Novel concept to allow automation of grazing management within a dairy farm system

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Abstract

Precise grass allocation is fundamental to economic return in the Irish and European grassland production systems. There is a strong relationship between the cost of production and the proportion of grass in the cow's diet. It is now widely accepted that grazed grass is the cheapest feed available on most European dairy farms. Grazing management usually involves subjective visual assessment and intuitive decision-making on farms implementing an intensive grazing system. The development of an automated grass measurement tool would add objectivity to the measurement of grass and the use of virtual fence (VF) technology would automate the process of grass allocation. The aim of this project is to develop a decision support tool (DST) with global positioning system (GPS) capability that will precisely measure herbage mass and integrate with an on-cow VF system, which is also GPS based to accurately and automatically allocate the grazing area. One virtual fence approach is to set virtual boundaries via GPS and Global System for Mobile Communications (GSM) integrated in an on-cow device. To stop an animal crossing the virtual boundary, negative reinforcement acting as a warning system will be used. This technology would potentially result in labour savings by removing the requirement to physically setup electric fences for grazing allocation. The measurement of herbage height and mass by the DST will be calibrated and validated along-side conventional measurement techniques on a number of research and pilot farms over an entire year. A variety of sward heights, types and herbage mass from pre-, intermediate and post-grazing swards in Irish paddocks will be measured. Once calibrated and validated the DST will be integrated with virtual fence technology and the communication between these devices will be evaluated on dairy cows. The impact of GPS error on the movement of the virtual fence boundary will be analysed and subsequent alterations implemented to enhance the accuracy of the device. An effective triggering system for negative reinforcement of the virtual fence boundary will be analysed, using acoustic and tactile cues when animals choose to test the boundaries. Improvements to the system will be implemented based on the initial calibration. The goal is to achieve an accurate, labour saving and economical method for precision grazing.

Keywords: virtual fence, decision support tool, grassland, ICT

1   Introduction

1.1   Precision Grazing & Management

In Ireland the profit per hectare is increased by €162 for each additional tonne in grass utilized within dairy systems (Dillon, 2011). The performance of a pasture based system of

dairy farming is reliant upon the precise estimation of herbage mass (HM) and the accurate allocation of the grazing area. The herbage allowance (HA) for the herd and the HM of the paddock are used to calculate the area required for grazing which is subsequently measured and fenced, these are necessary labour requirements for a dairy farmer implementing a pasture based system of farming. The precision of these measurements ensures the correct quantity of grass dry matter (DM) is allocated, to provide for the high energy demands of the lactating cow, and establishes the correct grass residual after grazing to increase the herbage quality of the paddock for subsequent grazing rotations (Lee et al., 2008). Pasture allocation is dependent on herbage allowance and the precise estimation of herbage mass, two key factors affecting the milk yield of the grazing dairy cow (Combellas & Hodgson, 1979; Peyraud et al., 1996). Previous studies indicate that precise daily allocation of pasture for lactating cows increased milk production by 10% (Fulkerson et al., 2005). Grazing pastures with a herbage mass of 1,700 kg DM/ha rather than 2,200 kg DM/ha, significantly increased sward quality and milk solids output per hectare (McEvoy et al., 2009). Recent studies have concluded that the highest milk output per ha and per cow, with low post-grazing residuals and enhanced sward quality, was achieved using the management strategy of grazing a low herbage mass (1,600 and 1,700 kg DM/ha) at a high herbage allowance (20 kg DM/cow/day) (McEvoy et al., 2009; Roca-Fernandez et al., 2011). Therefore, under-estimating herbage mass could potentially reduce milk solids per hectare and inadvertently increase the herbage allowance, thereby increasing the quantity of residual grass left behind and thus reducing the herbage quality in subsequent grazing rotations.

