DEVELOPMENT OF COMPLEX METHODOLOGY OF AEROSPACE SYSTEMS CONTINIOUS MONITORING AND FAILURE PREDICTION

The head of scientists teams

Professor Gela Kipiani

Secretary-General of the Georgian National Committee
of Theoretical and Applied Mechanics
Full Professor of the Department of Engineering Mechanics
of Georgian Technical University
M.Kostava 77
TBILISI 0175
GEORGIA
gelakip@mail.ru
gelakip@gmail.com
Tel : +995 32 2371984 (office)
+995 32 2342571 (home)
+995(8)599 106263 (mob)

1. Essence of the Project and its Scientific Value

1.1 Purpose of the project, tasks to be accomplished for each stage and indicators of the expected results

Nowadays one of the greatest problems in the world is building's and structure's damages, accidents of aircrafts, railways, vessels, gas and oil terminals, etc. accompanied with financial and human losses. Therefore, it is essential to elaborate the methods of detection of the defects caused by dynamic load at construction operation and of prognosis of the caused accidents.

The development and perfection of contemporary construction monitoring systems greatly depends on the improvement of their units without which device dependability can not be imagined.

Use of fiber-optical and intellectual sensors in technical diagnostics of structures damage can be assumed as a fundamental trend in technique development. The realization of constructions structural integrity monitoring with the created systems can boldly be considered as the newest most effective and realistic trend.

The contemporary systems of construction failure monitoring are to contain information diagnostic mechanisms equipped with intellectual sensors included in unite diagnostic system.

The urgency of the problem is mainly expressed by the fact that monitoring system elaborated in the project is very pressing and useful in emergency situations for information services. The tragedies of September 11, 2001 in USA, in 2004 in Moscow, in March 2011 in Japan caused with emergency (catastrophic) situations, revealed very acutely the crisis caused by the lack of modern information systems. The necessity of modern opto-electronic devices for forecasting of the expected dangers and permanent monitoring of constructions became evident.

Various theoretical and practical works performed in this sphere are known.

Here is given the list of practical works corresponding to the project:

- Checking of Baku-Jeihan oil main with fiber-optical sensors;
- Periodical tests of structures with portable checking equipment, recording of separate measuring parameters (deformation, pressure, temperature, humidity).

Positive sides of this equipment are:

- Structure durability control;
- Defects detection;
- Crack size determination;
- Temperature determination;
- Pressure measuring;
- Humidity estimation;

- Estimation of separate parameters.

Common negative sides of these systems are:

- Non-generality, periodicity, inability to measure several parameters simultaneously;
- At dynamic impact structural behavior is characterized with parameter spectrum where unique dependence of stress-strain has a great importance. There is no model for structure determination which shows the character of variation of impact load induced acceleration. Moreover, shock effect response is not considered as transient process;
- The existing approach depends on initial conditions which are not sufficiently studied. Therefore it is advisable to find new methods of failure monitoring as the existing methods do not give such possibility;
- These systems cannot prognosticate structure failure;
- Systems cannot not ensure permanent monitoring of structures;
- Monitoring is performed periodically and do not give dynamic picture.

Based on world achievements in the sphere of structures failure monitoring we can conclude that at present there exist high sensitive sensor devices with numerous single (or double) function which serve the solution of one of the enumerated functions: strain measuring, stress determination, diagnostics of pressure, temperature, dynamic action and structure state as a whole.

Preliminary study of patent researches confirms that universal monitoring system elaborated by the group of authors is noted with high accuracy of measurements and unique hardware and software and enable to perform permanent monitoring of structure condition. Nowadays such system has no analogy in the world.

Various theoretical and practical solutions are known in this sphere, they are attached to the presented project.

