A Load Balancing Surveillance Algorithm For Multifunctional Radar Resource Management

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For all multifunctional radar systems the allocation of resources plays an outstanding role. Many radars have low priority on surveillance tasks. In challenging situations this leads to neglecting of surveillance beams in directions where many other tasks are done. This document presents a technique that enables multifunctional radar systems to keep on scanning overloaded surveillance sectors under the condition that all sectors have a similar revisit time. Since radar resource management depends on the used system, two general configurations are considered in this paper. The focus lies on systems with a rotating antenna.

1 Introduction

Multifunctional radar systems (MFR) offer many opportunities to adapt to the scene. This leads to the challenging task of dynamically allocating resources for different tasks such as surveillance, tracking, classification or imaging in changing environments. Due to the growing demands modern radar systems have in directions where many other tasks are done. This document presents a technique that enables multifunctional radar systems to keep on scanning overloaded surveillance sectors under the condition that all sectors have a similar revisit time. Since radar resource management depends on the used system, two general configurations are considered in this paper. The focus lies on systems with a rotating antenna.

The remainder of the paper is organised as follows. In section 2 the problem is defined for the case that the available resources are known apriori. Afterwards in section 3 the NP-hardness of the problem is shown. Section 4 describes the algorithm and in section 5 the results are presented and compared to an optimal solution. In section 6 the assumptions on the problem are relaxed. Section 7 concludes the paper and gives an outlook on future work.
where the last element gives the main sector at execution time by \( m(i\Delta t) \). The components of a Task \( T \) are referenced by \( T_1, T_2, T_3 \). The set
\[
T_i := \{T | T_3 \leq i\}
\]
contains all tasks executed within \( t \), i.e. \( \lfloor \frac{t}{\Delta t} \rfloor \leq i \). This leads to the following optimisation problem:

minimise \( t \)
subject to
\[
\forall L \in \mathcal{L}, \exists T \in T_i: T_1 = L,
\]
\[
\forall T \in T_i : m(T_3 \Delta t) \in F_{T_i},
\]
\[
\sum_{T \in T_i \setminus T_{i-1}} T_2 < R_{m(i\Delta t)} \quad \forall i \in \mathbb{N} \text{ with } i \Delta t < t.
\]

The first condition enforces that no direction in \( \mathcal{L} \) is neglected. The second condition enforces for all tasks to be executed within the field of view. The third condition incorporates the resource restrictions for every sector. The term \( T \in T_i \setminus T_{i-1} \) means that only tasks that are executed within the same rotation are considered. The calculation of the current main sector \( m(T_3 \Delta t) \) depends on the time stamp of execution of the task \( T \).

Since the focus is set to rotating antennas, this optimisation problem can be read as minimising the number of rotations that are necessary to update all surveillance beam pointing directions. It is important to see that the available resources per sector are decoupled from the mechanical rotation time since \( \Delta t \) only gives a physical upper bound for the available time. Another option is to adapt the rotation rate in a next step. Relaxing the fixed resources per sector is done in a later section. In the next section the NP-hardness of this problem will be proven.

### 3 NP-Hardness

The NP-hardness of Problem (5) follows easily from a reduction to the bin packing problem [10]. To solve bin packing with (5) the field of view can be set to \( N \) such that any task can be executed on any sector. Additionally only results for \( t < \Delta t N \) are accepted. This leads to

minimise \( t \)
subject to
\[
\forall L \in \mathcal{L}, \exists T \in T_{N\Delta t}: T_1 = L,
\]
\[
0 \leq i < N : \sum_{T \in T_i} T_2 \leq R_i.
\]

This is already the bin packing problem.
This fraction is the absolute time demand to update all resource distribution per sector

\[ r_{opt} := \frac{\sum_{d \in D_P} d}{\sum_i R_i} \]  

(7)

This fraction is the absolute time demand to update all surveillance directions in relation to the total resources available per rotation. \( r_{opt} \) can be used to get the optimal resource distribution per sector

\[ r_{i, opt} := r_{opt} R_i \]  

(8)

Figure 2: This example shows on the left how the different sectors are occupied, where the stacked elements indicate the durations of each surveillance update. On the right the occupancy after equalisation in comparison to the given resources is depicted.

4 Algorithm description

Since the problem is NP-hard a simplified solution is presented. This is based on a greedy design and starts with a continuous calculation which makes the problem easy to solve because any portion of a task would be executable. In the next step the continuous solution is rounded off to a discrete guess. Therefore define the continuous optimal criteria:

\[ r_{opt} := \frac{\sum_{d \in D_P} d}{\sum_i R_i} \]  

(7)

This fraction is the absolute time demand to update all surveillance directions in relation to the total resources available per rotation. \( r_{opt} \) can be used to get the optimal resource distribution per sector

\[ r_{i, opt} := r_{opt} R_i \]  

(8)

Algorithm 1 generates a mapping from every sector to the beam pointing directions or rather their time demand. Figure 2 shows an example input and output of the algorithm. On the left side the update durations and their sector membership by position are shown. On the right side the available resources per rotation, and the equalised solution against the trivial solution which is just executing the task on broadside are drawn. In sector 5 one can see the advantage in this equalisation effect.

