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Conceptual Design of Radar Data Processor as Plot Extractor for Automatic Detection and Tracking

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Abstract*—According to the great increase in the number of aircraft flying and the inability of the conventional surveillance analog radar to detect and track all the flying targets manually, it is necessary to develop detection and tracking systems that work automatically. That is going to increase those systems capacity in detection of flying targets and improves their ability of tracking. Automation of radar functions facilitate the transfer of data of targets detected to distant points and storage of data for future use in faster and perfect way. Automatic detection and tracking facilitate linking of many types of radars and other detection equipment together, and structure big aeronautical information networks. In this article, a widespread study is carried out on the theory of automatic detection and tracking with the focus on the plot extraction and track-while-scan techniques. Some related topics like the theory of prediction of future positions of targets and false plot filtering are also introduced. Article includes case study that focuses on the principles on upgrading conventional search radar to track-while-scan aviation radar, using general purpose computer and a few hardware elements for the interface of the radar signal with the computer. The program of the data processor system is written in object-oriented language, mostly C++. Besides, other supporting programs are designed to test the system, which are the radar head emulator and the radar display simulator. Those programs are used to examine the capacity of the system to autodetect and track simulated targets. This article covers topics related to the use of general purpose computers to facilitate the transmission and storage of radar data and pave the way for building radar data networks and automatic detection and integrated tracking systems.

Keywords—**Radar Data Processing, Plot Extractor, Detection, Tracking, Track-While-Scan, Plot Extraction.**

I. INTRODUCTION

Surveillance radar is the most commonly used type of radar systems. In general, the antenna of surveillance radar rotates regularly about the vertical axis collecting information of objects inside the radar zone. On average, surveillance radar systems are two dimensional, while tracking radar systems are mostly three dimensional radar systems. In surveillance radar, the beamwidth of the antenna is very narrow in the horizontal plane so as to realize accuracy in the azimuth data of targets. On the other side, the beamwidth in the vertical plane is a little bit wider so as to ensure the coverage for all targets at different heights. The display of surveillance radar is usually plan position indicator (PPI), however a few search radar systems use other types of displays.

In old surveillance radar systems, targets data was generally plotted on a drawing board that looks similar to PPI, and then the plotted data was dictated through voice communications to other locations, such as the tower of an airport, air data center, air defense fire control unit or a central military command and control office. Since radar extracts information about expected and unexpected targets, it must be working continuously or in shifts with other surveillance radar systems. Thus, surveillance radar should be of high reliability. If the data is to be collected, plotted and sent manually, highly skilled personnel are required to achieve good performance.

Very important surveillance radar is that one used in air traffic control (ATC), in order to enable aircraft operate safely with tactical freedom, in all weather conditions, and to prevent collisions between aircraft in the air, and ensure an orderly flow of air traffic. With large numbers of aircraft operating in congested airspaces, the use of ATC radar in this role would be vital. The most important parameters of ATC radar are the data rate, maximum range, the horizontal beamwidth and the wavelength. For higher data rates, the aerial rotation speed should be higher, but not so high such that insufficient pulses per beamwidth strike the target. Keep in mind, increasing the pulse repletion frequency (PRF) will dramatically reduce the maximum operational range of the radar, as the interpulse period becomes smaller and ambiguity in range arises. Hence, the designer of radar is to compromise between high data rate and long maximum instrumental range of the radar [1].

II. RADAR TRACKING

Generally speaking, radar tracking of targets is mainly classified into two classes [2]. In one of these classes, a technique wherein radar with narrow searchlight beam of symmetrical shape in azimuth and elevation (pencil beam shape), acquires a single target at a time. It uses the returned signals to steer its antenna beam automatically, such that its boresight always points to the target as it moves.

That requires the target to exist within the beam of the antennal all the time. If the target moved out of the beam, it will be lost by the radar due to the narrow beam used. Search radar is required to guide that radar to the direction of that lost target. Changes occur in antenna azimuth and elevation angles together with the range of the target are used to calculate the three dimensional track of target. This technique is known as within-beam tracking [4] that requires sophisticated mechanical or electronic beam directing mechanism. See Fig. 1.

