Abstract

The instruments for search tasks can be defined as those used for surveillance (providing image), i.e. IR-Imagers or thermovisors. Their basic goal – to detect and visualize the remote heat radiating objects upon thermal disturbances or background.

Rather wide range of non-cooled IR-imagers is currently produced in Russia. These imagers are designed for various practical applications, have various functional options, sensitivity, weights, dimensions, etc.

In the paper the comparison analysis of available portable search thermalvision instruments (based on non-cooled multi-element solid state sensors for radiation registration) will be done as well as attempt to estimate the prospective of development of such systems in the future in Russia. The analytical review will evaluate products and ways of research works in this field conducted by the Research Institute of Introscopy of MSIA “Spectrum” – leader in engineering and manufacturing of handheld thermalvision systems.

In the IR-imagers of Russian production the IR cores manufactured by L3 Communication Company (USA) operating in the wave range 7 – 14mcm are used. In the paper will be discussed actual advantages and disadvantages of bolometric and pyroelectric cores implementation.

Specification of portable imagers of “Katran” and “Sprut” series will be given. These portable and wearable imagers can be used by individuals providing efficient surveillance of people at distance up to 1000m as well as transportation means at distance up to 2000m. The most efficient areas of application of IR-imagers, night vision instruments and highly sensitive TV-systems will be discussed.

New generations of cores (640x480 & 1280x1024 with pitch size around 17mcm and temperature sensitivity 20mK) open new possibilities for improvement of existing thermal vision systems.

The ways of development of integral, combined search and surveillance systems will be discussed, i.e. systems incorporating not only IR-channel but those for laser location, highly sensitive TV channel correlated with IT one, etc.

Development of thermal vision equipment from one side gives birth to practically universal diagnostics system and from the other side, due to new functionality, becomes a key element of search and surveillance systems providing public safety and security.

keywords: non-cooled IR-imaging systems, thermovision, surveillance systems, public safety and security

1. General review

Infra Red (IR) spectrum range of electromagnetic radiation is rather informative and interesting from point of view of search systems development and this can be explained by
the fact that in this very range the basic part of electromagnetic self-radiation of natural and artificial objects’ is concentrated. IR range covers waves with length from 0.76 to 1000mcm (correspondent to frequencies from 300 to 0.3THz). This is rather wide spectrum area is split in five intermediate ranges – near range (0.76 – 1.1 mcm), short-wave (1.1 – 2.5mcm), medium wave (3.0 – 5.5mcm), long wave (8 – 14mcm) and far wave (15 – 1000mcm). In some cases two first sub-ranges are considered as one sub-range (0.76 – 2.5mcm).

IR ranges of 3 - 5.5mcm and 7 – 14mcm are working areas for thermal NDT. More informative range of 8 – 14mcm is of special interest as it totally matches with the widest low-loss transmission window of atmosphere and corresponds to maximal radiation ability of monitored object within temperate range of – 50 to + 500°C.

Thermal testing method is based on the fact that any processes taking place in nature or as a result of human activity are accompanied with internal energy absorption or liberation causing, in its turn, object body internal energy that when in the state of thermodynamic balance is proportional to the substance temperature.

The major line of implementation of thermal testing method is development of equipment, i.e. thermal vision instruments, providing temperature distribution or IR radiation converting into visual image.

The basis of principal of operation of IR imagers is 2D transformation of self-radiation of objects and spot or background into visual image. The IR equipment has a number of advantages and inherent only to it features to detect remotely located heat radiating objects (or targets) irrespective to level of natural illumination as well as, to certain degree, heat and other disturbances (smoke, rain, fog, snow, dust, etc.).

The beginning of thermalvision equipment development in Russia has been started during second part of 60s of XX century by research and development of equipment done in two basic directions: with use of discrete radiation receivers in combination with scanning (sweep) systems implementing 2D IR-receivers. Today, conventionally, four generations of such equipment development can be listed.

**Zero generation** is based on use of single cooled receivers and 2D (line and frame) scan obtained with the help of scanning optic-mechanical system; **First generation** – uses line bar of receivers and simplified frame scanning; **Second generation** – uses several grouped bars (with time delay and accumulation functions) and low-speed scanning system. The second generation of equipment includes vacuum instruments with electronic scanning of receiving target, so called pyrocones.

Principally new **Third generation** based on use of “simultaneously watching”, i.e. focal-plane arrays (FPA), 2D solid states multi element (matrix) radiation receivers (MRR), i.e. in this instruments the scanning optic-mechanical system is not used.

