Internet of Beer

Subjects: Computer Science, Information Systems (/entry/subject/99)

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Today Internet of Things (IoT) is a widespread definition indicating a set of “smart objects” (smart devices) connected to and through the internet. Throug analyzed, and transferred, in a context in which “things” talk to each other and then carry out consequent actions.

Keywords: Brewing IoT Internet of Things wireless connection Raspberry Pi Arduino blockchain, Craft beer AI Artificial Intelligence Big data.

1. Introduction

The origin of the term is attributed to Kevin Ashton, in 1999, in a presentation made for Procter & Gamble. Kevin Ashton, raised how the initial idea of the t way almost all the information is generated by humans and specifying the enormous potential to have “objects” able to detect, through sensors, the surroundi

2. Infrastructure

Nowadays we have achieved most of what he pointed out. In this new era, we have a set of electronic devices, often man-independent, equipped with vario and sharing what has been observed to make decisions.

This evolution, if not technological revolution, is made possible by the enormous progress in the context of consumer electronics and wireless communica availability of increasingly powerful and less expensive microcontrollers, have started a process of maximum sensors capillarity and embedded technolo Internet. An IoT device needs three fundamental elements divided into macro-areas concerning (i) the microcontroller or processing unit, (ii) the sensors and connection to Internet. The elements belonging to these macro-areas can be found, to date, in most devices, not only within specific application context, but thermostat, a vehicle, etc., for the process of remote management and control.

The most popular boards used by IoT applications tend to directly integrate a radio module. Arduino MKR WAN 1310 for example is equipped with LoraWan and Bluetooth with possibility to interface sensors and actuators. The most widely used sensors find their place in an environmental monitoring context, th sensors on the market.

In the agrifood sector, many environmental monitoring cards are equipped with sensors to measure temperature, humidity, soil moisture, rain, UV, etc., wi valves and/or switches. Industrial context uses IoT devices for transferring the process to the network, expanding the potential for remote management and c

IoT technologies and devices are applied to a wide number of sectors with a steep growth[2]. Their enormous diffusion has given rise to dedicated networks t be transferred, the distances to be covered, or limitations of available energy (battery devices).

Moreover, to interconnect IoT devices specific infrastructures (e.g., cloud services) have been designed and developed according to different visions and r levels normally common to all the existing implemented forms (Figure 1). The first level includes the devices that collect the information and interact with eac represented by the IoT Gateways, whose fundamental role is to be the collector of all the devices, the various network typologies reside here (e.g., Lora, sig third level is represented by the IoT application service implementing all the logistics behind the management of the information coming from the devices (Database), application, and dashboard for Man-Machine interaction. The third level includes all IoT platforms, from the most complete ones, offered by cloud

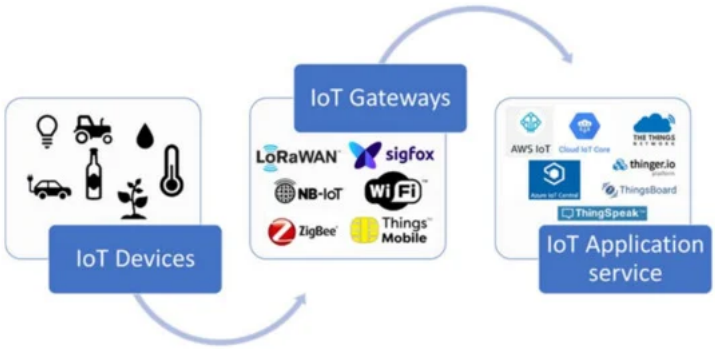

Figure 1. Scheme of the levels of the Internet of Things (IoT) infrastructure.

3. IoT Platforms

The increasingly popular IoT platforms today offer the same basic services aimed at creating dashboards, managing and storing and exporting data, managi statistics and data analysis, projecting the systems close to big data techniques available nowadays. By communicating with the IoT Gateways level the services. Nevertheless, through specific graphic elements, they provide many tools to simplify the real-time interaction and consultation of the system st accessible remotely, in real-time, and allows historical data queries.

Among the best known IoT platforms there are the Microsoft IoT Central based on Azure cloud, the Amazon Web Services (AWS) IoT of Amazon cloud, a offered by the modern big names in information technology; thanks to the potential of their clouds, they make available a set of services targeted for the I world. In addition to proprietary platforms there are open source solutions. These, expanding their services with connectors, mainly offer targeted services fo the control dashboard, to specifically targeted managements towards the IoT Gateways level. Table 1 reports a comparative scheme of the best IoT open concern the main characteristics of each platform such as the device management, security, the communication protocols towards the devices and othe perform data analysis, and the integrated database service.

