An RFID Agricultural Product and Food Security Tracking System Using GPS and Wireless Technologies

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ABSTRACT

In this paper we outline a system for tracking grain using GPS a new RFID grain chip technology. The system will enable tagging the location of the grain origination within individual fields. Attribute information including, for example, origination of variety seed stock, fertilizer and chemical applications, stress, disease or other quality attributes can then be linked to the individual batch loads from other GIS database layers. The RFID grain chips will be developed using existing passive microchip technology and encased in a durable container with the size, weight and texture characteristics of the grain being tracked, such as corn, soybeans, or wheat. At any tracking stage, we will have the ability to write and read data from the grain chip, insert new grain chips, and extract grain chips.

The purpose of the system stems from both the economic and food security value of physically tracking batch loads of grain and grain attributes from the harvest field to any point in the supply chain. Processors will be able to increase operational efficiency and value through improved and timely information regarding the attributes of grain, both available in storage and arriving at the processing facilities. End users and consumers are also willing to pay more for products which include documentation of the origin and proof of segregation from unwanted ingredients or attributes. Increased concerns regarding bio-terrorism dictate the need for a system by which we can measure commingling and trace back through the transportation and production systems.

Keywords: RFID, GPS, Grain tracking, Precision agriculture

INTRODUCTION

During a harvesting and production process for grain, the grain typically undergoes various grain handling stages. For example, a grain handling process may begin at a farm, where the grain is harvested and placed into a truck. The grain may be taken to an on-farm storage facility for storage, handling, and/or processing. Afterwards, the grain may be transported to long term storage, to a livestock facility site, or to an off-farm facility for processing. In later stages, the grain may be transported domestically or internationally to an end user and/or may be further processed. At any or all of these stages, however, the possibility exists for commingling of the grain with other product or foreign matter, or for other problems, such as damage, theft, etc. This concern has increased significantly in recent times with greater awareness of food security issues. It thus is desirable to have an indication of the history of a particular grain. To date, this problem is mainly unsolved in the grain industry.

In this paper, we present a conceptual design of a system for tracking agricultural grain, such as corn, soybeans, and wheat, from harvest to the final "whole" grain point in the supply chain process. The system includes:

- tracking units/chips that are deposited with the grain at harvest,
- the technology to systematically deposit the chips into the combine grain bin,
- the technology to clean the chips out of the grain at any point in the supply chain process,
- the hardware and software to write and read data to and from the chips at any point in the supply chain process and provide the relational database protocols,
- the handheld technology for the read/write functions, and
- the software data-base system which allows for storage and time/location based mining of the grain tracking history and attributes.

A radio-frequency identification (RFID) tag is the main component of the proposed grain tracking system. The tag is dimensioned to approximate a size of an individual grain and multiple such tags are deposited in a container of the grain at the harvesting stage. At each grain handling stage the tags are programmed with the time and location of the event as well as any other attributes relevant to the grain handling process, e.g., serial number of equipment, etc. Therefore, the entire history of grain handling is stored in the tags and can be red at any time. New tags can be inserted in the grain or removed from the grain at any grain processing stage, as needed.

From the context of food security and economic value the system has the ability to:

- trace back, with visualization tools, the entire transportation path of the tracked grain from the end use/processor to storage, road transport back to field of harvest and origination of seed stock,
- query the data base for information on identification/location of grain with specific attributes or characteristics,
- link to other spatial and non-spatial databases for identifying other attribute information associated with the grain, and

- identifying alternative sources of food and export safe grain when potential contamination or agro-bio-terrorism events occur.

In the remainder of the paper we outline how the proposed system can be used in practice to track grain movement throughout various grain handling stages. We also describe various hardware and software components included in the system.

GRAIN TRACKING APPLICATION OVERVIEW

Consider an example in which grain is moved along 11 possible processing stages (Figure 1). Stage 1 is at the point of harvest and stage 11 is the last whole grain point in the supply chain process (grain processor or export). At any of these stages we will have the ability to: 1) insert new RFID tag, 2) write and read data from the grain chip, and/or 3) extract grain chips. However, we envision that in most cases the grain chips will be inserted at stage 1 and extracted at stage 11. Reading and writing the tags do not need to occur at all ten stages however.

Beginning with stage 1 there will be detailed identity/tracking information written to each RFID tag. Each RFID tag will have its own unique identity number (ID). The tags will be deposited in the combine grain bin during harvest at some rate (e.g., one per every fifty bushels of grain harvested). At the point of deposit the tags will, through an RFID read/write device linked to the combine yield monitor and GPS, be encoded with the current clock date/time, the current GPS coordinates, and the serial number of the combine. At stages 2 and 3 (transfer to the grain cart and semi truck) the tags will again be programmed with additional information of the current time and GPS coordinates during the grain transfer process and with IDs of the grin cart, semi track, etc. In these first three stages the time and GPS coordinates will vary for each RFID tag.