The innovation of research can be formulated in the following stages:

1. Comparative analysis of damage diagnostic fiber-optical and intellectual sensors that serves for estimation of compatibility of the sensor to the stated task.
2. Investigation of the effect of aggressive medium and perturbation factors on sensors sensitivity and setting up of faults algorithm.
3. Investigation of the value of structure damage and deformation describing signals in sensors.
4. Investigation of methods of signal processing received for structure and device state monitoring.
5. Creation of logical and mathematical criteria and proving of the possibility of measuring of deformation processes with dynamic action fiber-optical sensors.
6. Test verification of research results and creation of monitoring system laboratory facility. In the Georgian Technical University over a period of years theoretical and experimental researches relevant to the project were being performed.

Research innovation is on the existing basis and with contemporary approach to develop such system which will be able to provide constant monitoring of structures and prognostication of structure failure.

The basis of project elaboration is Georgian patents 1173, 3415, 3416, 1107 received by authors group.

Fig. 1 presents block scheme elaborated by authors group. It consists of research object 1, fiber-optical sensor 2, fiber-optical accelerometer 3 and information processing block 4.

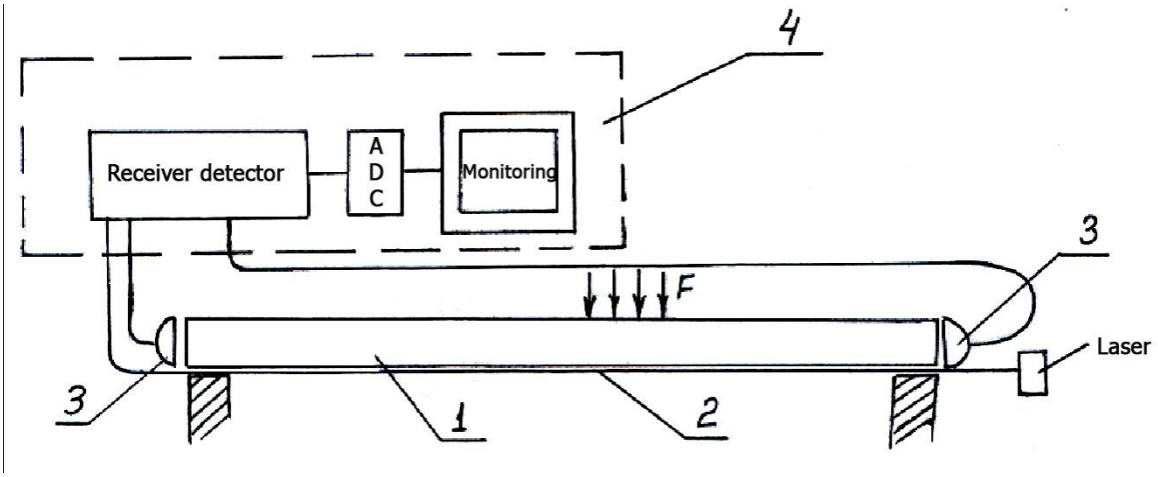

Fig.1. Test bench

Fiber optical sensor applied on the whole length of element enables to determine its deflection (deformation) and acting force value. Reaction forces in supports are determined with accelerometer. When reaction forces are stated it is possible to determine resultant force value and mesh point, i.e. expected dangerous section. With this scheme we need no deflectometer. With mathematical model elaborated by us and which is in computer we can determine the precondition of element failure.

Let's give some examples of the carried out tests.

Example 1. On metal beam lying on two supports of steel 3 a=10mm, b=20mm, l=300mm, E=210mPa acts force (Fig.2). Force application spot, deflection and force value, failure precondition and critical force are to be determined.

In order to solve the problem fiber-optical sensor is applied on the lower surface of beam on the whole span, while close to supports accelerometer is mounted for reaction forces determination.