1.2 Decision support tools for precise herbage mass estimation

To achieve efficient pasture utilization and high cow performance, regular estimation of herbage mass for each paddock on the farm is required to (a) optimise daily grazing management when allocating the grazing area for the herd and (b) make long-term planning decisions for feed budgeting. A variety of decision support tools have been previously developed and tested to define the HM of a paddock and categorized as either destructive, whereby herbage is cut and removed, or non-destructive, so that sward characteristics are measured and relate directly or indirectly to HM. Traditionally manually clipped quadrants have been use to estimate herbage mass however this destructive method is labour intensive and requires multiple measurements to achieve a reliable pasture estimate (Bummer et al., 1994). In a previous study by O'Donovan et al. (2002), four non-destructive methods of HM estimation were compared and results showed that visual estimation was more accurate than a rising plate meter (RPM), the Hill Farm Research Organisation sward stick (SS) and the pasture probe capacitance meter (PPCM). However, visual estimation of HM is subjective and therefore may be prone to variation between observers (Tucker, 1980). In addition to these manual non-destructive methods of HM estimation, more complex electronic devices have been developed to estimate HM, for example the electronic capacitance meter (Fletcher & Robinson 1956), sonic sward stick (Hutchings et al., 1990) and the combination of a ultrasonic sensor with high-precision Differential Global Positioning System (DGPS) on a vehicle (Fricke et al., 2011). Remote sensing and geographical information systems are modern technologies that are being used as decision support tools to assist in resource inventory, modelling and forecasting (López-Díaz et al., 2011). The advancement in and accessibility to modern information technology and information science has provided researchers with possibilities to provide farmers with improved decision support tools for management of grazing dairy systems not only for herbage mass estimation but also for pasture allocation. The ability to objectively quantify herbage mass will enhance the precision of pasture allocation and grass management decisions by farmers.

1.3 Virtual fence technology and pasture allocation

The primary concept of virtual fence (VF) technology is to keep cattle away from an area (exclusion) or within an area (inclusion) without the use of an observable physical fence or barrier. The implementation of global positioning system (GPS) technology with VF

technology is advantageous as it removes the requirement for installed infrastructure, such as a buried perimeter, which reduces costs over large areas and also makes the system more flexible for strip grazing in a dairy production system. In addition to existing as a static entity for containing cows, the VF can also function as a dynamic entity for the purposes of herding cows (Butler et al., 2011). In a pasture based system of dairy farming strip fencing and herding are two labour intensive activities that contribute to the daily work load of a dairy farmer. VF has the potential to both simplify and minimize labour and associated costs with these daily fencing and herding in a conventional batch milking dairy system. In voluntary automated milking systems integrated with grazing, virtual fence technology could ensure regular visits to the robotic milking machine. The method of choice to control cow location, for the majority of VF collars invented to date, is based on negative reinforcement by applying an initial audio warning sound on approach to the VF and a subsequent aversive electrical stimulation at the VF. However positive reinforcement has also been shown to work as an alternative approach to gather cows from the paddock by rewarding them with feed and water once they reach a desired location (reviewed by Umstatter 2011).

Although previous studies have developed virtual fence technology and decision support tools for estimating herbage mass independent of each other this study presents a novel concept to allow automation of grazing management within a dairy farm system by combing both technologies. The overall aim of this project is to develop a decision support tool (DST) with global positioning system (GPS) capability, that precisely measures herbage mass and integrates with an on-cow virtual fencing system based on GPS monitoring, to accurately and automatically allocate the grazing area.

2   Materials and methods

2.1   Decision support tool development and calibration

The decision support tool was developed with the functioning capacity to automate the process of herbage mass estimation. The development of the DST was outsourced to True North Mapping, Shannon, Co. Clare, Ireland and it is currently being calibrated throughout 2014 in Teagasc, Moorepark, Co. Cork, Ireland.

Technical Description of Microsonic Measurement Device

Measurements undertaken during this study were carried out using a microsonic measurement device (namely the "GrassHopper") manufactured by True North Mapping, Shannon, Co. Clare, Ireland. The microsonic sensor finds the distance from a module, placed on the shaft of a rising plate meter, to the circler plate by recording the time difference between the transmission and its reflective return from the plate (Figure 1). The compressed height of the grass sward is measured by the device with a range of between 3mm - 185mm and nominal accuracy of 1mm. The GrassHopper device can be adapted for use with both the GrassHopper and the standard Jenquip rising plate meters. The device also measures herbage mass within a paddock, computes grazing allocations based on the demand of a herd, records a timestamp for each sample taken, automatically geo-tags all samples taken via on-board GPS unit, outputs samples in spread sheet format for further yield / fertilizer application and analysis as well as recording temperature.

Data Logging

Data is logged to a remote device, e.g. a smartphone or tablet for display and storage. The data transmission, to and from the remote device, is carried out with a Class I Bluetooth. The files are saved as comma-separated values (CSV) documents which are populated with data such as herbage mass, computed allocations, timestamps, geo-tags and temperature. Survey averaging method for the compressed grass height uses the median.