Stages 4 through 6 include the on-farm storage and handling portion of the system. The RFID tags will again be programmed with additional time and GPS coordinate and ID information at stage 4 when leaving the truck to enter the first grain holding bin. In this case the GPS coordinate will be a fixed location for the site with an ID number for each bin at the site. In some situations there will only be a stage 4 recording. In cases, such as wet corn the grain may be transferred to a dryer (stage 5) and then to the final holding bin (stage 6). In these cases the tags will again be encoded with the time and ID at transfer, thereby allow later calculation of storage time in each bin and drying time.

Stage 7 will be similar to stage 3, with the transfer time and serial number of the truck and site GPS coordinates recorded. From that point the grain may move on to a stage 8a location, a rural elevator where there will be a processor encoding and reading similar to stage 4-6 while the grain is in storage and transfer within the fixed site. Alternatively, grain may move directly to a stage 8b livestock facility site where there will again be recording of the time and location of arrival at the site and then extraction and reading the RFID tags.

From stage 8a the grain will go through another stage 9 truck transfer and then on to a stage 10 terminal or processor where again the final encoding, reading and extraction will occur unless the grain goes on to stage 11 export where extraction can occur at the international processor.
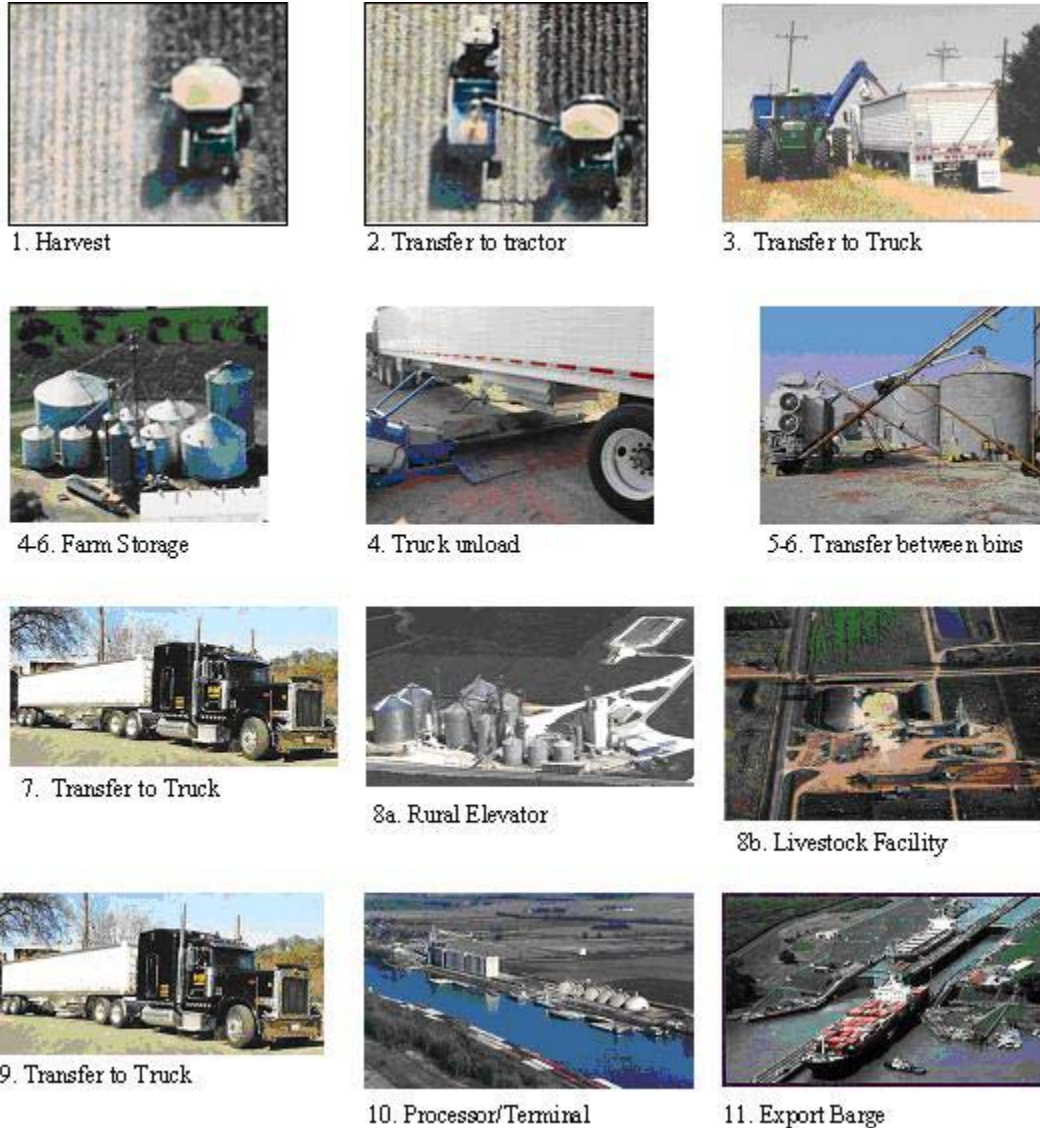
Figure 1. Various grain processing/storage/transportation stages.

