

Development of a System for Automated Finding and Tracking of Thermal Objects

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The presented paper describes the results of an applied research, the aim of which was to develop an optimum configuration of an optical system capable to detect and track thermal objects situated at 0.5 ... 10 m from a point of sight. In the course of the development of the design of the system we reviewed components from various producers, carried out selective comparisons of them and chose the most suitable for the achievement of the goal of the research. During the study we developed an optical scheme of infrared module and an objective consisting of germanium-made lenses. On the basis of the optical scheme we developed the design of the optical module with the combined optical system with an infrared detector of optical channel combined with an image detector in visible spectrum, as well as selected the material of the body taking into account the decrease of the weight of the system. In the course of the study it was decided to include an automatic focusing mechanism for the infrared objective and to measure focal length using a range finder. The study discusses advantages and disadvantages of the most widely spread types of range finders; the most suitable range finder was selected according to the set goal of the research. In addition, the paper discusses a problem of selection of a vacuum pump for the decrease of molecular heat exchange. The breadboard construction obtained in the result of the study represents a finished module and allows to install it on any base.

Key words: optical system, monitoring system, infrared module, tracking of thermal objects, finding of thermal objects, focusing.

Nowadays systems of remote monitoring are in demand in many fields. Security of private establishments or even countries pertains to those fields. As about systems for objects' security, first of all, the most widely spread are video surveillance systems. That kind of systems allows to monitor a certain object remotely. However, video surveillance systems widely spread nowadays have one significant disadvantage: their cameras operate in visible part of spectrum. However,

security often requires finding of thermal radiation by means of infrared optical systems.

In world practice, vision systems are provided with infrared channel (IR-channel) and television channel, which allows to increase sharpness of image (for instance, in systems with advanced visualization).

During development of the optical system we discussed existing image processing systems and analyzed their strong and weak points. On the basis of the analysis results we selected solutions for compensation of weak points of one system using elements of another system, which allowed to obtain combined optical system for finding and tracking of thermal objects.

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In order to obtain a sharper image, the major part of the existing systems uses manual or automatic focusing. Automatic focusing mechanism usually consists of a sensor, a control system and a drive, which moves an objective's mount or some of its individual lenses.

During design of the system for automatic finding and tracking of thermal objects (SAFTTO), initially it was decided to select a sensor for the infrared optical module, design the optical system, select material for the module's body, and then to select additional components for SAFTTO.

Selection of IR sensor

The infrared optical module consists of the infrared sensor and the objective. In order to decrease the weight of SAFTTO, we decided to use uncooled infrared sensors (a microbolometric matrix can be used for that purpose).

The number of IR-matrix elements defines the quality of the obtained infrared image. Aside from functional applicability, minimal size of a thermographic camera's matrix, which can be used for various purposes, can be specified in normative documents. For example, according to GOST R 54852-2011, the size of a matrix must be not less than 160 x 120, and according to RD-13-04-2006 – not less than 240 x 128¹. Size of the sensor's matrix defines resolution of IR objective. Nowadays, the most widely spread types are optical systems with sizes of 160 ÷ 120, 320 ÷ 240 and 640 ÷ 480 pixels. Thermographic cameras are example of that kind of systems.

Design of a matrix detector, which is a part of a thermographic camera is presented in Figure 1¹.

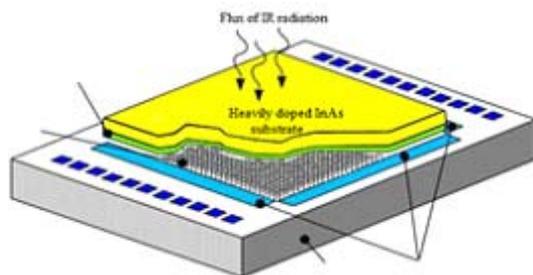


Fig. 1. Design of the matrix detector

The main producers of IR bolometric matrices and modules on their basis available in Russia are as follows:

- a) Raytheon (USA);
- b) Flir (USA);
- c) NEC (Japan);
- d) Ulis (France);
- e) Sensoror (Norway);
- f) Astrohn Experimental Design Bureau (Russia).

In order to meet requirements of a performance specification we selected the following modules and matrices:

- a) Astrohn Iridium 384 (Figure 2)²;
- b) Flir Tau324 (Figure 3)³.



Fig. 2. Module Iridium 384



Fig. 3. Module TAU 324

Comparison of Flir TAU320 and Astrohn Iridium 384 modules are presented in Table 1 below. Module Iridium 384 is the best solution for achieving goals of the research as it has the highest resolution with other characteristics being similar (Table 1).