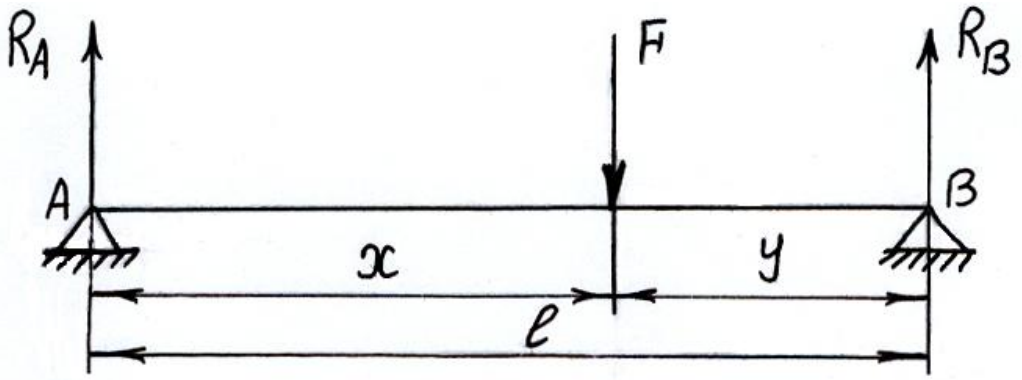

Fig.2. Design diagram

Results of measuring are given in Fig.3 which shows that reactions R_A and R_B are determined with accelerometers, then with the elaborated program x and y distances or F force mesh point are determined while acting force F is determined with optical-fiber sensor. Then F force is increased until beam failure which is fixed with optical-fiber sensors.

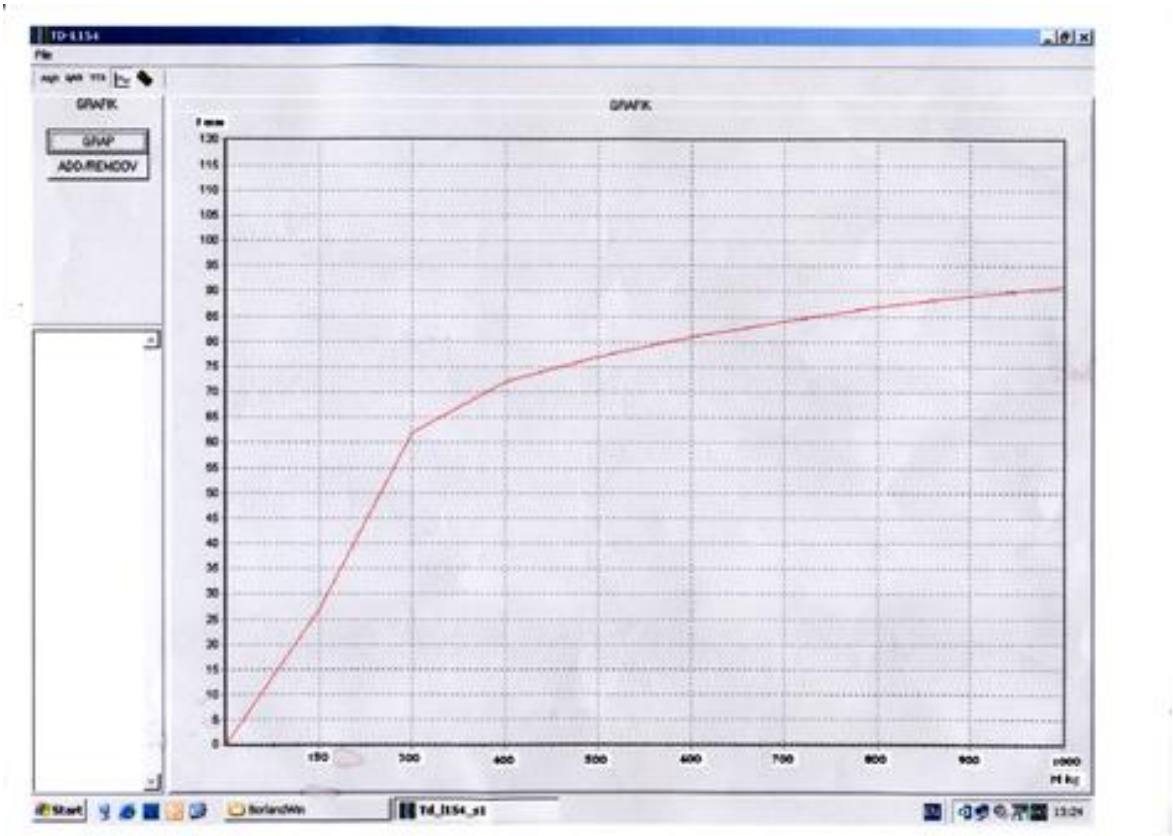

Fig.3. Measuring results.

