# Technologies for capturing and analysing animal health data in near real time

L.K. Holmstrom* & T.R. Beckham

Kansas State University, College of Veterinary Medicine, Manhattan, KS 66506, United States of America
*Corresponding author: lkholmstrom@gmail.com

**Summary**
Information technologies are rapidly advancing the way in which animal health data and information are collected, analysed and shared in order to support animal health management, disease surveillance and response, and decision-making. However, the full potential of these technologies for early detection and response to natural or intentional disease events has not been fully realised in animal health at the global level. This paper discusses advances made in these technologies and examples of how they have been applied in animal health for near real-time data collection and analysis. The technologies reviewed include: *i)* mobile health (mHealth) technologies, wireless sensors and biosensors for remote data collection; *ii)* crowdsourced and Internet-based data collection; and *iii)* electronic health (eHealth) technologies for data integration and analysis.
Experiences of implementing these technologies, and challenges with their use, are also discussed so as to provide recommendations on their future application in animal health. The world is ripe with opportunities to develop and enhance mHealth and eHealth technologies that are cost effective and capable of near real-time data collection and analysis. Such technologies have been shown to be valuable and capable of being implemented in both developing and developed countries, and ultimately will strengthen disease surveillance and reporting across the globe. International mechanisms and data standards are needed to facilitate the sharing and analysis of animal and human health data between countries. Identifying ways in which animal and human health data collection and analysis can be better integrated within a 'One Health' approach will enhance the coordination and capability of disease detection and response at the human–animal interface.

**Keywords**
Animal disease detection – Automated data analysis – Electronic health technologies – Information technology – Mobile health technologies – Real-time data collection – Surveillance.

# Introduction

In what is being described as a revolution, information technologies are rapidly advancing the way in which animal health data and information can be collected and analysed in order to support disease surveillance and response (1). These technologies have the capability to collect and analyse large volumes of data in near real time, which can allow for rapid detection and response to natural and intentional disease events as they occur. With the threat of bioterrorism and high-consequence disease outbreaks being part of the current global health landscape, real-time data collection and analysis is even more critical.

Figure 1 provides an overview of how information technologies that are currently available can be used to enhance traditional data collection and analysis methods. The utilisation of these technologies could provide critical information in near real time in developed and developing countries, even when robust veterinary health infrastructures do not exist (2). However, a recent study suggested that the implementation and utilisation of these technologies has not yet been fully realised. In 2015, a survey conducted on behalf of the World Organisation for Animal Health (OIE) aimed to assess the availability and current and potential uses of information technologies across different animal health settings within OIE Member Countries' Veterinary Services (1). The animal health settings that were assessed were: data management, disease outbreak reporting, active and passive surveillance, and emergency response. A key finding of the survey indicated that, while information technologies are widely available to Member Countries, they are used only at low levels, and sometimes not at all.
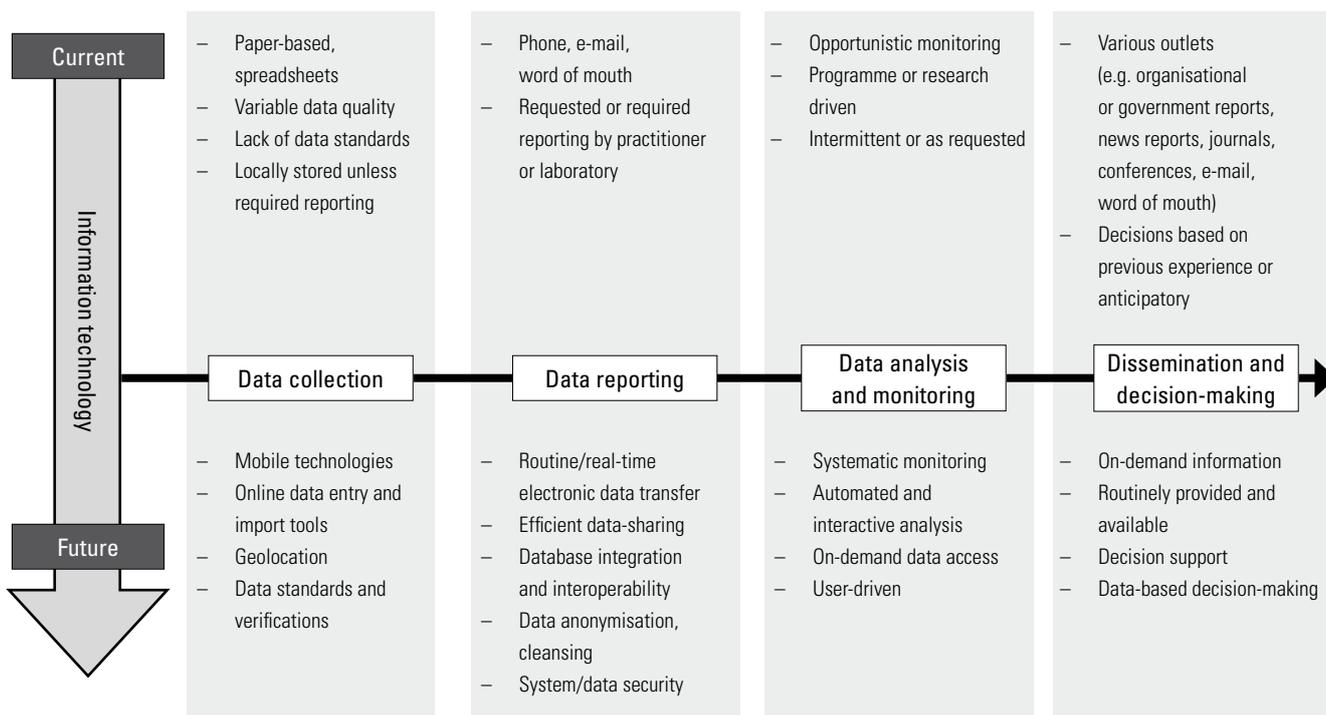
**Fig. 1**
**Characteristics of current data collection and analysis methods in animal health (top row) and how advances in information technology have enhanced how these methods can be performed today**

The occurrence of existing and emerging animal diseases continues to increase, and is combined with the added threat of the relative ease with which biological agents can be weaponised and intentionally introduced into human and animal populations. Therefore, there has never been a more critical time at which to leverage information technologies in order to enhance data collection and analysis for the early detection and surveillance of, and response to, natural and intentional disease events.

This paper identifies advances made in information technologies, their characteristics and how they are currently being implemented to support animal health. It focuses on technologies as categorised by Beckham and Holmstrom (1):

– technologies for remote data collection: mobile health (mHealth) technologies and wireless sensor technologies/ biosensors

– crowdsourced and Internet-based data collection

– electronic health (eHealth) technologies for data integration and analysis.

Key terms are defined in Table I so as to ensure a common understanding with the reader on how these terms are used within this paper.

# Technologies for remote data collection

Information technologies for remote data collection provide the capability to collect animal health and related data in the field either in person via mobile devices or remotely via remote sensing and biosensors. These collection methods allow data to be collected and/or accessed in near real time.