Power Requirements

The unit is powered by an internal 5V re-chargeable NiMh power source. The unit has an operating time of approximately 4 hours.

Positioning GPS

The unit uses operating channels 66 GPS / GLONASS receiver with Satellite-based augmentation systems (SBAS) augmentation and European Geostationary Navigation Overlay Service (EGNOS). The update rate of the GPS is between 1 – 10Hz.

Operating Environment

The unit is IP54 (IP code - splash proof) and has an Operating Temp range between – 0°C to 35°C.

Compatibility

 A smart-phone or tablet is required to be an Android version 4.3 or later.

Experimental Design for Calibration

Calibration and validation of the Grasshopper commenced in the spring of 2014 and I currently under way on two Teagasc research farms, the Dairygold Kilworth farm and the Moorepark farm. The sward type on the Dairygold farm was primarily perennial ryegrass and on the Moorepark farm the sward consisted of varying proportions of clover and perennial ryegrass. Paddocks with varying grass heights and herbage masses were selected for calibration and validation of the Grasshopper device. Within each paddock 1 or 2 areas of between $6m^2$ and $12m^2$ were used to measure the grass height and herbage mass. This involved (a) measuring the grass height with the Grasshopper within the area by taking 10 measurements evenly dispersed, (b) cutting the measured area with a lawnmower to a residual height pre-set to between 3.5 and 4cm (c) weighing the cut grass, (d) collecting a sample of the cut grass approximately 200g to measure the percentage dry matter of the grass, (e) cutting two quadrants ($0.25m^2$) for sward clover percentage using a clippers and (f) measuring the grass height with the Grasshopper post-mowing within the area by taking 10 measurements evenly dispersed. As part of the secondary adaptations, an adaption bracket was designed to attach the grasshopper to the industry gold standard in grass, Jenquip rising plate meter. The opening figure from the Jenquip is recorded and after ten samples are taken the closing figure is taken. This allows for a direct comparison for the heights returned from the grasshopper.

2.2 Virtual fence

The virtual fence collars and a 2 way network infrastructure between the collars on the cow in the paddock and a base station in an office near the paddock, which supports communication and relay of information to and from the cow and base station, are integrated with high precision GPS and have been developed. The development of the virtual fence collars and network infrastructure integrated with GPS was outsourced to True North Mapping, Shannon, Co. Clare, Ireland and it is currently being tested and trialed throughout 2014 in Teagasc, Moorepark, Co. Cork, Ireland.

Development of Network Infrastructure

Initially during the development stage of the virtual fence collars the ability to send manual commands to the cow from a smart device using Class I Bluetooth was required to optimise the functionality of the collars. This manual one way data transmission was required firstly to assign individual IDs to each virtual fence collar and secondly to activate a selected stimulus level on the collar for initial testing. The stimulus type can also be an automatic function of the firmware on-board the cow collar and a method of communicating the GPS position from the cow back to central control base, sending a command message from the base to the cow and subsequently receiving an acknowledgement message from the cow has been developed. The GPS proximity of each individual cow in the herd from the geo-fence is needed in order to determine if that cow needs to be prompted with either a warning or aversive stimulus to maintain their distance from the geo-fence. A channel that permits GPS correction data to be passed from the generation point (base station) to the individual cows in the paddock is a key component in the network infrastructure that has been developed to allow precise positioning of the virtual fence and accurate location information from each cow (Figure 2).

Channel 1: This is the cow based network over which all traffic to and from the cow is passed. It operates on the 433MHz ISM band. A command message is passed to the cow to which the cow responds. This operates around a simple protocol with a maximum herd size of 16 cows. Each cow may be addressed individually with either a command or a

housekeeping message type. Examples are – a command for a stimulus to be executed (this will be acknowledged by the cow on receipt and again on completion); or a housekeeping command requesting position, battery life and other data which is responded to immediately. All traffic on Channel 1 is recorded (Figure 2).

Channel 2: This is a super control network that sits on top of Channel 1 and to which the base station and field operators are connected. It uses the 868MHz ISM band for the moment in order to keep Channel 1 as free as possible of traffic. GPS correction data generated on-site will use this network also before being processed for an individual cow. Commands may be issued on Channel 2 and they will be passed to Channel 1 at a central point for relay to the cow and so that they may be recorded. In this way an operator (who may be out of range of the base station) can issue a command and have it logged. The Channel1/2 interconnection is close to the paddock within which the experimental trials will be carried out (Figure 2).