Fourier spectral analysis of the received signals is given in Fig.4.

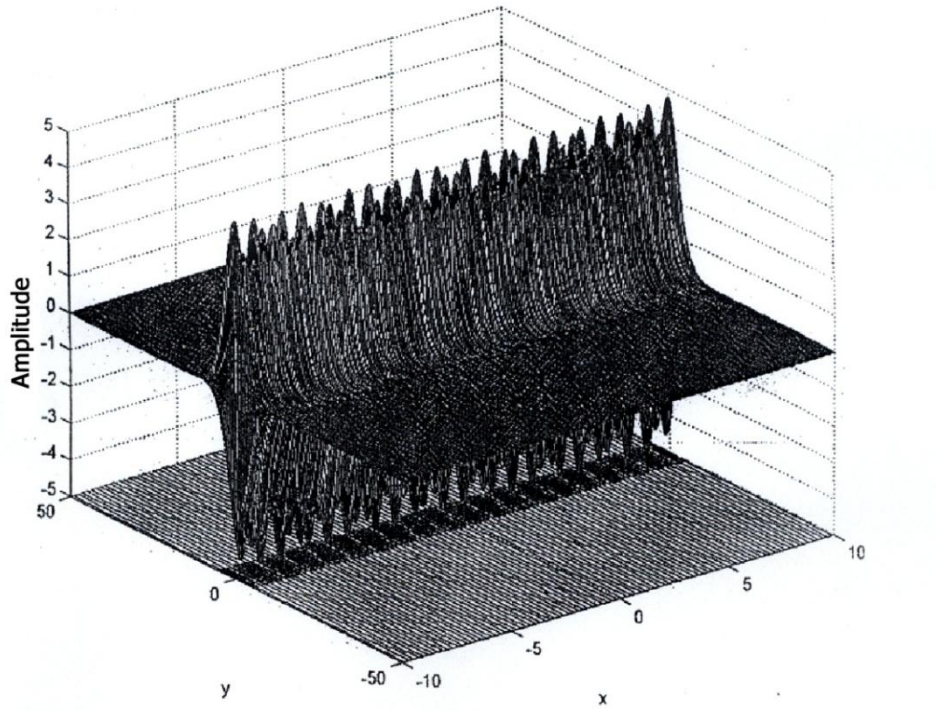

Fig.4. Fourier spectrum

Fourier spectrum analysis shows that peaks are gathered in maximum force mesh section and their amplitude achieves maximum which points the precondition of beam destruction.

Optical-fiber sensor was applied to the given plate which is shown in Fig.5, while Fig. 6 shows general view of test bench.

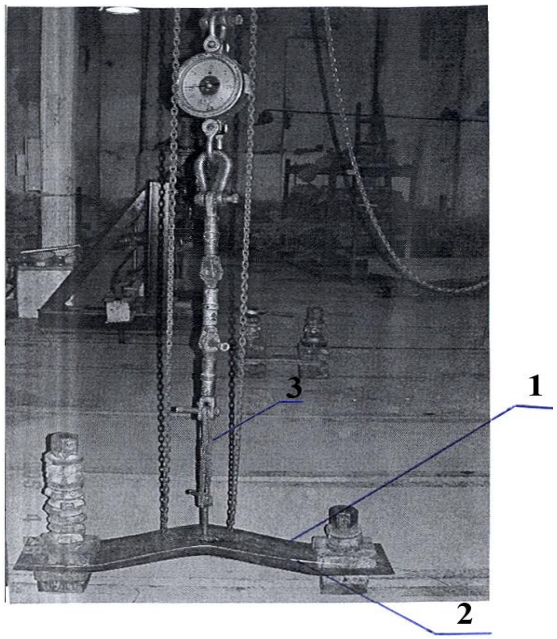

Fig.5. Diagram of test performance
1. Fiber-optical sensor, 2. Plate, 3. Applied force