## Mobile health technologies

According to the International Telecommunications Union, global interconnectedness continues to grow rapidly, with 95% of the world's population living in an area covered by a mobile network, and the majority of Internet users now located in developing countries (3). Network services and mobile devices are also becoming more affordable and their usage across the globe is increasing. As of November 2016, there were 7.5 billion mobile device subscriptions worldwide with smartphone subscriptions accounting for the majority of these (4). Mobile devices used to support mobile health technologies, or mHealth technologies, include handheld devices such as mobile phones, smartphones, and tablets that allow data to be collected at

**Table I**
**Definitions of information technology terms**

| Term | Definition |
|---|---|
| Biosurveillance | Active data-gathering with appropriate analysis and interpretation of biosphere data that might relate to disease activity and threats to human or animal health — whether infectious, toxic, metabolic or otherwise, and regardless of intentional or natural origin — in order to provide early warning for health threats, early detection of health events and overall situational awareness of disease activity |
| Electronic health (eHealth) technologies | The use of both information technology and health informatics/bioinformatics to integrate disparate data sources into a common technology platform capable of data monitoring, analysis, and sharing; decision support and/or information exchange and feedback |
| Information technology | The comprehensive management of animal health information across computerised systems and its secure exchange between consumers, providers, government and other entities. Technology systems allow data and information to be stored, processed, shared and analysed |
| Integration | The arrangement of an organisation's information systems in a way that allows them to communicate efficiently and effectively and brings together related parts into a single system |
| Interoperability | The extent to which systems and devices can exchange data and interpret that shared data. For two systems to be interoperable, they must be able to exchange data and subsequently present that data so that it can be understood by a user |
| Mobile health (mHealth) technologies | The use of mobile devices in collecting aggregate and animal-level health data, providing healthcare information to animal owners, community animal health workers, veterinary practitioners, researchers and animal-health officials, and real-time monitoring of animal health status, and direct provision of care (via mobile telemedicine/tele-diagnostics) |
| Syndromic surveillance | Surveillance that uses health-related information (clinical signs or other data) that might precede or substitute for formal diagnosis. This information may be used to indicate the sufficient probability of a change in the health of a population to deserve further investigation or to enable a timely assessment of the impact of health threats which may require action. This type of surveillance is not usually focused on a particular hazard so can be used to detect a variety of diseases or pathogens, including new (emerging) diseases. This type of surveillance is particularly applicable to early-warning surveillance |

the location and time (or soon thereafter) at which animals are examined. These technologies help to address the many challenges associated with current data collection and surveillance systems (i.e. data timeliness and quality, the lack of data standards and the ability to geolocate) that limit the speed of detection and the response to a disease event (5, 6). Mobile phone health technologies provide data collectors with the ability to quickly reach large numbers of people at a low cost. In addition, such technologies, by their portable nature, can be utilised in rural areas of developed and developing countries where livestock are commonly located (2, 5, 7, 8, 9). Furthermore, they enable all members of an animal health enterprise (e.g. livestock owners, community animal health workers and technicians, veterinarians, etc.) to be active participants in bidirectional information exchange. Participants provide data, and receive information and feedback from animal health experts (e.g. diagnostic laboratories) and authorities (e.g. government animal health officials). Information provided to veterinarians and livestock owners on animal health trends and events in their area can then be used to make production and animal-health decisions. The opportunity to leverage mobile and Internet connectivity for animal-health data collection, surveillance and disease detection continues to increase. The types of information technology platforms being used for data collection utilise both the voice and short message service (SMS) capabilities of mobile devices, and the mobile application ('app') and geolocation capabilities of smartphones and tablets.

## Voice-based technologies

Voice- and SMS-based technologies have the greatest global reach as they are compatible with both basic mobile phones and smartphones. Voice-based technologies primarily use an interactive voice response (IVR) platform for data collection and information exchange. IVR is a menu-driven system with audio teleprompts and instructions to which the user responds in order to access further information and submit data.

The advantages of IVR compared with other mobile technology platforms include:

– a lower cost to users (the user does not require a data plan on their phone to use it)

– its independence of user literacy

– a highly customisable interface for different languages and accents

– low technology development requirements (10).

A potential drawback of IVR is that the data collected through this mechanism may not be of as high quality as that

collected using other mobile phone technology platforms. This was recently observed during the 2014 Ebola outbreak in West Africa, in which both IVR and SMS were used for data collection (11). SMS provided higher-quality data that were similar in quality to data being collected via face-to-face interviews. The reason for this was that it allowed users to answer questions at their own pace and to read/edit responses before submitting them, capabilities which are lacking with IVR. The lower-quality IVR data resulted in these data being interpreted with caution (11).

There are many examples of IVR use in human health for automated data collection and health monitoring (12, 13, 14, 15, 16, 17); however, its use in animal health is limited and has been primarily restricted to facilitating information exchange. For example, programmes have been set up in Afghanistan and India that utilise IVR to receive information and/or advice regarding livestock production and current market pricing (18, 19). Still, there are situations where the use of IVR for data collection is preferable. For example, during the 2014 Ebola outbreak, IVR may have been the only feasible option for data collection in remote areas, where using SMS is not possible for technical reasons (11). Karimuribo *et al.* (2) identified IVR and SMS as technologies to target for data collection and information exchange with livestock owners in rural areas in Tanzania, given that basic mobile phones are owned by the majority of livestock owners rather than smartphones. The availability of support for voice and IVR capabilities on mobile phones may in part be due to the fact that these are currently the platforms that end users are most familiar with when compared with other mobile phone technology platforms. As such, a beneficial application of the voice capability of mobile phones could be for information exchange; information that could be used to incentivise end users to remain part of a larger network that also uses SMS and/or smartphone apps for data collection.

## Short message service-based technologies

Basic mobile phone and smartphone users routinely use SMS technology. Data collection can occur through questions that can be answered with simple codes (e.g. replying '1' for 'yes', '0' for 'no' or through numeric disease codes, etc.). This technology and method requires that users are trained or have a list of the codes available to them (20). As such, the length of the data collection form and responses are more restricted when compared with electronic forms or mobile applications that allow for data entry on smartphones. With many online applications available for data collection, such as FrontlineSMS, GeoChat, Kannel and RapidSMS (21, 22, 23, 24), SMS can be used for low-cost, effective, high-quality data collection. For example, data collected using SMS during the 2014 Ebola outbreak in West Africa required minimal data cleaning (11). In Tanzania, SMS data collection facilitated data analysis more easily and allowed

animal health officials to respond to disease events more rapidly (8).

SMS is also an effective tool for providing disease alerts of animal health events and for targeting end users who receive the alerts (21). In Kenya, SMS was demonstrated to be a tool that can notify health facilities of disease outbreaks in an effective and timely manner. It was also demonstrated to increase the likelihood by 16.2% that disease events would be reported to regional and national disease surveillance coordinators when compared with the non-use of SMS (25). SMS has also been used to provide information exchange and feedback between clients and diagnostic laboratories, thus enhancing animal health delivery services. For example, Karimuribo *et al.* (2) developed the e-SUAVetDiag® System in Tanzania that allows livestock field officers to send an SMS to the diagnostic laboratory. This message notifies the laboratory technician that the sample is on its way and of its expected arrival time. Laboratory results as well as animal health advice and treatment recommendations are then sent back to the field officer via SMS. This allows near real-time sharing of information and can aid more rapid decision-making in the field. In this way, animal health decisions can be made in near real time in consultation with laboratory experts (2).

## Mobile applications on smartphones

With the development of smartphones, their increasing capabilities, and wide distribution across the globe, the use of apps for electronic data collection is rapidly increasing (26). Permissioned users can enter data into an electronic questionnaire/survey that is accessible via a mobile device. Mobile apps can collect and transmit large amounts of a wide variety of data, including text, geolocation information, barcodes, photographs and videos. The ability to transmit photographs and videos allows for remote clinical assessment, diagnosis and treatment (i.e. telemedicine) (7). Mobile apps also enhance data quality and completeness as they allow for drop-down menus and single- or multi-select data fields that limit errors from free text entry, pop-up text boxes and images that can provide instructional help, and data entry verifications and validations. Through the data, and the app's verification and validation capability, an app developer can require a subset of, or all, data fields to be completed before a report can be submitted. In addition, the app can provide restrictions that allow for only biologically plausible data fields to be entered (27, 28). Apps can store data on a mobile device until the user next establishes a network connection. It is at this point that the data can be manually or automatically transmitted and submitted. This allows for data collection in remote areas to occur with the knowledge that, once a network connection is established, the data will be automatically submitted and added to the database for analysis (29, 30). Another advantage of smartphones is their ability to collect locational data using

*Rev. Sci. Tech. Off. Int. Epiz.*, **36** (2)

529

the device's global positioning system (GPS) (7). The spatial attributes of data enhance the quality of data analysis that can be provided to end users, and this analysis's subsequent use in the early identification and detection of disease outbreaks, or in the verification of the absence of disease, in a geographical location. Novel ways of using smartphones' GPS for spatial data collection are also being seen. A recent example of this was the use of de-identified mobile-phone voice-call records as a valid data source for estimating near real-time population movement patterns after a natural disaster (31). Additional capabilities continue to be developed that enhance the quality of data collection via mobile apps. For example, Jandee *et al.* (32) developed a customised language voice survey within a mobile app. This development allows for questions to be read aloud in the local dialect, and demonstrates the enhanced quality of the data collected.