Figure 2 shows an example of data recorded and retained on a single RFID tag through the first four event stages. At any given moment of time, the chips will contain complete history of product movement, storage, and processing, including time and location of transaction and serial numbers or IDs of relevant equipment, storage facilities, etc. Additional information, such as rate at which RFID tags were inserted, moisture content, etc., can be stored as well. In the initial implementation, the tracking chips will be designed to store the following data at each deposit and transfer stage:

- unique hard coded tag ID
- sequential event number
- clock time associated with the event (deposit, transfer, read, etc.)

- GPS coordinates (lat/long) at each time event
- vehicle/equipment serial number at each event
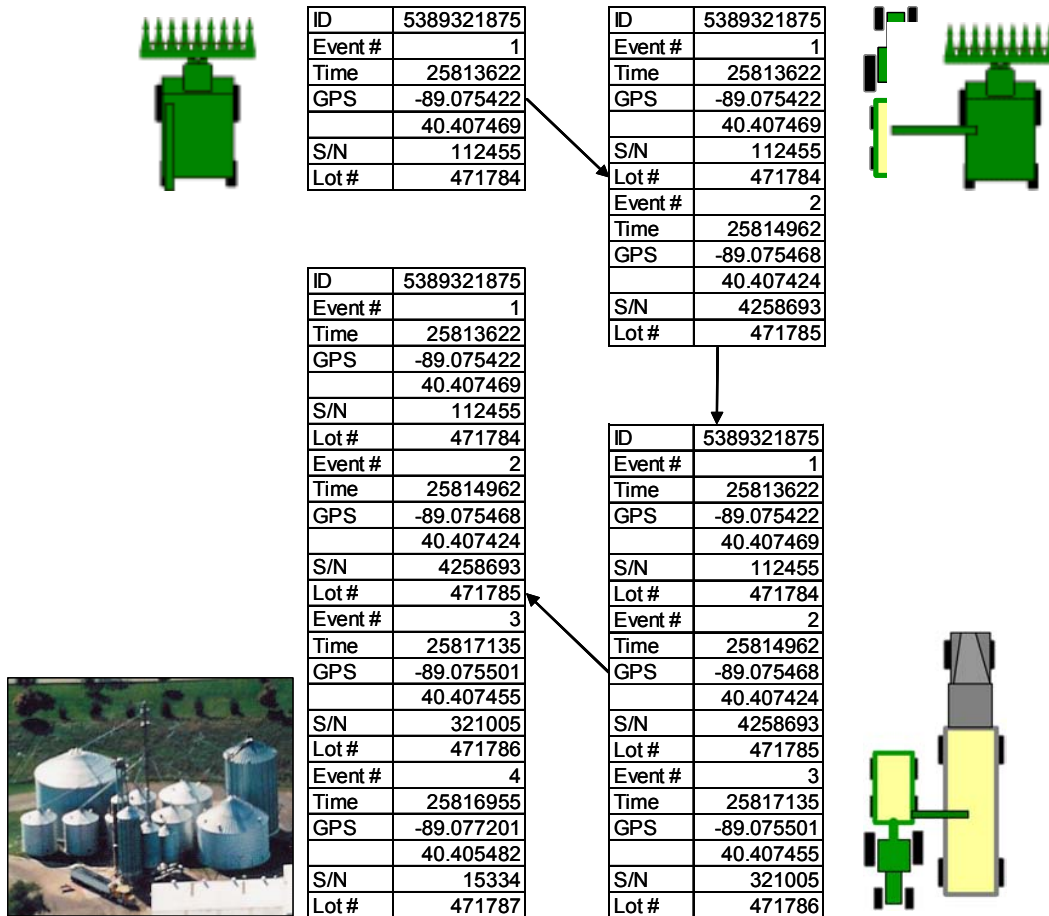- unique lot number for each transfer event

ID	5389321875
Event #	1
Time	25813622
GPS	-89.075422
	40.407469
S/N	112455
Lot #	471784

ID	5389321875
Event #	1
Time	25813622
GPS	-89.075422
	40.407469
S/N	112455
Lot #	471784
Event #	2
Time	25814962
GPS	-89.075468
	40.407424
S/N	4258693
Lot #	471785