Data Logging

All traffic to and from each cow is logged at the base station by a dedicated receiver/computer combination. Each item of traffic is time stamped with sub-second precision and stored on a dedicated drive for record and analysis purposes. Data is logged to a PC located in the control center using "tera term" data management software, (available free online), tera term logs all data (Cow ID, Alert level and a time stamp accurate to a tenth of a second). The files are saved as self-generating log files in a pre-named documents folder. It is also desirable to keep a time-stamped record of all traffic for later analysis or review by an independent party such as an ethics committee.

Power Requirements

The main elements for the on-cow power requirements are (a) GPS positioning (high end GPS requiring more power than conventional types) 60%, (b) Microprocessor Control unit: 20%, and (c) Stimulus Unit: 5-20% depending on usage. The on-cow power requirements vary with the elements of the system in current use. This can vary between 15mA and 150mA drain on the battery. A LiPo solution has been selected for capacity, short re-charge times, and weight. The total capacity of the battery is 4400mAh giving a design life with average consumption of 3-4 days. It is planned to extend this by employing power saving strategies when typical usage patterns become available during the trial. The tight nature of the trial paddock means that we will see a high power consumption as the GPS unit will need to be active at all or most times. The field transmission mast has a power requirment of 50mA at 5V and is powered from a lead-acid 12V re-chargeable battery backed up with a solar panel. The base station requirements are for a UPS backed system powering the main computer, logging and command radio links and the base station GPS unit.

Operating Environment

The operating environment for all the outdoor equipment is relatively harsh. The field based radio network elements are to IP67 (weather-proof) and the cow borne elements are designed to meet IP67 and do so in respect of the electronics housing, however an element of exposure to the weather will be encountered on the interface elements (sound and electrical stimulus) and so cannot be IP67.

Compatibility

A smart-phone or tablet is required to be an Android version 4.3 or later.

Experimental Design

The trails to be conducted in the second half of 2014 will evaluate the difference between sound and tactile stimuli which will be compared to a control which will be a conventional electrical strip grazing fence, considered the industry gold standard. The trail will be conducted over 9 weeks with 3 sets of 5 to 8 naïve cows (n=15 to 18 in total), in each of 3 different locations for 3 weeks. The trail will be set up in such a way that grass availability outside the inclusion zone will be of the same relative abundance for each treatment. The first week of each 3 week trial will be used as an adjustment period. This period is to allow for the cow habituation to equipment and to conduct a measurement of distribution of the cows in their assigned areas. All the positioning data will be logged but the stimulus will be turned off during the adjustment period. During the second week (of 3 weeks) the cows will be introduced to the treatments as described previously, all the data will be logged and the cows

will also be visually accessed. This will continue through week two and three. During this time a Standard Operating Procedure for training cows to the system will be developed.

3   Results & Discussion

This study presents a novel concept to allow automation of grazing management within a dairy farm system by combing two technologies to aid grazing management which include (1) a decision support tool (DST) with global positioning system (GPS) capability, that precisely measures herbage mass and (2) an on-cow virtual fencing system based on GPS monitoring. These technologies, the infrastructure and communication network that will accurately and automatically allocate the grazing area have been developed and are currently being tested. The results of these developments are detailed in Figures 1 and 2. The goal is to achieve an accurate, labour saving and economical method for precision grazing to enhance grazing management decisions and reduce labour for farmers in a pasture based system of farming.

4   Conclusions

The precise objective estimation of herbage mass and pasture allocation combined with the fine resolution control of each cow at an individual and herd level using GPS and VF have the potential to reduce labour associated with fencing, optimize pasture utilization and subsequently cow milk production. A DST and VF network infrastructure have been developed and further work will combine these technologies to advance the precision of grazing management in pasture based dairy systems.

