Chapter 4
Precision in Guidance of Farm Machinery

Hermann J. Heege

Abstract Georeferencing by GNSS has opened up possibilities for precise guidance of farm machinery along virtual lines in the fields. The guidance takes place either manually with the help of lightbar indications or in an automatic way. The driver concentrates on supervising the machinery.

In prior pass guidance, each run across the field follows the respective prior path offset by the operating width of the machine. Contrary to this, in fixed line guidance, the courses across the field are not defined by the respective prior path but instead solely by the first pass. Prior pass guidance is indispensable in irregularly shaped fields, whereas in rectangular fields fixed line guidance should be preferred.

On slopes, using more than one GNSS antenna allows to compensate for roll, pitch or yaw of the tractor. Downward drifting of implements on side slopes can be counteracted by passive- or active guidance corrections.

Keywords Automatic guidance • Fixed line guidance • Guidance on slopes • Lightbar indications • Pitch • Prior-pass guidance • Roll • Section control • Yaw

4.1 Principles of Guidance

Precision farming implies accurate guidance of farm machinery. The wider the width of operation is, the more difficult it is for the driver to navigate without inaccuracies between adjacent runs. Therefore, many farmers in Europe use **tramlines** in small cereals or rape (colza). These tramlines are created each year at the time of drilling by disengaging the respective seed metering rollers precisely there,

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Fig. 4.1 Tramlines in small cereals (From UK Agriculture 2013)

where during fertilizing and spraying operations the wheels of the machines go. This allows for a better aligning during in-season fertilizing and spraying, provided the operating width is an integer multiple of that of sowing. When tramlines cannot be used – as with cultivating, sowing or for all operations on permanent grasslands – either disc- or foam markers can assist in guiding the driver. With harvesting machines, mechanical feelers that slide along the still standing crop can control the guidance (Fig. 4.1).

Yet an accurate guidance for all field operations can be achieved on the basis of georeferencing by **global navigation satellite systems (GNSS)**. Via special computer programs, these systems make it possible to guide machinery precisely along **virtual tramlines** while respecting boundaries that result from headlands or grassed waterways even in irregularly shaped fields. The boundaries can be georeferenced in a prior, circuitous pass around the field. Once stored and mapped, they are available for several years.

The positioning information is provided either by differential GPS operating with carrier phase signals plus dual frequencies or by real-time kinematic differential GPS (Table 3.4). With manual- as well as with automatic steering, the start of the satellite based guidance is either along a prior pass- or along a fixed line.

With **prior pass guidance**, each run across the field follows the respective prior path offset by a given distance. Typically, this distance is the operating width of the machine. The driver starts by manually steering the machine just as usual on a first path – a so called guess row – along the field. This method is naturally used when the driver starts operating, *e.g.* along a waterway or along an irregular- or curved field boundary. Once the prior pass has been recorded, all other trips across the field follow on the basis of GNSS. The courses of all passes are georeferenced in order to get the following run. This method allows for adapting to field shapes. Yet limitations can arise because the following paths can end up with successively more bent curves.

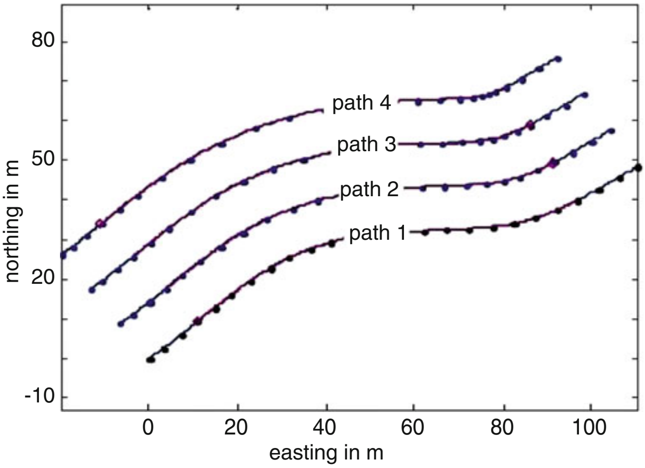


Fig. 4.2 Modification of the curvatures of subsequent implement paths. Note the change of curvature between path 1 and 4 on the *right side* of the graph (From Heraud and Lange 2009, altered)

The geometrical explanation for this is simple: a flexible horizontal strip that is bent laterally has a steeper curve on the concave side than on the convex side. The differences in the respective **radii of curvature** between the concave- and convex side increase with the width of the strip. Hence if in the field strip by strip are joined, the radii of curvature of the paths on the concave side get shorter and shorter (Fig. 4.2). Finally when the implement cannot follow the sharp bent curve any more, farmers either have to leave a gap between passes or add a short corrective strip.

