27	48
Harvesting	32	25	54
Post-harvest storage*	3	4	14
Scouting of crop and/or soil	189	26	41
Other	**	**	**

The SFTs on products hold a wide range of possibilities for application. We had entries from 18 different countries in Europe. The applicability of the SFTs is not region specific; most SFTs can be applied throughout Europe, only in very few cases countries were listed as the best location for application of the SFT. Spain, the Netherlands, France and Germany are some examples that have been chosen a few times.

Six statements on the application of the SFT could be filled in by level of agreement (Table 3). In total 143 entries were given in total for this question. In 62% of the cases the SFT product replaces a tool or technology that is currently being used. SFT can be often used without making major changes to the existing system (66%). The SFT products are presented as very easy to use and in most cases do not require significant learning (69%), although this is different in a few cases (9%). In 45% of the SFTs there is an expectation that the SFT could be beneficial in other ways than what is originally aimed by the inventor. In 74% of entries, the SFT is estimated to have effects that can be directly observed by the farmer. Only 3% of entries foresee a large time investment by the farmer and 75% disagree. In 61% of the entries the SFT produces information that can be interpreted directly.

Table 3 Statements on application

	Application statement	SD	D	A	SA	NO
1	This SFT replaces a tool or technology that is currently used. The SFT is better than the current tool.	2	10	50	39	42
2	The SFT can be used without making major changes to the existing system	1	10	57	38	37
3	The SFT does not require significant learning before the farmer can use it	2	11	45	54	31
4	The SFT can be used in other useful ways than intended by the inventor	2	17	43	22	59
5	The SFT has effects that can be directly observed by the farmer	1	5	43	63	31
6	Using the SFT requires a large time investment by farmer	54	53	4	0	32
7	The SFT produces information that can be interpreted directly (example of the opposite: the SFT produces a vegetation index but nobody knows what to do with it)	3	5	42	45	48

SD = strongly disagree, D = Disagree, A = Agree, SA = Strongly Agree, NO = No Opinion

Table 4 presents different users of SFTs are listed. Similarly to the research SFTs entries, the stakeholders that are most likely to actually use the SFT are contractors meaning also consultants that are advising farmers directly. Users of SFTs are similar to results that were found earlier in research SFTs.

Table 4 SFT users

	Who will use the SFT?	Scientific article	Research projects	Product
1	Contractor	333	53	104
2	Supplier	28	25	23
3	Buyer of farm products	17	7	16
4	Processor of farm products	21	8	12

Figure 1 presents a pie chart of the different keywords that could be chosen as relevant for the SFTs is shown.

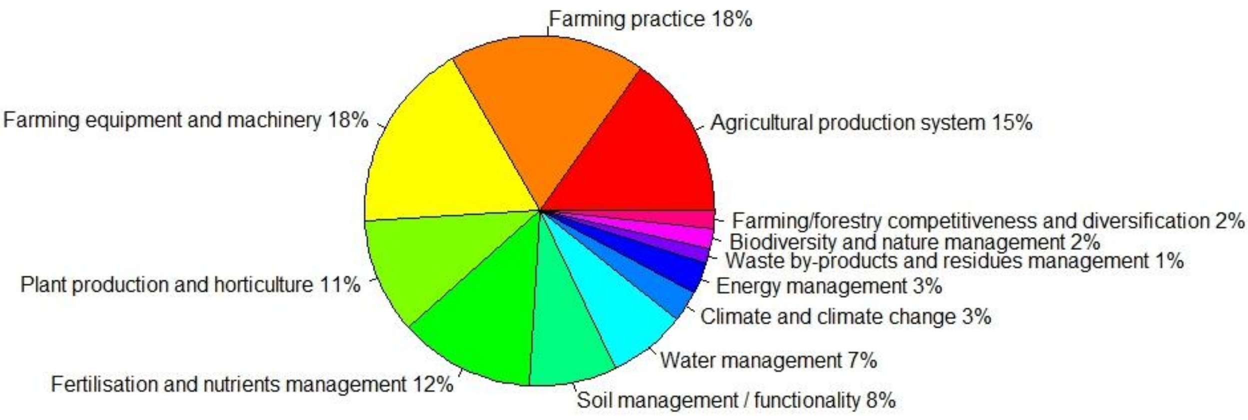

Figure 1. Relevant keywords (incl. rounded %)

The options farming equipment and machinery, farming practice and agriculture production were checked most cases. These keywords have often been combined with one of the other options. Production, fertilization and soil and water management are chosen quite often in contrast, however, the options that are more often related to environmental aspects such as farming/forestry competitiveness, biodiversity and nature management, waste byproducts and residues management, energy management and climate and climate change were less frequently chosen.