Table 1. Scheme of the principal open IoT platforms and relative characteristics.

IoT Software Platform	Device Management	Integration	Security	Protocols for Data Collection	Analytics	S
Kaa IoT Platform	YES	Portable SDK available to integrate any particular platform, REST API	Link encryption (SSL), RSA key 2048 bits, AES key 256 bits	-MQTT; -CoAP; -XMPP; -TCP; -HTTP.	Real time IoT data analytics and visualization with: -Kaa; -Apache Cassandra; -Apache Zappelin.	Y
SiteWhere	YES	REST API, Mule AnyPoint, and more	Link encryption (SSL), spring security	-MQTT; -AMQP; -STOMP; -Websockets; -Direct socket connections.	Real-time analytics (Apache Spark)	N
ThingSpeak	NO	REST MQTT APIs	Basic authentication	http	MATLAB analytics	N
DeviceHive	UNKNOWN	REST AP, MQTT APIs	Basic authentication using JSON Web Tokens (JWT)	-REST API; -WebSockets -MQTT.	Real-time analytics (Apache Spark)	Y
Zetta	NO	REST APIs	Basic authentication	http	Using Splunk	N
Distributed Services Architecture (DSA)	NO	REST APIs	Basic authentication	http	No	N
Thingsboard.io	YES	REST APIs	Basic authentication	-MQTT; -CoAP; -HTTP.	Real time analytics (Apache Spark, Kafka)	N
Thinger.io	YES	REST APIs	Link encryption (SSL/TLS) and basic authentication	-MQTT; -CoAP; -http.	Yes	N

WSo2	YES	REST APIs	Link encryption (SSL) and basic authentication	-HTTP; -WSO2 ESB; -MQTT.	Yes, WSO2 data analytics server	Y
Mainflux	YES	REST APIs	JWT encrypted and signed tokens, OAuth2.0, public key infrastructure (PKI) and client-side certificates	-HTTP; -MQTT; -WebSocket; -CoAP.	Yes (integrated) platform not confirmed	Y

In the context of IoT, the open source concept plays a fundamental role. The term that was firstly introduced in 1998, when Netscape decided to publish the s concept has undergone a division, creating two macro-categories, identified as open source software and hardware. The IoT field embraces an entire h network infrastructures, and software platforms. Therefore, it is important to address the world of open source, to distinguish and consider the open source regards the devices, the considerable growth in consumer electronics, is mainly attributable to the release of devices under open source hardware license "open", allow to create a customized IoT infrastructure, molding it to specific needs. Although the open source hardware and software are very different in ter to the advantages and disadvantages that can be broadly summarized by the following aspects.

Possible benefits that could derive from their use regard: (i) no/reduced cost, (ii) large community of developers and/or supporters, (iii) accessible source c profit). The disadvantages instead may regard: (i) regularity of updates at risk if the product is no longer supported by the community, (ii) ancillary co modifications of the source code, (iii) often higher technical skills required.

Finally, thanks to the open source philosophy, it was possible to observe the evolution of the IoT world, leading to the emergence of diversified devices and pl world increasingly connected[6].

At last, regarding the security aspect concerning the data involved with IoT systems, a series of technologies are gaining always more attention being natur blockchain[7][8], RFID (Radio Frequency Identification), and other used for traceability purposes[9][10].

4. Applications Retrieved and IoB Technologies

The ultimate and ideal scope of these technologies is to attempt to connect the entire brewing process using digitally linked hardware and software from th following a feedback loop scheme.

It is necessary to say that at the moment, the benefits coming from the use of such technologies are mainly retrievable from producers claims and inc literature quantifying their advantages. However, in light of the strong and increasing interests, sales, and the digital implementation within other sectors reported applications.