The other class of tracking is the one wherein surveillance radar continually scans in azimuth. Adjacent echoes that come from a target are detected and stored for future use. Each group of those adjacent echoes (or strikes) creates a target plot. At each successive antenna revolution, plot position changes are sought and found. Average speed and heading of targets are calculated from their displacement within the time taken for one antenna revolution. This technique is known as track-while-scan (TWS), which is mainly used in surveillance radar and some modern tracking radars. Within-beam tracking technique is widely used in air defense radar systems for tracking enemy targets and guide defensive missiles or to direct anti-aircraft guns towards them.

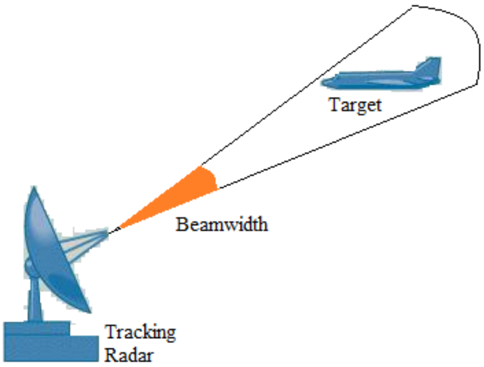

Fig. 1. Within-beam Tracking.

III. DETECTION AND PLOT EXTRACTION

In radar, detection is a terminology that is used to indicate several operations, rather than one. For instance, within the radar receiver there is one or two devices that are known as detectors, which are the crystal RF detector (1st detector in microwave radar), and the demodulator that extracts video signals out of the received signal. The crystal is a sensor that transforms electromagnetic waves into electrical signals. The 2nd detector is either an envelope detector or a phase detector.

Another level of detection is performed by the operator monitoring targets plots on radar display. It is the operator who decides which object is a valid target or not. An object may be a known mountain for him, or another plot is so small in size so that he decides that object is a big bird. An important point of concern is the accuracy with which human senses manage to measure various parameters of the observed targets. Also due to the physical nature of man, the operator works continuously without having a rest for a limited period of time. Surely it can't be done unless by dividing the operators between shifts, which puts in the need for more operators. Another important limitation to manually operating radar is the capacity of the system, i.e. the maximum number of targets that it is able to maintain simultaneously. The operator can deal only with some of the targets and miss the rest of them.

Voice communication between the radar crew and the other parts of the network, such as air defense missile launcher, reduces the response of the whole system. That depends also on the experience and mentality of the operators at both ends of the line. If the information about the traffic state during the day or the week should be stored for future, fast and systematic method will be required. Writing data on paper by hand or typewriter depends on the editor's neatness and the way that these papers are stored.

For these limitations and the cost of manual operation of radar systems and to improve the overall performance, the trend is to automate what one can in surveillance systems. Although some restrictions still exist on full automation of radar systems controlling weapons, there are many search and tracking radar systems that are fully automatic. In order to minimize the errors due to the manual detection of targets that observed using the PPI, and to enhance the speed of detection, there are several methods developed for the automation of radar targets detection.

Basically, automatic detector is a device making decisions regarding the signal to noise ratio (SNR), as conveyed to it by its input data derived from the radar receiver. A 3rd detector integrates the video signal to output a signal with much energy, and an energy detector is then used to detect signals with high energy levels. However more generally defined, an automatic detector or a plot extractor performs the following functions:

1. Integration of the echo pulses received.
2. Decision on target existence and its validity.
3. Determination of the target coordinates.

Most of automatic detection algorithms start with the operator in front of the PPI as the basic model of a plot extractor. The operator job is to seek for accumulations of strikes (plots) on the display. If one of those displayed plots is so small, he/she is going to neglect it. He assumes that it may be due to a small object like a big bird or may be just due to noise. A line going towards the Sun or a TV station is assumed due to the effect of interference caused by radiation received from the Sun or that station. These techniques are not the only detection techniques used by operators. Each radar operator adds his own experience and develops new techniques to enhance his ability to detect targets with the minimum errors.