ID	5389321875
Event #	1
Time	25813622
GPS	-89.075422
	40.407469
S/N	112455
Lot #	471784
Event #	2
Time	25814962
GPS	-89.075468
	40.407424
S/N	4258693
Lot #	471785
Event #	3
Time	25817135
GPS	-89.075501
	40.407455
S/N	321005
Lot #	471786
Event #	4
Time	25816955
GPS	-89.077201
	40.405482
S/N	15334
Lot #	471787

ID	5389321875
Event #	1
Time	25813622
GPS	-89.075422
	40.407469
S/N	112455
Lot #	471784
Event #	2
Time	25814962
GPS	-89.075468
	40.407424
S/N	4258693
Lot #	471785
Event #	3
Time	25817135
GPS	-89.075501
	40.407455
S/N	321005
Lot #	471786

Figure 2. Data recorder at the first 4 processing stages.

The software to facilitate the tracking, data queries and movement/location visualization will include the following:

- Stand-alone software for recording the data code components at initial deposit, final extraction and each "write" phase of the system,
- linkage to external GIS and non-spatial databases for referencing other attribute, time, and spatial data layers,
- visualization tools for static identification of the grain with attribute location information (in-storage)
- visualization software for backtracking grain movement, storage and origination
- visualization software for identifying buffer/isolation regions (in field, storage or transport), transport routes for segregating high value or potentially contaminated grain.

Figure 3 provides an example of how visualization software might be implemented to trace back the grain from processor to storage facility back to an individual location in a field. An overlay of the unique RFID tag recording points can be shown on a satellite image or other geographic referenced maps. By highlighting particular locations within the depicted lots (e.g., by linking the visualization with absolute coordinates) and highlighting the extracted coordinates in the display, individual points for a particular RFID tag can be shown on the display. An individual tag record can be recalled showing the unique tag id number, event number, atomic clock time of harvest, GPS coordinates, the serial number of the combine and a unique lot number. Moreover, a complete list of RFID tags in storage can be displayed as shown at the processor level in the upper right image. The id numbers from the tags may then be linked to the database for displaying the compete history of the first to last stage events, time, location, etc. Such backtracking can effectively illustrate movement of the grain, when and where the grain was stored, and/or origination of the grain. Further, visualization software may be provided for identifying buffer/isolation regions, for example, in the field, storage, and/or transport routes for segregating high-value or potentially contaminated grain.
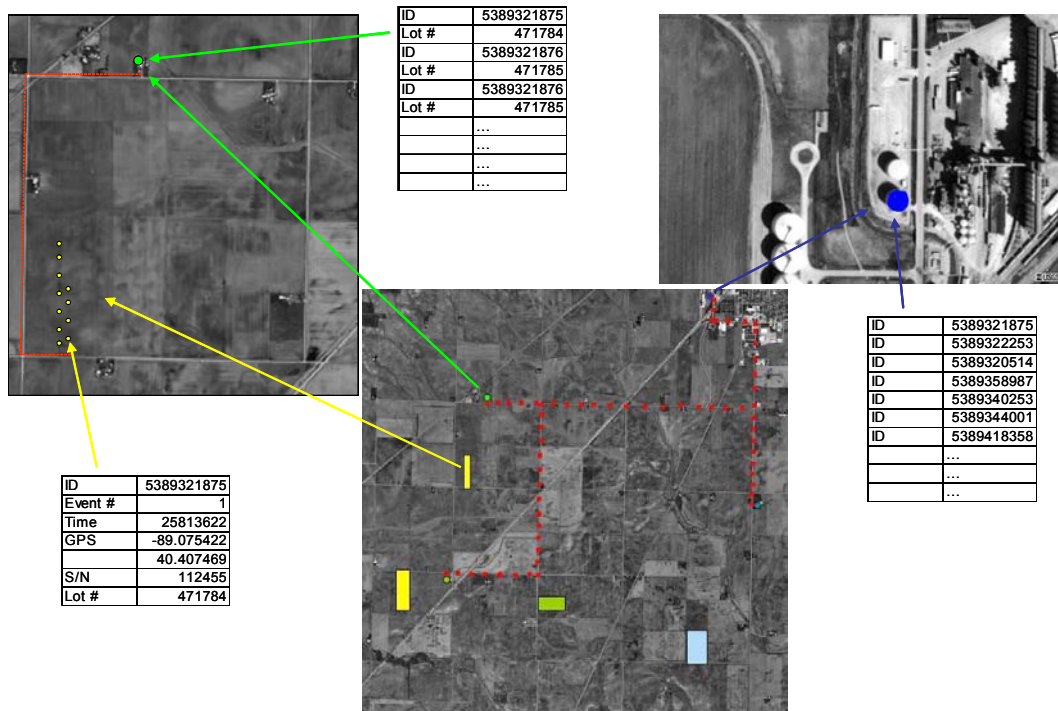

Figure 3. Trace back from processor to farm storage to within field location of individual chips.