Lately the development of IR equipment mostly implement non-cooled multi element MRRs, physical parameters of which are rather high and practically not surrender to cooled systems. Modern Thermal Vision Systems (TVS) can be split in two basic classes:

- observation (visualizing);
- measuring or radiometric (thermographs).

**Surveillance** TVS are designed for detection, recognition and visualization of remote heat radiating objects (or targets) on the background of heat disturbances. Such systems can be complemented by autonomous channels containing, as a rule, scaled TV channel and channel of remote temperature measurement with laser pointer as well as by laser range finder. Such additions to observation TVS provides partly performance of measuring function.

**Measuring** (radiometric) TVSs mostly are used for qualified thermal diagnostics of various industrial objects, equipment, buildings, structures, mechanisms, etc.

Each of mentioned classes of TVSs has specifics of their applications (market niche) and specific operation functions and possibilities.
Further in the paper the surveillance TVSs that take special place in the process of search and watch tasks will be discussed and presented. The TVSs realizing such functions are usually called *search and watch* or *search* systems.

Search TVSs provides possibility of objects observation at fair distances independently of natural illumination level, intensity of light disturbances, and degree of atmosphere transparency. These instruments are able to register heat radiation from objects through walls, media that is non-transparent for visual or short-range IR radiation, but transparent for heat radiation in selected range like foliage, camouflage nets, small lay of soil, pile of items, etc., making it possible to reveal camouflaged or covert objects. Search TVSs can be used for all around the clock and in any weather conditions monitoring, intelligence actions, targeting, and target tracing, objects protection, customs activity, for solution of forensic tasks, driving of automotive vehicles, rescue of wounded and injured persons as a result of military activity or natural disasters, for land mines detection, etc.

The possibilities of search TVSs to detect and recognize technics and people at rather big distances are demonstrated in Fig. 1. The Fig. 1 demonstrates the results of various objects detection by thermovision system based on non-cooled bolometric IR matrix with sizes 320\[240\] pixels (pixel size is 50mcm) with lens focal length 100mm. The figure demonstrates the limiting achievable results of detection and recognition. In practice the same results will look more decent that can be explained by the fact of non-optimal terms of observation, reduced atmosphere transparency and some other factors having negative impact on the equipment parameters. In more details such factors will be discussed further on.

**Fig. 1. Abilities of search TVSs to detect and recognize technics and people at rather big distances.**

The atmosphere impact on the process of IR radiation propagation when observing remote objects show up as object self-radiation attenuation and is due to two basic reasons:
- radiation absorption as a result of energy conversion in its other forms;
- energy' attenuation or scattering.

The result of above factor impact show up as attenuation of energy signal generated by examined object, reduction of image contrast, distortion of its special structure that finally cause image degradation and reduction of vision distance.

Conventionally all TVSs can be split in three groups depending on vision distance:
- Short range TVSs: from 0.7 to 1.0km for detection of standing person and 1.5 – 2.0km for vehicle detection;
- Medium range TVSs: 1.2 – 1.5km and 2 – 4km correspondingly, as well for airplane detection at distance up to 8km;
- Long-range TVS (increase distance of operation), these are systems operating in range exceeding correspondent ranges for medium-range TVSs.

The TVSs of the first group include portable, hand held IR imagers with weight up to 2kg, portable sights for small arms, helmet and heard mounted observation modules. The TVSs of the second group include carried and temporarily mounted on tripod observation instruments. The TVSs of the third group include stationary mounted observation instruments equipped with long-focal-length optics as well as transported or mounted on self-floating installations.

The modern Russian observation TVSs are based on non-cooled converters of IR-radiation. The last ones present focal-plane multi-element arrays that are able to register temperature contrasts within the range from 50 to 80mK.

In non-cooled IR-imagers operating within spectrum range 8 – 14mcm as converters used are microbolometric (MB) focal arrays of large format and multi-element receivers based on pyroelectrics (PE) or ferroelectrics, the last ones step by step pale into insignificance due to several reasons.
Format of implemented MB arrays in most cases of TVSs types is 320x240 (384x288) and 160x120 pixels while pixel size does not exceed 50x50mcm. A lately appeared array with size 640x480 pixels and pixel size is down to 28x28mcm, while NETD parameter reached value of 50mK. It is expected that in 2009 the arrays of 1280x1024 pixels with pixel size 17mcm and sensitivity less than 20mK. The use of arrays of new generation will improve spatial and temperature resolution of TVSs.

As about other type of matrix IR-receivers based on pyroelectric (PE) elements, their sensitivity is slightly less than this parameter for MB matrixes. The PE NETD does not exceed 8mK, a standard parameter value is in limits of 100….150mK. Most widely are used arrays with sizes 320x240 pixels. Lately has appeared arrays with formats of 640x512 and 512x256 pixels. There are applications for which use of pyroelectric arrays is preferable in comparison with microbolometric ones – these are systems for all around the clock monitoring for which exists the possibility of direct impact of sun light on the sensitive array elements. The failure probability in such a case for pyroelectric array is much less that the same for microbolometric matrix.

