CIGR - International Conference of Agricultural Engineering
XXXVII Congresso Brasileiro de Engenharia Agrícola

Brazil, August 31 to September 4, 2008

COVERAGE PATH PLANNING FOR FIELD OPERATIONS WITH SERVICE SCHEDULING

TIMO OKSANEN[1]; ARTO VISALA[2]

[1] Researcher, D.Sc. (tech), Helsinki Univ. of Technology (TKK), Automation and Systems technology, timo.oksanen@tkk.fi
[2] Professor, D.Sc. (tech), Helsinki Univ. of Technology (TKK), Automation and Systems technology, arto.visala@tkk.fi

Presented at
CIGR INTERNATIONAL CONFERENCE OF AGRICULTURAL ENGINEERING
XXXVII CONGRESSO BRASILEIRO DE ENGENHARIA AGRÍCOLA – CONBEA 2008
Brazil, August 31 to September 4, 2008

ABSTRACT: If the shape of field plot is not rectangular and if it contains obstacles, the coverage path planning problem is hard to solve for a non-omnidirectional machine. Scientists have developed several algorithms to solve this coverage path planning problem, but all of them have pros and cons. If the machines were omnidirectional and turning times were decreased to insignificant, the problem would be quite easy to solve using known robotic path planning methods. Servicing (refilling or emptying) is integrated to the algorithm. This algorithm is designed for real-time usage and it solves the problem recursively: the operated area is removed from the field and the algorithm is repeated until the whole field plot is completed. In this paper the focus is on servicing add-on to the algorithm. In servicing subalgorithm it is first detected through simulation when servicing is required. When the servicing is required, the subalgorithm finds best possible phase to make servicing. Generally, the algorithm tries to minimize the distance from ends of operational swaths to the service points. The results of this algorithm together with earlier developed coverage path planning algorithm are sensible.
KEYWORDS: coverage path planning, agricultural machines, field operations, service scheduling

INTRODUCTION: There is no perfect algorithm to solve coverage path planning problem for agricultural machines in agricultural fields. Attempts to develop such has been made by e.g. STOLL (2003), SORENSEN et al. (2004), BOCHTIS et. al. (2006), OKSANEN et al. (2006 & 2007), RYERSON et al (2006) and JIN et al. (2006).

A predictive recursive online approach to solve coverage path planning problem was developed by authors (Oksanen et al. 2007). In that algorithm the point-of-view is machine and all possible routes over certain future horizon under constraints are simulated, the best is selected and this is repeated after every swath and until the whole field is operated.

Refilling or emptying is a crucial part of field operations. Seed drills, fertilizer spreaders, sprayers, dung and sludge spreaders, lime spreaders and several other implements spread various input materials into the field and usually tanks of those implements have to be refilled during the operation. Combine harvesters, forage harvesters and other crop harvesting machines collect the harvest and those machines empty their tanks usually to some trailer or truck in the field (BUSATO et al. 2007).

In this paper the algorithm presented in (Oksanen et al. 2007) is extended to support refilling or emptying (=generally servicing). The service points are considered stationary and there may be more than one, either inside or outside of field. Crucial thing in service planning in online path planning algorithm is the distance from ends of operational swaths to the service points and this has to be minimized somehow.

The refilling or emptying rate depends on the rate and tank size of machines. For sprayers the refilling rate may be 15 hectares and for combine harvesters it may be 0.5 hectares. In this paper, automatic planning of servicing during the operation with the following subalgorithm is presented. It is assumed that the application rate / yield is known, the application rate may be variable within the field, but yield is assumed to be constant as it can be measured only after the operation has been applied (harvested) in a certain position, and it may be hard to predict. However, if the prediction method is available, variable yield can also be handled with this algorithm.

METHODOLOGY: The service support to the original path planning algorithm is presented through an example. Let's take one generated route at a time. A schematic diagram in a case of three segments is presented in Figure 1. The vehicle is currently at state S. The swaths to be operated are A_1–A_2 , B_1–B_2 , C_1–C_2 and the route always includes the return to the first point. As without servicing, the time, working distance and turning distance are calculated through simulation for this scenario. Shown route is only one of the possible next routes in the coverage path planning algorithm.