Design of the objective

After selection of the sensor we designed the objective, which allowed to observe objects situated at 0.5 ... 10 m from viewpoint.

In order to solve that problem we developed the objective made from germanium with 1:1 relative aperture and operating in 7.8 -14 μm range for joint work with microbolometer matrix

Table 1. Comparison of IR modules

Characteristics	TAU324	Iridium 384
Producer	FLIR	ASTROHN
Micro-bolometer	Uncooled Vox micro-bolometer	Uncooled micro-bolometer
Image aspect ratio	324 × 256 (PAL)	384 × 288 (PAL)
Size of pixel	17 μm	17 μm
Spectral range	7.5-13.5 μm	7.5-13.5 μm
Full frame frequency	7.5 Hz (NTSC)/8.3 Hz (PAL)	25 Hz PAL
Frame frequency for free export	7.5 Hz (NTSC)/8.3 Hz (PAL)	License is not required
Power supply	4.4-6.0 V DC	3.7-6V
Power dissipation	~1.0 W in operational mode	~1.2-1.5 W in operational mode
Sensitivity (temperature equivalent of noise)	50 mK for f/1.0 with proprietary noise reduction FLIR technology	50 mK for f/1.0 with proprietary noise reduction technology
Time to obtain an image	3.5 s	3-5 s
Video with automatic gain control (AGC) as factory setup, which can be turned on by user	Yes	Yes
DDE	Yes	Yes
Physical parameters		
Dimensions (without objective)	38 × 38 × 29.5 mm (1.5" × 1.5" × 1.16")	45 × 45 × 49 mm
Configuration with objective and without it	Yes	Yes
Mounting holes (M2 × 0.4) from 3 sides (2 holes per side)	Yes	Yes
Sealing mounting on partition at an objective's tube (M29 × 1.0), only wide-angle	Yes	Yes
Compliance with directives ROHS, REACH and WEEE	Yes	Yes
Interface and control		
Parallel CMOS (16 or 6 bit)	Yes	Option
BT.656 (8 bit)	Yes	Yes
NTSC (30 Hz)/PAL (25 Hz) (with fast switching)	Yes (requires license)	PAL (25 Hz)
Slow video (7.5 Hz NTSC/8.3 Hz PAL) (factory setup)	Yes	No
Inverting/Restoration (analogue and digital 8 bit)		Yes Yes
Control of polarity	Yes	Yes
Digital zoom 2x, 4x and 8x	Yes	Yes
Change of dynamic range	Yes	Yes
Symbols (256 grey and 256 color)	Yes	Yes
Color and black-and-white palette	Pseudo-color	PAL w/b
Connection		
Compatibility with RS-232	57,600 or 921,600 baud	57,600
USB-RS-232 adapter	Yes	Not required
User setup via SDK and GUI	Yes	Yes
Camera Link	Yes	Option
Input/Output	Yes	Option
Discreet control via input/output	Yes	Yes
Environment parameters		
Range of working temperatures	From -40 °C to +80 °C	From -40 °C to +60 °C
Range of storage temperatures	From -55 °C to +105 °C	From -55 °C to +105 °C
Temperature drop (5/min)	Yes	Yes
Working height (+12 km or 40,000 feet)	Yes	No testing results
Humidity (5-95 % no condensate) of the Russian Federation	Yes	Group 5 according to GOST
Vibrations (4.3 g along 3 axes for 8 hours)	Yes	
Impact resistance (200 g with difference during 11 μs)	Yes	Yes
EMP according to B class FCC/CE	Yes	Yes

with 384×288 form factor, size of sensitive area of 10.88×8.16 mm and size of sensitive layer of an element of $17 \times 17 \mu\text{m}$.

It is worth mentioning that size of image of a point source must not exceed size of a sensitive element.

Focal length of the objective was selected according to the necessary value of field of vision $2W = 30^\circ$, which corresponds to the large size of the microbolometric matrix:

$$f' \cdot \text{tg} W = L' \text{ max} \quad \dots(1)$$

where

- f' – focal length of the objective,
- $2W$ – field of vision,
- L' – size of a sensitive area.

Field of vision of the objective is $30^\circ \times 22.7^\circ$ (37° – diagonal). The objective layout is presented in Figure 4, where 1 – first lens with a positive meniscus, convexity directed towards the objective, 2 – second lens with a negative meniscus, concavity is directed towards the objective, 3 – third length with a positive meniscus, concavity is directed towards the object, 4 – fourth lens with a positive meniscus, convexity aimed towards the object. Backward focal distance $S_2 f_2 = 9.8$ mm.