Both online software platforms and custom-developed mobile apps are being used increasingly in animal health for near real-time data collection. Several online software platforms are available that allow users to develop their own questionnaires which are then accessible via mobile apps on iPhone and Android devices for data collection (e.g. EpiCollect, Magpi [previously known as Episurveyor], Open Data Kit) (30, 33, 34). For example, EpiCollect has been used in Kenya by farmers and veterinarians to report animal disease outbreaks and track vaccination and treatment campaigns, as well as in West Africa for tick surveillance (28, 35). Mwabukusi *et al.* (8) used both EpiCollect and Open Data Kit for collecting animal and human health disease event data in remote areas in Tanzania, which successfully alerted animal health authorities to a foot and mouth disease (FMD) outbreak. In other cases, mobile apps have been custom-developed for specific projects or organisations. The decision to do so is typically based upon the scope of the project requirements being beyond the use of a tool solely for remote data collection, such as integration within a broader surveillance information technology system (see the eHealth section below), and/or preference that data are not transmitted by, or stored with, outside/commercial entities (29, 36). For example, the Food and Agriculture Organization of the United Nations (FAO) developed an Android mobile app called Event Mobile Application (EMA) that integrates disease information collected in the field with FAO's Global Animal Disease Information System (EMPRES-i; http://empres-i.fao.org/eipws3g/) (37). EMA has been successfully piloted in Uganda since 2013 with plans to expand its use across the country for tracking animal diseases, as well as additional pilot projects planned in other countries (38). Regardless of the platform, mobile apps have been well received when applied in animal health to remote data collection and have been shown to improve the timeliness of this collection as compared with paper-based questionnaires (2, 8, 27, 32, 39). While the current process for mobile app development

is device-specific (i.e. Android and iPhone apps are developed separately), newer methods for cross-platform mobile app development are emerging that allow one data collection form to be developed and deployed to Android and iPhone operating system (iOS) mobile phones/tablets simultaneously, eliminating the need to develop forms separately and thus decreasing the time from development to deployment (40).

Another advantage of mobile apps is the enhanced capability to provide near real-time feedback to end users using visual and analytical tools, such as spatial trends and anomaly detection algorithms (28). This feedback can be viewed by end users on their mobile devices, as well as through Web-based applications such as eHealth technologies (see the eHealth section below). For example, EpiCollect has the option for users to integrate their collected data with online spatial visualisation and analytical tools through a website (spatialepidemiology.net) (30). These technologies can control the type and granularity of the feedback, such as sharing the data in anonymous format and in aggregate form at a higher resolution than the level at which the data were collected. Like SMS, mobile apps on smartphones can communicate in the form of alerts from a central authority, such as from government animal health authorties, to all or a subset of users. Additionally, mobile apps can further support bidirectional information flow through the use of within-app messaging between users in the field, and animal health experts and/or authorities (27, 29). These capabilities overcome the challenges of current surveillance systems characterised by hierarchical data flows resulting in slow data collection, analysis and sharing of information (5, 28). Furthermore, they allow animal health status information to be instantaneously available to the frontline animal health workforce in the field, thus increasing the likelihood of the early detection of disease as well as enhancing overall point-of-care animal health decision-making from treatment to interventions by veterinarians and animal health workers (27, 41).

With the increasing availability of mHealth technologies, the decision regarding the most appropriate platform(s) for data collection should be guided by the objectives and data to be collected, as well as factors such as accessibility and cost (28, 39). Appropriate training is essential to ensure that users are familiar with the mobile technology and its use in data collection. IVR, SMS and mobile app technology platforms are still in the infancy of their implementation and sustainability within animal disease surveillance and outbreak response systems globally. Still, the use of mobile technologies will only continue to increase and it would be prudent to take advantage of their use for electronic data collection, as well as to identify novel ways in which they can be used in animal health.

530

*Rev. Sci. Tech. Off. Int. Epiz.,* **36** (2)

## Wireless sensor technologies and biosensors

In what is called 'precision livestock', wireless sensor technologies, including biosensors, are being developed and used in animal health in order to remotely collect various types of data on livestock, from biometrical to behavioural data on individual animals or the herd (42). These technologies provide continuous, remote and real-time data to monitor animal health status and welfare. Various types of data can be collected, such as animal body temperature and heart rate, animal movements, stress levels and changes in body analytes (e.g. protein or enzyme levels), and detecting the presence of disease pathogens (43). Such data can allow for the early detection of disease events even before the onset of overt clinical signs. For example, infrared thermography has been demonstrated to detect FMD in cattle and mule deer based on increased foot temperatures that signalled the disease before the onset of clinical signs (44, 45). Biosensors within ear tags in pigs were shown to detect African swine fever based on increased body temperature and decreased movement before or as clinical signs were first observed (46). Uses of radio-frequency identification (RFID) have extended beyond animal traceability and can now be injected/ingested and connected via wireless networks and mobile devices for measuring animal biometrics, location and behaviour, including contact with other animals (47, 48). Other wireless technologies incorporated into animal equipment are also being used in the early signalling of changes in animal-health status, such as decreased visits to feed bins or decreased feed intake based on real-time data measurements from computerised feeders for dairy cattle (49). Such data can also be incorporated within the mobile apps used for data collection as described above, having the capability to connect to sensor technologies via Bluetooth or a wireless network in order to collect the 'sensed' data and add them to the mobile data collection form (33).

Similar to mHealth technologies, integrating biosensor and wireless sensor technologies into information technology platforms allows data that are being collected continuously, and remotely, to be transmitted in real time for data integration and further analysis (see the eHealth section). Still, the current limitations of wireless sensor technologies, such as the costs of their use per individual animal and the variable success of their use due to environmental conditions, has limited their broader application in animal health (50). For the early detection of disease events, such technologies may still have value for real-time data collection and monitoring within targeted disease surveillance strategies, such as the use of sentinel herds for early disease detection in an at-risk geographical area (46).

# Crowdsourced and Internet-based data collection

A wealth of valuable disease information can be accessed from the public via the Web and can provide real-time and geolocation data on disease events. Called 'digital disease detection' or 'Internet-based epidemic intelligence', crowdsourced and Internet-based data collection, such as the data-mining of online social media or other sources on the Internet, can be a quick and efficient method of providing situational awareness and detecting disease events earlier than transitional surveillance systems can (5, 7, 51). Crowdsourced data collection, such as that through social media platforms like Twitter, can provide information proven to predict disease trends and to identify disease outbreaks. The current applications of its use in animal health have mostly been related to zoonotic-disease data collection within the public-health sector. For example, Chunara *et al.* (52) showed that informal data sources, such as Twitter, provided epidemiological patterns for cholera in Haiti two weeks before official disease data had been reported, while Chew and Eysenbach (53) showed that Twitter combined with routine epidemiological data could detect H1N1 outbreaks in 2009. Taking advantage of the capability of crowdsourcing and the ability of the public to serve as disease sentinels in order to monitor or predict disease outbreaks, websites have been developed to facilitate the active reporting of disease events by the public. The website HealthMap (www.healthmap.org) has a mobile app called Outbreaks Near Me that allows the public to report disease events in its geographical area, while the website Flu Near You (www.flunearyou.org) allows people to report their own health status on a weekly basis. These websites then aggregate the reported data to provide real-time intelligence on the geographical locations of disease events. With regard to bioterrorism, crowdsourced data using social media can provide an earlier alert of such events to authorities as opposed to traditional emergency response communication networks. This was the case during the 2013 Boston Marathon bombing in which individuals near the explosion used Twitter to post locational data and specifics of the explosion within minutes of its occurrence, providing rapid insight as the emergency developed in advance of media and official public reports (54).