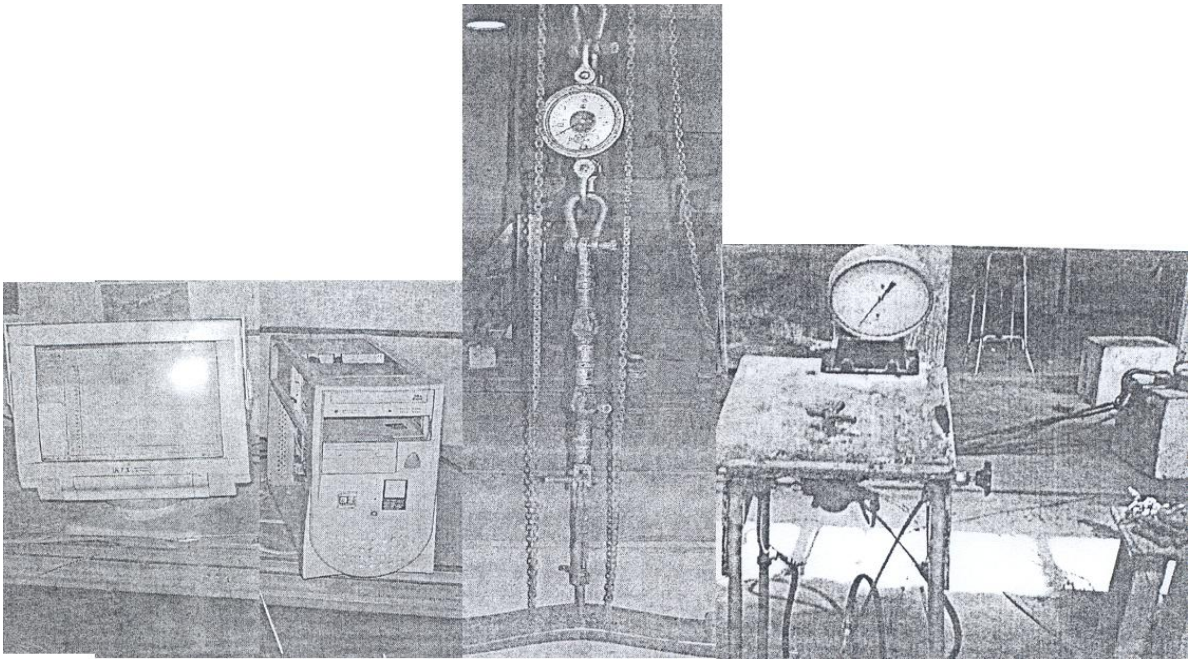

Fig.6. General view of test bench

Fig.7 shows the diagram corresponding to experimentally received pulses in case of 1500 load and Fig. 8 gives the respective spectral analysis.

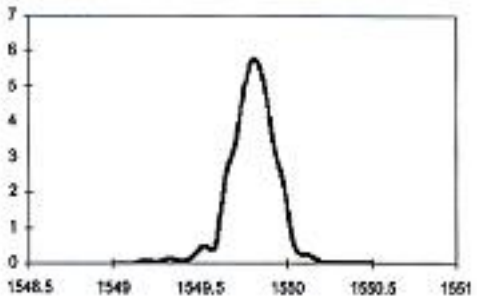

Fig.7 Results of measurements

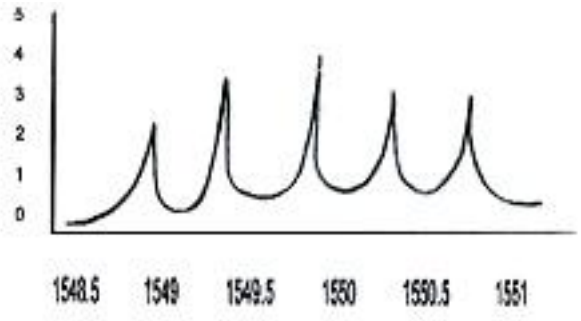

Fig.8. Fourier spectral analysis

Disadvantages at structural integrity monitoring of buildings indicate the necessity of creation of simplified system of multi functional monitoring (diagnostics) which will be able to study stress-strained state of investigated object, to perform integrity control of the whole structure (equipment) and to give prognosis on the prospective breakdown.