The data and software structure will virtually eliminate the potential to manipulate or falsify the coding information. By coding the time, location and serial number of equipment used we have built in redundancy, which will allow

checking for errors in terms of the time-line of chip read/write information, location/spatial error checks, reference to appropriate harvest, transport and storage equipment, and time-line reference to appropriate batch loads. The visualization software will enable time and spatial movement of grain and depicting origination of any data outside the prescribed control parameters.

RFID GRAIN TRACKING TECHNOLOGY

RFID Tag

The RFID Grain Tracking Tag is the device that travels with the grain being tracked. It has roughly the same size, shape and weight of the grain being tracked so that the tag remains with its host bushels of grain as the grain moves from the field to its extraction point. Figure 4 provides an example of two commercially available tags whose size is comparable to the size of the corn and soy grain. The RFID Grain Tracking Tag is a passive RFID device, that is, it does not contain a battery and is powered solely by the electromagnetic field generated by the RFID Grain Tracking Reader/Writer. Figure 5 shows the architecture of the tag.

The physical materials that constitute the tag's packaging are magnetic, durable, and non-toxic. A magnetic component is chosen so that the tags may be extracted from the grain. Durable exterior is needed so that the tag's packaging does not wear appreciably after thousands of cycles of reuse. Non-toxic will be used so that what little wear that does occur as the tag jostles with its neighboring grain does not contaminate the grain.

Figure 4. Examples of RFID tags whose size is comparable to the size of the corn and soy grain.
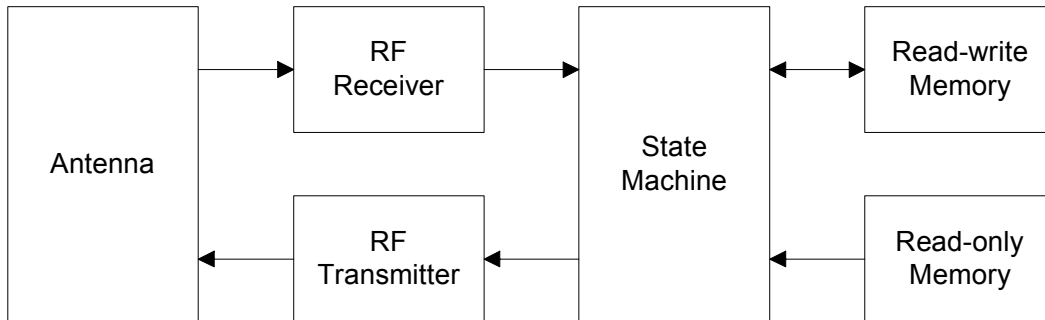

Figure 5. RFID grain tracking tag architecture.

The antenna receives and stores electromagnetic energy from the RFID Grain Tracking Reader/Writer. After sufficient energy has been received and stored, the remainder of the circuit becomes active. The density of the Reader/Writer transmitter on times in the message bit stream is high enough to keep the tag circuitry powered throughout a given operation. The state machine controls the sequencing and timing of these three operational commands:

- If the RF Receiver successfully receives and decodes a "read ID" command from the RFID Grain Tracking Reader/Writer device, the State Machine reads the tag's identification number (ID) from the non-volatile Read-only memory and sends this ID back to the RFID Grain Tracking Reader/Writer via the RF Transmitter and Antenna.
- If the RF Receiver successfully receives and decodes a "read data" command from the RFID Grain Tracking Reader/Writer, the State Machine reads the tag's ID from the Read-only Memory, appends all data in the non-volatile Read-write Memory to the ID, and sends the composite message back to the RFID Grain Tracking Reader/Writer via the RF Transmitter and Antenna.
- If the RF Receiver successfully receives and decodes a "write data" command from the RFID Grain Tracking Reader/Writer, the State Machine writes the received bits into the non-volatile Read-write Memory.

The capacity of the non-volatile Read-only Memory is sufficient to contain the tag ID information. This memory space is fixed and set at the time that the tag is manufactured. The capacity of the non-volatile Read-write Memory is sufficient to contain the maximum number of sets of data that a tag is expected to receive throughout a single grain tracking cycle.