Internet-based data collection involves analysing search terms entered into Internet search engines, such as Google or Yahoo, or monitoring other Internet sources that provide news on disease events, such as the Program for Monitoring Emerging Diseases (ProMED-mail; www.promedmail.org), HealthMap or Canada's Global Public Health Intelligence Network (GPHIN; https://gphin.canada.ca/cepr/). Similar to crowdsourcing, Internet-based data collection has been shown to be highly predictive of disease events (7).

*Rev. Sci. Tech. Off. Int. Epiz.,* **36** (2)

531

For example, Ginsberg *et al.* (55) were able to model influenza incidence based on trends in public searches on Google for terms/phrases related to the disease. ProMED-mail reports have been shown to provide early warnings of disease events before they were reported through official government channels, and GPHIN reported on the 2002 severe acute respiratory syndrome (SARS) outbreak in China two months before it was reported through the World Health Organization (56, 57).

With both crowdsourced and Internet-based data collection, 'big data' methods such as data/text mining, machine learning and predictive algorithms can be used for the automated analysis of the huge volume of data available from these sources. These methods allow for continuous querying, filtering, integrating and visualising of disease data in near real time (7). When combined with spatial and temporal epidemiological analyses, such methods generate new knowledge on disease events and risks. Big data is at the crucial point of being increasingly utilised and applied in animal health, has the capability to fill knowledge gaps, and the ability to allow for the effective management of animal- and human-health risks (58).

Digital disease detection has the capability to engage and develop a public network capable of disease recognition and to provide a forum for quick information feedback during disease events. Still, limitations on the use of such technology for data collection need to be considered. Since the data are informal and unstructured, there can be 'noise' in the data that prevent disease events from being recognised or cause false positives to result (7, 59). While the data are timely, care must also be taken to verify them before further posting the information in public forums. Still, there is potential in animal health for the continued development and application of near real-time data collection of these novel data sources and early warning of disease events to complement more traditional surveillance systems (7, 26). Combining such data with other verified data sources can help to increase their sensitivity and specificity so they can be used effectively for disease surveillance and response (43).

# Electronic health technologies

Electronic health (eHealth) technologies encompass the use of information technology and health informatics/bioinformatics to integrate disparate data sources into a common technology platform capable of data monitoring, analysis, sharing, decision support, and/or information exchange and feedback (60, 61). Within animal health, these technological systems are commonly Web-based platforms that perform part or all of these capabilities, including integrating data from the data collection technologies discussed in the previous sections, in order to support early warning and monitoring of diseases at the regional, national and global levels. Figure 2 provides an overview of the process for using information technology to support real-time data collection, integration, analysis and sharing in animal health.
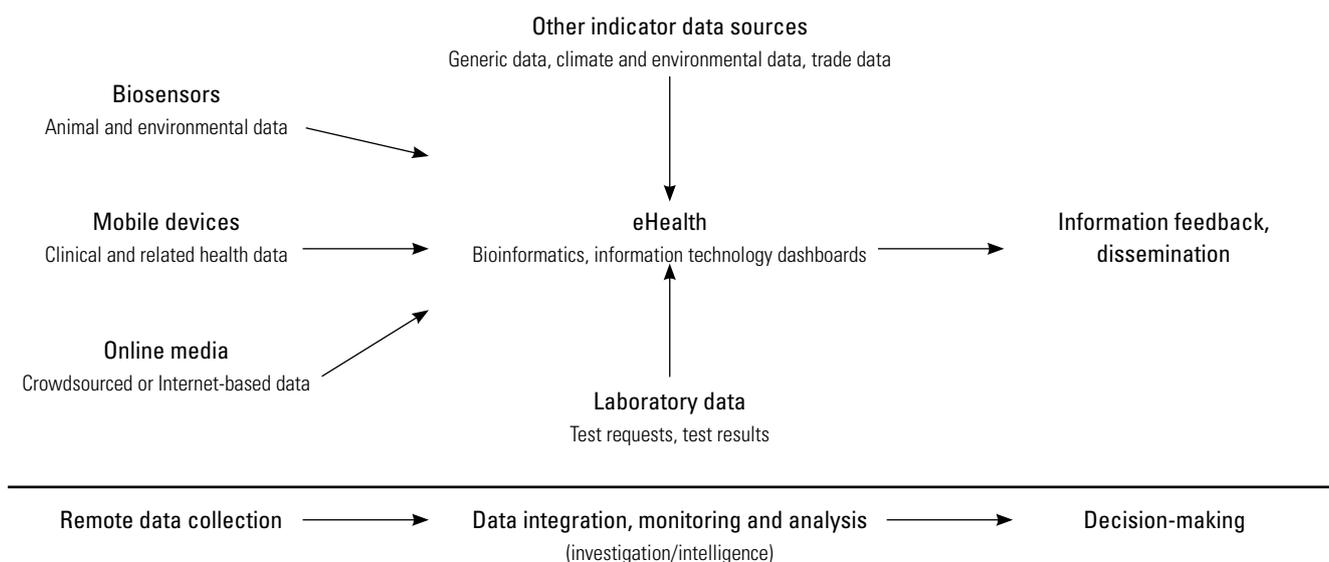
eHealth: electronic health

**Fig. 2**
**Application of information technology in animal health for near real-time data collection, integration, analysis and sharing**
Adapted from Vasudevan *et al.* (5)

The OIE's World Animal Health Information System (WAHIS; www.oie.int/wahis_2/public/wahid.php/Wahid home/Home) provides public access to domestic and wildlife animal data, and information on disease outbreak notifications, health statuses and control measures that are received from official reports from Member Countries/Non-Member Countries (62). Separate links are available to allow users to query and visualise the data on maps or charts, as well as to download data. WAHIS also has a secure portal through which Member Countries can submit their official disease reports. The OIE intends to enhance the WAHIS interface (termed WAHIS+), based on technological advances and user needs related to data access and display (63). The FAO's EMPRES-*i* technology system integrates data from WAHIS, mobile devices (via EMPRES-*i* EMA), Internet-based data (ProMED-mail, HealthMap), and genetic data into a common computer display, or dashboard, so as to provide current information on animal disease events and threats (64). The EMPRES-*i* dashboard is accessible to the public for disease event data query and visualisation on maps and charts, as well as for data download. The system also integrates additional optional data layers on the map, in order to enhance data visualisation and analysis, such as animal density and environmental data (e.g. the location of rivers). Users can also create free accounts to personalise and save their dashboard. Additional data sources are accessible based on assigned user permissions (e.g. data collected from mobile devices). While both WAHIS and EMPRES-*i* integrate disparate data sources that facilitate disease monitoring and data analysis, spatial resolution is usually restricted to administrative centroids versus exact outbreak locations, and this may affect the ability of users to perform more advanced data analysis unless access to the detailed data is obtained (7).

Electronic health technology systems are also being developed and enhanced to support syndromic surveillance and biosurveillance initiatives, which integrate various data types from Web-accessible databases to provide a situational awareness of the health status in a geographical area as well as the early detection of natural or intentional disease threats (see Fig. 2).

The data types these systems integrate include:

– clinical and related health data such as those collected using technologies for remote data collection

– data on real-time animal movement or animal product movement (e.g. feed and milk trucks) from in-house or commercial databases

– diagnostic laboratory and genetic data

– other indicator or risk-factor data such as climatic and environmental data (6, 65).

