Radio-Based Distance and Positioning Systems Applied to Tracking and Safety Applications in the Tubular Industry

Wherever tubes, rods, billets, coils, slabs — any type of steel products — are buffered or stored in the production process, an optimization of inventory, tied-up capital and material tracking is mandatory. These products represent a high value due to raw material cost and energy/equipment expenses required to produce and handle these goods. Optimization therefore needs to be based on the number of products in stock, their location in the production process, and the undisturbed operation of cranes, forklift trucks and other heavy handling equipment.

Counting produced units is not a difficult task; however, tracking of the products in a mill environment is more of a challenge. Products must be tracked by detecting pickup or drop points, combined with the respective position of a crane or transport vehicle handling the goods. By this principle, location updates are generated with every single product move.

Products may be tagged with handwritten letters, bar codes or radio-frequency identification (RFID). This provides for identification but not location tracking. Production wants to differentiate between similar products from various batches and, even more, changing material qualities, surface treatments or customer lots. Knowing the various products to be tracked throughout the production process.

Radio-based distance and position sensors have been adopted widely in the steelmaking industry due to the fact that harsh conditions like dust, heat or vibration do not influence the signal quality. This paper presents a number of applications in steel plants worldwide, with benefits including uninterrupted operations, increased operational safety and reduced maintenance cost.

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Figure 1

Various products to be tracked throughout the production process.

This article is available online at AIST.org for 30 days following publication.
Location tracking does not require any hardware on the product — it monitors the movement of the material handling equipment and respective load status changes of these handling devices. Pickup and drop events with location coordinates are provided to a warehouse management system (WMS), which then updates the location of every product in the database. Highly reliable position sensors are required to avoid any downtime, during which material movement would otherwise not be recognized.

Movements between production process steps, as well as to indoor and outdoor storage yards, need to be monitored accurately and with high reliability under typical conditions of a mill: abrasive dust, dirt, fog and steam, rain and snow. Optical sensors have a high probability of failure and may require permanent maintenance and cleaning. Maintenance-free, radio-based position sensors have proven to be able to meet these requirements in the metals industry. Radio signals are not affected by the challenging mill or outdoor yard environment and do not even require cleaning or re-adjustment.

Once cranes and transport vehicles are equipped with reliable, real-time position sensors, these machines can also be protected against collisions. This can involve simple applications to avoid overhead crane collisions, and can also be expanded to collision avoidance systems where all moving and even fixed objects (e.g., high-value machines, buildings) are protected against false moves.

**Functional Principle of Radio Distance Measurement**

Radio signals travel at the speed of light, commonly denoted as $c$, known to be 299,792,458 m/second, or approximately 186,282 miles/second.
A velocity, $v$, is generally defined as:

$$v = \frac{d}{t}$$  

(Eq. 1)

where

$d = \text{distance and}$

$t = \text{time}.$

A radio distance sensor measures the time of flight ($t$) of a signal from the sensor to the target (distance $d$) and back ($= 2d$) to determine the target distance.

The speed of the signal being $c$, the following simple formula applies:

$$d = \frac{t \cdot c}{2}$$  

(Eq. 2)

The main task with this simple equation is to determine $t$ with enough precision — it takes only 5 µs for the signal to run 1 mile and picoseconds accuracy to measure this distance with 1-inch precision.

Radio signals are reflected by most surfaces. This was the initial use of radar waves — detecting remote objects. Such reflections also exist in today’s precise distance and position measurement applications. The sensor emits a signal and receives a directly reflected echo and also multipath echoes from other reflections. Only the direct signal that has taken the shortest route, the line of sight, is used for precise distance measurement; other reflections take a longer path, need more time and are discarded.

**Passive Radar Measurement**

Similar to optical or acoustical signals, radio signals are emitted in a focused beam. This beam can be reflected either by an object’s surface or by a dedicated reflector. Radar reflectors are ideally shaped as a corner reflector, made of metal. The corner reflector reflects incoming waves back to the source, always parallel to the incoming signal.

Due to the given signal strength, such reflections may be received only over a distance of up to 300 feet. Typical applications for a mill environment are measurement of a crane trolley position in very hot environment (ladle crane) or a ladle transfer car. In those cases, the corner reflector is mounted on the “hot” moving object, while the measurement unit is in the cooler remote zone to determine the dynamic position.