Search IR-imaging systems, as any other functional unit, are characterized by a set of parameters determining their efficiency; some of them are listed below:
- Probability of detection, differentiation and recognition of object at set distance;
- Minimal detected temperate difference;
- Minimal differentiated temperate difference;
- Angle (linear) resolution;
- Scenario capture bandwidth (view field);
- The number of reproduced temperature gradations.

In spite of the fact of rather completed and universal applications, basic parameters of efficiency cannot be used for instruments itself description as they are strongly dependent on terms of equipment use and parameters of object and background as well. That is why for evaluation of specific thermal vision equipment it is reasonable to use its basic (generalized) technical features as follows:
- Sensitivity threshold level (NETD – Noise Equivalent Temperature Difference);
- Element of angular discrimination;
- Field of view;
- Spectral operating range;
- Range of registered temperature difference;
- Range of image densities;
- Performance;
- Distance of object’ detection / recognition.

For search TVSs the distance of object’ detection / recognition is a generalized parameter taking into account weight-dimensions of equipment and its usability for specific search and surveillance tasks.

Currently Russian manufactures of non-cooled TVSs offer rather wide range of products making it possible to select such type of products that maximally satisfy requirements of the user on functionality, weight—dimensions as well as price to solve specific task.

One of such manufacturers of the non-cooled TVSs based on solid-state multi-element focal-plane arrays is Scientific-Production center of anti-terrorist and forensic equipment «SPEKTR-AT» (SPC «SPEKTR-AT» ), offering to its clients four types pf search IR-imaging systems presented in Fig. 2:
- hand held;
- mobile;
- stationary;
- mounted on installations of various types.

Fig. 2. Non-cooled IR-imagers produced by STC «SPEKTR-AT»
2. Hand-held IR imagers

«KATRAN» and «SPRUT» type instruments can be qualified as short-range operating instruments. Their parameters are presented in table 1 in which for comparison also are presented parameters of hand-held IR-camera x200XP (USA). This instruments are designed to be used by law enforcement forces, state security bodies and Ministry of interior units, private security companies, Ministry of emergency units, agencies providing environment monitoring, etc.; all those who needs all around the clock and in any weather conditions monitoring including monitoring in sever conditions (presence of smoke, fog, etc.). These instruments also can be used for solving tasks of land and sea border control, control activities to prevent drugs circulation, protection of buildings, etc. Hand held TVSs are very efficient in case of conducting rescue operations, evidences detection, detection of hidden graves, night patrolling and covert observation and tracking, security and safety provision in the process of public events, environment protection, etc.

The principal users of mobile IR-instruments are special units combating organized crime and terrorist, border control services etc. On mobile TVSs imposed are specific requirements that to some extern are in contradiction with each other. From one side – they shall have high quality optics, good temperature and spatial resolution to provide observation and intelligence activity at distance of 1000….20000m. From other side – they shall have maximal small weight and dimensions, low power consumption providing long autonomous operations, high level of protection from influence of dust and humidity, robust casing and be easy to operate. In fact all these requirements are fulfilled in instruments of «KATRAN» and «SPRUT» types.

IR-imagers of «KATRAN» type has high temperature and spatial resolution providing detection of people and technics at distances up to 1000m and 2000m correspondingly. Plastic thermo- and shock resistant casing guarantees high level of protection from dust and water while having rather small dimensions and weight. Separately should be mentioned IR-imager «SPRUT» that in fact presents integrated system, for observation. In addition to IR-channel based on modern microbolometric array (320x240 pixels) it has one of mentioned below channels:

1. Channel for laser location designed for detection at long distances of long-focal-length optics or, in other words, for detection of cases when hidden observation or aiming is carried on. In this modification the «СПРУТ» system combines IR-imager with parameters the same as «Katran-III3» and instrument as well manufactured by SPC «СПЕКТР-АТСГЕКТ» and named «SPIN-2», providing detection at distance up to 1 000m of sights, night vision instruments, photo and video cameras used for covert observation and recording. The laser location channel can be used and highly efficient active night vision device.

2. Highly sensitive TV camera with lens which parameters provide possibility to obtain examined object TV image with the same scale as IR-image of the same object.

