MULTI-RADAR SYSTEM DATABASE INTEGRATION USING METRIZED SMALL WORLD TECHNOLOGY

Dmitry Ponomarev, Vladimir Krylov, Yuri Pankratov
MeraLabs, LLC
Nizhny Novgorod, Russia
info@meralabs.com

***Abstract* — the present article describes the possibility of integrating the data from several radars with shared radiolocation areas in order to acquire precise information about the targets by means of analyzing the events in neighboring spatiotemporal resolution elements. The paper suggests an algorithm for integrating the data based on creating the graph which possesses the characteristics of the "Metrized Small World". A possibility of processing the integrated data in real time is analyzed. The article describes efficient metrics for integrating multi-radar data into a single Metrized Small World graph. Examples of such algorithms are given.**

keywords: multi-radar system, data fusion, database, small world, metrics

Introduction

Fusion of information coming from several radars with shared scanning areas can often significantly increase the efficiency of such an integrated system. By obtaining target signatures from different aspect angles, in different spectral bands and with different types of polarization, we can provide for their joint processing to solve the problems of detecting, classifying and measuring the target's parameters with precision unachievable for any of the radars separately.

The synergetic effect achieved with the help of such approach may even exceed the capacity of upgrading any of the radars used in the system, or, at least, this method provides for substantial reduction of costs required to achieve the same system performance as compared with other approaches. The traditional way of fusing data coming from several radars is the transfer of information from the secondary processing systems of each of the radars into a shared database [1]. The analysis typically uses data related to each of the selected radar's targets. Finding such data requires composition of series of queries to the database and that can often be quite a challenging task, especially in cases of multiple spatially distributed targets.

A significantly greater effect on the joint multi-radar data processing can be achieved if the data is processed as soon as it is received from the radar instead of integrating the data after secondary processing. However in such a case it is necessary to amalgamate all the information on each spatial resolution unit for each radar into one database. The transmission of such amounts of information into a single information processing and decision-making system is difficult and often impossible to implement due to limitation on bandwidth and time available to make a decision. On the other hand, contemporary technologies make it possible to store the information separately on each of the radars. It brings about the problem of collecting and processing the data distributed among the radars, efficiently using a limited bandwidth network that connects them.

Background

The problem of integrating the data which is stored on different spatially scattered computers is solved in different ways; each of these ways has its own advantages and disadvantages. We will consider these ways with respect to the above stated problem of integrating the data of several radars. Each data element in the problem contains a relatively small set of data concerning the returned signal related to the spatial volume, determined by the resolution of each of the radars.

The number of such data sets generally is the same as the number of the resolution areas covered by each of the radars. By means of preliminary selection their number may be decreased. However, it should be taken into account that the order of the value is approximated several billions data sets for each of the radars for each of the observation cycles. Thus we need to consider the organization of the database with a big number of small data sets distributed at maximum on several tens of scattered computers.

The classical way of solving such a problem is the use of distributed hash tables (DHT). This way is quite effective for storing a small number of relatively big data sets on many computers when the data sets are addressed by their names. For our problem the use of DHT method is inefficient, because of the high time costs related to writing and searching the data sets. Another well known method of creating such storages in case of big numbers of data sets is indexing the data sets in order to address them by their content. For solving our problem the use of this approach leads to the necessity of re-indexing all data at each analysis cycle, which also requires significant amounts of time and the use of a central processor to store the index the size of which is comparable to the total number of the stored data sets.

Thus, the analysis of the stated problem demonstrates significant limitations of the current methods used to solve it.

Using a metrized small world based data structure

The present article suggests the technology of integrating the data elements into a structure called Metrized Small World (MSW) graph, developed by the authors [2,3]. A visualization of a metrized small world segment is given on figure 1. The basic principle of MSW graph structure is storing each data element as a combination of data itself and a list of link to other elements. The list of links is created according to the algorithms which provide a search of each data element using a pre-calculated metrics. The metrics defines semantic similarity of the data to be stored. If there is one or more metrics defined, the developed algorithms make it possible to create one or more overlaid system of links for the available information data elements. The following is the typical algorithm of creating links for the new data elements to be stored.

There are existing methods of construction of such graphs described in [4] but those methods are not suitable for the peer-to-peer systems because they require iterating over the entire set of vertices to add a new vertex. A way of reorganizing the data in a peer-to-peer small world system using only local data of each vertex is discussed in [5]. We propose the method of dynamic creation of such structures from the given set of elements. Let V be the set of elements numbered in order of their appearance. The elements must be connected in such a way that the resulting graph is a Small World Graph. If a metrics M(Vi,Vj) -> R is defined on a set of elements V, it is possible to form the links in such a way that the elements are close according to the metrics are separated by only a small number of links. We suggest the following algorithm with n and m parameters where n is the number of algorithm steps (determines the join accuracy) and m is the number of links established by the newly added element, $n \geq m$. Let's assume that the structure already contains i-1 elements and the i-th element is being added. Then the algorithm is as follows:

Require: n,m, Vi,Vk where $1 \leq k < i$,
let *visitedList* be the set of visited elements
let *candidateList* be the set of candidates for link embellishment sorted by value of metrics to Vi in ascending order.
assume that *candidateList* initially contains only Vk
for i=1 to n do
sort *candidateList* by value of metrics to Vi in ascending order
select the first element p from *candidateList* not contained in *visitedList*
if no such element exists then
break
end if
remove p from *candidateList*
add p to *visitedList*

Figure 1. Metrized Small World graph segment visualisation

The use of metrics in the construction and search algorithms allows for successful search when the structure of the data is different from the query structure. This can be achieved by constructing metrics which would yield minimal values for the data elements which correspond to the query despite the differences in the internal structure.