Extreme effects of this are generally known when implements are used in a circuitous manner within a rectangular field with steep, rounded edges. This inevitably creates crescent-shaped gaps in the corners that are not treated by the machine.

Contrary to this, in **fixed line guidance**, the first path follows a smooth and mathematically predefined line, commonly called A-B line. In most cases this predefined pass is a straight line. Yet for fields that are center-pivot irrigated, it can be a circle. All additional trips are defined by a given offset distance – multiplied by an integer – from the first path. Again, the offset distance typically is the operating width of the implement. But contrary to prior pass guidance, the course of each line is – in a strict sense – independent of the respective preceding pass. Instead, it is only defined by the A-B line, the offset distance and the integer of the pass number. Therefore, errors between adjacent lines do not accumulate. Once the passes are recorded, they can rather precisely be followed again in subsequent operations even if these occur in later years. This would be possible with prior pass guidance as well, provided all passes are recorded, however, the errors resulting from curvature problems (see above) remain in this case.

From this follows that generally fixed line guidance should be the choice because it isolates errors. Topography and field shapes, however, often do not allow an exclusive use of fixed line guidance. The logical consequence of this situation is that prior pass guidance is restricted to fields or parts of them where fixed line

Fig. 4.3 Contour farming in a sloped field (From USDA NRCS 2013)

guidance is impossible. In many cases this means that one or a few passes in a circuitous pattern are necessary around a field and apart from that the main area inside these passes is handled in fixed line guidance. The number of headland turns can be minimized by choosing the longest field side respectively for the direction of the fixed lines.

In sloped regions with continental climate, often **contour farming** (Fig. 4.3) is essential since it substantially can reduce runoff of water, thus also can diminish soil erosion and improve water infiltration into the land. This implies guiding the machinery as far as possible along lines of similar elevation, hence straight paths hardly are possible and curved lines in most of the area must be dealt with. As long as the curvature is constant, this does not prevent the use of fixed line guidance. Yet when variations in curvature show up, prior pass guidance as outlined above is needed. All in all, guidance with contour farming is more complicated and often less precise.

4.2 Techniques of GNSS Based Guidance

Two main techniques are available, either the lightbar- or the automatic guidance system. The former often is also denoted as the manual guidance system.

Both techniques rely on GNSS signals for the indication of the cross-track errors. These are the deviations of the horizontal distance to the reference line, which can be the prior pass- or the fixed line as well as any offset line to it.

With the **lightbar guidance system**, the cross-track errors are indicated in a display by means of light emitting diodes (LEDs), which are arranged in a horizontal row (Fig. 4.4). The errors that occur from pass to pass depend on the guidance principle as well as on the driver because the steering is still manual. However, in

Fig. 4.4 Manual guiding assisted by lightbar indications (From John Deere & Co., altered)

combination with differential GPS on carrier phase signals and dual frequencies, the cross-track-error is on the average only 22 cm (Bombien 2005). And what is important when operating with modern present-day farm machinery: this average cross-track-error in **absolute values** does not depend on the working width, which is the case with conventional navigating. Compared to conventional manual steering without using GPS and with a working width of 6 m, the cross-track-error is halved. Based on a working width of 24 m, the cross-track-error is reduced to a quarter. And guidance at night is much facilitated.

An **automatic guidance system** (Fig. 4.5) is similar to a lightbar system except that now the signals that come from the computer algorithms do not induce the driver any more to steer, instead these signals go to electric- and hydraulic steering actuators. To engage the automatic system, the driver pushes a button. This allows the system to take control and hence to lead the vehicle along the closest guidance line. And manual control is simply resumed by turning the steering wheel.

In principle, automatic guidance systems can also be used for the headland turns. However, presently many farmers still use it only for the passes across the field and steer manually at the headlands. Hence most of the time, they are relieved from steering and can concentrate on supervising and adjusting the remote-controlled implements. Shortly before the machine arrives at the headlands, a sound reminds the driver. After having completed the manual turning, the driver again pushes the button for automatic control. With real time kinematic GPS, the **cross-track-error** is as low as 2–5 cm (Bombien 2005; Reckleben 2011). So compared to manual lightbar steering based on differential GPS with carrier phased signals plus dual frequencies, the cross-track error is reduced to about one sixth. In case conventional manual steering without any GPS and without tramlines is the basis of comparison, the cross-track-error for a working width of 6 or 24 m goes down to 1/12th and 1/24th respectively. Because again – contrary to conventional steering – the

