# Driving Adoption of Agricultural IoT Solutions Through Product Design

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**Abstract**

Ecosystem of connected devices, internet of things is gaining popularity in a diverse range of use cases. Use of IoT in the agrarian sector is nothing new. But despite this fact, the agrarian sector does not seem to have a firm grip on how to adopt this solution in a more complex way, on every level within the agrarian production process. Spread of use of IoT in various environments has a great impact on production efficiency and output quality. Yet, when it comes to agrarian enterprises, there seems to be a missing sector-wide drive to invest and use IoT on a broader spectrum, not just within some parts of the production process. This paper aims to identify most prominent problem areas causing problems to broader adoption of IoT solutions in Czech agricultural enterprises. Findings of this research establish grounds for connecting digital and physical product design patronization methods leading to conceptual approach for IoT product design recommendations. Potential impact of applied product design patronization on drive of usage of IoT in agriculture is also a key topic of this article. Result of this paper leads to a framework describing fields of use of product design patronization for IoT products in agriculture. Impact caused by well virtually and physically designed IoT solutions in agricultural enterprises on technology adoption is also described. Combination of this leads to methodology improving the drive of IoT usage in Czech agricultural enterprises.

**Keywords** [1]

IoT, Agriculture 4.0, Product Design, Usability, Precision farming

## 1. Introduction

Emerging global trends on effectivity and sustainability influenced almost every aspect of every industry including agriculture. Similar to Industry 4.0, the advanced use of new approaches and technologies in agriculture directly gave rise to the field called Agriculture 4.0 [2]. In its core Agriculture 4.0 is a combination of interconnected technologies, smart or precision farming, big data analytics, artificial intelligence, blockchain technologies etc. [9]. Thanks to these advancements we can talk about the fourth agricultural revolution, the same way as transfer from indigenous farming to mechanized farming caused the past industry revolution [1]. Established framework for smart agriculture brings the possibility of optimizing crop yields, increasing the quality and quantity of output while utilizing less inputs resulting in cost reductions with better impact on the environment [18].

Excessive number of articles and studies have been conducted about various smart agriculture topics ranging from security of IoT devices, quality and reliability of various sensors, whole frameworks for solution architectures, normalizations, and many others [8]. Yet, these systems on a scale remain a heavily specialized field of expertise, used mainly by bigger enterprises in developed countries with the appropriate resources and motivation for dedicated specialists grasping the capacity for implementing these systems in real life environments [20]. Thanks to the sheer amount of device types, technological layers, diverse datasets, and technologies it is easy for smaller enterprises and farmers from rural backgrounds to lose themselves in the ways of smart agriculture possibilities [10]. This fact is concerning from various perspectives, mainly because groups of small/ rural farmers could heavily benefit from implementation of these technologies [5]. The possible ecological impact of optimized fertilizer usage, better watering management with connection to increased adoption of these technologies could be very positive [20]. Farmers can leverage IoT in agriculture in various ways from

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farm management, production optimization and automation to supported decision making based on analyzed data and predictions. Fields of IoT use in smart agriculture according to Sinha B, et al. [7]:

- Water/ irrigation management
- Soil management
- Weather management
- Nutrient management
- Crop management
- Livestock monitoring

Most of the data used comes from specialized sensors. Table 1 sums up the main types and subtypes of IoT sensors.

**Table 1**
Basic IoT sensor categorization

| Sensor types | Sensor subtypes | Demo images |
|---|---|---|
| Biosensor | Acoustic, Amperometric, Calorimetric, Electrochemical, Potentiometric, Piezoelectric... |  |
| Environment | Chemical, Color, Humidity, Luminance, Temperature, Radiation, Gas, Magnetic field... |  |
| Mass measurement | Corrosion, Contact, Density, Deformation, Flow, Moisture, Pressure, Volume, Strain... |  |
| Motion | Acceleration, Movement, Rotation, Velocity, Vibration.... |  |
| Position | Location, Orientation, Proximity, Presence, Inclination |  |