One of the most commonly used automatic detectors is the sliding window detector [2], which is a binary detector that is known also as the binary moving window detector. It receives binary video pulses, which are either low or high. This black and white video signal is the output of a level detector. The detector counts the number of pulses inside each window, and if the counted number of pulses exceeded a prespecified value, a valid plot is declared to exist. The sliding window detector basically is a form of an integrator. Because it delivers binary output for binary input, the sliding window detector is sometimes called the double threshold detector [2].

The sliding window passes rapidly through the surface of an imaginary PPI, such that its leading edge is incremented by the azimuth angle resolution so the last area elapsed by the window is almost covered by the current window. After completing a revolution, the window jumps out with the range resolution to start a new round. The center of the window is taken as an estimate to the detected target position, which is known as beam splitting. The length of the window is a curved line in units of the azimuth angle, while the depth is in units of the range, as shown in Fig. 2 below.

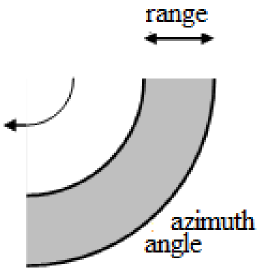

Fig. 2. The Sliding Window

Post-detection integrator is a good energy integrator that enhances the SNR in white noise environment. On the other hand, the sliding window detector receives two state pulses, so it has nothing to do with energy. Although the sliding window detector is less efficient than ideal post-detection, it acts well in fading and non-Gaussian environments.

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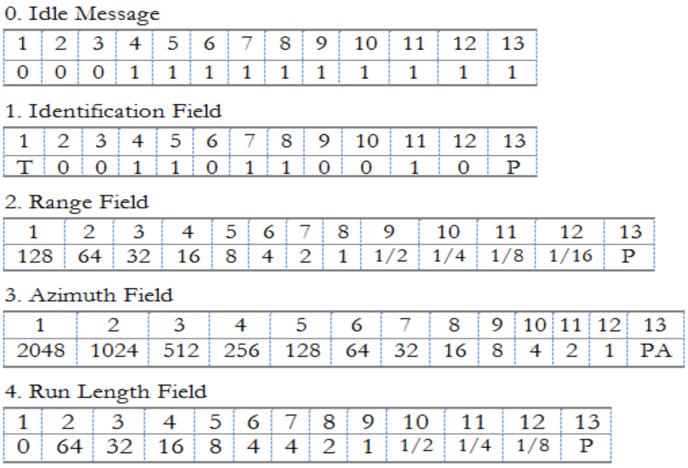
IV. TRACK -WHILE-SCAN

In TWS radar systems, tracking takes place after the plot extraction which has been discussed above. Subsequent logic examines stored plots history, makes judgments on current valid plots and, commonly, makes complex predictions about the future expected positions of the targets. TWS radar is typically surveillance radar that scans the whole environment around it, while its antenna is rotating continuously with uniform speed. Thus, it is not like within- beam tracking radar, whose antenna movement is non uniform and unpredictable. Radar video signal is passed to the plot extractor so as to auto-detect targets. A track is initiated for each target and is updated per each antenna revolution. After a target has disappeared, its corresponding track is terminated. To get the maximum detectability, the false alarm rate (FAR) is set to a higher value. This makes the plot extractor generate a large number of false plots. Thus to prevent these false plots reaching the tracker, a false plot filter (FPF) is required. FPF is relatively simple in operation, by which every plot generated (true or false) is sorted and is the subject of a potential track. Only after the track is established with very high probability, the plots are released to the tracker or to the display. Usually that occurs at the third association plot, and the first two plots having been used to establish the potential track. Thus, each of the new tracks will have the first two plot reports suppressed, but commonly retained in store for possible later track associations [7].