The degree of data integration within the technological system can vary, from allowing these data sources to be accessible as additional data layers to display on maps, to the data being fully incorporated as parameter inputs into analytical tools developed within the technology system that allow for data queries, visualisations and analysis across all integrated data sources. To achieve real-time data monitoring and analysis, these systems use innovative technological methods for automated data cleaning, integration, storage/processing, visualisation and analysis (29, 65, 66).

Analytical methods continue to be developed and applied within eHealth technologies in an automated fashion in order to achieve real-time data analysis, disease monitoring and the early detection of disease events. Broadly categorised under the umbrella term 'aberration detection algorithms', these methods use historical data to establish a baseline of expected data behaviour in order to determine if current events are abnormal or unexpected (67). The type of data integrated into the technological system, the length of time during which these have been collected, and the disease of interest all determine the choice of algorithm to be used (65). In addition, syndromic surveillance systems typically implement more than one algorithm to increase the overall sensitivity of the system so as to detect true anomalies in the data. Examples of algorithms used in animal health include temporal analysis (e.g. control charts), spatio-temporal analysis (e.g. space–time scan statistics), phylogenetics and regression analysis (65). Big data methods, such as machine learning and multi-criteria decision analysis, are also being increasingly used for disease detection and are becoming more favoured given the continuous and dynamic nature of real-time data collection (58, 68).

Dórea *et al.* (65) provide a review of recent initiatives in the development of syndromic surveillance in veterinary medicine and the extent that the above technology methods have been incorporated into these systems. For example, the Small Animal Veterinary Surveillance Network (SAVSNET) in the United Kingdom integrates test-result data via online submissions of the data by individual diagnostic laboratories, as well as near real-time (within 24 h) data collection of syndromic data from veterinary practitioners. These veterinarians submit data directly through their practice management systems which interface with the SAVSNET system, thus preventing dual data entry (69). Automated analytical tools within SAVSNET provide spatio-temporal analysis of the integrated data for the benchmarking and monitoring of disease trends and interventions. In Australia, the Bovine Syndromic Surveillance System (BOSSS) was piloted with cattle producers, inspectors and workers who electronically submitted data via a Web interface and received immediate feedback in the form of a list of potential disease differentials based on a rule-based diagnostic program integrated within the system (70).

*Rev. Sci. Tech. Off. Int. Epiz.,* **36** (2)

533

The Enhanced Passive Surveillance (EPS) system piloted in the United States developed animal species-specific mobile apps for point-of-care data collection by veterinarians, which were then integrated into a dashboard for automated spatial and temporal visualisation and analysis of baseline determination and anomaly detection (27, 29). Information feedback through data visualisations on maps and charts was provided to participants via the mobile app.

With the continued threat of bioterrorism, information technology systems are also needed by the biodefence community for biological threat detection and reduction. These systems would require the above concepts of biosurveillance to be combined with database inventories of existing and correctly classified biological agents, and would use bio-forensics to discern natural from intentional disease events and to help to inform attribution. In this regard, the selection of specific motif fingerprints and genomic signatures can provide not only discriminatory parameters for pathogen classification, but can strengthen the regulatory framework for pathogens of interest in biodefence for detecting known and unknown biological threats. When coupled with big data analytics and visualisation, such a quantitative, genomic-based approach could allow for biological threats to be quickly detected and attributed.

# Discussion

With the increased availability of mHealth and eHealth technologies, the potential for harnessing them to strengthen disease surveillance and reporting of disease events is evident. Moreover, it is becoming more critical because the risk of the spread of existing and emerging diseases also continues to increase (58, 71). While the development and advancement of mHealth and eHealth technologies continue to expand, their implementation within animal health has generally been limited to pilot projects with varying degrees of success in demonstrating their capabilities for early disease detection (26, 65). However, the experiences gained from projects that have used these technologies and the challenges experienced provide valuable information for planning and successfully implementing mHealth/eHealth technologies in animal health in the future. For instance, performing initial pilot projects with selected users or in local areas first before expanding their scope is more likely to lead to a successful scale-up and project sustainability because challenges can be identified and addressed. Key to the adoption of these technologies at the national level is coordination with and engagement of national Veterinary Services, veterinarians and livestock owners and interest groups. Such a level of interest by these groups is required at all phases of implementation, including when thinking of methods of long-term financial support for mHealth

and eHealth technologies. This includes ensuring that personnel resources are available for both maintaining and troubleshooting the technology systems. In addition, it includes providing technical support to users, as well as personnel capable of monitoring and analysing the collected data and responding to disease events so end users can see the value of providing the data continuously. Incentivising the use of these technologies and providing feedback on the information at all levels is also critical for their adoption and sustainability. In addition, identifying how these technologies can be incorporated into existing data collection and analysis processes and using the data for multiple purposes will help to support their adoption and sustainability, and prevent data siloes that limit global disease detection and response.

The above-mentioned requirements were identified by Beckham and Holmstrom (1) as resource constraints that currently limit the broader adoption and use of information technologies in OIE Member Countries, but could be addressed through a global and coordinated approach to technical capacity-building, technology guidance, and establishing data standards and guidelines for technology use that could be shared with all nations. Such international mechanisms are critically needed in order to facilitate and further enhance data-sharing and data analysis between countries. An example of such a mechanism in human health is the Early Alerting and Reporting project, which pooled data from seven Internet-based biosurveillance systems from different countries into a common portal and, when tested, was able to successfully detect intentional biological events with no false positives (72). The project demonstrated how epidemic intelligence for detecting biological threats can be advanced through information technologies implemented across an international network. It is necessary to identify additional opportunities in which technologies for animal- and human-health data collection and analysis can be better integrated for a One Health approach in order to better coordinate and enhance disease detection and response at the human–animal interface (1).

# Conclusions

Information technologies are rapidly advancing the way in which animal health data and information can be collected and analysed in order to support early detection and response to natural and intentional biological introductions. The world is currently ripe with opportunities to develop and enhance mHealth and eHealth technologies that are cost-effective and capable of real-time data collection and analysis. Such technologies have been shown to be valuable and capable of being implemented in both developing and developed countries, and ultimately will strengthen disease surveillance and reporting across the globe.

# Les technologies de collecte et d'analyse des données de santé animale en temps quasi réel

L.K. Holmstrom & T.R. Beckham

**Résumé**

Les technologies de l'information font rapidement progresser la façon dont les données et l'information sur la santé animale sont recueillies, analysées et partagées afin de soutenir la gestion de la santé animale, les activités de surveillance et de réponse en cas de maladies et les processus de décisions. Toutefois, le potentiel de ces technologies n'a pas encore été entièrement exploité au niveau mondial dans le but d'assurer la détection précoce et d'organiser la réponse du secteur de la santé animale à des événements sanitaires dus à des causes naturelles ou intentionnelles. Les auteurs examinent les avancées accomplies par ces technologies, en particulier les exemples d'applications en santé animale pour la collecte et l'analyse de données en temps quasi réel. L'article aborde les technologies suivantes : *i)* les technologies mobiles de santé, les capteurs sans fil et biocapteurs pour la collecte de données à distance ; *ii)* la collecte de données via l'internet ou des initiatives de masse ; et *iii)* les technologies numériques de santé pour l'intégration et l'analyse des données.

Les auteurs examinent également des exemples de mise en place de ces technologies, font état des difficultés rencontrées lors de leur utilisation et formulent quelques recommandations sur les applications futures en santé animale. Le moment est venu de saisir les possibilités de développement et d'amélioration de technologies mobiles et numériques de santé qui soient à la fois rentables et capables d'assurer la collecte et l'analyse des données en temps quasi réel. L'utilité de ces technologies a été démontrée, ainsi que leur aptitude à être appliquées dans les pays développés et en développement, ce qui à terme renforcera la surveillance des maladies et leur notification à l'échelle planétaire. Le monde doit se doter de mécanismes internationaux et de normes sur les données afin de faciliter le partage et l'analyse des données relatives à la santé humaine et animale entre les pays. Les modalités d'intégration de la collecte et l'analyse des données de santé publique et de santé animale dans une approche « Une seule santé » permettront d'améliorer la coordination et les capacités de détection et de lutte à l'interface humains-animaux.