Sensors are of course not the only part of smart agricultural systems. Sensors gather information and need to work together with other hardware like transmitters, water pumps, energy management parts and more along with supporting software [23]. This just amplifies the real complexity of building and using these systems to some extent, especially for people with no advanced technical background [17]. Thanks to enormous technological advances these components became very inexpensive and widely available, so long gone are the times, where the main roadblock for implementation was inaccessibility of components and supporting software [12]. As new opportunities arise, so do the complications. Various studies discovered key areas posing challenges for broader adoption of IoT in agriculture:

1. **Standardization:** To promote open and unified standards for communication across very heterogeneous IoT device types promoting easy interoperability on high scale is an issue hopefully covered in future studies and research.
2. **Data:** In IoT data there is one major topic, Data reliability, be it missing data from mechanical parts or transmission, weather conditions, mislabeled data etc. [7]. Although multiple data mining techniques exist [24], noisy and abnormal data can stand in the way of successful use of data mining techniques and undistorted data analysis.
3. **Regulation:** As in any field, regulations can be an unpleasant roadblock, but sometimes necessary, this topic is not easy to grasp because how it should be approached differs from country to country and heavily impacts how data could be used, what hardware specifications and properties are valid and much more [25].
4. **Costs & awareness:** Even do IoT technology is much more available and cheaper today than a decade earlier, its implementation still represents costs not only for obtaining solution packages, but also the runtime and maintenance costs, be it electricity, server plans etc. But a much bigger issue impacting wider adoption of IoT in agriculture is lack of awareness in this specific market [7]. There seems to be a missing clear message about how this technology can help every individual farmer for their use case and how it can be achieved. Understanding that smart agriculture is not expensive, hard

to use a piece of hardware, but rather practical technology with potential for improving their everyday life [13].

There are much more defined challenges for agricultural IoT usage but listed above are the most relevant to specific problems driving adoption, especially between smaller farmers with fewer resources and motivation or awareness [15]. Another whole new breakpoint for advancement of agricultural IoT adoption is scientific research focus. Many studies are focused on finding the best communication protocols, circuitry architecture, UAV frameworks and other deeply technological problems [4], but few actually use design driven approaches and take into consideration the end user. This is one of the reasons smart agriculture seems to be a very advanced topic only experts and few technology enthusiasts really understand [11]. This sets an opportunity to think about how or if it is possible to create framework for approaching the whole user lifecycle from product idea onboarding to actually using the product in the easiest and most pleasant manner possible, so the use of smart agriculture could be adapted beyond large enterprises and experts, but also to a small farmer just wanting to automate his vineyard watering workflow [22]. This is the primary motivation for the focus of this article, to examine product design approaches to IoT in agriculture, rather than already well documented research on various functional and technological backgrounds. Some of the most popular smart agriculture solutions were compared based on criteria most relevant to setting up new use cases and rated by end users. Table 2 shows ratings in various segments sorted by importance. Ease of use: most important, performance: less important. These discovered criteria were used in framework design and the solution testing scenarios. Mentioned design driven development focuses primarily on ease of use, which as could be seen in table 2 is the criteria with highest priority amongst smaller farmers. What could be also seen from table 2 is the fact that average ease of use value for selected solutions is around 5.63/10 and this pattern was observed in most, even unclassified solutions. Ease of use is one of the most important aspects to take into account when creating adoptable, broadly used products [28].

**Table 2**

Comparison of smart agriculture solutions by small farmer criteria

| Criteria | Farm Works | AgDNA | AgroSense | Sentera |
|---|---|---|---|---|
| Ease of use | 4.2/10 | 7.3/10 | 6.2/10 | 4.8/10 |
| Features | 7.8/10 | 5.4/10 | 7.5/10 | 5.0/10 |
| Integration | 7.9/10 | 8.4/10 | 8.3/10 | 5.5/10 |
| Performance | 5.1/10 | 7.6/10 | 5.3/10 | 4.4/10 |

Focus groups were used to determine most prominent issue areas and set the base for comparative testing. Combination of public data, custom survey and deep dive interviews are also the supporting cornerstone of this research. Survey is designed for 30 individuals from the agriculture sector with various specializations, regions, and technological advancement. Deep dive interviews are conducted with selected participants to understand specific problems in depth. In person user testing is conducted to study the thought processes linked to certain tasks like creating new use cases, configuring devices, or managing existing setup. Gathered data are then synthesized to indicate most workable areas and ideate solutions. These solutions can be then evaluated from the perspective of feasibility and real benefit to the framework of the problem.