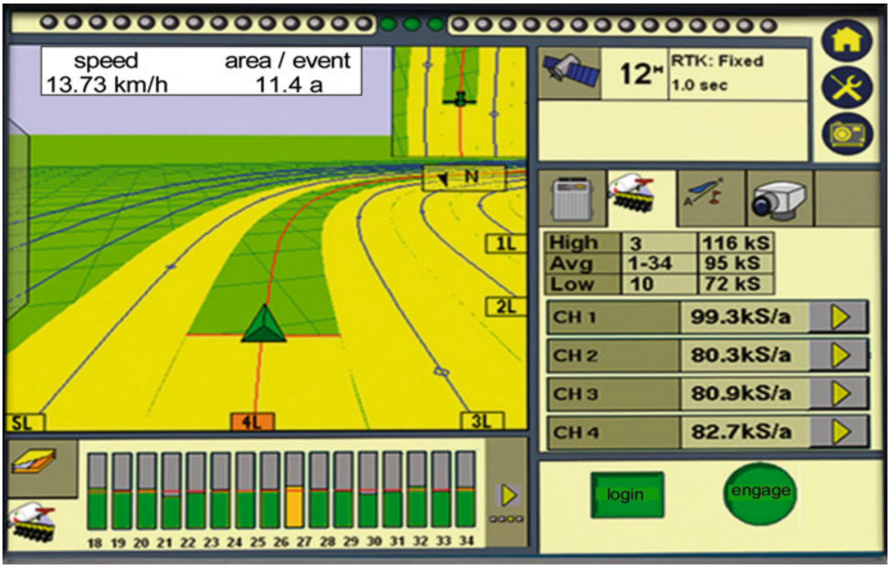


Fig. 4.5 Display of an user interface to an automatic guidance system. The lightbar (*top*) indicates cross-track errors. The signals from two different GNSS satellite systems can be used simultaneously in order to improve availability. Site-specific section control of implements (*e.g.* sprayer) is possible (Courtesy of Trimble Agric. Div., Westminster, USA, altered)

absolute accuracy of the GPS technology is independent of the working width (see above).

The basic components needed for manual lightbar- or automatic guidance are:

- a GPS receiver
- a user interface for displaying cross-track errors and for user input, *e.g.* the working-width or the location of the first guidance line
- algorithms for path-planning that compute cross-track errors relative to a guidance line.

In addition to these items, automatic guidance always requires to install

- an actuator for vehicle steering and a detector for manual override.

In hilly fields or when very precise guidance is needed, additional components for automatic guidance can be useful, *e.g.* components for terrain compensation (Sect. 4.4) and a steering angle sensor. The still dominant practice is to **retrofit** farm machines with the guidance components. For this, a hydraulically- or electrically driven servo-motor is connected to the steering wheel in the cab. Its friction roller runs against the rim of the steering wheel and thus turns it. In many cases, the retrofitted components including the actuator for steering and the manual override for it can be moved from one tractor to another. So one set of components can be used for guiding in successive farming operations with different machines.

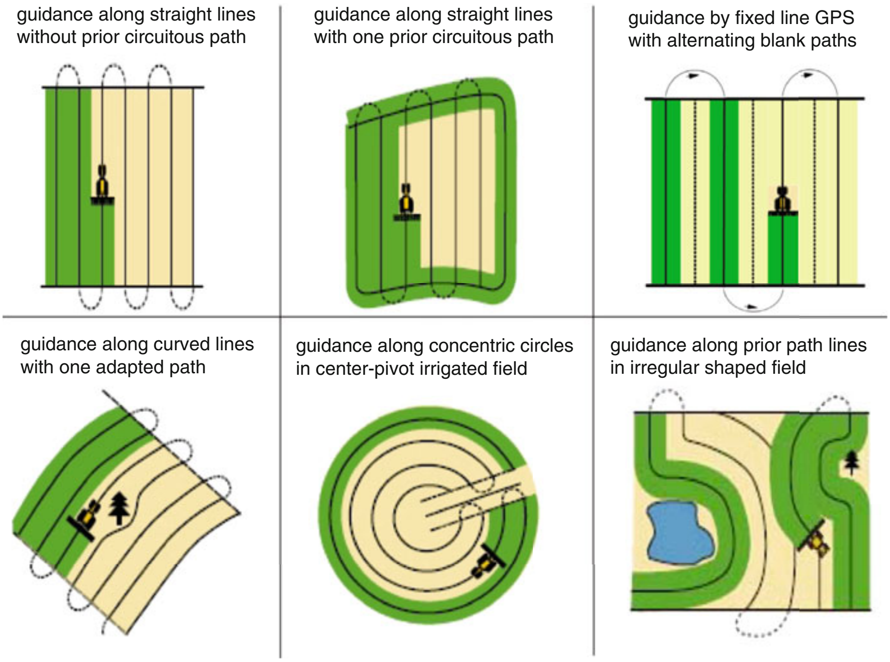


Fig. 4.6 Driving patterns (Courtesy of Agri Con GmbH, supplemented and altered)