Lenses of the objective have antireflective coating for the working range.

Weight of the objective is 0.0308 kg.

Length of the objective with the backward focal distance is 42.3 mm.

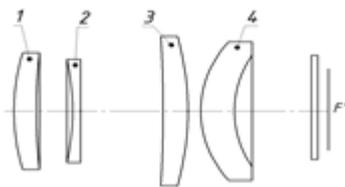


Fig. 4. Layout of the objective

Figure 5 demonstrates function of concentration of the objective's energy.

Figure 6 demonstrates contrast transfer function of the objective.

The objective features high image quality, which allows to effectively use it with bolometric matrices including matrices with $17 \mu\text{m}$ pixel.

In a case of using of that objective at

distances of 0.5 ... 10 m it is necessary to carry out overfocusing:

For 0.5 m – 0.82 mm;

For 10 m – 0.04 mm.

We decided to use automatic focusing system for overfocusing.

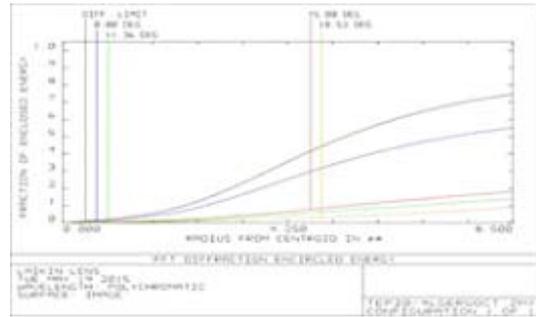


Fig. 5. Function of concentration of the objective's energy

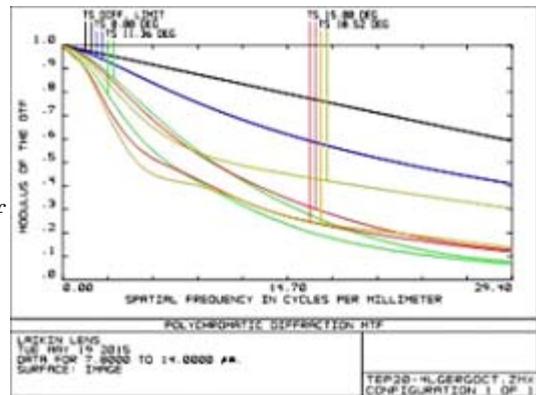


Fig. 6. Contrast transfer function of the objective

Selection of the body's material

For manufacturing of the body we selected several types of materials (stainless steel 4, D16T aluminum, PA6 polyamide (kaprolon)).

Initially, we selected AISI 304 steel as the main structural material. That grade of steel is the most widely spread and universal austenitic chrome-nickel heavily-doped corrosion-resistant steel, together with AISI 304L. That grade of steel has the following advantages as structural material:

- a) Resistance to oxidation;
- b) Good weldability;
- c) Mechanical processibility;
- d) Significant mechanical strength (ultimate tensile strength 515 N/mm^2).

AISI 304 (08H18N10) steel has the following characteristics ⁴:

- a) Density 7,800 kg/m³;
- b) Brinell hardness 123;
- c) Knoop hardness 138;
- d) Tensile strength, Ultimate 505 MPa;
- e) Tensile strength, Yield 215 MPa;
- f) Elongation at Break 70 %;
- g) Modulus of Elasticity 193-200 GPa;
- h) Poisson's ratio 0.29;
- i) Shear Modulus 86-200 GPa;
- j) Electrical Resistivity 7.2e⁻⁵ Ω/cm;
- k) Magnetic Permeability 1.008;
- l) Specific heat capacity 0.5 J/(g.K);
- m) Thermal conductivity 16.2 W/(m.K);
- n) melting temperature 1,400-1,455 °C.

Designed weight of the module manufactured from AISI 304 steel was, approximately, 300 g. It was decided to select material, which would allow to decrease weight of the IR module.

Weight of the module with the same design can be decreased by means of application of other materials. We used PA6 kaprolon (polyamide) as structural material.

Kaprolon has the following characteristics ⁵:

- a) Density 1,150-1,160 kg/m³;
- b) Melting temperature 220-225 °C.
- c) Working temperature 110 °C;
- d) Modulus of elongation 3,000 MPa;
- e) Rupture at tension stress of 80 MPa;
- f) Relative elongation 15-30 %;
- g) Water absorption for 24 hours 1.5-2 %;
- h) Thermal conductivity 16.2 W/(m.K);
- i) Dielectric permeability 3.3;
- j) Brinell hardness 160-180 MPa;
- k) Breakdown strength 30-35 kV/mm;
- l) Charpy impact energy 20-70 kJ/m.