## 2. Challenges and findings

When designing an adaptable system for people, design approaches should be used [28]. The same way design driven development skyrocketed use of smartphones shifting the paradigm from niche PDAs to mass smartphone usage driven by the revolutionary iPhone [27]. What Apple did to promote adoption of this technology is exactly what is needed to happen in the smart agriculture field, employing design thinking instead of bare technology focus. During pre-research frame definition, a set of 10 deep dive interviews revealed the first area of challenge. For research purposes, a generic use case was created based on a 4-layer design model proposed by Yang, et al [18]. When users were first introduced with the physical hardware and setup workflow, it made no sense to them. As expected, human behavioral research were true, people are deeply visual minded, clinging to any possibility of visual associations for better adaptation to problems [28]. In this research case, end users interact primarily with first and last layers. First, it's the physical sensor deployment, for example moisture sensor in soil, and then the last layer represents fe. dashboard for device management, configuration, and reports. This is where the first problem occurred: farmers don't think in sensor names and port numbers, but rather in concrete problems and ideal solutions with as little effort as possible. In short, users did not know where the device (sensor) was represented in the application UI. Based on this knowledge, a middle layer, linking visually the first and last layer was added.

In practice this means physical devices are visually updated with e.f., 3d printed colored casings. These designs align with visual device representation in app UI with possibility to sort device types and use cases based on these visual properties. Two main distinguishing parameters have been discovered to be most considered by end users. Colors, for example: orange devices are specialized to work with water, red are for electrical detection and shapes: if its sensor or other type of mechanical part, for demonstration see Figure 2, which demonstrates updated visuals of physical IoT device and corresponding enhanced setup UI, working visually instead of technically and guides the user through setup process instead of causing information overload with excessive number of non-guiding, generic text fields, which the users have no chance of working successfully with [26]. This visual framework was the first step in improving users' chances to successfully solve the problem.

The use case based on this approach was as follows: Based on a brief introduction about what smart agriculture can do for the end users and how they can benefit from its use, users were introduced to a demo dashboard with one task. Set up anything they would like to actually use. The interface offered a technical view in the first run and simplified walk-through view in the second run. Most users picked up simple problems like automatic watering of small tomato plots or automatic greenhouse atmosphere regulation with opening windows and other issues they are invested in real life scenarios and can imagine using smart agriculture for. With the base field set, deep dives and focus group experiments could begin to determine key pain points in using smart IoT systems to successfully solve real life problems. From additional discussions, hands-on testing, and surveys 4 main problem areas have been discovered. These problems are listed in Table 3 along with % of impacted users and severity of this problem blocking the users from advancing in adapting this technology.

- P1: Motivation and benefits, the smallest top discovered problem, but still impacting more than half of selected respondents. This touches on the topic of technological literacy and benefit awareness [7]. Users don't not know why this (IoT solution) should be better, mainly because of decades of doing everything the old way, they could not imagine the real benefits, what does it mean for them, that something is automated, why they should pay extra money etc. Severity of this problem is not that high, because this problem can be easily solved. After presenting practical use case descriptions along with ROI and time savings and other quantitative data, put to the user's context, this problem was no blocker in task finishment chances.
- P2: Plug and play expectations. When faced with an excessive number of devices, cables and utilities, users did not know what to actually do with it.
- P3: Device management setting up new solutions, managing existing setups and easy access to analytics. The Introductory demo worked very technically, and users were not able to create a simple workflow setup. This problem was a huge blocker since information overload and technical difficulties made it impossible for users to complete the task.
- P4: Configuration. Similar to management, users did not know which values and thresholds should be set to achieve the task goal. Which correlates with the thinking process of finding a solution for a problem: Users want optimal soil humidity for their tomatoes, but don't know how to set the exact values of thresholds for water pump activation etc.