The creation of the structure according to the proposed method is strongly dependent on the properties of the metrics used. It is impossible to guarantee that every time a new element is added to the structure it is connected to the closed element according to the metrics. To be sure of this it is necessary to inspect all the elements in the structure. This problem is eliminated by imposing an additional condition to the algorithm: the new elements must be ordered by ordering relationship the metric induce. In this case each element must be connected to its processor and successor elements according to the metrics. For instance, if the elements are real numbers, the metrics can be defined as an absolute difference between two elements and the order of the elements will correspond with their natural order. Then the creation algorithm differs from the above given one and consists of three stages. On the first stage the *Vmin* element is found whose neighbors have equal or greater values according to metrics to the element Vi that is being added rather than the *Vmin* element itself. The *Vmin* element is a "local minimum" of the metrics between Vi and the elements of the structure. Vmin is either the previous or the processor or the successor of *Vi*. On the second stage Vi is connected to its successor and predecessor elements. *Vmin* would be one of these elements and the other one is one of the neighbors of *Vmin*. On the third stage of the algorithm the algorithm described above is executed to find m closed elements and to establish connections with them assuming that $Vk = Vmin$ and $n = m$.

One of the limitations of the method is that the new elements must be added in a random order relative to the order prescribed by the metrics.

IV. Mapping radar data to metrized small world structure

This section describes the basic schemes which illustrate the method of efficient conversion of the data coming for the radars into data elements integrated into the MSW structure. Let us assume that each radar with the number $k \in \{1,..N\}$ scans a certain area so that at each moment of time t for spatial resolution volume at distance ρ and angles ϕ and θ, the data set $(k,t,\rho,\varphi,\theta)$ is created as a result of data processing.

To be more precise we will be consider this data set a line of number $(d,\ k,t,\rho,\varphi,\theta)$, which includes both the data from radar d and the values of the five arguments, defined above. For each of the lines it is necessary to create a set of links to other lines regardless of physical location of the line's storage. Let us define the components of the metrics tensor in order to assess the similarity of the data sets data$(k,t,\rho,\varphi,\theta)$. We will identify the metrics signature elements connected with the sets of numbers in the lines defined by the radar signals and coordinate elements connected with spatiotemporal similarity of the lines. The consideration of choosing different signature metrics is beyond the score of the present article. Lets point out at the trivial binary metrics μs $(d,\ k,t,\rho,\varphi,\theta)\alpha,\beta$=0 if dα and dβ refer to the same target and μs $(d,\ k,t,\rho,\varphi,\theta)\alpha,\beta=\infty$ otherwise. Applying these metrics to the data from several radars leads to creating links among data sets describing the vision of the same target by different radars in their coordinate systems. There are also more interesting possibilities - to detect and measure the target parameters by means of analyzing the signature data in the lines describing the spatiotemporal elements common for all the radars. For this we need to define the coordinate metrics. Let us assume that it is possible to introduce a universal coordinate system for all the radars in the scanned area (e.g. GPS). Let us the define these coordinates as (x,y,z). Now we can introduce a coordinate metrics μc $(d,\ k,t,\rho,\varphi,\theta)\alpha,\beta$ as a spatial distance (x,y,z) α,β for $(k,\rho,\varphi,\theta)\alpha,\beta$. It means that for each radar and each data line it is possible to map the individual radar coordinates (ρ,φ,θ) to the universal coordinates (x,y,z) and to define the metrics as a simple Euclidean distance between the obtained universal coordinates. The temporal similarity can be taken into account by means of adding the 4^{th} Euclidean coordinate of the time values. The metrics should be invariant with respect to the physical storage location. That is why the value k of the data line is not taken account in the metrics calculation. Thus, the list of links between the data lines will be created according to the algorithm described in the previous paragraph with the use of one coordinate metrics in the four dimensional space-time.

In the MSW structure created in this way the data referring to the signals received by all radars from the objects located closely in space and time will be linked.

Conclusion

The results described in the present paper should be viewed as the basis for a proposal to carry out research into the possibility of creating multi-radar systems on the basis of integrating the data obtained by each of the radars. In this case there is no need to transmit the data from all the radars to a single database for further analysis. The data may be stored in the memory of the radars and its integration may be achieved by means of generating a set of special links that unite all the available data sets and the employing algorithms that use the links in analyzing data samples. This approach significantly decreases the requirements to the telecommunications network used to connecting radars into a single system and allows to create high parallel processing systems.

References

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