Design weight of the IR module decreased to 60 g. However, the difficulty in manufacturing kaprolon body is that range of kaprolon products (plates, bars, blocks) doesn't include pipes. Therefore, manufacturing of the bodies will require turning and milling, which will lead to high amount of waste materials. In addition, mechanical processing of kaprolon can lead to formation of residual stresses in the material, which, in turn, can lead to failure of calibration of the device. Another method of manufacturing using polyamides is jet molding. Jet molding doesn't

produce waste materials, but it requires large investments for preparation for manufacturing.

After design of the optical module we simulated thermal processes in Ansys software, which demonstrated that kaprolon body doesn't provide enough heat removal from IR matrix. Thus, there is a need to select material with density close to kaprolon, but with higher thermal conductivity. Among structural materials with high thermal conductivity there are copper (401 W/m²°C) and silver (430 W/m²°C). However, these materials have not only high thermal conductivity, but also high density 8,940 kg/m³ and 11,500 kg/m³, respectively. High density makes application copper and silver alloys unreasonable. Light materials with high thermal conductivity and density, which is close to those of kaprolon are alloys of aluminum and titanium. We selected aluminum alloy D16T and titanium alloy VT22 (Table 2) as applicable materials.

Table 2. Comparative characteristics of structural materials

Characteristics	Kaprolon	D16T (1160 alloy)	VT22
Density, kg/m ³	1,150-1,160	2,770	4,620
Melting temp., °C	220-225	650	1,668
Operating temp., °C	110	175	350
Modulus of elongation, MPa	3,000	70,000	110,000
Relative elongation, %	15-30	Up to 19	2.5 - 30
Thermal conductivity, W/(m.K)	0.3	130	Up to 20
Brinell hardness, MPa	160-180	420	103
Charpy impact energy, kJ/m	20-70		0.12

From the table it is clear that D16T alloy is the most suitable for solution of the problem. Thus, design weight of IR-module is, approximately, 120 g, and heat removal through walls of the body is sufficient for cooling of IR-matrix, which allows not to avoid forced cooling.

Overview of the body is presented in Figure 7.

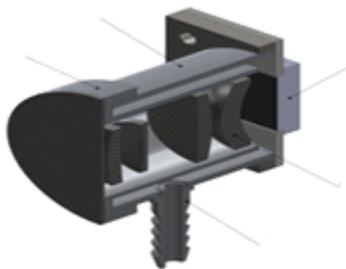


Fig. 7. Overview of IR-module

According to the optical scheme it is necessary to move the objective in ranger 0.04-0.082 mm. For that a notch is to be made on the body similar to regular photo cameras of visible spectrum. Focusing in range of distance 0.5 ... 10 m will be carried out by means of rotation of the objective.

Image registration in visible range

We considered CMOS and CCD matrices as options for image registration in visible range (Figure 8) ⁶.

CCD stands for charge-coupled device. The principle of operation consists of initial selection of image in analogue mode and further digitalization ⁷.

CMOS stands for complementary metal-oxide-semiconductor

The main advantages of CMOS matrices as compared to CCD are as follows ⁶:

- Low manufacturing cost.
- 100 times lesser power consumption.
- High performance.
- Capability to free reading of cells, which eliminates smearing effect.

CMOS has the following disadvantages as compared to CCD

- Smaller light sensitivity due to small size of a light-sensitive cell as compared to pixel's size, the major part of space is occupied by electronic components.
- Increase of noise on an image due to need to use of preamplifier.
- Rolling shutter effect. It is observed, generally, in cases of taking images of rapidly moving objects, and it consists in distorted imaging of objects.

Advantages of CCD as compared to CMOS:

- Electronic shutter, which allows sharp fixing of rapidly moving objects.
- Absence of vibrations and rolling shutter effect.

For solution of the set problems the most important factors were power consumption and low cost. Appearance of rolling shutter effect was considered unlikely, because speed of scanning of space was comparatively low. Thus, the optimal solution was application of CMOS-matrix for registration of images in visible part of spectrum.

Nowadays, there are following main producers of CMOS-matrices

- CMOSIS (Belgium);
- Aptina (USA);
- Sony (Japan);
- Anafocus (Spain).