Table 5 lists the amount of entries by SFT developers in the market on the different options for farm size. There is a slight tendency towards larger farm sizes, starting from 50 ha. An opposite result was found in the scientific articles entries, where a slight tendency to smaller farm sizes was seen.

Table 5 Farm size

	Farm size (ha)	Scientific article	Research projects	Products
1	<2	303	67	62
2	2-10	306	71	68
3	11-50	311	76	97
4	51-100	368	78	107
5	101-200	283	73	110
6	201-500	271	72	110
7	500>	254	69	113

Table 6 lists the different effects on the 26 different agronomic subjects that we have identified.

Table 6 SFT effects

The SFT has an effect on	No effect	Large decrease	Some	Some increase	Large increase

				decrease		
1	Productivity (crop yield per ha)	35	1	0	67	40
2	Quality of product	47	1	0	50	45
3	Revenue, profit, farm income	25	0	1	52	65
4	Soil biodiversity	100	0	2	31	10
5	Biodiversity (other than soil)	113	0	2	17	11
6	Input costs	42	33	40	18	10
7	Variable costs	51	28	46	11	7
8	Post-harvest crop wastage	95	9	30	6	3
9	Energy use	65	26	35	12	5
10	Variable costs	129	3	10	1	0
11	CO_2 (carbon dioxide) emission	106	9	19	8	1
12	N_2O (nitrous oxide) emission	123	5	12	2	1
13	NH_3 (ammonia) emission	124	4	11	3	1
14	NO_3 (nitrate) leaching	125	4	11	2	1
15	Fertilizer use	67	29	32	6	9
16	Pesticide use	60	37	31	6	9
17	Irrigation water use	100	18	18	3	4
18	Labor time	57	38	37	7	4
19	Stress or fatigue for farmer	48	45	35	6	9
20	Amount of heavy physical labour	112	10	15	2	4
21	Number and/or severity of personal injury accidents	117	13	8	5	0
22	Number and/or severity of accidents resulting in spills, property damage, incorrect application of fertilizer/pesticides, etc.	104	19	14	3	3
23	Pesticide residue on product	89	20	27	4	3
24	Weed pressure	103	6	26	4	4
25	Pest pressure (insects etc.)	96	7	32	3	5
26	Disease pressure (bacterial, fungal, viral etc.)	96	5	33	4	5

The market stakeholders indicate strong effects on most of the 26 effects that have been identified. The results from product entries also show quite strong effects in comparison to the previously listed research entries. Most positive effects are seen in productivity, quality, revenue, (soil) biodiversity and variable and input costs. On the other hand, emission reductions are often expected to decrease as well as a relief of stress or fatigue for farmers. Quite often reductions are also expected in the amount of pesticide residue that stays behind on produce and weed pressure.

Conclusions

SFTs can be classified mostly as recording or mapping tools. The development of applications is also an important type of SFT. There are many efforts directed at the development of applications as reacting or variable rate technology. Slightly fewer entries were about SFTs that are involved in guidance or controlled traffic farming technology or robotic systems. Overall, there is a quite even variation in the different types of SFTs that we have classified. Many products that were presented can be used for fertilisation, pest- and disease control and pesticide application related operations. On the contrary very few SFTs are about post-harvest storage, similarly to the SFTs found in research. Market SFT inventors are positive about the application of products. Often the SFT product replaces a tool or technology that is currently being used. SFT can often be used readily without making major changes to the existing system. In contrast to research SFTs, product SFTs are mostly presented as very easy to use and in most cases do not require significant learning. Sometimes, the SFT could be beneficial in other ways than what is originally aimed by the inventor. SFTs are estimated to have effects that can be directly observed by the farmer and they do not require large time investments. Results from SFTs can often be interpreted directly. Similarly to the research SFTs entries, the stakeholders that are most likely to actually use product SFTs are contractors. The results from product entries show quite strong effects in comparison to the previously listed research entries. Most positive effects are seen in revenue, (soil) biodiversity and variable and input costs. On the other hand emission reductions are often expected as well as a relief of stress or fatigue for farmers.

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