To successfully handle these problems various solutions have been tested and it was discovered that main added value lies in simplification of product design, user centered setup process with simple walkthroughs and visual association between physical and digital representation. These ideas have been put into the creation of a framework which is then tested on from various aspects.

Table 3
**Problem areas in agricultural IoT adoption**

| Problem | Area | % Respondents | Severity |
|---|---|---|---|
| P1 | Motivation & benefits | 60 | 3/5 |
| P2 | Plug & play | 75 | 4/5 |
| P3 | Management | 83 | 5/5 |
| P4 | Configuration | 91 | 5/5 |

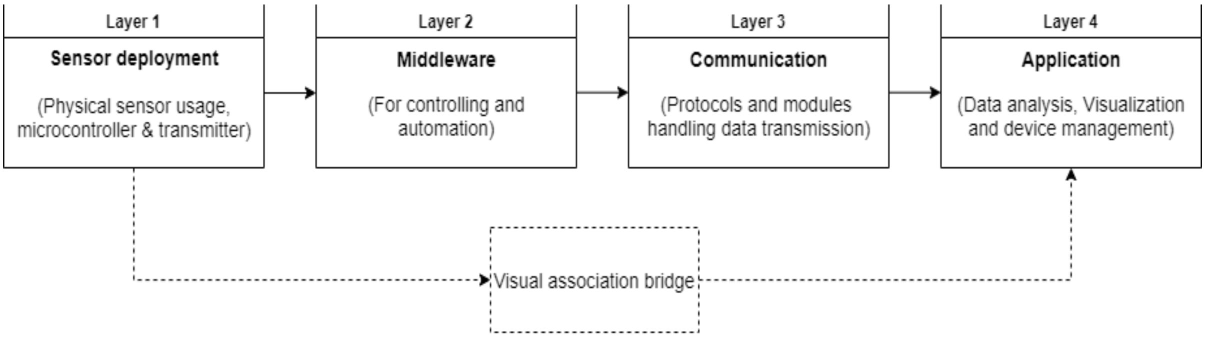


**Figure 1**: Enhanced 4-layer architecture

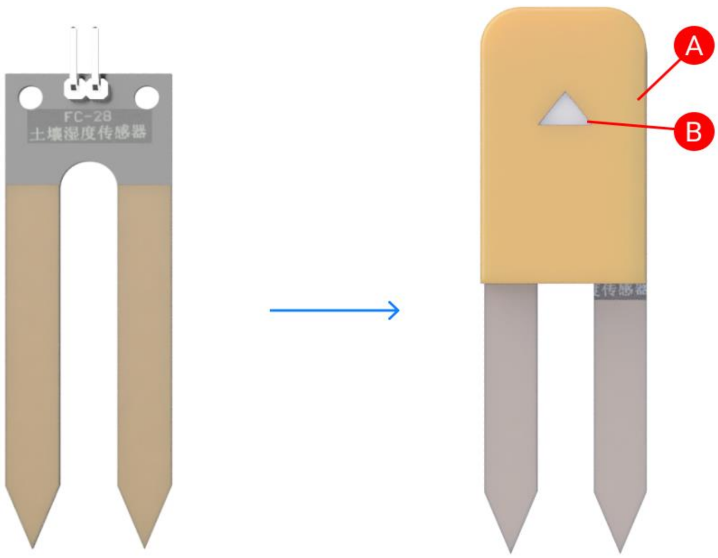


**Figure 2**: Visualized association

## 3. Testing framework ideas

Proposed system design aimed at solving discovered problems based on existing research and experiments. This system design consists of three main parts, Goal of the user, initial setup and finishment. Proposed design simplifies the existing workflow paradigm and enhances it with user centric approach to system design. Interaction with the system is built around real user needs and starts with problem definition (what the user needs to achieve). To avoid decision paralysis, databases with common use cases is utilized. Thanks to this system the user does not have to start with a blank slate, but rather start with predefined problems which can be customized to perfectly fit end users' needs with dynamic step-by-step setup walkthrough. This has a great potential of eliminating the severity of P3, because the user automatically gets recommendations which devices to use, the quantity and setup based on preselected preferences with visual aid to help further improve orientation in available devices. Concrete example can be this: Farmer wants to have his crops automatically irrigated. Does not know what is needed, just knows how big his plot is, what crop he cultivates, and which climate type is present at his plot. First step introduces the user to problem selection, for example: Irrigate crops, second step would be choice of crop, plot dimensions and geological location with additional optional requirements.