For applications related with image recognition at 0.5-10 m required and sufficient solution is a module with 720p resolution. As the result, we selected ICX278AK matrix of 1/4" form-

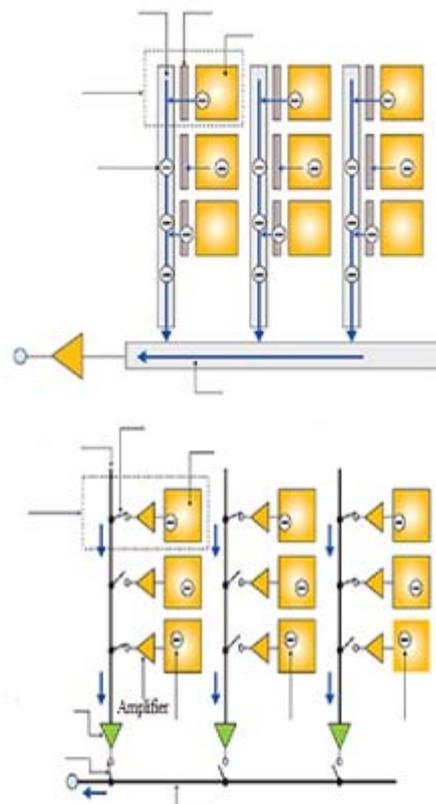


Fig. 8. Structure of CCD (a) and CMOS matrices (b)

Selection of range finder

In a case of combination of two objectives the main goal will be to focus both of them at one point in range 0.5-10 m.

For focusing of IR-objective we planned to develop the objective with germanium-made lenses and electronic focusing. An objective with electronic control also will be installed onto the matrix of visible range. Thus, during manufacturing it will be necessary to only adjust both objectives for operations in the designated range of distances,

In order to automatically focus objectives it is necessary to know distance to observed object. In order to measure distance to an object it is necessary to use a range finder.

Nowadays the most widely spread type of range finders for domestic applications are laser range finders (Figure 9) and ultrasonic range finders (Figure 10) ¹⁰. The discussed problem requires distance measurement in range of 0.5-10 m.

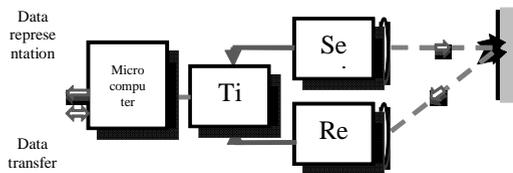
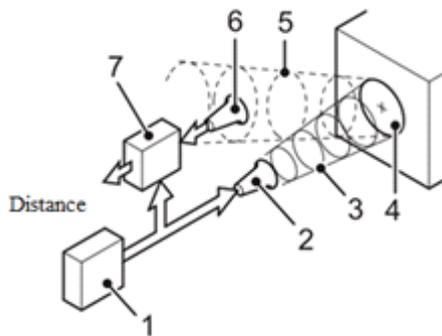


Fig. 8. Scheme of operation of a laser range finder



1 – generator, 2 – ultrasonic transmitter, 3 – transferred ultrasonic pulses, 4 – measure object, 5 – reflected wave (echo), 6 – ultrasonic receiver, 7 – calculator unit

Fig. 9. Scheme of operation of an ultrasonic range finder

Laser range finders’ principle of operation consists in comparison of phases of sent and received light signals That kind of range finders don’t have the major part of disadvantages of

ultrasonic range finders. Laser range finder allows to detect precise distance for any point of any size. Maximum distance of measurement is 250 m, however, it, generally, doesn’t exceed 50 m; moreover, laser signal is not dampened by carpets and door curtains. At that, measurement inaccuracy is minor – about 1-5 mm. However, in outdoors conditions with bright sunlight laser beam losses its brightness, which complicates operation at big distances.

Ultrasonic range finders are operating in a manner, which is similar to sonic depth finder: the device sends directed beam of sound waves in ultrasonic range (about 40 KHz), picks up their reflection from a distant object; after that on a basis of analysis of time of sound waves’ return it calculates the distance and shows values on a display. That kind of design has disadvantages, the main of which is that the end point must be a quite big object, which can reflect cone-shaped beam of sound waves. As the beam is cone-shaped maximum measurement distance doesn’t exceed 35 m. Also, it worth mentioning that many materials (fabrics, carpets, sound insulation, etc.) can effectively dampen sound and therefore measurement results will have higher inaccuracy.

Analysis showed that for solution of the set task a laser range finder is better as compared to an ultrasonic range finder. It is related with the fact that there can be several observed objects, and size of an object can be small.