3. Laser range finder that expand area of application of discussed instruments.

Table 1. Hand-held IR-imagers

<table>
<thead>
<tr>
<th>Array size, pixels</th>
<th>Katran-I</th>
<th>Katran-II</th>
<th>Katran-III</th>
<th>Sprut</th>
<th>x200XP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of View, deg</td>
<td>17x12</td>
<td>11x8 / 17x12</td>
<td>12x9</td>
<td>12x9</td>
<td>11x8</td>
</tr>
<tr>
<td>MTR, °C</td>
<td>0.1</td>
<td>0.06</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
</tr>
</tbody>
</table>
### Table 2. Mobile IT-imaging systems

<table>
<thead>
<tr>
<th>Array size, pixels</th>
<th>TN-4604 MB</th>
<th>TN-4604 MP (50, 70)</th>
<th>Skat</th>
<th>Thermal-Eye 250D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of View, deg</td>
<td>18x14</td>
<td>18x14 / 14x10</td>
<td>18x14 / 14x10</td>
<td>18x14; 12x9; 9x6; 6x4.4</td>
</tr>
<tr>
<td>MTR, °C</td>
<td>0.15</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
</tr>
</tbody>
</table>

2. **Mobile IR-systems (MIRS)**

The MIRSs produced by STC «SPEKTR-AT» in the capacity of IR-converters use both: bolometric arrays of formats 160x120 and 320x240 pixels and non-cooled pyroelectric arrays with size of sensitive area 320x240 pixels. In table 2 given are basic specifications of medium-range MIRSs, for comparison given are specifications of American IR-camera of similar type - Thermal Eye 250D. Area of application of MIRSs is wider than of the hand-held instruments as in addition to tasks solved by means of hand-held systems the mobile systems can solve more complex search tasks, for instance, all-round surveillance due to implementation of pan and tilt modules (PTM). Weight and dimensions parameters of MIRSs are better than those of hand-held instruments because, as a rule, MIRSs have lenses with longer focal length, built-in microprocessor systems for image processing and vision improvement; they are equipped with external LCDs, memory for image recording and storage (from several to hundreds frames), additional channels expanding functional options. One of the rapidly developing areas of MIRSs application is their use for driving vehicles at night or in terms of restricted visibility (in presence of mist, fog, Rain, snow, dust, smoke, smog and light disturbances, etc.).

From presented in table 2 MIRSs the most interesting is IT-imager TN-4604MP. This imager implements pyroelectric array 300D of company “L3 Communications Infrared Products”, it has been in production for several years and is popular with customers.

In addition to IR-channel there is option to equip this imager with scaled TV channel and remote temperature meter with laser pointer. Integrated processor provides easy switching between IR and TV channels as well as switching on of temperature measuring channel. It also has memory for 100 frames of IR or TV image.
IR-imager «SKAT» is modification of imager TN4604MP, and designed for use on-site. Robust, thermal and shock resistant casing as well as dust and water protection, absence of any moving parts and provided lens protection make this imager reliable instruments for surveillance and control during search and watch activities in sever operation conditions. As IR converter used is pyroelectric array of 320x240 pixels. Also provided is possibility to use this imager with various lenses, i.e. focal length from 18 to 150mm. The «CKAT» instrument can be easily mounted on tripod or pan-tilt module. In several cases this imager and its receiver is used as remote instrument (up to 200m) controlled from remote unit activated via RS port.

3. Stationary IR-systems

The basic specifications of stationary IR-systems produced by STC «SPEKTR-AT» are given in table 3. For comparison given are specifications of American IR-system of similar type - Thermal Eye 5000XP (manufacture company «L-3 Communications Infrared Products» (USA). In infrared imagers of this group used are pyroelectric (similar as in TN4604MP-100 and TSN-MP-50) and bolometric (TSN-MB-2-12 ) IR-converters as well as lenses with various focal length. The IR-imager TN4604MP-100 is equipped with wide aperture, 100mm lens and can solve not only tasks of surveillance, search and tracing but more comprehensive tasks of detailed examination and analysis of heat fields at reasonable distances (up to до 10 м). This instrument also can be equipped with additional channels for temperature measurement, TV, and distance measurement (range finder), etc.