RFID Reader

A depiction of the RFID Grain Tracking Reader/Writer is shown in Figure 6 and the architecture is shown in Figure 7. The microcomputer receives a timestamp and location data through its GPS electronics. When an RFID Grain
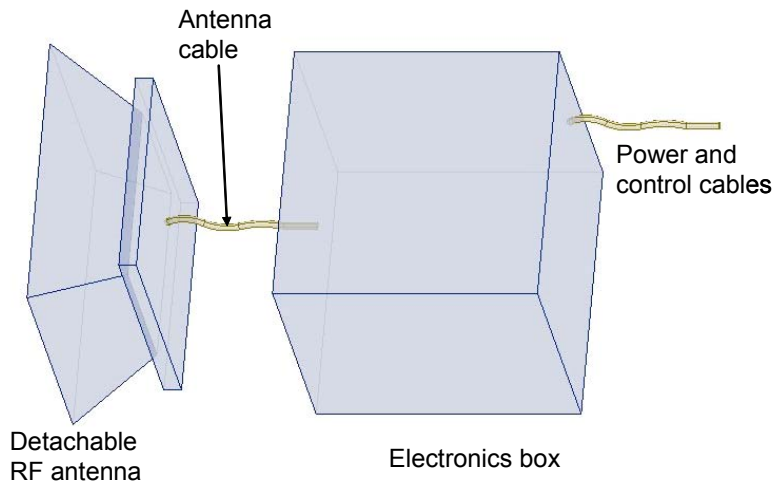
Figure 6. RFID grain tracking reader/writer.

Tracking Tag is detected (by obtaining a valid tag ID from a tag via the RF Receiver), the current timestamp, location data, and any other defined system data is written out to the tag via the RF Transmitter. The microcomputer may also store all the records in all of the tags that it has read in a local database. When a network connection is available, these data may be transferred to a centralized or regional computer system for analysis.
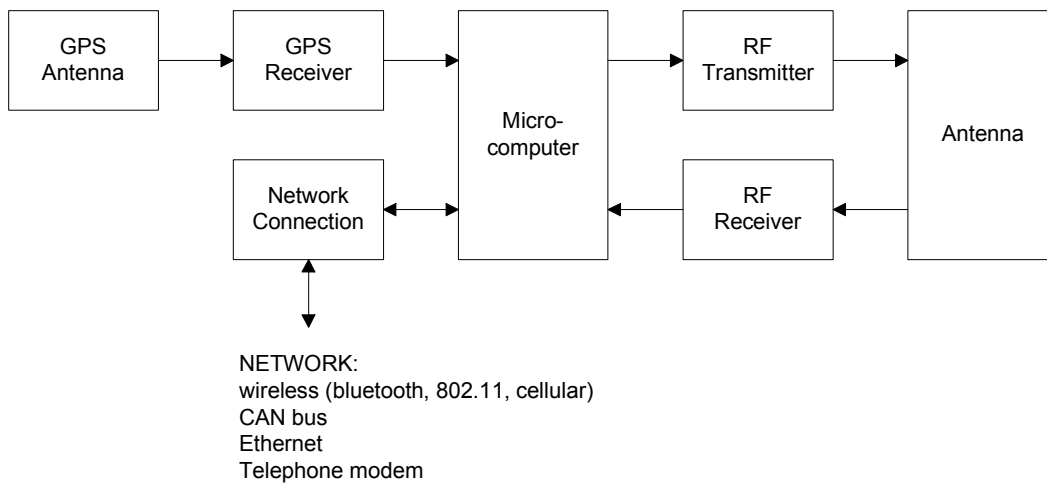

Figure 7. RFID Grain Tracking Reader/Writer Architecture.

The packaging of the RFID Grain Tracking Reader/Writer is suitable for the expected environmental conditions at the locations it is to be used. Power for the RFID Grain Tracking Reader/Writer is provided by standard house current (120VAC), if available, or by a battery/solar panel combination if not.

Tag Dispenser

Figure 8 shows the RFID grain chip tag dispenser, reader/writer and the RFID tags and grain in free falling mode, similar to that which would be used in a combine grain bin. Conceptually, the grain tracking tags dispenser consists of tags tank, dispensing door, solitron, tags guide, and control electronics (Figure 9a). The tags tank is filled in with RFID tags. The tags dispensing door will open when a single tag needs to be dispensed. It consists of a disk connected to a rod. The other end of the rod is inserted into a solitron. When a positive current is applied to the solitron, the rod is pulled in, thus the dispensing door disk opens the hole in the bottom of the tags tank and a single tag is released into the tags guide pipe. When a negative current is applied to the solitron, it pushes the rod out, thus closing the dispensing hole. Tags guide pipe allows directing the released tag to an appropriate location to be released into the grain stream.
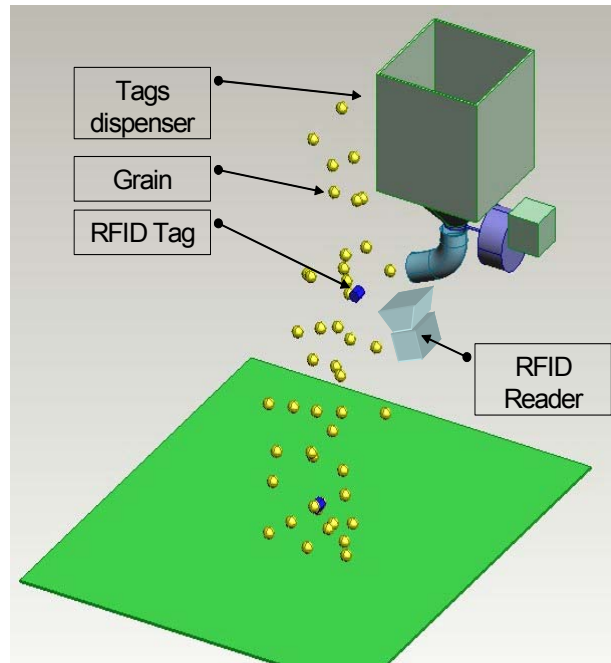