A range finder must meet the following requirements:

- a) Minimum measurement distance 0.5 m;
- b) Maximum measurement distance not less than 10 m;
- c) Measurement inaccuracy 5 cm;
- d) Analogue and digital output.

We selected a laser range finder from the following producers: Astech (Germany), Flir (USA) and Schmitt Measuring Systems (USA).

There are many laser range finders that meet the requirements among the products of the mentioned producers.

Astech company: range finders of LDM30x, LDM40x, LDM51 and LDS30 series ^{11,12}.

Flir company: laser ranger finders of K series and very compact laser range finders of MLR series.

Schmitt Measuring Systems company:

laser range finders AR200, AR1000 and AR4000¹³. Laser range finders of these producers have established reputation in world markets. For solution of the discussed design problem we excluded range finders supplied in a body as a finished product from the selection. The main reason for that was large sizes of a body and big weight of a device.

Thus, we reduced the selection set to the following modules:

- OEM laser module RF41 (Astech) (Figure 10, Table 3)¹⁴;
- OEM laser module LDS30M (Astech) (Figure 11, Table 4)¹²;
- OEM laser module RF51 (Astech) (Figure 12, Table 5)¹⁵;
- MLR 100 (Flir) (Figure 13, Table 6)¹⁶.



Fig. 10. Module RF41

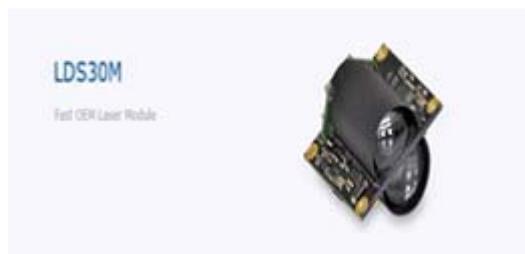


Fig. 11. LDS30M



Fig. 12. Module RF51

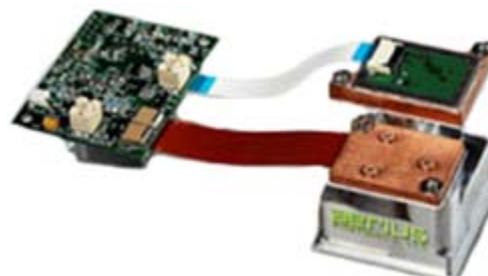


Fig. 13. MLR 100

Table 3. Specification of module RF41

Characteristics	Value
Measurement distance	0.2 ... 30 m
Measurement inaccuracy (from -10 °C to +50 °C)	From ±2 mm to ±5 mm
Resolution	0.1 mm
Repeatability	0.5 mm
Operating temperature	from -10 °C to +50 °C
Power supply voltage	10 ... 30 V DC
Power consumption	1.5 W
Interfaces	RS232, RS422, relay output, analogue output
Weight	220 g

Table 4. Specification of module LDS30M

Characteristics	Value
Measurement distance	0.2 ... 30 m
Measurement inaccuracy	±5 mm
Resolution	0.1 mm
Repeatability	±2 mm
Operating temperature	from 0 °C to +50 °C
Power supply voltage	6.5 ... 7 V DC
Power consumption	3 W
Interfaces	RS422
Weight	50 g

Table 5. Specification of module RF51

Characteristics	Value
Measurement distance	0.1 ... 500 m
Measurement inaccuracy	± 1 mm
Resolution	0.1 mm
Operating temperature	from -40 °C to $+60$ °C
Power supply voltage	10 ... 30 V DC
Power consumption	10 W
Interfaces	RS422
Weight	50 g

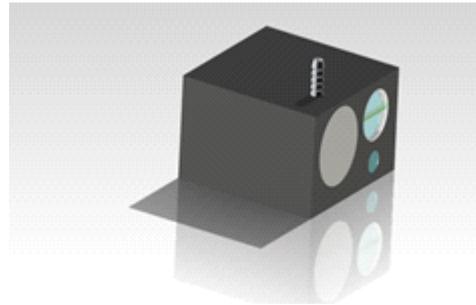
Table 6. Specification of module MLR100

Characteristics	Value
Measurement distance	0 ... 30 m
Measurement inaccuracy	± 5 mm
Resolution	0.1 mm
Repeatability	± 2 mm
Operating temperature	from 0 °C to $+50$ °C
Power supply voltage	6.5 ... 7 V DC
Power consumption	400 mW
Interfaces	3-wire serial clock, RS232
Weight	22 g