However, the trend is from retrofitting of used machines to **factory-fitting** of new vehicles with the components that are needed. For this, the actuator for automatic guidance replaces the conventional hydraulic steering motor and thus does not operate in the drivers cab any more. Yet this makes it more difficult to use the same actuator on several vehicles. On the other hand, factory fitting saves much time by doing away with harnessing and bothering about technical details.

Efficiency and precision of field operations depend on the **driving pattern** that is used (Fig. 4.6). In rectangular fields, circuitous driving around and around parallel to all field boundaries should be avoided whenever possible. If this driving pattern is used without disengaging the implements, crescent-shaped gaps that are not dealt with are inevitable at the corners (see text near Fig. 4.2). On the other hand, when driving around is done in a dead end pattern with a turn at each corner, time is lost because of the high number of turns per unit area. The lowest number of turns in rectangular fields with dead end driving patterns is needed when driving is done parallel to the longest field side (Fig. 4.6, top). With many machines, this can be in the pattern of adjacent strips. However, sometimes this would require a back-up for every headland turn. This can be avoided by using fixed line GPS guidance and alternating between strips that are dealt with and left blank at first (Fig. 4.6, top right).

There can be obstacles in rectangular fields for driving up and down parallel to the longest field side. With some harvesting machines, it must be taken into account that unloading onto wagons on-the-go is possible only to one side. Consequently, with these machines driving up and down along adjacent strips is not possible. Yet this limitation does not apply to harvesting machines that temporarily store in tanks – like combines – or that load onto hitched wagons.

Driving along curved lines always is more complicated. But if the curvature is constant – as with the guidance along concentric circles of a center-pivot irrigated field – an automatic fixed line GPS guidance mode still is possible. With contour farming the situation can be different, the curvature can change. The same applies to irregular shaped fields (Fig. 4.6, bottom right). Modern guidance systems allow to switch between prior pass- and fixed line guidance as well as between automatic- and manual steering and hence to adapt to different field shapes that might be within a single farm or within the area of a contractor.

4.3 Economics of GNSS Based Guidance

The **investment** for guidance systems can vary considerably. A main factor for this is the respective investment for the georeferencing system (Table 3.4). Normally, manual lightbar guidance systems are not combined with real-time kinematic differential GPS. This is because typical drivers are not able to guide with an error that is below 10 cm on the average (Heraud and Lange 2009). Consequently, using a very accurate positioning system that is much more precise than this is not justified. Differential GPS that operates with carrier phase signals plus dual frequencies would suffice. Based on this, the investment for a manual lightbar guidance system can be around 10,000 Euros. On the other hand, automatic guidance systems can steer so precisely that the accuracy of real time kinematic differential GPS can be utilized fully. The investment for such an automatic guidance system based on RTK-GPS can be close to 40,000 Euros.

The ***costs*** from the investment should be offset by savings that result from more precise guidance. Theoretically, the basis for these savings could be the economical effects of fewer gaps between passes as well as of less overlapping of strips. In practice, however, savings of a result of fewer gaps between adjacent strips hardly occur. This is because farmers hate the visual impression that gaps make and therefore by and large prevent them by a narrower alignment of passes. A consequence is that instead of gaps more **overlapping** results. Therefore, an economical analysis can concentrate on the effects of less overlapping. These effects have an impact on either the costs of machinery plus labour or of the fertilizers and pesticides that are applied. Since overlapping reduces the capacity of the machinery plus the driver, it is appropriate to assess the overlapped area with the respective costs of the operations. Undue overlapping furthermore results in wasted fertilizer and pesticides, so these costs must be considered too.

The **relative overlapping** that occurs, when no GPS based guidance techniques are used, can be different. Bombien (2005) and Reckleben (2008 as well as 2011) calculated 8 % overlapping for operations, which are carried out without some visual aid for the driver such as cultivations or operations on grassland. When these operations were done either with the manual lightbar- or with the automatic GPS guidance method, the overlapping dropped to 4.4 % or to 0.96 % respectively.