The TSN IR systems have thermo-casing providing its use in low temperatures( from minus 45 to minus 50°C), they also have high level of protection (IP66-IP67) from humidity, dust, etc., all-purpose lock-up for tripod mounting or pan-tilt module. Inside the casing there is slot fro RS PCB installation providing imager control from distance up to 500m.

| TN4604 MP-100 | Spektr (2 & 3-channel) II | TSN-MP-50 (70, 100) | TSN-MB-2-12 | Thermal Eye 5000XP |
| 320x240 | 320x240 | 320x240 | 320x240 | 320x240 |
The most interesting is multi channel surveillance system «SPEKTR». This system may have 2-, 3- and even 4 channels operating in different spectral ranges and unified in one casing mounted on pan-tilt module. Each channel has its own number of input windows and can work separately or simultaneously with other channels. The channels that can be integrated in this system are as follows:

- **IR-channel**, working wave length range 7….14mcm;
- **Laser location**, working wave length range 780….940nm;
- **Near IR**, working ranges 700….1000nm and 1000…1700nm;
- **TV**, working range 350….700nm with spectral sub-ranges with bandwidth 20…50nm, selected automatically by interference filters
- **Measuring** (range finder), working wave length – 1.54mcm;
- **Auxiliary**, to mount various types of IR-torches.

Such combination of various informative channels in one system helps to compensate disadvantages of one channels by advantages of other ones and, as a result, to provide efficient all around the clock work. In table 3 presented only specification of IR-channel of system «SPEKTR» with 100mm lens.

### 4. IR-systems mounted on various platforms

The group of IR-systems mounted on various platforms is rather new, the general view of such systems is presented in Table 4.

In the system «SPLIT» the Unmanned Aerial Vehicle (UAV) is used as a platform for IR-channel. This type of equipment is most efficient and rather promising for monitoring and control over lengthy objects and/or territories nowadays. Due to the fact that it is difficult to compete with the UAVs from the point of controlled area size, there is no any other alternative to be used for surveillance and monitoring of land areas with comprehensive terrain irregularity, reach vegetation, human settlements, i.e. in all places, where direct visibility of objects of interest located close to the land surface is absent.

#### Table 4. IR-systems mounted on various platforms

<table>
<thead>
<tr>
<th>Field of View, deg</th>
<th>9x6.6</th>
<th>9x6.6</th>
<th>18x14</th>
<th>14x10</th>
<th>9x6.6</th>
<th>12x9</th>
<th>24x18</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTR, °C</td>
<td>0.1</td>
<td>0.1</td>
<td>0.12</td>
<td>0.05</td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral range, mcm</td>
<td>7-14</td>
<td>7-14</td>
<td>7-14</td>
<td>7-14</td>
<td>7-14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection / recognition distance, m</td>
<td>1000/600</td>
<td>1000/600</td>
<td>From 500/300 to 1000/600</td>
<td>1000/500</td>
<td>400/200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Standing person</td>
<td>1600/1000</td>
<td>1600/1000</td>
<td>From 800/500 to 1600/1000</td>
<td>2000/900</td>
<td>600/320</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Vehicle</td>
<td>135x210x145</td>
<td>625x305x250</td>
<td>190x320x200</td>
<td>115x390x111</td>
<td>290x280x282</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>5.8</td>
<td>23</td>
<td>4.2</td>
<td>3.1</td>
<td>4.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous operation time, h</td>
<td>IP44</td>
<td>IP44</td>
<td>IP67</td>
<td>IP67</td>
<td>IPX6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The «SPLIT» system is designed for remote monitoring of land and water surfaces in selected area with the aim of detection and control of objects status with simultaneous, referencing to specific point due to on-line transmission to control station of collected via UAV information, i.e. video-image, IR-image, coordinates, etc. In the capacity of objects of interest can be human beings, transportation vehicles, self-floating installations, buildings, etc. The complex consists of miniature UAV, IR-module as well as land based control system implementing Laptop, transmitting-receiving unit and antenna (see Fig. 3). The UAV is battery powered.

**Fig. 3. General view of system «SPLIT» based on UAV.**

The UAV has two operation modes: automatic and manually controlled.

In automatic mode the UAV is flying in accordance with program loaded in control station. While in manual operating mode all commands are generated by Operator via keyboard of control station.

In the flight process the UAV transmit via radio channel information from TV camera and IR-imager with current coordinates of UAV. The flight rout can include up to 99 turn points with set coordinates, operator in any moment can switch on the manual operating mode or return back to automatic one as well as to switch to mode of flyby of interesting point with coordinates correspondent to the moment of receiving of command to maneuver.

The UAVs are used in several countries of the world and first of all in USA for boarder control and airspace protection especially with taking in view of terrorist threats.

In Russian this, so far, is experimental trials because still several technical problems should be solved to enhance the quality of obtained images.

**Conclusions**

It is necessary to say that lately IR equipment is rapidly developing. The results of these works will provide occurrence of universal diagnostic instruments for solving of tasks in various application areas.
Fig. 1. Abilities of search TVSs to detect and recognize technics and people at rather big distances.
Fig. 2. Non-cooled IR-imagers produced by STC «SPEKTR-AT»

Fig. 3. General view of system «SPLIT» based on UAV.