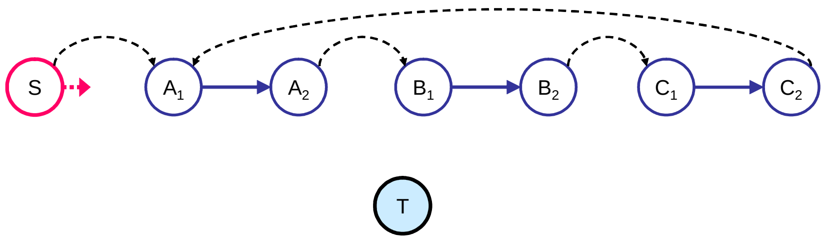

FIGURE 1. Tanking scenario

Now the tank fillment level is also simulated. At the current state, there is also a variable for tank fillment level. The tank fillment level is simulated over the generated route. If in the simulation it is noticed that the tank reaches the critical level (either in harvesting the tank is full, or in spreading the tank is empty), the following procedure is applied. Otherwise, if no critical level is reached, the coverage path planning algorithm works as normal, just the tank fillment level is simulated over the action. But if the tank reaches the critical level, then the segment in which it happens is searched. In the example the service point is marked with T. In this example, the new generated routes would be (S-T-A_1-A_2-B_1-B_2-C_1-C_2-A_1), (S-A_1-A_2-T-B_1-B_2-C_1-C_2-A_1) and (S-A_1-A_2-B_1-B_2-T-C_1-C_2-A_1). After this modification of routes, the route is resimulated and checked if it requires another service (this is a very rare situation). If service was needed, the same procedure would be applied to the generated route with already servicing, but the new services would be simulated only after the first service. After these modifications of generated routes, it is guaranteed that in every generated route the operation can be performed safely. After the selection phase, the service is performed if the servicing is scheduled before the first segment, otherwise the first segment is applied as usual and no servicing is performed in that step.

So for every generated route:

1. simulate the degree of filling of the tank (integrate over application rate map),
2. if the tank is empty or full after simulation, service is needed:
    a. find the route segment in which zero crossing happens,
    b. replace the original route with all such routes that cover the same segments and include the visit to the service point before the zero crossing happens,
    c. check if another service is needed.

In the simulation phase, three parameters are needed: application rate, tank capacity and safety margin (measurement or prediction errors).
If multiple service points exist (in large fields this may be practical), in the replacement phase, the quickest visit to the service point is selected in every case (T is replaced with $T_1 ... T_N$). Non-stationary service points, such as tractor-trailers moving alongside a combine harvester, are not supported in this algorithm. However, the slowly moving service points are supported. The condition is that the service point must be stationary over the prediction horizon, they may move during the swath and the movement should be predictable.

RESULTS AND DISCUSSION: The refilling or emptying of the tank of the machine was included in the algorithm. In the following examples, the functionality of the approach is shown.

In the first example, in Figure 2 left, the field is square. The field is 200 m x 200 m, so the area is 4 ha, the machine tank capacity is 400 and the spreading rate is 500 ha^{-1}. The physical unit for tank capacity may be liters or kilograms, but here only the ratio of spreading rate and tank capacity matters. The service point is marked with T, and, in this example, is located "outside" of the field on purpose in order to clarify the visualization. The starting point is at the edge of the field. The center lines of operational swaths are drawn in blue, normal turning trajectories with magenta and visits to the service point are represented with bold black lines. As it can be seen, the solution is reasonable. No trip to the service point is made from the far edge. Six services were completed, and the tank was full at the start.

As described in the algorithm above, it is possible to handle multiple service points as far as they are stationary. The field is the same as in the previous example, but now there are two service points, in two opposite corners, see Figure 2 middle. The route is automatically organized so that the nearest service point is used each time; six services were also needed in this example.

The number of services depends partly on the location(s) of service point(s). If the service points are available so that, when the service is required, the tank level is so low (or high) that it is not anymore possible to operate any of the possible segments, the number of services needed should decrease or remain the same. In Figure 2 right, four service points are supplied, and, in practice, there is always the possibility of making a visit to service point at the end of every swath. In this case, the number of services needed is only five, compared to the six in the previous two examples.