In the tracking process, there has to be an initial plot. Obviously, plots which don't form tracks will not be displayed. So using this kind of tracking and false plot filtering allows the radar to be operated with very high sensitivity with a FAR as low as one in a million. The FPF is used also to eliminate low speed targets such as ground vehicles and inhibit track initiations in noisy areas. Furthermore, FPF terminates the tracks of targets that are no longer detectable, such as targets which have moved out of the radar zone. It takes that action if the target is missed for three to five antenna revolutions. TWS surveillance radar is usually used to feed synthetic radar displays, which are digital computers. Symbols of targets are displayed on the screen, instead of displaying raw video plots that are displayed on an old-fashion PPI [5]. Targets are shown in a smart, easier and clearer form.

The displayed target symbol could be an asterisk, triangle, circle, oval or square. Furthermore, it can be displayed as an animated airplane. In addition, other data of target is shown beside its symbol such as text indicating the label generated by the system for that target or data that is supplied by another external source of detection, such as height finder or secondary surveillance radar (SSR), which is able to supply the identity and height of the target, as well as its range and azimuth information. Normally, the radar display is located at a distant point from the radar, such as an ATC centre or the watching tower of an airport. Data commonly is transmitted to the display system through a communication link such as an optical fiber cable or wireless link. The same data link is frequently used to remotely control the radar head and monitor its performance. There exist many formats of data structure used to transfer radar data. The former but familiar and simpler format that was standardized by the international civil aviation organization (ICAO) is the civil aviation authority (CAA) format, shown in Fig. 3 below. That format was used for most of the displays of surveillance radar systems in air traffic control. Nowadays, all-purpose structured Euro-control surveillance information exchange (ASTERIX) data format is more common.



0. Idle Message

1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	0	1	1	1	1	1	1	1	1	1	1

1. Identification Field

1	2	3	4	5	6	7	8	9	10	11	12	13
T	0	0	1	1	0	1	1	0	0	1	0	P

2. Range Field

1	2	3	4	5	6	7	8	9	10	11	12	13
128	64	32	16	8	4	2	1	1/2	1/4	1/8	1/16	P

3. Azimuth Field

1	2	3	4	5	6	7	8	9	10	11	12	13
2048	1024	512	256	128	64	32	16	8	4	2	1	PA

4. Run Length Field

1	2	3	4	5	6	7	8	9	10	11	12	13
0	64	32	16	8	4	4	2	1	1/2	1/4	1/8	P

Fig. 3. Fields of CAA Data Format

V. TRACK SMOOTHING IN TWS RADAR

One of the most important decisions to be made by the TWS radar tracking system is whether to include new reported plots into one of the existing tracks or to assume them as due to new detected targets. TWS system associates valid plots with their corresponding tracks. So, the system needs to have the history of each track, which includes current and past target positions as well as its speed and the heading, which are estimated with computations.

But to exactly fit a plot into its track, the next plot position is to be predicted. Estimation of the next plot position is calculated with the aid of a prediction filter, using the data stored in the track as its input. When the radar obtains the next position of a target by measurement, it is compared to the predicted position. Obviously there will be a difference, but the mean value is calculated together with a value for the error estimation. This latter value is used as a weighting factor in setting the next estimate [7]. Applying prediction filters to the tracks of targets in TWS radar systems is known as smoothing or filtering of tracks. It is necessary to use smoothing filters especially with large number of targets, which may pass near each other and sometimes cross each others' tracks

Frequently, there exists weighting factors which are assigned values that are calculated from the knowledge of the radar's own errors and how those errors are distributed. In some trackers, the weighting factors are varied automatically. Variation is based upon the success of the estimating process, which is judged by the magnitude of corresponding errors with time. The advantage of the adaptive adjustment of weighting factors is obvious when one considers the great variability of the plot measuring accuracy in the radar, i.e. measuring errors, because of variable signal strength due to wide range of target sizes and distance, as well as effects of clutter and noise