Based on these parameters in the language even the most rural and small farmers understand a set of recommended devices and amounts is automatically proposed to the user along with drag and drop interconnection visual builder. Thanks to parameter setting in previous steps, problem P4 can be also eliminated. The same way device recommendations work on desired use cases, device configuration for task automation can be automatically set based on these preferences. This means the user does not have to think about anything, only, if needed to edit pre-filled configuration. This framework is then used for designing mock prototypes of user interfaces. Walkthrough of this interface is then compared to existing solutions on the market. For demonstration purposes ThinkSpeak IoT platform has been chosen as a benchmark for non-technical users to complete the desired task against newly proposed design. Figure 4 demonstrates differences between technological vs user centric approach with gaze plot analysis. In the case (A) of advanced technological solutions, users with little to no technology background (majority of test subjects) had an atomic problem even understanding what they should do, gaze plot in this case shows desperate attempts to find some orientation point or guide to successful task completion. On the other side (B) the gaze path is far more streamlined, following the path as users scan familiar topics instead of blank generic fields, and read additional descriptions to point the user in desired location without any guess work and frustration.

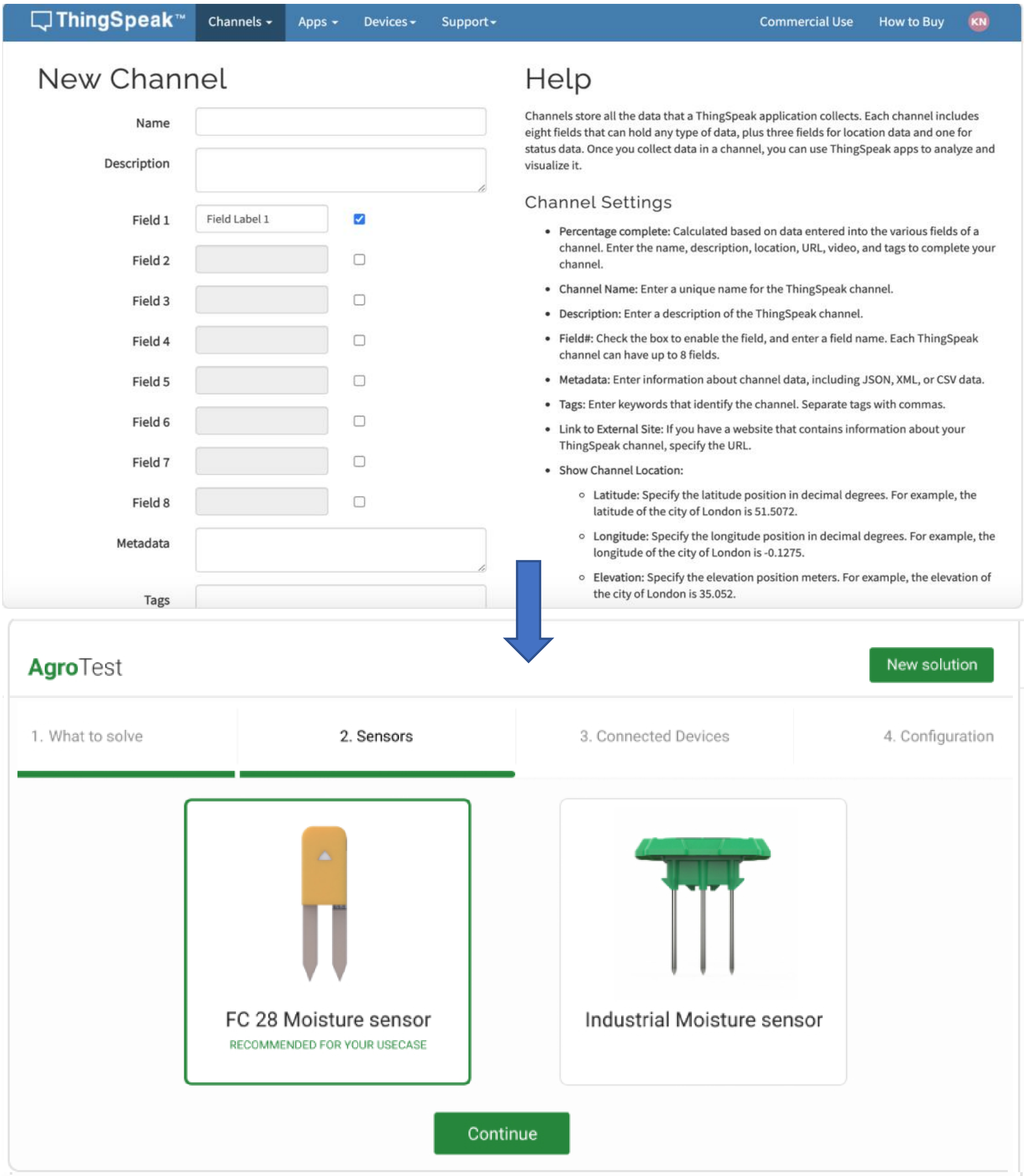


**Figure 2**: (continue)

Figure 1 displays just the first step of the mock workflow, as testing progressed following steps reproduced similar patterns. Success of individual steps was also measured. Flow was built on 3 steps: Initial setup, device selection/ pairing, configuration. In scenario (A) 90% of users did not manage to finish even the first step without aid, in contrast, all users were able to create their first use case in scenario (B). Thanks to smart recommendations and automatic configurations proposed in Figure 3, scenario (B) had a massively better overall aid-less finishment rate. Result of this experiment could be summarized as follows: Farmers with little technical backgrounds find it practically impossible to set up and configure agricultural IoT solutions of any size in the manners of advanced technical toolsets. After applying user centric approaches, the same process was greatly better in performance, not only the end users easily configured the solution, but also gained an understanding how IoT conceptually works, benefiting various agricultural aspects.