4.1. IoB Technologies for the Brewery

To improve and constantly produce high quality beer, all the breweries, including craft ones, are starting to use IoT sensors or digital implementations. Internet of Things devices allow the collection of crucial and valuable information that helps in a variety of fields: from analyzing the evolution of crops on a monitoring how users consume a certain product and if they appreciated it. The application of IoB (Internet of Beer) technology can begin even with the p sensors that allow to monitor crops and predict the treatments to be carried out[11]. During the production phase it is important to monitor several factors i stages of the production chain could present higher problems with respect to industrial breweries. These for example include the impossibility to monitor t the weekends, this commonly being manually controlled. In this phase, the yeast consumes the sugars, increases the alcohol content, and decreases the variations outside the prefixed range can negatively affect the final aroma stimulating an excessive production of esters or other aromatic compounds. To industrial breweries. In craft brewing, due to often not optimized installations, limited space available, and budget problems, wired installation can be prob related to the contamination and size of the equipment used. An innovative practice is represented by the use of Bluetooth sensors that now provide overcome indoor flow problems, Cassia Networks used long-range Bluetooth sensors (battery powered) boxed inside acrylic tubes easy to sterilize. These the wort. A long-range Bluetooth router connects to the low energy Bluetooth sensor monitoring density and temperature of the liquid inside the tank. This n than wired sensors, is low-cost and therefore accessible to microbreweries, where operators through smartphones or tablets can monitor productio smartphones are all Bluetooth Low Energy enabled and represent a COTS (Consumer Off-The-Shelf) method compared to other expensive monitoring equ

Normally industrial big beer groups use proprietary software while average to small breweries rely on commercial software or even free/open source one available nowadays aggregate a lot of information and represent the communication structure for sensors and other devices. Please note that some of helpful for the traceability and logistics but being in the first place used for brewing and batch management they are reported in the present paragraph.

An example is represented by Orchestratedbeer[13], a complete solution including modules dedicated to the management of activity planning, inventory, p control, reports, and dashboard for each step, all in real-time. While the information used by the software are acquired through sensors (e.g., fermentat inserted by operators. This aspect is common across many software and some of them completely rely on manual data entry. BeerifyMe![14] is another customer's management and cloud solution 24/7. The platforms available for both are numerous (pc and mobile based). Ekos brewmaster, like its siblings, continuously recording data relative to the brew, fermentation, and conditioning logs for beer production and relative equipment maintenance. Brewplann specific effect of an action on other areas in order to understand the limitations and capabilities of the brewery and to apply real-time correction. Iconic® BM

software that include also mobile POS tools enabling to handle B2B sales directly on the road and B2C sales at events or in the tasting room. VicinityBrew[1] software in multi-stage production runs since, in the producer's opinion, most systems are not able to do that. The software can manage interdependent p for each stage. Interestingly, it offers dedicated tools for "contract brewing" helpful to manage batches done for beer firms.

Besides these comprehensive commercial softwares, of which just a small number was cited, there is a huge number of smaller software mainly aimed Generally, the main goal of these tools is to provide the environment for managing inventory, planning recipes, following and recording the batches until fini beer styles defined by the Beer Judges Certification Program (BJCP),[18], importing/exporting recipes files, and writing notes. Valid examples are Brewtar 3[20], Brewfather[21] and many more upcoming or discontinued like e.g., the well-known in the past ProMash[22] or open source HobbyBrew[23]. Among all, structured as a webapp or mobile App. It is probably the only software, at this level, which at the moment offers a solid integration with a growing numbe pilot and homebrewing levels.

The supported devices include Plaato Airlock[24][25], a digital airlock that can be easily mounted on the fermenter in place of a normal bubbler to continu bubble) and converting it to information inherent specific gravity, ongoing fermentation, alcohol percentage, and the ambient temperature (Figure 2). It inc information is sent from the Plaato device to a smartphone App via Wi-Fi for real-time monitoring and stored for later use and batch comparison. The sa Speidel[26] allowing you to monitor the fermenting process remotely (Figure 2). As in the previous case, the device counts the number of bubbles from specific temperature probe, and sends data to a MySpeidel account over Wi-Fi. Speidel claims that the data collected by the GÄRSPUND mobil, that car device, can enables to supervise and analyze the fermentation to predict and plan the bottling date, and to correlate the fermentation and the temperature brewing process. Similar tasks are accomplished by the open source device iSpindel[27] and TiltTM hydrometer[28] which however work through a different connection and include low-cost components. The systems are built around the concept of a tilting cylinder without the need of any external reference exce clean and to maintain. Their inclination angle changes in relation to the buoyancy and thus is directly related to the liquid density and therefore the s necessary or when batteries are changed. It is interesting to consider that these last devices can be used in fermenters of any size (if there is enough signa the size of the base of the fermenter. Devices such as the cited hydrometers and thermometers monitor the fermentation relying on a smartphone, but a va the Raspberry Pi[29] or Arduino[30]. These are small single-board computers used all over the world for open source (and not only) applications for robo extreme portability, very high flexibility, and extremely low cost. Thus, sensors can be read setting up a webserver on one of these or through specifically d complete fermentation telemetry solution for brewing. Another interesting device, which is implemented within Brewfather, and very rich of features, is re designed, with several dedicated applications among which one is for brewing. In the specific case the Smart homebrewing app, once installed, lets you Bag), RIMS (Recirculating Infusion Mash System) and HERMS (Heat Exchange Recirculating Mash Systems) both, manually or in full automatic mode. M mashing and hot liquor tank, fully configurable PID-PWM control and ON/OFF control with hysteresis, heating or cooling, IoT connection via WiFi to clou Telemetry Transport (MQTT) standard protocol, full compatibility with the Arduino ecosystem. A similar one, but with different features is the AxHTherm sma chambers that can be can remotely managed with the aid of BrewFather and/or ThingSpeak integration.