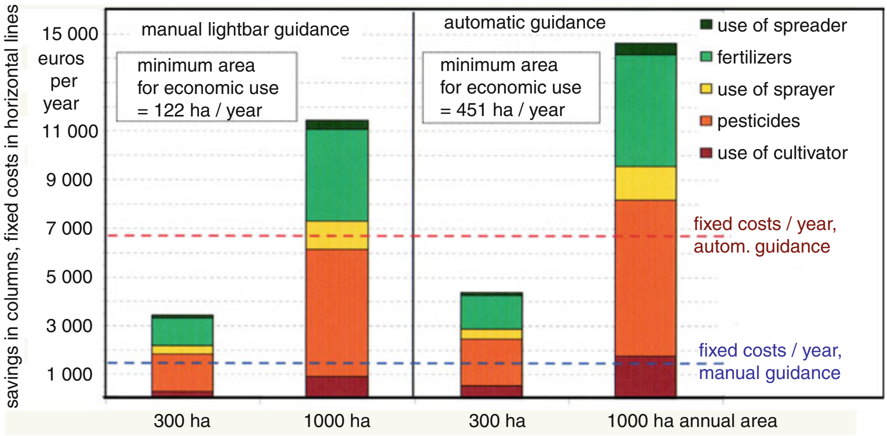


Fig. 4.7 The columns show savings with small grains that can be realized by the reduction of overlappings when using GPS guidance methods for soil cultivation, for spreading of fertilizers and for spraying of pesticides. The operational savings for the use of the cultivator, spreader and sprayer include saved labour costs. The savings for fertilizers and pesticides are based on costs of respectively 115 and 160 Euros/ha. Any savings for seeds would be small and are not included. The *dashed horizontal lines* represent fixed costs of the guidance systems. It is obvious that the savings can be much higher than the fixed costs (From Reckleben 2008, altered)

On the other hand, the overlapping without using GPS guidance was much lower – only 4.20 % – when fertilizing- and spraying operations were carried out in **tramlines**. This cross-track error of 4.20 % includes inaccuracies that occurred when the tramlines were generated during sowing. However, the errors that result from inaccuracies in the course of tramlines often have a multiple effect. Because the tramlines are used several times during a growing period for spreading agrochemicals. Furthermore, also this error of 4.20 % was still significantly reduced when GPS guidance methods were used for all operations. With the manual lightbar method and carrier phase signals plus dual frequencies, the overlapping dropped to 0.92 %. And when the automatic guidance with RTK-GPS was used, it went down to 0.10 % (Bombien 2005; Reckleben 2008, 2011). For the respective cross-track errors in absolute- instead of relative data see Sect. 4.2.

The **savings** from less overlapping shown in Fig. 4.7 refer to operations for small grains in Germany. Those for fertilizing and spraying are based on driving in tramlines. The main savings come from reduced expenses for fertilizers and for pesticides and not from the improved use of the capacity of the machines (Fig. 4.7). Consequently, the savings will increase with the yield of crops and the respective use of agrochemicals. Any savings in expenses for seeds would be small and are not included. Yet apart from this, it is obvious that the savings from less overlapping can be much higher than the fixed costs from GPS guidance.

The general situation is that the manual lightbar system suits to medium sized farms and the automatic system to larger farms. Yet special possibilities that are associated with the precision of automatic guidance based on RTK-GPS and the repeatability of the same tracks after long time periods can be important too, *e.g.*:

- no-till sowing into the inter-row strips of the previons crop
- strip-tilling in autumn and sowing into the strips in spring
- hoeing up to a distance of 3 cm from plant rows
- applying chemicals in narrow bands precisely between narrow rows of plants
- precise operations for expensive crops as *e.g.* potatoes, beets, vegetables, asparagus *etc*.

Hence it may be that not only the use in traditional farming, but in addition such special fields of application will define the potential for modern guidance techniques in the future.

4.4 Problems and Solutions on Slopes

4.4.1 Tractors and Self-Propelled Implements

The techniques that were dealt with above work well on flat land. Yet a large portion of the global agricultural area is sloped. This makes precise guidance more difficult. Whenever soil erosion on sloped land is a problem, contour farming is essential as a corrective, even if this implies guiding along curved lines and inaccuracies that are associated with this (Sect. 4.1). However, this is not the only problem with guiding on slopes.