Figure 8. Tracking tag dispenser and reader/writer design for a combine bin.

Dispenser control electronics box provides positive or negative current to the solitron based on the control program. It also provides interface for setting up tags release frequency and interface to other system components. In one instance, human operator can program the control electronics box to release a user-specified number of tags within a user-specified time interval. In another instance, human operator can program the control electronics box to release a tag every some number of bushels based on the harvester yield monitor.
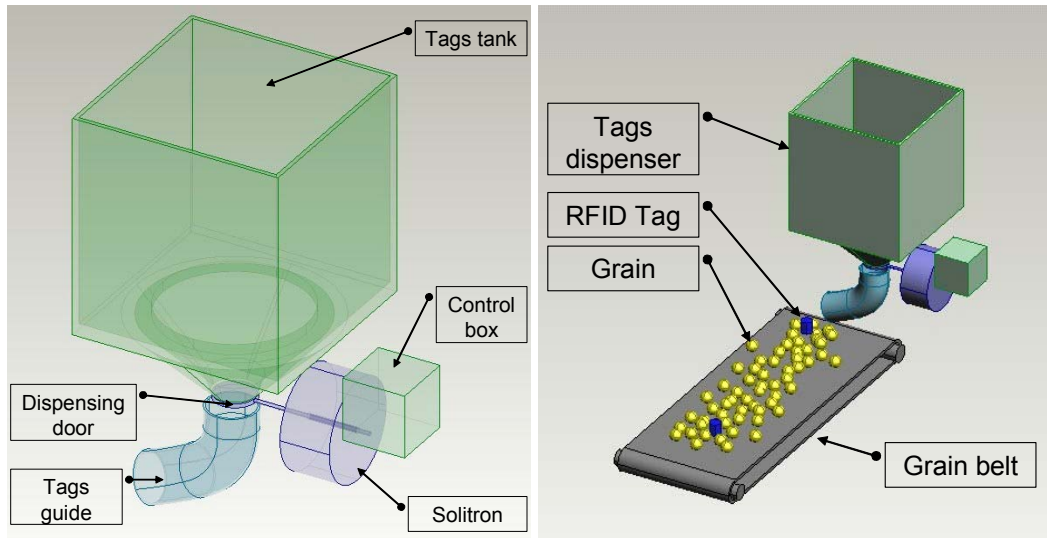
Figure 9. a) Grain tracking tags dispenser design; b) Dispenser deployment with a belt-based grain handling system.

Tag dispenser can be used to dispense tags into a stream of grain moved by the belt-based grain handling system, into a stream of freely falling grain, and into a stream of grain moved by an auger. In the belt-based grain handling systems, the dispenser is located above the belt and its tags guide pipe is directed towards the belt (Figure 9b). In the case of a freely falling grain, the dispenser is located next to the free fall volume and its tags guide pipe is directed towards the falling grain. In the case of an auger-based grain handling system, the dispenser tags guide pipe is directly inserted into the auger pipe or is positioned above the auger intake system.