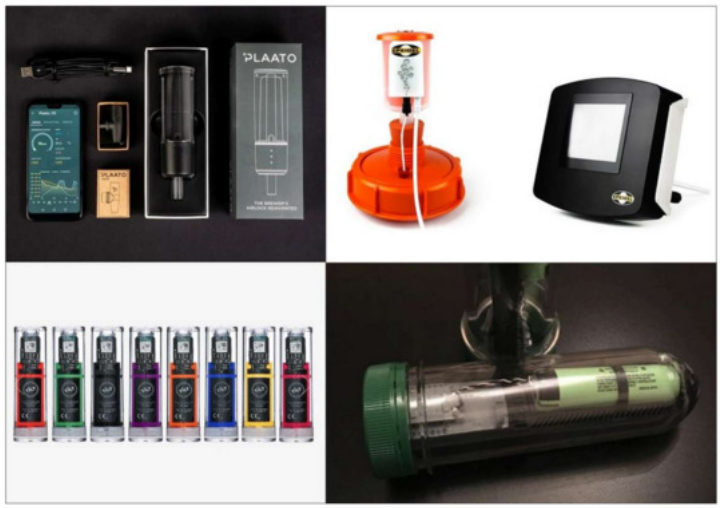

Figure 2. Devices. Top left—Plaato Airlock (image source: https://plaato.io/products/plaato-airlock)); Top right—Speidel GÄRSPUNDmobil (image source: gaerspundmobil-and-gaermeister-control.html); Bottom left—Tilt Hydrometer (image source: https://tilthydrometer.com/); Bottom right—iSpindel DIY electro

Another tool that allows to control mashing (including pumps) and the beer fermentation temperature with an accuracy of 0.1 ◦C is BrewPi Spark 3. T sensors, the temperature of beer and a refrigerator working as fermentation chamber switching on and off the heater and radiator when necessary. In the S in this way it is completely autonomous to control the beer processing but integrates the possibility to monitor the process from a smartphone or tablet. A Spark over USB connection for recording the delivery data. Moreover, it has also a web interface to monitor and control the process via the browser. (mixture, change the temperature profile, view graphs, and change settings[34]. The system is powered by the open source software project CraftBeerPi, b number of customizable applications from mash to fermenting with preset or custom profiles[35][36]. Raspberry Pi, Python language, and Linux OS are we scopes[37].

All the above-mentioned devices can use several communication strategies. Zhao et al.[38]experimented and tested a fermentation control through an IoT though a ZigBee network. The authors firstly analyzed the IoT technology available and the hysteresis process of beer fermentation, and then designed t chip CC2430 was used to achieve automatic detection and control of beer fermentation. The research showed the wireless network control structure communication at low costs. It concludes underlining the potential of the tested system in reducing the investment needed for the beer fermentation and hu already examples of feasible applications relying on Wireless Sensor Networks (WSN). This is testified, for example by the experience of Queen City Bre fermentation monitoring solution using the LORD wireless sensors[40].

However, wireless sensors are not exclusively used by craft breweries. Normally, fermentation is represented by a curve whose shape is determined by the which is not always predictable. Yeast can be more active in some batches than others and can degrade over time if more generations of the same yeast a fermentation data showed that it has ceased, and the density stopped decreasing long before the original fermentation program, often 40–50 h in advanc combined with TZEROBrew software, is possible to monitor the fermentation status in real-time. Hence, TZERO offers a digital version of the ferment understand the status of the entire fermentation process[41]. Precision Fermentation company claims to offer the first world real-time monitoring complet process. Their flagship product, the BrewMonitor® System, is advertised to potentially raise business profitability by monitoring pH, density, pressure, c temperature[42]. Pentair[43][44] launched a new Internet of Things (IoT) solution for beer membrane filtration (BMF) systems. This, following the producer clai performance, optimizing efficiency and improving the final product quality while lowering operation and upstream costs.