Among these modules the most suitable for installation are RF41¹⁴ and RF51¹⁵. Another important advantage of these modules is power supply voltage of 10 ... 30 V, because that voltage is required for step motors used in the design. The main disadvantage of RF41 module is its high weight. As a laser range finder is to be installed on a rotating platform, it is reasonable to reduce weight of a laser range finder as much as possible. Modules LDS30M¹² and MLR 100¹⁶ have the lowest weight. They have the common disadvantage, which is power supply voltage of 6.5 ... 7 V, which will require installation of an additional power supply; however, a power supply is installed inside the electronic module, but not on the rotating platform, therefore its weight is not critical. As the result, we selected LDS30M¹² module for solution of the discussed design problem, because it is the most convenient from the point of view of installation into the body.

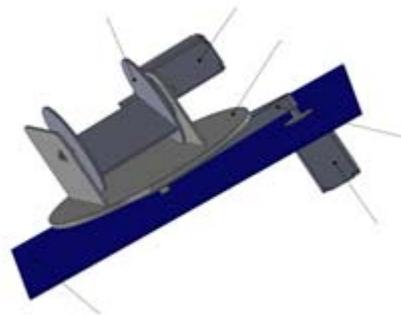
Design of the body's model

The IR-module together with the module of image registration in visible range and a laser range finder is installed in the plastic case.

**Fig. 14.** Module of image registration

In order to meet the requirement for scanning of space the module of image registration of the micro system device (MSD) is installed on the rotating platform, which allows to rotate the optical part for at least 90 degrees in horizontal plane and at least 30 degrees in vertical plane.

The rotating platform consists of a horizontal base plate for rotation in horizontal plane. Rotation of the plate is carried out by means of the step motor with a belt drive. A carriage for vertical rotation, on which the optical module can be installed, is attached to the platform. The carriage for vertical rotation is attached using bearings. Rotation of the carriage is carried out by means of the step motor and the belt drive (Figure 15).

**Fig. 15.** Rotation mechanism of SAFTTO

As the step motor we tentatively selected FL28STH51-0956A motor produces by SPC Electroprivod¹⁷ with the following characteristics:

- Capacity – 11.5 W in quasi-static mode.
- Power supply voltage – 12 V in quasi-static mode.
- Torque – 0.9 kg.cm².
- Moment of inertia – 1.8 g.cm².
- Weight – 0.2 kg.

Thus, the total consumed power of the rotation mechanism is 23 W with the total current consumption of 1.8 A, while according to the requirements specification the current consumption is not to exceed.

The total weight of the rotation mechanism is approximately 550 g.

The plates and the carriage are produced from ABS-plastic in order to reduce weight of structure.

The rotation mechanism with the installed module of image registration is mounted onto SAFTTO control unit (Figure 16).

There are several modules placed inside the control unit:

- a) Power supply module.
- b) Step motors control module.
- c) Vacuum pump control module.
- d) Focusing module.

The power supply module distributes power coming to MSD between the components.

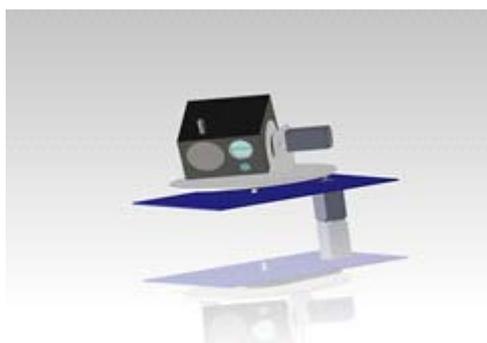


Fig. 16. Rotating platform with image registration module

Step motors control module is a power module, which supplies power from the power supply module to step motors. The module controls speed of rotation of step motors to provide an object's tracking and direction of the motors' rotation. We decided to use two programmable step control units produced by SPC Electroprivod SMSD-1.5 as the module for control of the rotating platform with two step motors (Figure 17, Table 7)¹⁸. That unit was selected as the recommended by SPC Electroprivod for control of FL28STH51-0956A step motors.