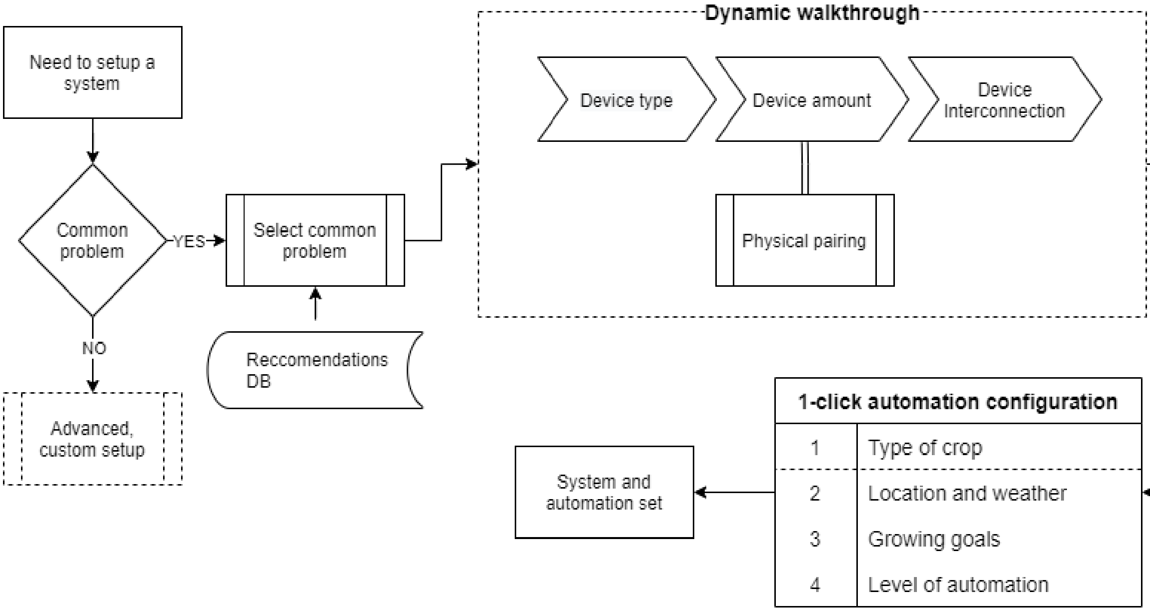


**Figure 3**: Setup system design

## 4. Discussion and recommendations

Primary goal of this article was to discover problems slowing adoption of IoT in smart agriculture and test approaches with the potential to help this situation. Thanks to conducted experiments, multiple areas that might be worth exploring further in detail to drive the smart agriculture growth further between smaller and rural farmers were uncovered and tested. No in-depth technological solution was proposed as it is out of scope of this article and would require more quantitative data and test subjects. Results of this article paved a way to possible further research, which would need to be conducted to really put these recommendations into quantitatively significant results and present real-life impact. Figure 5 sums up 4 main recommendations for further research based on identified problems both from existing research and conducted experiments.

### 4.1. Value proposition

Key starting point is motivation and awareness for the end users. There is little to no reason IoT frameworks for smart agriculture shouldn't be marketed as any other product improving people's lives. Marketing or landing project pages could be created, highlighting real benefits for every individual farming use case, offering solutions for real life problems while demonstrating ease of use and benefits. This alone might not be enough to shift industry awareness miles ahead, but it's a starting point to bring smart agriculture to the spotlight for every farmer.

### 4.2. Bridged physical and virtual design

Connecting the physical and digital world has proven to be a step in the right direction. Thanks to enhanced physical device product design corresponding with the application layer, users found it easier to select and manage devices. It also provided a path to new understanding how IoT works leading to new sources of technological knowledge in this sector. Instructional device design can lead to better understating and elimination of fears of unknown technology for individual farmers.

## 4.3. Automated configuration

During experiments with users, device configuration was the most intimidating step during the whole research process. With automated configuration based on intuitively sourced data this problem can be entirely skipped. Users can just check and edit proposed optimal configuration for desired use cases without any technical knowledge or advanced needs of things like pump waterflow for individual threshold values and hundreds of other possibilities. If this manual process is replaced with one click, potential to grow its usage can be large, but how exactly should be examined in further research.