Furthermore, another technological advancement in IoB is represented by all in one IoT brewing systems suitable for (mainly) homebrewing and real available on the market. Brewbot is a high tech small-scale brewing device IoT enabled. As reported by Samuel Khamis (chief science officer at Brewbot), b able to perform a series of steps independently, communicating with the user via the Brewbot app. The device targets large-scale breweries, for pilot plant p maximum production of 45 L[45]. Other systems, that work similarly, include the Grainfather[46] producing up to 70 L, Brewtools up to 150 L[47], Speidel Br many others. Their aims differ on the basis of the production potential, from 150 to 200 L a nano brewing system can be potentially useful for a restaur products onwards can work for a microbrewery.

An interesting and very new trend is the creation of micromalting systems equipped with sensors, real-time data reading, display, and remote control. As proper malting from kernels germination to roasting. Sprowtlab[49] created the Acro remote controllable small malting system relying on a dedicated softw quality malt. The same has been done by BBC Inox[50] that produces micro malting systems starting from higher production level with a minimum of 100 kg promising system is being developed by Arzaman S.r.l.[51] starting with a system able to produce around 10–25 kg of malt including special ones due to t system relies on the SmartPid controller described above presenting very high process control precision. It is Wi-Fi connected, so even when the operator i monitor the process through web app to read real-time malting data.

Another interesting aspect regards the objective quality control these technologies can enable which is often a prerogative of big breweries. Di Caro et a measurement of beer color in relation with the European Brewery Convention (EBC) international method. The color is a crucial quality parameter for the of spectrophotometric techniques that have been adopted as international standard by many brewers' associations in the world. The study proposes breweries that cannot afford expensive devices.

Finally, Nimbalkar et al.[53] studied the use IoT technologies for the breweries and underlined that these are crucial to obtain relevant real-time, and for later production and sales processes. The authors agree on how modern breweries can use a computing and communication core system based on IoT to mo engineered systems. Moreover, they pointed out that the interactions between humans and systems create dynamic networks potentially improving cost stru

4.2. IoB for the Traceability and Logistic

Traceability is usually defined as the ability to follow the movement of a food, through its entire supply chain, from production to distribution and product lo systems such as smart tags (RFID, NFC, and barcodes) to obtain traceability information[9][10]. In the beer sector, transport is a phase of the supply cha product arrives as quickly as possible from its place of origin to the table and above all in optimal conditions, preserving its original qualitative characteristi to excessive temperature and direct sunlight. This is particularly true for craft beers that are generally not pasteurized or heavily filtered e.g., with diatomace

The transport phase along the beer supply chain is not only important for the finished beer but starts with hops extremely vulnerable to temperature and ox a short shelf life, so it must be transported to the production plant within a short time. To overcome eventual problems, Rogue Farms (Newport, Oregon), th monitor and trace the hops, controlling its temperature and humidity during transport and estimating the time of arrival. The shipment of hops is controlled receive an alert on the status of location every 10 min and when the product is halfway through, the plant begins with the production phase. In this way, th to make the hops use coincide with its delivery and thus to reduce the deterioration of the raw material[54]. IoT technology are not only important for the bee when the barrels or pallets of beer are ready to be shipped. In this regard, the US beer distributor, B United International, uses satellite sensors (Ovinto) t hundreds of brands of beer, cider, and mead as they are shipped to breweries around the world. Thanks to sensors relying on satellites for positioning it is of each container, even if in transit across the ocean. As a result, real-time data will be shared with business customers and consumers. The IoB system m fluctuations, with the result that complex naturally refermented beers will taste in the end point as similar as possible as they did when they left the brewery "Bock Chain" beer has been brewed. The beer relies on a blockchain system to track ingredients and beer from field to can. The can has a final QR code o retrieve details about the product and its origins. The QR code unlocks a microsite containing videos, photos, maps, data, timestamps related to the entire barley growing in the field and animated maps illustrating various stages of the supply chain. Each step contains photos, videos, and descriptions of th allows consumers to share their Bock Chain experience through a social link[56]. In addition, to reduce fraud, theft, and losses related to barrel and keg tra keg tracking process, i.e., Asset Tracking Platform based on Blockchain and IoT. The platform uniquely identifies each keg/bottle and its content and ca chain. Using the Blockchain enabled system, breweries get accurate and up-to-date information and reports about keg filling, status, movement, cu maintenance. The structure was created on a private blockchain based on Hyperledger, so there is no need for intermediaries. The solution allows c transparency in their supply chain by recording the origin of barrels or casks[57]. Another use case of Blockchain paired with IoT is represented by the syst by Alpha Acid Brewing (Belmont, California, CA, USA). Oracle claims their Blockchain Applications can enhance traceability and transparency throughou services enabling end-to-end traceability of goods and transactions in the supply chains, product genealogy and provenance, monitoring and tracking the recommendations to optimize processes, and much more[58]. Kyle Bozicevic, Alpha Acid Brewing Company owner said "With Oracle Blockchain solution suppliers and analyze sensor data from the production process. Oracle Blockchain Platform tracks where we are getting the highest quality hops, malt, an around our products"[59] so the system help as well in creating a storytelling to enhance the marketed products. In addition, the consumer can read all the and give a feedback helpful to identify and solve problems where and when he is not satisfied with the product[60].