Table 7. Specification of SMSD-1.5 control block

Winding peak current, A:	0.16-1.6
Coefficient of step division (microstep)	1/2, 1/4, 1/8, 1/16
Range of frequencies of moving pulses, Hz	1-10,000
Power supply voltage, V	10-30
Environment temperature	-25 ... +30 °C
Relative humidity	Up to 90 % for 25 °C
Atmospheric pressure	(650 ... 800) mm Hg

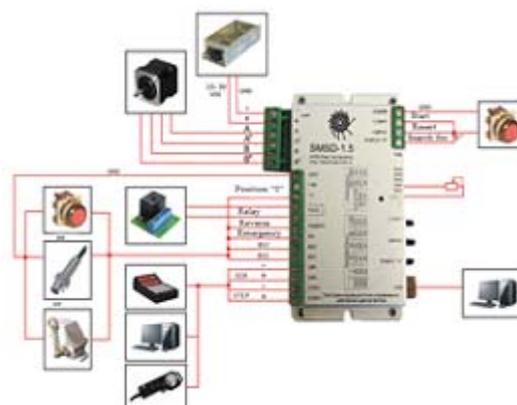


Fig. 17. SMSD-1.5 control block

The vacuum pump control module is a power module, which receives data from a vacuum sensor, which is situated in the IR-module, and controls a vacuum pump.

As the vacuum sensor we selected PSE561¹⁹ with measurement range of 0~101 kPa.

Selection of the vacuum pump

Analogue signal of the sensor comes on controllers of a control card of the vacuum pump. In a case a value from the sensor is lower than a setting, the vacuum pump is started. We selected the vacuum pump for the solution of the discussed design problem from plate-rotor, membrane and spiral type vacuum pumps.

Plate-rotor vacuum pumps can belong to two sub types: oil and non-oil. That type of the vacuum pump is the most efficient in range of low vacuum. The main advantages of that kind of pumps: air cooling, capability to pump out vapors, low level of vacuum with large capacity.

Membrane vacuum pumps are the most compact, practical and multi-functional type of vacuum pumps. The main advantages of that kind

of pumps is their simple design, small sizes and ease of operation.

Spiral-vacuum pumps consists of two spirals placed with 180° shift, Thus, principle of operation consists of rotation of areas with different volumes. A spiral rotated by a motor commits orbital revolutions, and, thus, appeared gas cavities are decreasing and gas is pressed from center to periphery. The main advantages of that kind of pumps are absence of oil during compression process, high efficiency, low residual pressure, low weight and low power consumption²⁰.

We considered low weight, small sizes, low power consumption and durability as main requirements for a vacuum pump.

Spiral and plate-rotor vacuum pumps are quite big and heavy, which doesn't allow to use them in the designed structure. Thus, we selected membrane vacuum pump.

There is no wide variety of products in vacuum compressors market. The major portion of the market is occupied by Chinese producers. KNF company is one of European producers.

KNF company has KNF FLODOS division, which specialized in production of membrane mini-pumps of OEM series²¹.

For solution of the discussed design problem we selected a pump from NMS series (productivity will be selected experimentally) (Figure 18).

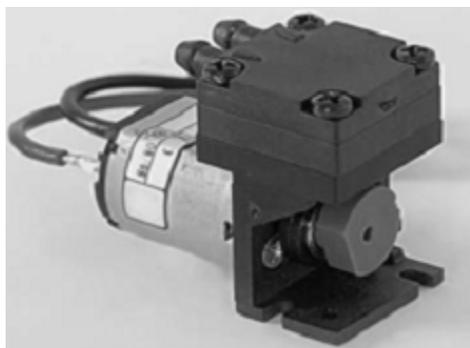


Fig. 18. NMS series pump produced by KNF company

CONCLUSION

As the result of the applied research aimed at development of design of SAFTTO we selected the components and implemented the design

solutions as follows:

a) IR-module is produced from D16T aluminum. The main body is produced from pipe of 32 mm diameter and wall thickness of 3 mm. Flanges are manufactured from plates by means of milling. Parts of the objective are produced from D16T aluminum alloy by means of milling and turning. The objective is fit with germanium-made lenses according to the optical scheme. Iridium 384 module is used as IR-matrix.

b) The IR-module together with the laser range finder and the matrix for image registration in visible range is placed inside the plastic body. We used LDS30M laser range finder produced by Astech company. As the matrix for image registration in visible range we used ICX278AK matrix produced by Sony. The laser range finder allows to measure distance to an observed object, and the software sends commands to the automatic focusing mechanism's drives for focusing on the object.

c) The plastic body with the IR-module, the matrix for image registration in visible range and the laser range finder are mounted onto the rotating platform, which can rotate in X and Y axes. The rotating plate is actuated by means of FL28STH51-0956A step motors produced by SPC Electroprivod. Step motors are managed by means of the control unit SMSD-1.5 produced by SPC Electroprivod.

d) The rotating platform is situated on the body of the electronic unit, in which there are 24 V power supply, SMSD-1.5 control unit, control cards and interface cards.

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