**Measurement Between Two or More Active Radio Components**

Distance measurement, e.g., on cranes in a tube mill, will sometimes have to cover crane bay lengths of 1,000 feet or more. Radio sensors have to comply with Federal Communications Commission (FCC) rules and must be limited in signal strength. Over larger distances, a simple reflection is therefore not strong enough to be detected. This problem is solved by applying active components, not only reflecting a signal but responding with a much stronger answer signal when a trigger signal is detected. This allows radio distance measurement to be accurate over several thousand feet.

Since the signal travels at the speed of light, any uncorrected signal processing in the actively responding units, even if it takes only 1 millisecond, would in this case be inaccurate by 186 miles, which is...
unacceptable. Active components therefore need to be synchronized to 10 picoseconds ($10^{-11}$ of a second or 0.000,000,000,010 second) to come down to centimeter/inch measurement precision. Given that high level of time synchronization, radio participants can determine the arrival time of a signal and respond with an amplified “echo” that is time-corrected to make it look like it had been echoed by the active component without any delay.

The time synchronization principles applied for two units can be extended to several units in a certain area. This is required for 2D position measurement. So-called transponders mounted at known locations serve as reference marks for all position sensors in a certain area, a positioning cell.

Cells can be as large as 1,000 x 1,000 feet, and any area can be covered by overlapping cells. Transponders need only power, not interconnection, which supports fast and easy installation. All position sensors in a cell “listen” to the synchronized messages of each transponder and can determine their position independently without any host connection. As position sensors are only listening and transponders are only sending, there can be an unlimited number of position sensors that have the same high accuracy and update rate.

Crane and Vehicle Tracking in a Mill Environment

In a mill environment, there are single pipes/tubes or tube bundles to be handled. Depending on the type and size of operations, crane and forklift vehicles are used to transport these products between process steps and to/from storage areas. In order to trace all relevant product movements and have a continuously updated WMS database, crane and vehicle movements and load-change events are monitored by radio position sensors.

The following example uses tube bundles. Bundles in this application are tied together by synthetic fiber ropes or, in case
of very hot tubes, steel ropes to withstand high temperatures.

Several bundles are stacked above each other, and each bundle is tagged and identified with a bar code label. Upon retrieving the bundle from the storage, a reader verifies the correct bundle has been hooked to the crane by the storage operators. Here is the main difference between tube bundles and single tubes/slabs/billets — loose bundles sometimes roll out of the position they were placed in the storage. Therefore, just picking up bundles without verification of the bundle ID could lead to a mixed product error.

When bundles are sent to the storage sections between production processes, the WMS needs to take several things into account, such as:

- How long is the expected storage time? How quick is the retrieval from storage?
- Is the bundle part of a batch production that should be stored in the same location for the consecutive production steps?
- What is the bundle temperature?
- Are there synthetic fibers at the planned storage location that could be damaged by putting hot tubes on top?

Based on these logistical considerations, the WMS will assign a transport job to the best positioned crane or forklift and provide the destination location for the crane/truck driver to store the bundle.

Bundle movement and pickup/drop positions can be tracked by radio positioning sensors that determine the exact coordinates of the center of a bundle upon the load-change trigger that comes from a load cell on the crane.

If the load cell on the crane is precise enough, verification of the right bundle picked up can also occur by comparing the weight that is stored in the WMS database from the initial pickup of this bundle.

Tracking the movement of cranes and forklift trucks will generate a continuous location update for all products in the production process and will allow for minimized search times and housekeeping movements, as well as avoiding errors by picking the wrong product for a subsequent process.

**Crane Position Measurement**

Cranes are the most common means of handling products between various production processes and
Figure 11

Screenshot of WMS database: crane driver’s view with target position for current bundle.

Figure 12

Plan view — two cranes on one bay; 1D distance sensors with multiple antennas.

Figure 13

Plan view — three cranes in one bay; combined LPR-2D and LPR-1D allow for precise positioning of all cranes independently.

storage areas. There are crane bays with only one or two cranes in which the position of each crane bridge and crane trolley can be easily measured by 1D distance radar.

The sensors exchange the x and y coordinates between radar devices through their own radio signals, independent of and without interfering with WiFi. Therefore, the full x-y crane position is available on the trolley, on the bridge and also at the end of the crane rail. If additional data, such as the load-change trigger or the weight from a load cell, is collected on the trolley, this information will also be automatically distributed to all radio units.