A simpler smoothing and prediction filter is the alpha-beta tracker, which is frequently used in ATC radar systems [2]. This kind of filter has one fixed weighting factor with two components; α which is the factor that is concerned with the position error, and β which is the factor that is concerned with the velocity error. In its mathematical formulae, the alpha-beta tracker computes the smoothed position of each target and its smoothed velocity as follows

$$\overline{x_n} = x_{pn} + \alpha(x_n - x_{pn}) \qquad (1)$$

$$\overline{v_n} = v_{n-1} + \beta(x_n - x_{pn})/T_s \qquad (2)$$

Where; x_{pn} is the predicted position at the n^{th} scan, x_n is the measured position at the n^{th} scan and T_s is the time between samples. The values of the constants α and β are between zero and one. If $\alpha = 0$, the smoothed position will be equal to the predicted position and the measured position has nothing to do with it, while if $\alpha = 1$, the smoothed position will be equal the measured position and no prediction is done.

On the other side, if $\beta = 0$, the smoothed speed is assigned the last measured speed of the target, which means that the target is considered moving with constant speed, while if $\beta = 1$, the smoothed speed is modified with the error in the predicted position divided by the time between samples, which is the predicted average speed error of target. Not all radars measure Doppler frequency, hence they are not able to measure the speeds of targets. Thus, average speed is computed as the difference in the positions of two consecutive scans, divided by the duration of a complete antenna revolution as follows

$$v_n = (x_n - x_{n-1})/T_s \qquad (3)$$

And the predicted position at the $(n+1)^{th}$ scan in terms of the smoothed position and velocity is given as

$$x_{p(n+1)} = \overline{x_n} + \overline{v_n} T_s \qquad (4)$$

For optimum smoothing, the values of the constants α and β are to be found empirically for the process in concern. Benedict suggested the following relation between α and β of the alpha-beta tracker used in TWS systems as the optimum [1]

$$\beta = \alpha^2 / (2 - \alpha) \qquad (5)$$

For precise tracking radar, $\alpha\beta$-tracker extends to $\alpha\beta\lambda$-tracker to consider acceleration besides position and speed. Although the $\alpha\beta$-tracker is simple and easy to implement, it is less efficient with maneuvering targets, such as fighters and missiles. For such targets other prediction filters may be used, such as Kalman filter and its extended version. Such filters are more complex and costly to implement types of prediction and smoothing filters.

VI. SYSTEM DESIGN OF TWS RADAR

The basic block diagram of the complete TWS radar system proposed here is shown in Fig. 4 below. The radar head, which is conventional surveillance radar, sends high RF energy into the space and receives echoes from different reflecting objects inside its zone. Various signal processing operations are done to those echo signals like amplification, filtering, Doppler processing, and constant false alarm rate (CFAR). The output of that surveillance radar is a stream of baseband video pulses. For TWS systems applying automatic detection, the video signal is regularly binary signal (black and white).

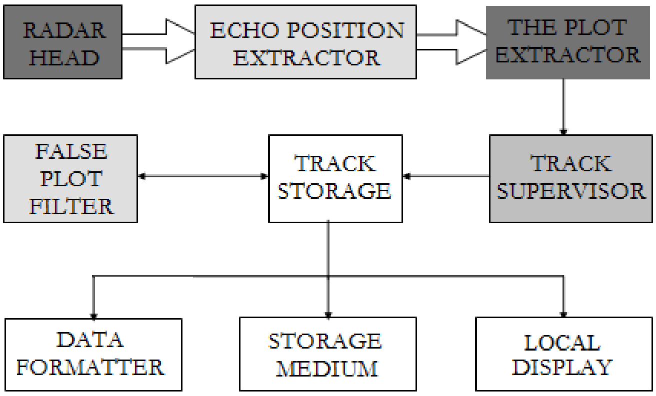


Fig. 4. Block Diagram of TWS Radar System

In old fashion surveillance and search radar systems, the range of an echo is observed on the range display or the PPI, as the distance between the origin point on the display and the location of the echo on the display. It is not necessary to get a unique signal whose value is the echo range. We can say that, the range of a target on such displays is observed in an implicit way, rather than explicit.