5   Acknowledgements

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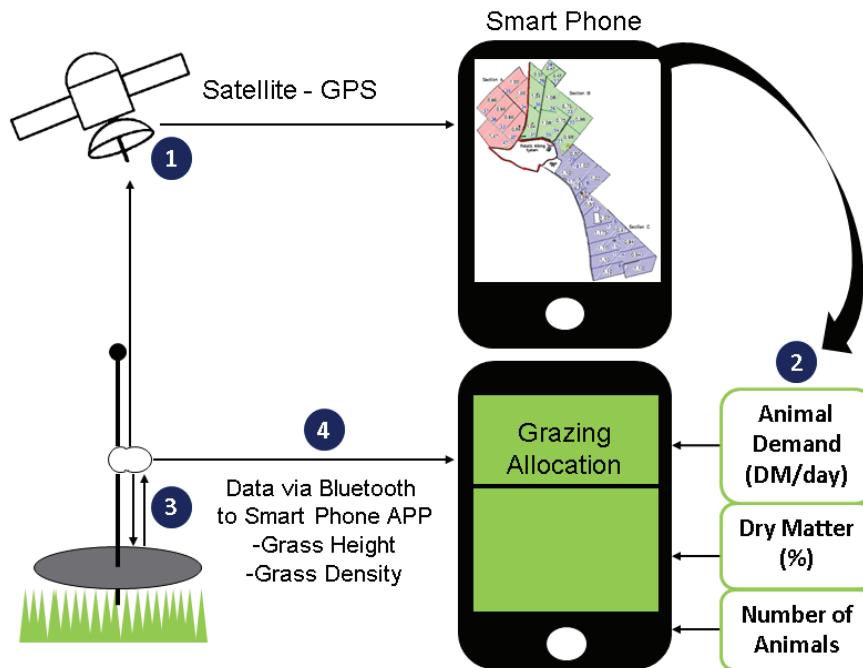
Figure 1: Decision support tool (DST) network and communication infrastructure required to estimate precise herbage mass within a paddock. (1) The DST makes a connection to a satellite via GPS. (2) On a smart phone app the operator pre-selects the paddock area to be measured and inputs other data required to calculate the herbage mass. (3) Grass height measurements are then taken by the DST. (4) The data is transferred via Bluetooth to the smart phone app and the operator is informed of the grass height, herbage mass and where to place the fencing wire within the paddock to achieve an accurate grazing allocation.
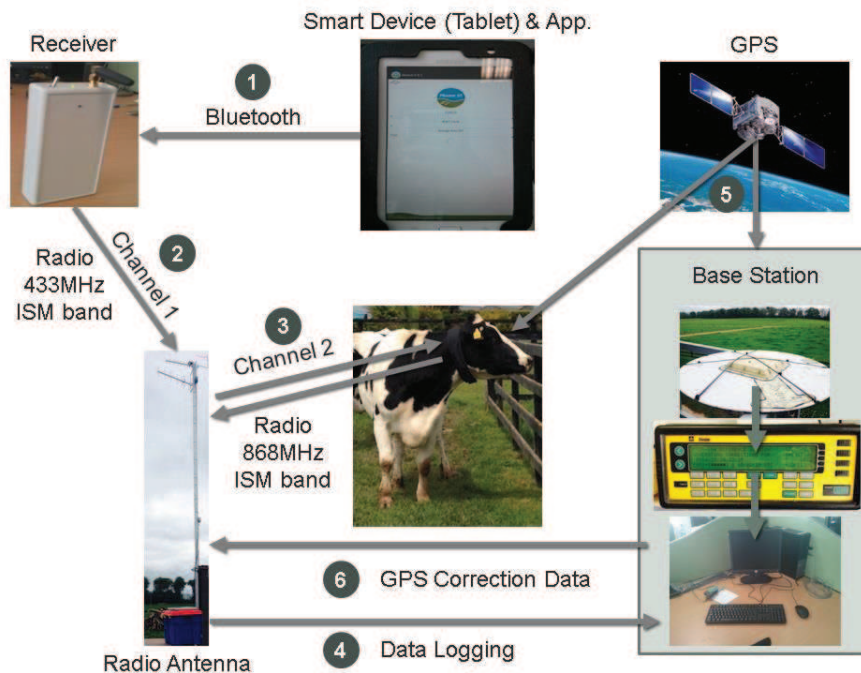

Figure 2: Virtual fence (VF) communication network and infrastructure required to contain cows within an inclusion zone and to allocate pasture area for grazing. (1) Command sent from smart device to reviewer via Bluetooth, (2) converted into a radio signal and sent via channel 2 to a radio antenna, (3) command then sent from radio antenna to the cows VF collars in the paddock via channel 2 and the response to the command is returned back to the radio antenna which (4) transfers the data logged back to the base station via the internet cloud (5) GPS correction data generated ny the base station on-site uses (6) channel 2 before being processed for an individual cow.