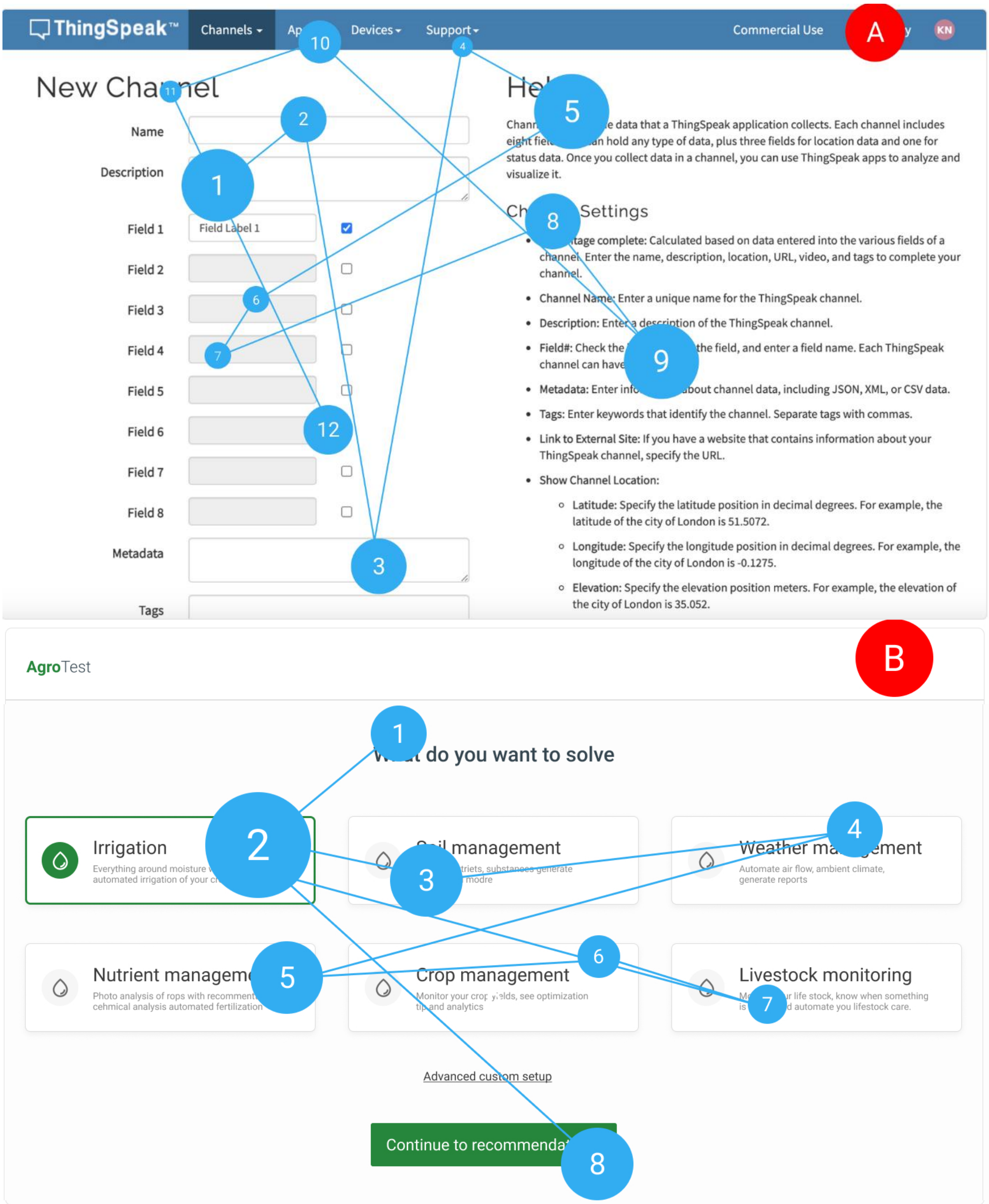


**Figure 4**: Prototype for walkthrough comparison

## 4.4. Open framework

For these standards to be widely available and inexpensive, an open approach should be utilized. This allows for greater experimentation, cost reductions and other initiatives