For tracking radar systems, there exists a unit called the range measuring unit. It extracts the range of an object by calculating the time delay between the trigger pulse and the video pulse of the echo. Since the TWS requires the target range in an explicit form, i.e. numerically, echo position extractor is essential. A way to measure the range is by using range gates [2], which are pulses generated using a counter that resets by the trigger pulse coming from the radar. So, the range counter starts at the zero range and reset to zero, just after the maximum range of the radar. A range gate pulse that coincides with a video pulse will be registered as its range.

The azimuth angle of the echo is obtained measuring the direction of the radar antenna at that moment. Usually, antenna rotation unit generates azimuth clock pulses (ACP's) starting from the North direction, which is the starting position of zero azimuth angle. For standard ATC radar, there are 4096 ACP's for a complete antenna revolution, i.e. 360°.

The track supervisor is the block that is responsible for initiating new tracks and updating existing tracks with the corresponding target information. The track data is stored in the track storage which is temporal read/write storage medium, such as random access memory (RAM). This store is accessible for almost all other parts of the system. Tracks are established inside it in a certain fashion so as to arrange the access and the speed of data transfer in and out of the store. The information stored will then be ready to be transferred to the outer world.

Data is commonly sent to a remote distant place through cables or RF links. It is normally outputted serially with a certain data format, such as the CAA standard format, by means of the data formatter. Targets information may also be stored in a permanent medium like a magnetic disk or printed on papers. A video display unit is used as the radar display, such as synthetic display, located at a distant point. A local display is regularly placed at the radar site for testing and maintenance purposes.

VII. TECHNIQUES FOR SYSTEM IMPLEMENTATION

In this article, a case study to modify conventional search radar to a TWS radar system is presented. The design is mainly based on software rather than hardware in order to simplify the process and reduce the cost of implementation. The hardware elements included in the design of this TWS system are kept to minimum, which include the interface between the TWS computer and the position extractor. The later may be built inside the software; however this affects the speed and the performance of the system.

A. Hardware Implementation

The hardware elements which are needed in the suggested TWS system are the search radar under development, a general purpose personal computer, the position extractor unit and the interface to the computer. If a radar display is to be implemented as a part of the TWS system, it is desirable to have enhanced super VGA monitor or newer to obtain high-quality graphics with acceptable resolution.

Though there are several means to interface other systems with personal computers, serial communications between the PC and the outer world is the most common practice. RS232 input/output serial communication ports are available in most desktop PC's so there is no need to import additional hardware except connecting cable. Otherwise, one can use USB to RS232 converter. However, for long distances, internal or external data modems are required.

A threshold detector is used here to convert demodulated video pulses to black and white video pulses. These B/W video pulses are sent to the range measuring unit in the position extractor unit to find the range of each echo pulse. Then, the range data which is digital is sent in its parallel form to the interface with the computer as well as the azimuth angle of the antenna at that moment. See Fig. 5 below.

The position extractor receives the signal delivered by the radar and computes the coordinates of each echo. The extractor receives the following signals: detected video signal, trigger pulse, ACP and North mark pulse from antenna turning unit. A range counter which resets by the trigger pulse is used to generate the range gates. When a target video pulse is received, the corresponding range gate is marked as the range of that strike. That is can be done by the aid of a tristate buffer or AND gates, which outputs the range to the computer interface. The number of range gates is selected according to the required range resolution. North mark resets azimuth angle. Typical ATC radar use 12-bit code and thus has 4096 range bins.

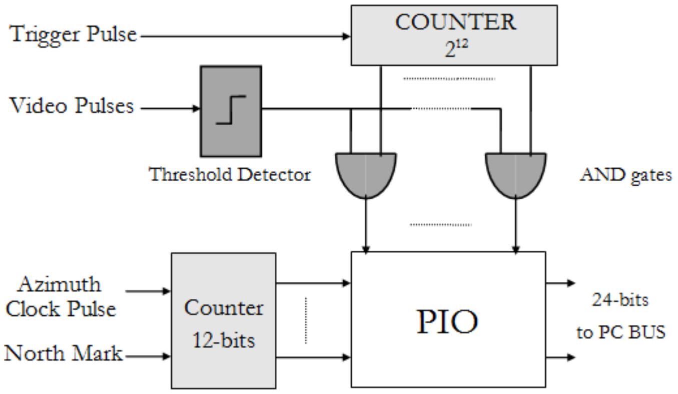


Fig. 5. Complete Position Extractor.