In general, breweries are relying on IoT and blockchain technologies to improve profits, optimize product quality and transparency towards consumers. malfunctions along the beer supply chain. Through a system equipped with sensors, conditions can be monitored and notified in real time during delivery, re time, the blockchain applied to food traceability allows all participants to see the data recorded in the previous steps, which means that customers will b

provides customers, producers, and anyone involved in the network with detailed information on a product and its traceability. The end user will be able to types of labels[61].

Hershberger et al.[62] patented a system (based on RFID and pressure sensors) for the brewing industry logistic to improve the low efficiency of the traditi and kegs filling level. This is just one out of many technologies that need to be combined together to create a digitalized supply chain. A study conducted beer logistics" concludes that this digitalization needs some internal and external changes to be effective. Among the first cited is the necessity to e digitalization of the material/products flow, to automate the identification of products for precise monitoring of the batches, to apply RFID as a full ider (smartphones, smartwatches, and tablets). Among the external changes that need to be made, the study cites the importance of a cooperative approa wholesalers through digitalized and standardized processes.

The cooperation among stakeholders, and thus the information standardization, is also one of cores of big data and AI applications depending on data acc efficiency within the supply chain. Heineken uses big data and AI on data regarding various beer brands it owns to increase efficiency and manage it experience[64]. Anheuser-Busch InBev, at the moment the world's biggest beer company, is undergoing a huge digital transformation project trying to amal of their properties into a unified data central structure called Enterprise Data Hub (EDH) using data to enhance their business processes, improve consur platform, running in Microsoft Azure, consists of a blend of Microsoft and third-party utilities, uses several layers of data, including layers for raw, clean, and use cases including demand forecasting, fraud detection, social media listening, and IoT analytics. In an interview to datanami[65] the group declare that have the same indicators, so they are easily scalable to all breweries.

4.3. IoB for Beer Service, Marketing, and Consumption

Probably, the least exploited stage through the IoT, and therefore one of the most innovative, regards consumers' behavior and feedback. Knowing when, liked is valuable information and a very powerful tool for any company. Geeksme (a Spanish company) for example, is working on an IoT device that, amon taps and bottle openers so they can extract information about their customers' consumption[11]. There are different types of IoB technologies that are s Taptronics from Pubinno, is a technological system that allows the bartender to be informed about the content left in the keg as a clever, connected plug ar beer, monitoring temperature and pressure in one touch in every single glass. In addition, the producer claims how its use may save up to 20% of the cost Pubinno was also the creator of BeerPoint technology, an IoT-enabled self-service beer vending machine that uses prepaid NFC cards sold in stores. Cu drink with a simple tap. Serving a glass of beer in less than a minute reduces waiting time and increases customer satisfaction[66][67]. An innovative IoT ser is basically a coaster that uses a strain gauge membrane sensor to determine the level of beer (evaluating its weight) in a glass placed above it. When th enough liquid and need a refill, reports the information directly to the bartender or using a server, wirelessly. Given an RFID-enabled beer glass decorated signal the beer brand you need to refill[68]. The beverage manufacturer Carling has also launched the world's first "Beer Button". It is a technology tha drinkers to online shopping baskets from the comfort of their own homes, exactly what Amazon did with its product specific "Dash Button". The Beer Button the user's account at a retailer of their choice. Customers only need to press the button to automatically add beer to their shopping basket and buy[69]. A beer service is the Kegtron. This is a tool that allows to precisely trace the levels of the drums, displaying the information on your mobile device. It consists and the tap to which the barrel is connected. The box hosts a flow meter that accurately measures the amount of liquid dispensed a processor and a wi device on which the Kegtron application is installed (available for both iPhone and Android devices)[70]. Another (patent-pending) machine-to-machine con order processing is SteadyServ's iKeg. Through the iKeg application, retailers can also know exactly what they have in their cooler and which draught bee turned efficiently. A correct tap list needs to observe principles regarding proper beer differentiation. Orders can be placed via voice, text, and e-mail throu the beers are running out and when they need to re-order. The iKeg app also allows you to send automatic, customizable social alerts on Facebook and T provides a fully integrated set of tools to advertise a club, a special event, or a unique beer. A similar technology is represented by iPourIt. Customers, or details, receive a wristband with RFID technology. As he pours a beer, the sensor in the handle of each keg that reads the ID of the unique bracelet, a amount of beer he pours, allowing the company to charge per ounce poured[71][72][73]. An innovative device not yet on the market is the WECHEER.IO, a ga able to instantly identify the person, time, place, and brand of any bottle with crown cap. Working via Bluetooth, WECHEER.IO allows users to share their movements the night before. It is speculated that it may cost $55. Surely it is a pretty expensive item, designed more for restaurants than for individual cus Research Centre VTT and the Finnish company UpCode, within the European project TagItSmart!—funded by the Horizon 2020 programme. Th thermochromic sensors and inks in consumer goods, such as beer. These thermochromic inks reacting to light and temperature variations, are made of pl intelligent sensors on beer labels, the consumer knows whether the beer can be consumed and the circumstances under which it was brewed. The smart (Vaasa, Finland) to track the opinions of Finnish consumers[75].