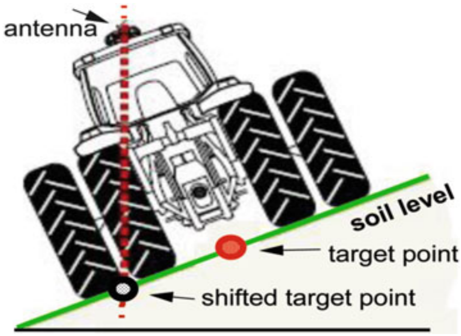
Generally, the GPS receiving antenna is installed on the roof of the tractor. So this is the location for which positions are received. On the one hand, the position on the roof allows rather unobstructed access to signals from the satellites. Yet on the other hand, this location is some distance above the point, at which the implements for most farm operations work.

In flat land, this vertical distance from the antenna to the control point on the soil is no problem. But on slopes, this distance results in additional errors of georeferencing (Fig. 4.8). When the antenna has a height of 3 m above the soil, 1° of side slope causes a lateral deviation from the target point on the soil surface of 5.2 cm. The deviation increases proportionally to the trigonometric tangent with the degrees of side slope. With a moderate slope gradient of 10°, the deviation is 52.1 cm. This is not trivial any more. Control algorithms that are based on the sensed slope have to correct this error.

Contour farming implies that the driving occurs as much as possible along lines of approximately the same elevation. With this driving pattern, therefore, the machines are mainly tilted sideways to the direction of travel. This side slope – often denoted as **roll** – is the main problem for which target point corrections are needed.

In a maritime climate and its drizzling rain, soil erosion is much less a problem and hence driving on the contour not essential. But if instead of contour farming

Fig. 4.8 Shifting of the target point on side slope



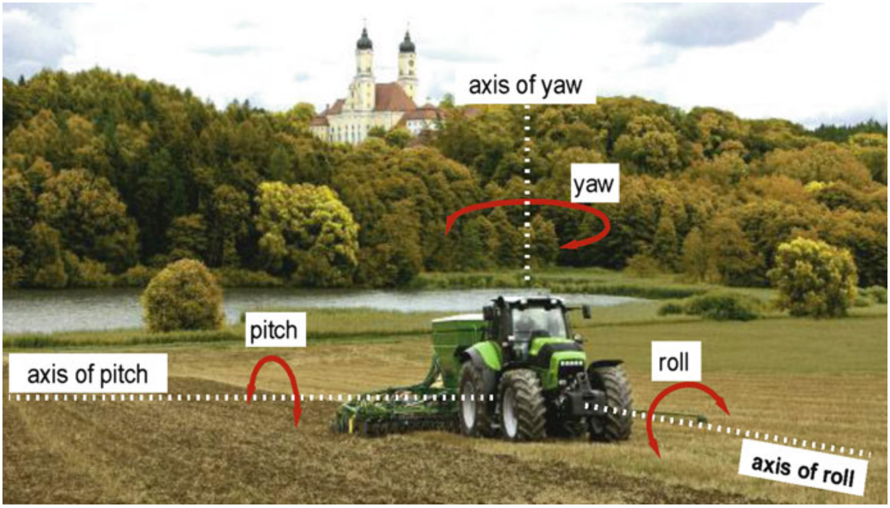


Fig. 4.9 The three-dimensional position of a tractor on a slope depends on topography and heading. Topography defines the roll angle (side slope angle) and the pitch angle (down slope angle). Heading depends on the guidance and is defined by the yaw angle, which is the deviation between the path- and the tractor direction. This yaw angle may be close to zero on flat land, but along side slopes it may be not because the tractor crabs along the slope

fixed line guidance along straight paths is practiced, the slope directions – side slope or down slope – can vary. As a result, not only roll (side slope), but **pitch** (down slope) and yaw of the tractor as well may need attention (Fig. 4.9). **Yaw** is the heading error of the tractor that may result from crabbing and slipping, especially on side hills. Because of this, a deviation between the direction of the planned path and the heading position of the tractor can exist.

Roll, pitch and yaw can be measured via GPS in order to adapt the guidance. In case mainly the effects of **roll** are a problem – as with contour farming (Fig. 4.8) – the remedy is rather simple. If two antennas are mounted on the roof – one on the left side and the other one on the right side of the driving direction – the roll can be indicated via their relative height. And by simple trigonometric calculations concerning the target point, the path can be corrected. The **yaw** of the tractor can be obtained via the relative forward positions of these two antennas. Finally, if three antennas are used – with the third antenna mounted in front of the other two – it is possible to indicate **pitch**. Adapting the steering control to the positional data requires suitable algorithms (Heraud and Lange 2009). Yet correcting the guidance on slopes on the basis of several antennas is state of the art.