B. Software Implementation

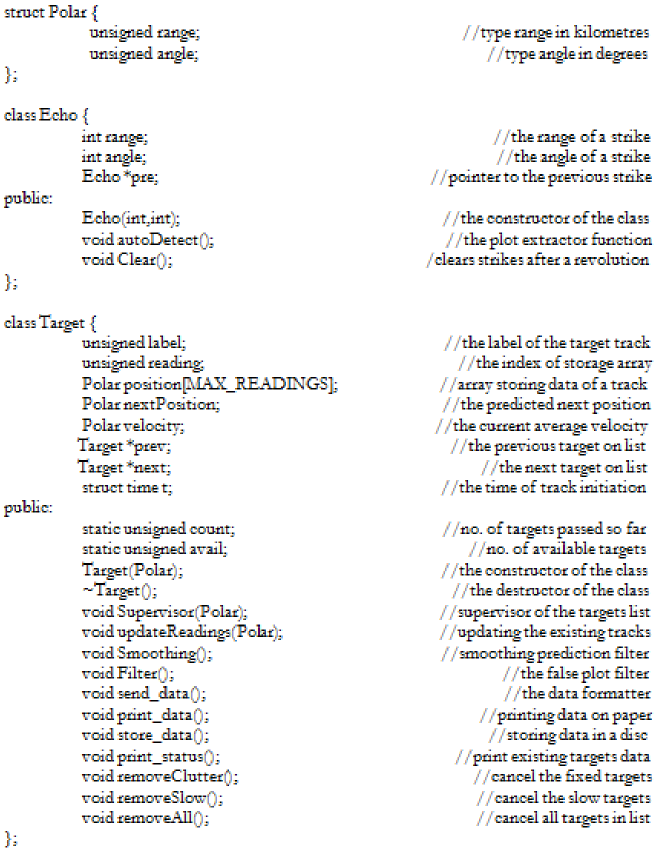
The software of such a system will be easily manageable and more flexible to modifications if it is written using a high level language, such as C. Complicated designs may include some programs written in low level languages so as to enhance the speed or to reduce the size of the coded programs. C++ provides capabilities for object-oriented programming, which makes it easier to build software quickly and correctly [6]. Objects are essentially reusable software components that model items in the real world.

Besides, C++ language offers an easy and a straightforward way to create dynamic objects during the execution of the program which is known as the dynamic allocation of objects [6]. With the dynamic allocation of data in memory, it is not necessary to reserve specific area in memory for this data during coding of the program by declaring the data to the compiler. This property is essential for the programs that are written for radar systems that deal with unexpected number of objects, which are aerial targets in this case.

Another important feature of the C++ language is used to develop the TWS radar software is the ability to store the objects in linked lists. This enables easy access of any of the objects in the list since its order is known to the program. Linked lists may be singly linked or doubly linked. In a singly linked list of objects each object points to the object next to it or that before it, where in a doubly linked list each object points to the previous object and the next object in the list.

The range and the azimuth information above represent the strikes received. These strikes are stored in the computer memory and then processed later by the plot extractor to detect valid target plots. Those plots are the most important data that the TWS radar system is concerned with. It is the mission of the system supervisor to deal with the stream of plots delivered by the plot extractor. The supervisor puts these plots in the memory of the computer in the form of tracks of targets. It decides which plot belongs to which track with the help of smoothing and prediction filter.