Tag Remover

The tag remover combined with the reader/writer is show in Figure 10. This depiction presents the approach which could be used for removing the tags from free falling grain from an auger spout or grain flowing out the bottom of a truck or rail hopper. Conceptually, the magnetic grain tracking tags belt remover consists of a moving belt, permanent magnet located inside the belt, and a storage box for removed tags (Figure 11a). The permanent magnet pulls up metal-cowered RFID tags. The tags are then moved by the tags removing belt to the tags storage box. Tags storage box should be positioned right at the edge of the permanent magnet, thus allowing the captured tags to be immediately released to the storage box. The dimensions of remover, speed of the tags removing belt, and the power of the permanent magnet are defined by the deployment environment.
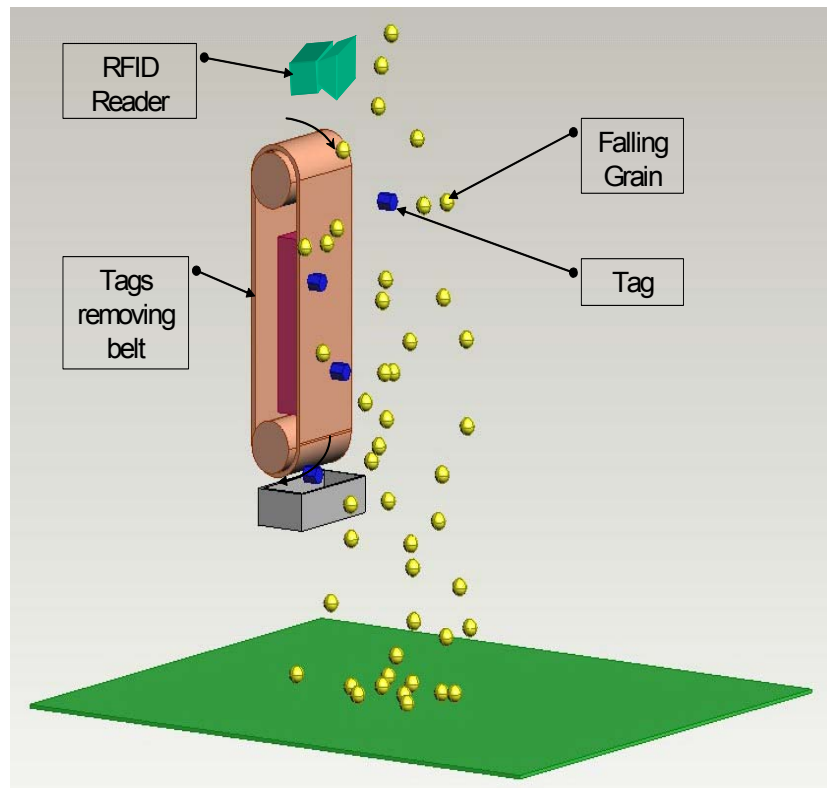
Figure 10. RFID grain tag belt remover and reader/writer design for free falling grain.
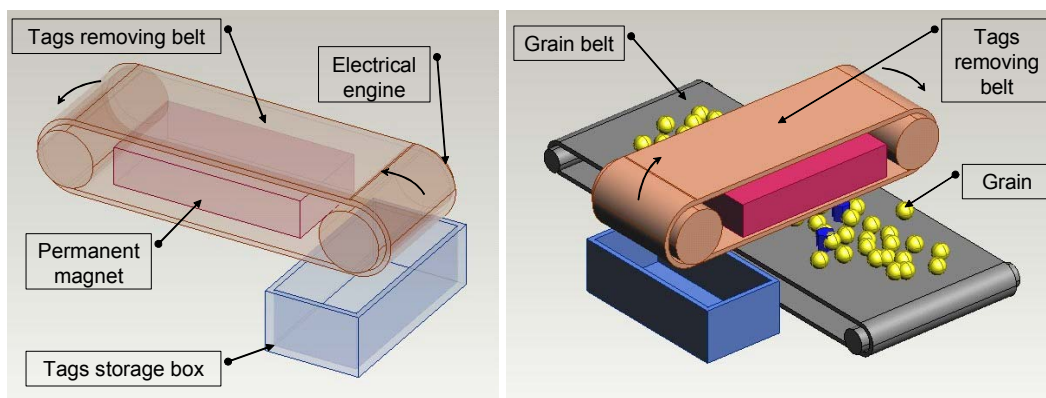

Figure 11. a) Grain tracking tags belt remover design; b) Remover deployment with a belt-based grain handling system.

Tags remover can be used to remove tags from a stream of grain moved by the belt-based grain handling system and from a stream of freely falling grain. In the belt-based grain handling systems, the tags removing belt is positioned above the grain belt and the tags storage box is located next to the grain belt (Figure 11b). In the case of freely falling grain, the tags removing belt is positioned along

the path of the falling grain and the tags storage box is placed right below the tags removing belt. In both cases, the side of the tags removal belt close to the grain moves in the direction of the storage box, thus moving the pulled tags to the storage box. In the case of an auger-based grain handling system, the tags removing belt can be positioned just above the auger intake system.

CONCLUSIONS AND FUTURE WORK

The proposed system shows great potential for tracking grain and grain attributes while improving food security and efficiency of the agricultural food supply chain. This system has the ability to: 1) trace back, with visualization tools, the entire transportation/movement of grain from the end use/processor to storage, road transport back to the field of harvest and origination of seed stock, 2) query the data base for information/location of grain with specific attributes or characteristics, 3) link to other spatial and non-spatial database for identifying other attribute information associated with the grain, and finally, 4) identifying alternative sources of food and export safe grain when potential contamination or agro-bio-terrorism events occur. Additional work is underway to develop and test the various components of the system. Work is also needed to further evaluate the economic feasibility of the technology.