**Mots-clés**

Analyse automatisée des données – Collecte de données en temps réel – Détection des maladies animales – Surveillance – Technologies mobiles de santé – Technologies numériques de santé – Technologies de l'information.

■

# Tecnologías para obtener y analizar datos zoosanitarios en tiempo casi real

L.K. Holmstrom & T.R. Beckham

**Resumen**

Las tecnologías de la información están haciendo progresar con rapidez los procedimientos con que se obtienen, analizan y ponen en común la información y los datos de sanidad animal que sirven para respaldar las labores de gestión

zoosanitaria, vigilancia de enfermedades, respuesta a ellas y adopción de decisiones. Sin embargo, en el ámbito de la sanidad animal aún no se aprovechan plenamente, a escala mundial, todas las posibilidades que ofrecen estas tecnologías para detectar con prontitud episodios infecciosos de origen natural o intencionado y responder rápidamente a ellos. Los autores describen los progresos realizados en estas tecnologías y ofrecen ejemplos de cómo se han aplicado en sanidad animal para reunir y analizar datos en tiempo casi real, deteniéndose especialmente en las siguientes grandes familias: *i)* tecnologías móviles de salud, biosensores y sensores inalámbricos para la obtención de datos a distancia; *ii)* obtención de datos por sistemas de participación popular o por Internet; y *iii)* tecnologías de cibersalud para la integración y el análisis de datos.

Los autores también examinan la experiencia adquirida hasta ahora con la aplicación de estas tecnologías y los problemas que plantea su utilización, y a partir de ahí formulan recomendaciones sobre su aplicación futura en la sanidad animal. El mundo rebosa de oportunidades para desarrollar y perfeccionar tecnologías móviles de salud y tecnologías de cibersalud que sean eficaces en relación con el costo y permitan obtener y analizar datos en tiempo casi real. Está demostrado que estas tecnologías son interesantes y pueden implantarse en países tanto desarrollados como en desarrollo, y que a la larga servirán para reforzar la vigilancia y notificación de enfermedades en todo el planeta. Para facilitar el intercambio y el análisis de datos sanitarios y zoosanitarios entre los países hacen falta mecanismos y normas internacionales referidos a estos datos. Abordando la cuestión desde los postulados de «Una sola salud» es posible dar con fórmulas para integrar en mayor medida entre sí la obtención y el análisis de los datos de salud humana y de los de sanidad animal, cosa que servirá para mejorar la coordinación y la capacidad de detección y respuesta ante las enfermedades en la interfaz del hombre con los animales.

**Palabras clave**

Análisis automatizado de datos – Detección de enfermedades animales – Obtención de datos en tiempo real – Tecnología de la información – Tecnologías de cibersalud – Tecnologías móviles de salud – Vigilancia.

■

# References

1. Beckham T.R. & Holmstrom L.K. (2015). – The use of information technology in animal health management, disease reporting, surveillance, and emergency response. *In* Final Report of 83rd General Session, World Assembly of the World Organisation for Animal Health, 24–29 May, Paris. Available at: www.oie.int/fileadmin/Home/eng/About_us/docs/pdf/Session/A_FR_2015_public.pdf (accessed on 15 September 2017).

2. Karimuribo E.D., Batamuzi E.K., Massawe L.B., Silayo R.S., Mgongo F.O.K., Kimbita E. & Wambura R.M. (2016). – Potential use of mobile phones in improving animal health service delivery in underserved rural areas: experience from Kilosa and Gairo districts in Tanzania. *BMC Vet. Res.*, **12** (1), 219. doi:10.1186/s12917-016-0860-z.

3. International Telecommunications Union (ITU) (2016). – ICT facts and figures 2016. ITU, Geneva. Available at: www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2016.pdf (accessed on 5 December 2016).

4. Cerwall P., Lundvall A., Jonsson P., Carson S., Möller R., Bävertoft S., Furuskär A., Kronander J., Lindberg P., Ludwig R., Öhman K., Singh Sehti J. & Gully V. (2016). – Ericsson mobility report: on the pulse of the networked society. Ericsson, Stockholm. Available at: www.ericsson.com/assets/local/mobility-report/documents/2016/ericsson-mobility-report-november-2016.pdf (accessed on 1 December 2016).

5. Vasudevan L., Ghoshal S. & Labrique A.B. (2016). – mHealth and its role in disease surveillance. *In* Disease surveillance: technological contributions to global health security (D.L. Blazes & S.H. Lewis, eds). CRC Press, New York, 131–138.

6. Gates M.C., Holmstrom L.K., Biggers K.E. & Beckham T.R. (2015). – Integrating novel data streams to support biosurveillance in commercial livestock production systems in developed countries: challenges and opportunities. *Front. Public Hlth*, **3** (74), 1–13. doi:10.3389/fpubh.2015.00074.

536

*Rev. Sci. Tech. Off. Int. Epiz.,* **36** (2)

7. Stevens K.B. & Pfeiffer D.U. (2015). – Sources of spatial animal and human health data: casting the net wide to deal more effectively with increasingly complex disease problems. *Spatiotemp. Epidemiol.*, **13**, 15–29. doi:10.1016/j.sste.2015.04.003.

8. Mwabukusi M., Karimuribo E.D., Rweyemamu M.M. & Beda E. (2014). – Mobile technologies for disease surveillance in humans and animals. *Onderstepoort J. Vet. Res.*, **81** (2), E1–E5. doi:10.4102/ojvr.v81i2.737.

9. Robertson C., Sawford K., Daniel S., Nelson T.A. & Stephen C. (2010). – Mobile phone-based infectious disease surveillance system, Sri Lanka. *Emerg. Infect. Dis.*, **16** (10), 1524–1531. doi:10.3201/eid1610.100249.

10. Corkrey R. & Parkinson L. (2002). – Interactive voice response: review of studies 1989–2000. *Behav. Res. Methods, Instruments, Comp.*, **34** (3), 342–353. doi:10.3758/BF03195462.

11. Bauer J.-M., Mouillez A.-C. & Husain A. (2015). – Not a Rolls-Royce but it gets you there: remote mobile food security monitoring during the Ebola crisis. *Human. Exch.,* **64**, 22–25. Available at http://odihpn.org/wp-content/uploads/2015/06/he_64.pdf (accessed on 15 September 2017).

12. Lam M., Lee H., Bright R., Korzenik J. & Sands B. (2009). – Validation of interactive voice response system administration of the short inflammatory bowel disease questionnaire. *Inflamm. Bowel Dis.*, **15** (4), 599–607. doi:10.1002/ibd.20803.

13. Stritzke W.G.K., Dandy J., Durkin K. & Houghton S. (2005). – Use of interactive voice response (IVR) technology in health research with children. *Behav. Res. Methods*, **37** (1), 119–126. doi:10.3758/BF03206405.

14. Harvard Pilgrim Health Care (2008). – Pilot test of IVR outreach calls as a mechanism for collecting REL data. National Health Plan Collaborative, Hamilton, New Jersey. Available at: www.rwjf.org/en/library/research/2008/09/the-national-health-plan-collaborative-toolkit/section-5-case-studies/harvard-pilgrim-health-care-pilot-test-of-ivr-outreach-calls-as-.html (accessed on 15 September 2017).

15. McDaniel A. (2004). – Interactive voice response technology for outcomes monitoring. *Clin. Nurse Spec.*, **18** (1), 7–8. doi:10.1097/00002800-200401000-00003.