Each target has its own private parameters like its label, position and detection time. Also there are public parameters and behaviours which targets share with other objects of the same class (i.e. with the same data type). Some of the data types are structures of data with more than one data member. For example, the position of the target is of the polar type which has range and angle components. Using classes and structures to declare data makes data handling more easily and gives a more readable program. The C++ code illustrates the declaration of principal structure, classes and member functions for the TWS program, which are typically saved in a heard C++ file.



```
struct Polar {
         unsigned range;                       //type range in kilometres
         unsigned angle;                         //type angle in degrees
};

class Echo {
        int range;                                 //the range of a strike
        int angle;                                 //the angle of a strike
        Echo *pre;                         //pointer to the previous strike
public:
        Echo(int,int);                        //the constructor of the class
        void autoDetect();                    //the plot extractor function
        void Clear();                     /clears strikes after a revolution
};

class Target {
        unsigned label;                      //the label of the target track
        unsigned reading;                     //the index of storage array
        Polar position[MAX_READINGS];        //array storing data of a track
        Polar nextPosition;                   //the predicted next position
        Polar velocity;                     //the current average velocity
       Target *prev;                          //the previous target on list
       Target *next;                              //the next target on list
        struct time t;                       //the time of track initiation
public:
        static unsigned count;                //no. of targets passed so far
        static unsigned avail;                   //no. of available targets
        Target(Polar);                       //the constructor of the class
        ~Target();                            //the destructor of the class
        void Supervisor(Polar);              //supervisor of the targets list
        void updateReadings(Polar);          //updating the existing tracks
        void Smoothing();                     //smoothing prediction filter
        void Filter();                              //the false plot filter
        void send_data();                           //the data formatter
        void print_data();                        //printing data on paper
        void store_data();                          //storing data in a disc
        void print_status();                   //print existing targets data
        void removeClutter();                     //cancel the fixed targets
        void removeSlow();                         //cancel the slow targets
        void removeAll();                         //cancel all targets in list
};
```

Fig. 6. Snapshot of Declarations for TWS Program

VIII. CONCLUSION

Automation of radar systems facilitates the transmission of radar data to distant points with the minimum bandwidth. Reduction in the transmission bandwidth results because the data is free of redundancy. This data carries only the position information of targets instead of the transmission of the echo video pulses. Automation of radar also facilitates the storage of data for future use and enables the radar to operate as a part of a network contains different types of radar systems.

The plot extractor has been built as a function inside the TWS program though commonly it is an independent program or hardware. After it was tested making use of secondary programs, it has realized good performance in plots detection with a low rate of errors. But on the other hand, the sliding window plot extractor function has caused the major source of delay in the program. That delay is due to the non-dynamic nature of the sliding window, which moves contiguously on the plane of the radar zone faster than antenna, looking for valid plots.

The radar head emulator program designed was simple, yet satisfied the testing requirements. Likewise, the radar display simulator was relatively simple, as it was just designed for testing purposes. It decodes the messages sent to it serially from the TWS computer. The screen looks like what is shown in Fig. 7 below. The same program written can be upgraded to work for a practical display. In such a display, the graphics could be of high resolution and contains other elements such as maps and airways. The label and emulated position of each simulated target are displayed beside its symbol.

In conclusion, it is to be stated that the main objectives of the work presented in this article were highlight principles of automatic detection and tracking, and to establish a solid platform to easily upgrade old surveillance radars to more useful and modern systems.

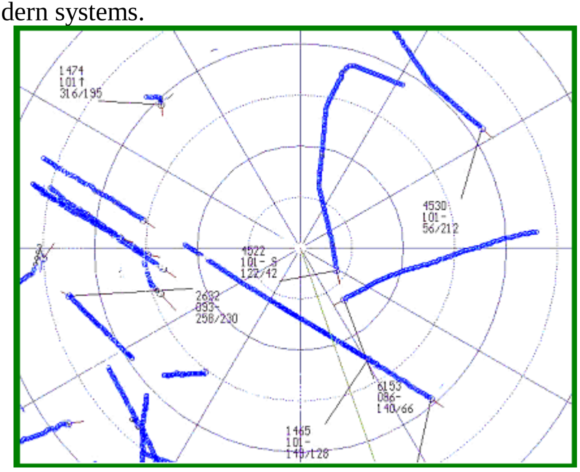


Fig. 7. Radar Display.

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