The use of GNSS guidance sometimes is supplemented by signals from **inertial sensors**. These inertial sensors measure either linear- or rotational accelerations and hence can also indicate changes in positions of vehicles (Yazdi et al. 1998). They are very tiny devices and used in huge quantities for a variety of applications, *e.g.* in automobiles for airbag employment and for dynamic stability control. When used adequately, these inertial sensors can measure translations as well as rotations in three spatial dimensions, hence with six degrees of freedom along and around the axes of roll, pitch and yaw.

Despite these abilities and their low cost, normally inertial sensors are not used to completely replace guidance by GNSS. Instead there are commercial solutions that rely on several GPS antennas plus inertial sensors for terrain compensation.

Because inherently, inertial sensors are not able to steer precisely for a long time period along fixed lines, let alone to guide along paths that were used months or years ago. This inability of inertial sensors results from the operating principle: they rely totally on **motion memory**. Their basis is that when a vehicle starts from a known position and then moves in a known direction for a known time, the final position is known. But this motion memory inherently includes the accumulation of errors along its path, often denoted as drift. Whereas with GNSS guidance, the errors that arise are corrected – constantly and automatically – by new signals that are received from satellites and base stations, with inertial sensors this does not occur. The present recommendation therefore is to use the signals from inertial sensors not primarily for controlling the **heading** or the **yaw** of vehicles, for which properly used GPS signals are superior.

The situation is different when it comes to controlling the effects of the **attitude** that are defined by roll and pitch. These attitude errors hardly can accumulate, since they do not occur in the direction of the path or of the heading of the tractor. Hence in controlling the effects of roll and pitch there is a choice: this could be on the basis of either additional GPS antennas or of inertial sensors. Li et al. (2009) as well as Kellar et al. (2008) got about the same accuracies in guidance of vehicles when either using GPS with multiple antennas or – as an alternative – employing inertial sensors for the control of roll and pitch in combination with a single antenna GPS for the control of yaw. They mention that the expenses for the latter alternative are lower.

However – even for the same positional dimension – there are reasons for combining GPS receivers and inertial sensors. GPS indications that are received have a rather long-term stability, but its signals can be unavailable or blocked by trees, buildings or a mask angle (Sect. 3.7). If both systems are combined for a fused navigation control, it is possible to bridge short-term disruptions of GPS signals by a control via inertial sensing.

4.4.2 Drawn- and Mounted Implements

The implement is the actual device doing the field work. But on a side-slope, it is possible for the tractor to follow the desired line, but have the implement widely off the path. This results mainly from side forces that act on the implement and drag it downhill. And crabbing of the tractor along a side-slope can have an effect too. The downhill drift on the implement occurs with towed machines as well as with those that are mounted on the three-point-hitch of the tractor. However, towed implements are particularly susceptible.

Corrections for this downhill drift can be made based on GPS signals from an antenna that is located on the implement itself. However, relying solely on signals that come from the implement without having an antenna on the tractor is not recommended. The reason for this is that then the driver would have to spend much effort for keeping the heading of the tractor in the vicinity of the path. Hence the signals from the GPS-implement-antenna are used in combination with the respective signals for the tractor.

The systems for correcting the downhill drift rely on either passive- or active steering of the implement. **Passive guidance** corrections of the implement are based on compensations via the heading of the tractor by steering somewhat away from the path in order to make up for the drift of the implement. Instead, a**ctive guidance** corrections are made by steering devices on the implement itself. The result is that with active guidance both the tractor and the implement follow the desired path, whereas with passive steering this holds only for the implement, while the tractor is on a line that is slightly offset (Fig. 4.10).

This offset-position of the tractor can be a problem on steeper slopes, which cause more offset-distance. This can make driving and operating in inter-row strips impossible, *e.g.* of potatoes, beets, vegetables and maize. Active guidance does away with these problems, but in return requires steering tools on the implement. These steering tools vary as much as the implements do. Common devices used for this are

- steerable tires
- laterally movable hitches
- steerable frames
- steerable coulters (Fig. 4.11).

The assumption that implements on a **three point hitch** do not drift downwards does not hold well. The position of these implements is approximately parallel to the rear axle of the tractor. This means that the implement "tails out" when the attitude of the tractor changes. Tractors tend to a crab-attitude with a corresponding