Another interesting solution is represented by "Simple Beer Service" application and hardware. The idea developed by Amazon Web Services Startup P kegerator (draft beer system) to measure when a pour is occurring, post the data to Amazon API Gateway and on a dedicated web page through a dashbo be applied and scaled up for use in a pub. It demonstrates how informative and affordable these kinds of technology and services can be[78]. An alternat represented by Kegbot[79]. The system enables real-time keg monitoring to always know how much beer is left in the kegs tracking in detail the history of w Moreover, being open source results to be very extendable and well supported by the developer community supporting the project. The system final price meter, the necessary barbed fittings, an RJ45 ethernet, and a micro USB cable. To operate the system requires an android smartphone, or tablet for b showing keg status, statistics, and pictures taken (e.g., indicating brewery logo and/or beer label). A more advanced system is I-TapR2[80], an intellig developed in order to improve beer taps efficiency through the data acquired and analyzed. The system, with respect to the previous cases, operates u monitors the entire beer system through a web interface. It features advanced beer inventory and analytics behind consumption that, following their clair board. In detail, besides basic parameters, it monitors also CO2 pressure, glycol temperatures, and more for real-time tracking and visualization on laptop Nevertheless, it allows inventory control reporting automatically which lines need new beers and can place kegs or CO2 cylinder orders autonomously by auto shutdown the lines in the case of problems preventing waste, e.g., caused by involuntary emptying of beer lines, and represents a valuable tool for were poured at what time and where. Finally, recent studies show a clear trend regarding the use of low-cost techniques using robotics, AI, computer vis and consumer preferences regarding beverages[81][82].

4.4. IoB Technologies and Potential Use Summary

Of course, the available technologies are more than those cited by this work that, rather than find all the possible solutions available or under development from the introduction of these in the beer panorama. Table 2 reports the potential impacts IoT systems might have on beer processing, logistics, and servi categories (Intervention Level) since many technologies reported are potentially relevant for several sub-fields e.g., processing steps.

Table 2. Examples of Internet of Beer (IoB) use cases and their potential impact within the three reported macro areas on intervention. The letters H a Hardware is normally supplied with its own software, sometimes open for developers to produce their own code.

Technology Intervention Level	Impact Benefits	Technologies	References
Brewing process	• Energy use reduction; • Product value increase; • Workload reduction; • Raw material monitoring and optimization; • Problem identification; • Increase of the production level; • Time optimization; • Product standardization; • Improvement of temperature and fermentation control; • Client management; • Sales management; • Real time parameters monitoring (pH, density, pressure, conductivity, dissolved oxygen and internal/external temperature; • Automation of the fermentation process;	• Cassia Networks Bluetooth Sensor; (H) • Orchestratedbeer; (S) • Beerifyme!; (S) • Brewplanner; (S) • Iconic® BMS; (S) • Vicinitybrew; (S) • Brewtarget; (S) • Beersmith 3; (S) • Brewfather; (S) • Promash; (S) • Hobbybrew; (S) • Plaato Airlock; (H, S) • Gärspundmobil Speidel; (H, S) • Ispindel Hydrometer; (H, S) • Tilt™ Hydrometer; (H, S) • Raspberry Pi board; (H) • Arduino board; (H) • Mybrewbot; (H, S) • Smartpid; (H, S) • Tzerobrew; (H, S) • LORD Wireless Sensors; (H, S) • Brewmonitor® System; (H, S) • Brewbot; (H, S) • Grainfather; (H, S) • Brewtools; (H, S) • Speidel Braumeister (H, S)	[12][13], [14][15], [16][17], [19][20], [21][22], [23][24], [25][26], [27][28], [29][30], [31][32], [33][34], [35] .