16. Corkrey R., Parkinson L., Bates L., Green S. & Htun A.T. (2005). – Pilot of a novel cervical screening intervention: interactive voice response. *Aust. N.Z. J. Public Hlth*, **29** (3), 261–264. doi:10.1111/j.1467-842X.2005.tb00765.x.

17. Levin E. & Levin A. (2006). – Evaluation of spoken dialogue technology for real-time health data collection. *J. Med. Internet Res.*, **8** (4), e30. doi:10.2196/jmir.8.4.e30.

18. African Press International (2013). – SMS or interactive voice response (IVR) messages give Afghan farmers and traders information on crop and livestock prices in specific locations. Available at: https://africanpress.wordpress.com/2013/07/14/sms-or-interactive-voice-response-ivr-messages-give-afghan-farmers-and-traders-information-on-crop-and-livestock-prices-in-specific-locations/ (accessed on 3 October 2016).

19. LifeLines (2017). – LifeLines Agriculture. Available at: http://lifelines-india.net/agriculture/LifeLines%20Agriculture (accessed on 3 October 2016).

20. Groupe Speciale Mobile Association (GSMA) (2014). – GSMA mobile for development: blueprint: Ebola mobile response. GSMA, London. Available at: www.gsma.com/mobilefordevelopment/wp-content/uploads/2014/10/gsma-Ebola-Mobile-Response-Blueprint.pdf (accessed on 9 October 2016).

21. Innovative Support to Emergencies Diseases and Disasters (2017). – GeoChat: GeoChat is a collaboration tool that allows anyone to chat, report, and get alerts on their phone. Available at: http://instedd.org/technologies/geochat/ (accessed on 8 October 2016).

22. FrontlineSMS (2017). – Frontline: send a better message. Available at: www.frontlinesms.com/ (accessed on 6 October 2016).

23. RapidSMS (2017). – About RapidSMS. Available at: www.rapidsms.org/ (accessed on 6 October 2016).

24. Kannel (2017). – Kannel: open Source WAP and SMS gateway. Available at: www.kannel.org/ (accessed on 7 October 2016).

25. Toda M., Njeru I., Zurovac D., O-Tipo S., Kareko D., Mwau M. & Morita K. (2016). – Effectiveness of a mobile short-message-service-based disease outbreak alert system in Kenya. *Emerg. Infect. Dis.*, **22** (4), 711–715. doi:10.3201/eid2204.151459.

26. Walker J.G. (2013). – New media methods for syndromic surveillance and disease modelling. *CAB Rev.,* **8** (031), 1–13. doi:10.1079/pavsnnr20138031.

27. Holmstrom L.K., Biggers K.E. & Beckham T.R. (2013). – Enhanced passive surveillance system: a Texas and New Mexico pilot, 2012–2013. Final Report for the United States Department of Homeland Security. Institute for Infectious Animal Diseases, College Station, Texas.

28. Madder M., Walker J.G., Van Rooyen J., Knobel D., Vandamme E., Berkvens D., Vanwambeke S.O. & De Clercq E.M. (2012). – e-Surveillance in animal health: use and evaluation of mobile tools. *Parasitology,* **139** (Special Issue 14), 1831–1842. doi:10.1017/S0031182012000571.

29. Thompson C.W., Holmstrom L., Biggers K., Wall J., Beckham T., Coats M., Korslund J. & Colby M.M. (2016). – Improving animal disease detection through an enhanced passive surveillance platform. *Health Security,* **14** (4), 264–271. doi:10.1089/hs.2016.0016.

30. Aanensen D., Huntley D., Feil E., al-Own F. & Spratt B. (2009). – EpiCollect: linking smartphones to web applications for epidemiology, ecology and community data collection. *PLoS ONE,* **4** (9), e6968. doi:10.1371/journal.pone.0006968.

31. Wilson R., Zu Erbach-Schoenberg E., Albert M., Power D., Tudge S., Gonzalez M., Guthrie S, Chamberlain H., Brooks C., Hughes C., Pitonakova L., Buckee C., Lu X., Wetter E., Tatem A. & Bengtsson L. (2016). – Rapid and near real-time assessments of population displacement using mobile phone data following disasters: the 2015 Nepal earthquake. *PLoS Curr.,* **8**. doi:10.1371/currents.dis.d073fbece328e4c39087bc086d694b5c.

32. Jandee K., Lawpoolsri S., Taechaboonsermsak P., Khamsiriwatchara A., Wansatid P. & Kaewkungwal J. (2014). – Customized-language voice survey on mobile devices for text and image data collection among ethnic groups in Thailand: a proof-of-concept study. *JMIR Mhealth Uhealth,* **2** (1), e7. doi:10.2196/mhealth.3058.

33. OpenDataKit (2017). – OpenDataKit: home. Available at: https://opendatakit.org/ (accessed on 15 October 2016).

34. Magpi (2017). – Magpi: advanced mobile data, messaging, and visualization. Available at: http://home.magpi.com/ (accessed on 10 October 2016).

35. Food and Agriculture Organization of the United Nations (2013). – Cell phones revolutionising Kenya's livestock sector. Available at: www.fao.org/news/story/en/item/170807/icode/ (accessed on 19 September 2017).

36. Waidyanatha N., Sampath C., Dubrawski A., Sabhnani M., Chen L., Ganesan M. & Vincy P. (2010). – T-Cube Web interface as a tool for detecting disease outbreaks in real-time: a pilot in India and Sri Lanka. *In* Proc. International Conference on Computing & Communication Technologies, Research, Innovation, and Vision for the Future (RIVF), Hanoi, Vietnam. doi:10.1109/rivf.2010.5633019.

37. Larfaoui F., Blasetti L., Demaio E., Colonna A. & Pinto J. (2012). – What is new in EMPRES-i? EMPRES-i EMA: an integrated tool for animal disease field surveillance. *Transbound. Anim. Dis. Bull.*, **40**, 34–35. Available at: www.fao.org/3/a-i2811e/i2811e08.pdf (accessed on 15 September 2017).

38. Food and Agriculture Organization of the United Nations, (FAO) (2015). – EMA-*i*: a mobile app for timely animal disease field reporting to enhance surveillance. FAO, Rome. Available at: www.fao.org/3/a-i4853e.pdf (accessed on 1 October 2016).

39. Hounmanou Y.M.G., Agonsanou M.S.S., Dougnon V., Vodougnon M.H.B., Achoh E.M., Mohammed J. & Karimuribo E.D. (2016). – The necessity of mobile phone technologies for public health surveillance in Benin. *Adv. Public Hlth*, (Article ID 5692480), 7 pp. doi:10.1155/2016/5692480.

40. Smutný P. (2012). – Mobile development tools and cross-platform solutions. *In* Proc. of the 13th International Carpathian Control Conference, 653–656. doi:10.1109/CarpathianCC.2012.6228727.

41. Braun R.C.C., Wimbush J. & Israelski D. (2013). – Community health workers and mobile technology: a systematic review of the literature. *PLoS ONE,* **8** (6), e65772. doi:10.1371/journal.pone.0065772.

42. Ruiz-Garcia L., Lunadei L., Barreiro P. & Robla J.I. (2009). – A review of wireless sensor technologies and applications in agriculture and food industry: state of the art and current trends. *Sensors (Basel)*, **9** (6), 4728–4750. doi:10.3390/s90604728.

43. Neethirajan S. (2017). – Recent advances in wearable sensors for animal health management. *Sens. Biosensing Res.*, **12**, 15–29. doi:10.1016/j.sbsr.2016.11.004.

44. Rainwater-Lovett K., Pacheco J.M., Packer C. & Rodriguez L.L. (2009). – Detection of foot-and-mouth disease virus infected cattle using infrared thermography. *Vet. J.*, **180** (3), 317–324. doi:10.1016/j.tvjl.2008.01.003.