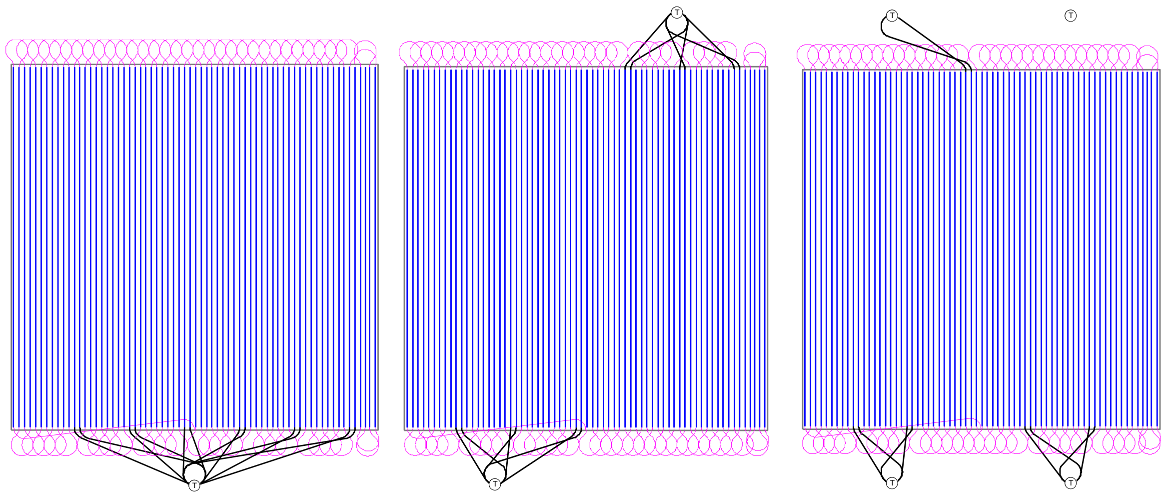

FIGURE 2. Results for square field (at left 1 service points (sp), at middle 2 sp, at right 4 sp)

Another example is shown in Figure 3. The purpose of this example is to demonstrate that servicing also changes the route compared to solution where no service is needed. The color of swaths indicates the order of operation: blue is the first and red the last. If no service was needed, the route would mainly follow the top edge of the field. However, in this case after eight swaths along the top edge the algorithm "sees" that the service is needed and the best way to make it is to change the driving direction so that it first drives the line parallel to the left edge of the field (in order to get near to the service point without useless driving), then makes the service and returns along the left edge back to the longest edge (top) and continues. First two services are made using this strategy, and in the third time it is more efficient to drive the tank all empty along the top edge and after that directly go to service point. In its entirety the solution is very nice and reasonable.

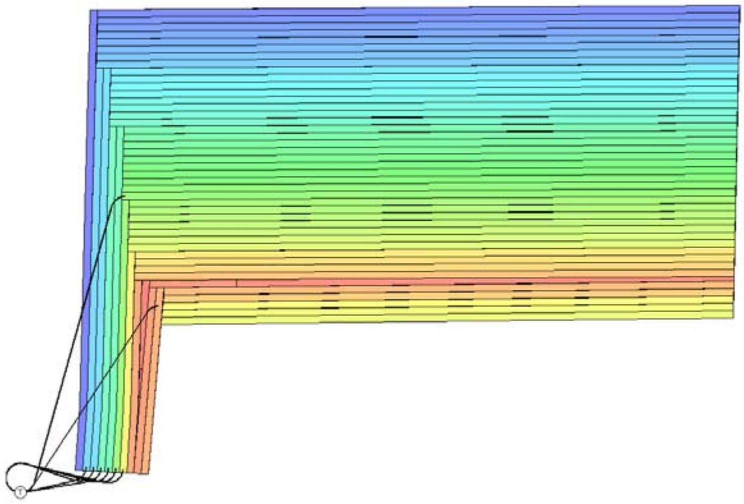

FIGURE 3. L-shaped field with servicing

CONCLUSION: The refilling or emptying (servicing) subalgorithm presented in this paper, used together with coverage path planning algorithm presented earlier by authors, seems to work well; its behavior is similar to common practice. One problematic situation where this algorithm is not leading to an optimal solution is when the field has a long edge and the service point is in the middle of the longest edge. In this algorithm, the service is always made at the end of the segment, and this leads to some unnecessary driving.

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