Technology Intervention Level	Impact Benefits	Technologies	References
		• Sprowtlab; (H, S) • Micro malting system BBC Inox (H, S) • Arzaman S.R.L.; (H, S) • Low-Cost Spectrophotometer; (H)	
Traceability and logistics	• Transport tracking; • Logistic optimization • Stock control and storage of raw materials; • Monitoring the position, temperature, and pressure during transport; • Sharing traceability data with the consumer and stakeholders; • Protection against fraud and leakage of beer kegs; • Transparency of supply chain; • Reduce malfunctions along the beer supply chain;	• Rfid,Nfc; (H) • ROGUE Smart Sensors; (H) • OVINTO Satellite Sensors; (H) • Bock Chain and Qr Code Systems (H, S) • Blockchain systems; (S) • Big Data and AI; (S) • Microsoft Azure Platform; (S)	[9][10][59][54][55][56][57][58][60][61][62][63][64][65].

Technology Intervention Level	Impact Benefits	Technologies	References
Service, marketing, and consumption	• Consumer feedback; • Customer consumption information; • Reducing waste and fraud; • Increase customer satisfaction; • Optimize beer service; • Real-time keg monitoring; • Smarter business decisions.	• Sensors applied to beer taps and bottle; (H, S) • Taptronics (Pubinno); (H, S) • Beerpoint Technology (based on Nfc System); (H, S) • Robiotic (Rfid-enabled beer glass); (H, S) • Beer button; (H, S) • Kegtron (keg monitoring); (H, S) • Ipourit (wristband with Rfid technology); (H, S) • Wecheer.Io (intelligent bottle opener); (H, S) • Functional thermochromic sensors and inks; (H, S) • Simple Beer Service; (H, S) • Kegbot (keg monitoring); (H, S) • I-Tapr2 (tap and keg monitoring); (H, S)	[11][66][67][68][69][70][71][72][73][74][75][76][77][78][79][80]

5. Conclusions and Future Prospective

The IoB systems and the applications reviewed in the present work have the potential to bring benefits to the whole brewing chain from the beginning of may arise range from energy and cost saving to increased management strategies including feedback coming from consumption analytics. It appeared a from some of the presented technologies. These were firstly implemented by bigger brewing groups which have higher needs for product standardizatio technologies firstly implemented are proprietary, or developed following specific needs, and rely on cabled sensors and expensive infrastructures locally sensors, the presence of small elaboration boards, the increasingly popular IoT platforms offering both basic and advanced services at reasonable pr companies such as craft breweries. However, the potential benefits need to be carefully considered in relation to the implementation costs. A cost-relate many devices and software. These normally have much lower price with respect to proprietary ones but do require increased management skills. In t implementations or complete systems. In the first case low technology skill may be enough while a whole optimized environment requires discrete work complete system step by step considering devices and ecosystems that follow the same standards or allow for high flexibility.

The first step is always to monitor and register parameters a second one regarding the creation of a decision support system (DSS) for practice optimizatio optimize production and logistic since craft beers are generally more delicate and less stable with respect to industrial ones. For a big group, instead, a marketing strategies. Nowadays software are potentially powerful DSS tools that acquire data through sensors, share data with the supply chain and th feedback for each beer lot.

The trend that the future beer sector will face, will be a very fast increase in the use of IoB systems to drive efficiency, productivity, quality, and safety. This decision-making. These aspects that are and will become more and more crucial likewise in many other sectors, imply considerations regarding the data ov to IoB devices and apps is destined to significantly go down while their diversification on the market will grow. This will lead to a massive future imple favoring the skilled companies that will implement correctly sized solutions in advance. Finally, many of the cited IoT apparatus, software, and hardware, ca far from the beer one, potentially producing the same benefits. If in the future, if standard protocols and data formats will be applied and embraced, differe from data provided by other ones, e.g., production from logistics.

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