45. Dunbar M.R., Johnson S.R., Rhyan J.C. & McCollum M. (2009). – Use of infrared thermography to detect thermographic changes in mule deer (*Odocoileus hemionus*) experimentally infected with foot-and-mouth disease. *J. Zoo Wildl. Med.*, **40** (2), 296–301. doi:10.1638/2008-0087.1.

46. Martínez-Avilés M., Fernández-Carrión E., López García-Baones J.M. & Sánchez-Vizcaíno J.M. (2017). – Early detection of infection in pigs through an online monitoring system. *Transbound. Emerg. Dis.*, **64** (2), 364–373. doi:10.1111/tbed.12372.

47. Ting J.S.L., Kwok S.K., Lee W.B., Tsang A.H.C. & Cheung B.C.F. (2007). – A dynamic RFID-based mobile monitoring system in animal care management over a wireless network. *In* Proc. 2007 International Conference on Wireless Communications, Networking and Mobile Computing, 21–25 September, 2085–2088. doi:10.1109/WICOM.2007.521.

48. Kim S.-H., Kim D.-H. & Park H.-D. (2010). – Animal situation tracking service using RFID, GPS, and sensors. *In* Proc. 2nd International Conference on Computer and Network Technology, 23–25 April, 153–156. doi:10.1109/ICCNT.2010.40.

49. González L.A., Tolkamp B.J., Coffey M.P., Ferret A. & Kyriazakis I. (2008). – Changes in feeding behavior as possible indicators for the automatic monitoring of health disorders in dairy cows. *J. Dairy Sci.*, **91** (3), 1017–1028. doi:10.3168/jds.2007-0530.

50. Ruiz-Garcia L. & Lunadei L. (2011). – The role of RFID in agriculture: applications, limitations and challenges. *Comput. Electron. Agric.*, **79** (1), 42–50. doi:10.1016/j.compag.2011.08.010.

51. Hartley D.M., Nelson N.P., Arthur R.R., Barboza P., Collier N., Lightfoot N., Linge J.P., van der Goot E., Mawudeku A., Madoff L.C., Vaillant L., Walters R., Yangarber R., Mantero J., Corley C.D. & Brownstein J.S. (2013). – An overview of Internet biosurveillance. *Clin. Microbiol. Infect.*, **19** (11), 1006–1013. doi:10.1111/1469-0691.12273.

52. Chunara R., Andrews J.R. & Brownstein J.S. (2012). – Social and news media enable estimation of epidemiological patterns early in the 2010 Haitian cholera outbreak. *Am. J. Trop. Med. Hyg.,* **86** (1), 39–45. doi:10.4269/ajtmh.2012.11-0597.

538

*Rev. Sci. Tech. Off. Int. Epiz.,* **36** (2)

53. Chew C. & Eysenbach G. (2010). – Pandemics in the age of Twitter: content analysis of tweets during the 2009 H1N1 outbreak. *PLoS ONE,* **5** (11), e14118. doi:10.1371/journal. pone.0014118.

54. Cassa C.A., Chunara R., Mandl K. & Brownstein J.S. (2013). – Twitter as a sentinel in emergency situations: lessons from the Boston marathon explosions. *PLoS Curr.*, **5**. doi:10.1371/ currents.dis.ad70cd1c8bc585e9470046cde334ee4b.

55. Ginsberg J., Mohebbi M.H., Patel R.S., Brammer L., Smolinski M.S. & Brilliant L. (2009). – Detecting influenza epidemics using search engine query data. *Nature,* **457** (7232), 1012–1014. doi:10.1038/nature07634.

56. Cowen P., Garland T., Hugh-Jones M.E., Shimshony A., Handysides S., Kaye D., Madoff L.C., Pollack M.P. & Woodall J. (2006). – Evaluation of ProMED-mail as an electronic early warning system for emerging animal diseases: 1996 to 2004. *JAVMA,* **229** (7), 1090–1099. doi:10.2460/ javma.229.7.1090.

57. Mykhalovskiy E. & Weir L. (2006). – The global public health intelligence network and early warning outbreak detection: a Canadian contribution to global public health. *Can. J. Public Hlth*, **97** (1), 42–44. doi:10.17269/cjph.97.756.

58. Pfeiffer D.U. & Stevens K.B. (2015). – Spatial and temporal epidemiolgical analysis in the Big Data era. *Prev. Vet. Med.*, **122** (1–2), 213–220. doi:10.1016/j.prevetmed.2015.05.012.

59. Brownstein J.S., Freifeld C.C., Reis B.Y. & Mandl K.D. (2008). – Surveillance sans frontières: Internet-based emerging infectious disease intelligence and the HealthMap Project. *PLoS Med.*, **5** (7), e151. doi:10.1371/journal.pmed.0050151.

60. Oh H., Rizo C., Enkin M. & Jadad A. (2005). – What is eHealth (3): a systematic review of published definitions. *J. Med. Internet Res.*, **7** (1), e1. doi:10.2196/jmir.7.1.e1.

61. Eysenbach G. (2001). – What is e-health? *J. Med. Internet Res.*, **3** (2), e20. doi:10.2196/jmir.3.2.e20.

62. World Organisation for Animal Health (2017). – World Animal Health Information Database (WAHIS) Interface. Available at: www.oie.int/wahis_2/public/wahid.php/Wahidhome/Home (accessed on 2 November 2016).

63. World Organisation for Animal Health (2017). – World Animal Health Information Database (WAHIS+). Available at: www.esurveyspro.com/Survey.aspx?id=4e78ca08-2f86-41ed-940d-cb00e0f62e5b (accessed on 2 November 2016).

64. Food and Agriculture Organization of the United Nations (2017). – EMPRES-i Global animal disease information system. Available at: http://empres-i.fao.org/eipws3g/ (accessed on 2 November 2016).

65. Dórea F.C., Sanchez J. & Revie C.W. (2011). – Veterinary syndromic surveillance: current initiatives and potential for development. *Prev. Vet. Med.,* **101** (1–2), 1–17. doi:10.1016/ j.prevetmed.2011.05.004.

66. Blazes D.L. & Lewis S.H. (2016). – Introduction to electronic disease surveillance. *In* Disease surveillance: technological contributions to global health security (D.L. Blazes & S.H. Lewis, eds). CRC Press, Boca Raton, Florida, 197 pp.

67. Mandl K.D., Reis B. & Cassa C. (2004). – Measuring outbreak-detection performance by using controlled feature set simulations. MMWR *Morb. Mortal. Wkly Rep.* , **53** (Suppl.), S130–S136. doi:10.1037/e307182005-024.

68. Shameer K., Badgeley M.A., Miotto R., Glicksberg B.S., Morgan J.W. & Dudley J.T. (2017). – Translational bioinformatics in the era of real-time biomedical, health care and wellness data streams. *Brief. Bioinform.*, **18** (1), 105–124. doi:10.1093/bib/bbv118.

69. Small Animal Veterinary Surveillance Network (2017). – Small Animal Veterinary Surveillance Network (SAVSNET): welcome to SAVSNET. Available at: www.liverpool.ac.uk/ savsnet/ (accessed on 3 November 2016).

70. Shephard R.W. (2006). – The development of a syndromic surveillance system for the extensive beef cattle producing regions of Australia. PhD dissertation, University of Sydney.

71. St Louis M. (2012). – Global health surveillance. MMWR *Morb. Mortal. Wkly Rep.*, **61** (3), 15–19.

72. Riccardo F., Shigematsu M., Chow C., McKnight C.J., Linge J., Doherty B., Dente M.G., Declich S., Barker M., Barboza P., Vaillant L., Donachie A., Mawudeku A., Blench M. & Arthur R. (2014). – Interfacing a biosurveillance portal and an international network of institutional analysts to detect biological threats. *Biosecur. Bioterror.*, **12** (6), 325–326. doi:10.1089/bsp.2014.0031.