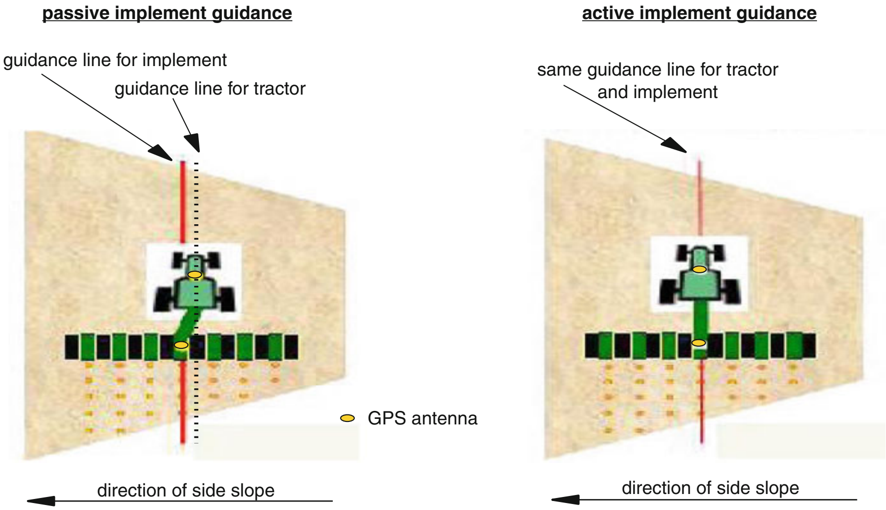


Fig. 4.10 Passive- and active guidance of towed implement by GPS (From Deere & Co., altered)

Fig. 4.11 Active guidance of a seeding machine on a side-slope. The GPS antenna on the roof of the tractor is hidden (From Orthman Mfg.Co., altered)

yaw angle in the direction of travel (Fig. 4.9) on side-slopes. The yaw angle varies with the side-slope, and hence with it the position of the implement. Active implement guidance that relies on GPS can prevent this uncontrolled "**tailing out**". This is achieved by GPS controlled lengthening or shortening of the respective lower arm of the three point linkage. Furthermore, devices as listed above sometimes are used for implements on three point hitches as well.

In short, solutions for precise guidance on slopes exist. The most important decision on slopes is about the best driving pattern and its effect on soil erosion.

4.5 Precision in Section Control of Farm Machines

The operating width of present day farm machines and irregular field shapes causes situations where overlapping cannot be avoided. But if overlapping of machinery parts cannot be prevented, twice sowing, -fertilizing and -spraying the same area should not take place. It results in waste of seeds as well as of agrochemicals and reduces yields. Section control of farm machines avoids these disadvantages.

Basis of modern section control is that all field boundaries, previously treated areas, not cultivated regions and grassed waterways within fields are georeferenced. This prerequisite holds for all automatic guidance systems that rely on GPS. The sections refer to either **single units** of the respective machinery – *i.e.* planter units, nozzles on the sprayer boom and outlets of pneumatic spreaders – or alternatively to **several units** respectively that are grouped together. Each section has an actuating- and control device that permits switching on and off by a central controller, which has the field data and communicates with the GPS receiver. When properly used, these automatic techniques allow for precisions in irregular fields as outlined and shown in Fig. 4.12.

An economical use of section control techniques calls for frequent applications in irregularly shaped fields. The savings in seeds and agrochemicals can be as much as 25 % in very oddly-shaped fields and be almost zero in rectangular land (Stombaugh et al. 2009).

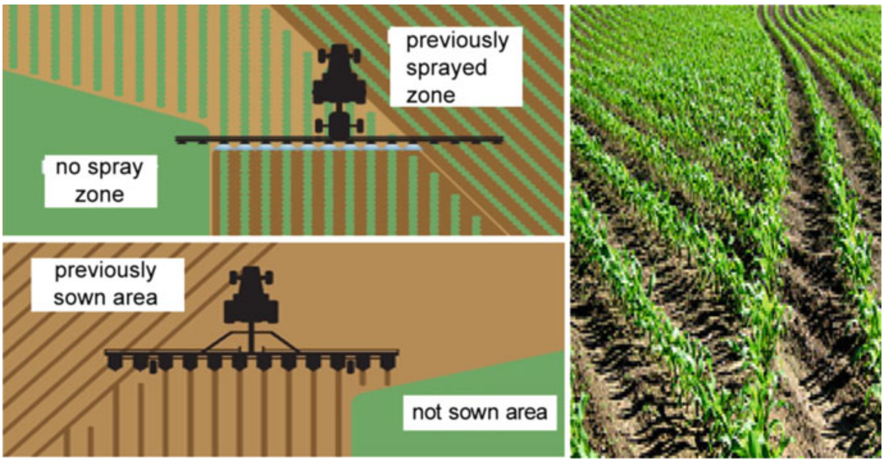


Fig. 4.12 Schematics of section control for sowing and spraying in irregular fields (*left*, from Raven Industries Inc., altered) and a result with maize (*right*, from John Deere & Co.)

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