In words the algorithm chooses a maximal subset of \( L \) for every sector for which the resource allocation is lower than the optimal value \( r_{i, opt} \). Maximal in this case means that there is no task in the given set of tasks that can be added without exceeding the threshold. So the set \( P \subset \tilde{L} \subset L \) is maximal in relation to the set \( \tilde{L} \) on sector \( i \) iff:

\[ \sum_{d \in D_P} d > r_{i, opt}, \quad \forall d' \in D_{\tilde{L} \setminus P} \]  

(9)

and

\[ \sum_{d \in D_P} d \leq r_{i, opt} \]  

(10)

After that is done for all sectors there usually will be some unassociated tasks. They are associated to that sectors, where the violation of the threshold \( r_{i, opt} \) is minimal in a relative manner.

The set \( E \) is a storage for all executed tasks. The reference \( r_{i, opt} \) is used to decide how much load a sector should handle.
The partition produced by the algorithm now defines what surveillance tasks have to be executed depending on the current main sector. At this point the rotation rate is considered which is not used to generate the scheme itself. The decision which task will be executed next within the main sector, is then done by comparing the time of last illumination, for all $L \in B_i$.

5 Results

To test the proposed algorithm, a random input is generated. The results are compared to the resource distribution without equilibration and to the optimal solution $r_{opt}$.

Figure 3 shows an example input with 30 sectors and a field of view of 11 sectors ($n = 5$) which is about 130°. This is a realistic standard scenario for many cases. The upper shows the update directions and their durations. The lower shows the available resources per sector. The output is shown in Figure 4 where the upper shows which tasks are executed within their sector and which were used for equalisation. In sector 30 all own tasks are executed by other sectors such that only tasks from neighbouring sectors are left. The reason for this is that the equalisation spreads the resources on all sectors such that there is no task left in FOV for this sector to associate. An additional shifting step would be necessary to overcome this problem. Since this is an underload case, the worst case revisit time is not directly increased. The overall performance and the optimal continuous solution are similar, which can be seen in the lower graph of Figure 4. This relative load can be read as the number of rotations needed to completely update $L$. In this case it is about 2.3 rotations since the worst case sector is decisive. If the rotation rate is adjustable it can be decreased to match a lower worst case value or increased to match a higher worst case value.

If this is not possible the SNR guarantee in every update step can be increased by decreasing the field of view. Figure 5 shows the same experiment as before but with a field of view of 3 sectors ($n = 1$) which is about 36°. As expected the resulting performance decreases a bit. The advantage is, that the steering losses decrease as well. This leads to a simple method in either adapting the rotation rate to the available performances or adapting the usage of the resources to the rotation rate.

6 Algorithm with other scheduling requirements

In many cases the radar resource management does the resource allocation for the surveillance tasks dynamically. This contradicts to the assumption that this is an input parameter for the algorithm. For dynamic allocation, as it is done for instance by a priority-based scheduler [6], the allocation is measured over time. Under the assumption that the allocation does not change drastically the result of the proposed algorithm still can give a usable scheme. The disadvantage is that it depends on the worst guess. If for a sector the available resource was estimated two times the actual available resource the revisit time will be approximately two times worse than estimated. An additional online algorithm for fast adaptation will be presented in the future.

7 Conclusion and further work

In this paper a simple surveillance algorithm for multifunctional radar systems that equalises the revisit time of surveillance tasks for all beam pointing directions is presented. The goal was to decouple resources and their corresponding revisit times per sector. To achieve this, a sector which has resources above the average, can support other sectors that are occupied with other tasks such as track updates or classification measurements. An additional advantage is the fast computability due to greedy approaches. An easy adaptation to existing scheduling schemes is possible such that even existing radar systems could be upgraded.

In the future the adaptation due to sudden and drastic
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These graphs represent the result of the algorithm for the input shown in Figure 3. The upper shows the result after equalisation. The portion of tasks that are executed on broadside are compared to those tasks that are executed away from broadside. The lower shows the attained relative load on each sector.

Figure 5: These graphics show the result for the same experiment as in Figure 3, but with a field of view defined by $n = 1$. Changes in the environment will be improved. This may be done by intelligent sorting of the update tasks within each sector. It was mentioned that the rotation rate can be adapted to the dynamic surveillance scheme. In a next step a realistic optimising condition for this will be investigated as well. Additionally a comparison to earliest deadline first will be conducted.

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