driving IoT technology further. Open framework could contain proven recommendation, app research or software platform, 3D printing schematics parts lists and more.

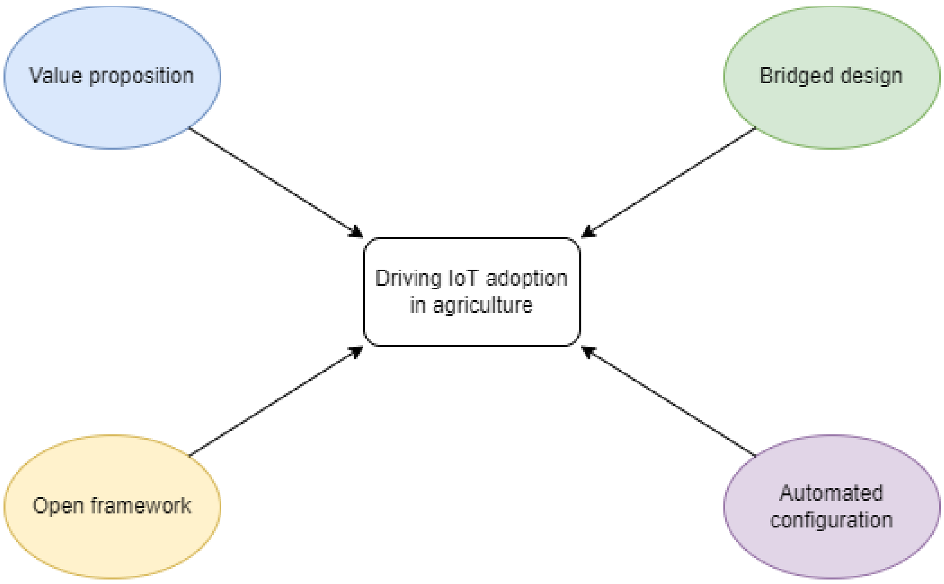


**Figure 5**: Areas for improvement

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