On longer bays with several cranes, there may sometimes be space constraints for 1D measurement to all crane bridges, and therefore a 2D solution with transponders along one side of the crane rail is a reliable and cost-efficient solution.

The two omni-directional antennas on the bridge use the transponders along the crane bay to determine the bridge position (x coordinate). The third (planar) antenna directs to the trolley, where a separate device establishes a 1D measurement for the trolley position (y coordinate). The full x-y position is available on the trolley and on the bridge, and can even be transmitted through the sensors’
own radio communication to a data collector transponder that is wired to the network for data transfer to the WMS.

In both cases, positions are updated 20 times per second and can either be sent to the WMS continuously or triggered by a load-change event.

Vehicle Tracking

Tracking of vehicles requires a precise position of the vehicle itself, including the vehicle’s heading angle in plant coordinates. This is achieved by two independent antennas on the vehicle. Each antenna determines its own position, and knowing the antenna mounting pattern on the vehicle allows for the vehicle’s orientation to be easily determined. The given distance from the center of the vehicle to the center of the fork or pin to pick up the load is then computed for each position update, and the WMS receives the real center coordinates of the load to update the database.

As for crane transports, the vehicle position sensor also connects to the load change signal or to a load cell and creates a trigger to transmit coordinates and load information to the WMS. Today’s technology provides simple and cost-effective mobile interfaces (HMI) inside and outside the vehicle.

Collision Avoidance for Overhead Cranes

The simplest and most typical collision avoidance application is on cranes operating in the same crane bay. Accidents happen mostly when crane drivers are concentrating on a load under the hook, or when a ground-based operator moves the crane by means of a remote control, focusing on the ground movement of the hook, but not on the crane movement overhead.

Not only can crane collisions be dangerous for crane drivers on the machine, but in most cases they cause a long production stop in order to determine and repair damages. In most cases, it is difficult or impossible to compensate for such a breakdown. Collision avoidance sensors are therefore an inexpensive insurance against such losses.

The radio sensors are equipped with onboard relays (dry contacts) to provide warning or stop signals without the need for an additional programmable logic controller (PLC) on the cranes.

In case position and collision avoidance is introduced simultaneously, only one set of hardware is required. This combines the reliability of radio
Collison Avoidance for Free-Ranging Vehicles

Radio sensors provide the position and heading angle of free-ranging vehicles and cranes. Starting from the outer dimensions of a moving object and depending on the direction of movement and speed, a collision danger zone is defined. Two redundant radio modules are responsible for broadcasting the current position, speed and heading, while a third module transmits information on the 3D collision shape. In addition to the collision shape, each vehicle also has a defined proximity radius. In order to avoid unnecessary computing, the onboard collision algorithm can ignore other objects, provided the proximity radii do not overlap because other objects have a large and safe distance.

Fixed infrastructure, such as buildings, light poles or expensive machines that must be protected, can be entered into the fixed objects database of each position sensor with a given safety distance. As soon as moving objects come too close, a warning will be triggered.

The radio collision warning ensures that all participants — cranes, heavy-duty vehicles and obstacles — can “see” the position and movement of each other and sounds an alarm if a warning threshold is reached or if a wireless module fails during the continuous self-monitoring.

There is no central point of failure, no central hardware at all and no network connection required for the full function of a radio collision warning system.

Conclusions

Radio position sensors with accuracy up to 1 inch have made their way to into heavy industries over the past six to eight years. Numerous steel mills in all corners of the world experience the advantage of maintenance-free crane and vehicle positioning in indoor and outdoor applications, even under very harsh conditions.

Tracking of tubes, pipes, and all sorts of slabs, plates and coils has become possible because WMS databases can now receive uninterrupted, reliable product location data to build storage maps. Search times are eliminated, and so are errors in processing and shipping.

Collision avoidance can be achieved as the main goal of an application, or even as a side effect of a positioning application. When planning for both, cost-efficiency will be maximized.

Acknowledgment

All figures and schematics are courtesy of Symeo GmbH, Germany.

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This paper was presented at AISTech 2013 — The Iron & Steel Technology Conference and Exposition, Pittsburgh, Pa., and published in the Conference Proceedings.