The implementation of the mentioned project will support the development of new effective trend for studying structural integrity of structures.

The developed device can be successfully used in continuous structural integrity monitoring of buildings, bridges, flyovers, tunnels, flying vehicles, railways, oil and gas conduits, dams and other risk objects.

The realization of the mentioned project will be a great progress implementation of effective direction of structures failure monitoring.

The problem is urgent as device re-equipment is impossible without the mechanisms worked out in the project. In this case emergency service acquires a special role.

The essence of the project consists in the increase of safety of different type structures conditions, in elaboration of reliability and constant monitoring systems.

The purpose of the project is to develop such system of constant monitoring which will control structures workability and integrity, creation of pre-prognostication logical-mathematical criteria of strength estimation of structures which will help to avoid prospective accidents and catastrophes.

In order to achieve the goal the following objectives were aimed to be solved:

1. Comparative analysis of fiber-optical and intellectual sensors which serves sensor connection to the assigned task in order to realize continuous monitoring of failures.

2. Study of the effect of aggressive medium and perturbation on sensor sensitivity and setting up of flaw algorithm.
3. Research of sensor signals depicting construction failure and deformation.
4. Research of the methods of received signals processing for construction state monitoring.
5. Creation of logical mathematical criteria and proving of the possibility of deformation processes measuring with dynamic action fiber-optical sensors.
6. Creation of software-hardware complex block-diagram of monitoring, choosing its joints and elements, software of complex control. Creation of signal detection program from sensors.
7. Checking of software-hardware complex operation with numerical experiments with simulation of different problems
8. Elaboration of the method of data processing received from sensors, elaboration of the method of estimation of defective constructions stability.
9. Establishment of destruction criteria, establishment of risk-levels for breakdown prognosis.
10. Development of hardware-software complex test device of monitoring and drawing up of the final report.

List of Tasks with timeline and personnel involved

No	Title of the task	Expected time needed for accomplishment of the task, in months	Personnel
1	Analysis of literary material; working out and creation of technological and experimental basis of future researches; comparative analysis of contemporary systems of structural integrity monitoring and choosing the appropriate method for task realization; estimation of electronic parameters of noise-immune circuit and eradication of incidental gaps	1-3 months	
2	Analysis of stress-strained state of researched objects structure elements – plate (steel), slab (reinforced concrete and structure units and drawing of qualification schemes by structure parameters; creation of mathematical and calculation models for strenght analysis; research of the methods of alarming factors at outer action on sensors; analysis of the effect of different alarming factors at functioning; working out of different alarming factors eradication algorithms on light beam effect in sensors	4-6 months	
3	Elaboration of new intellectual sensors block-diagrams according to the stated tasks; elaboration of mathematical model for the created sensors; manufacture of sensors and metrological estimation	7-9 months	
4	Drawing up of block-diagram for monitoring of hardware-software complex; selection of units and elements of the complex; software of hardware-software control; creation of the program for sensor signals detection	10-12 months	

5	Check of hardware-software complex operation with numerical experiments with different problems simulation; gaps eradication in hardware-software complex operation and estimation of final version of the scheme; research of simple design elements with the created hardware-software complexe at different force action from crack generation to disintegration using one sensor	13-15 months	
6	Analysis of test results and decision making; elaboration of data processing received from sensors; selection of the method of stress-strained state analysis; working out of the method of defective structure stiffness determination	16-18 months	
7	Processing of the method of Furie spectral analysis of the received signals	19-21 months	
8	Determination of failure criteria; estimation of risk levels for accident prognosis; creation of test device of monitoring hardware-software complex and information acceptance from specific objects (reinforced concrete and steel structure) using the respective sensors	22-24 months	

For each stage stage: Countable indicators of the accomplished work's expected outcomes in the reporting period

No	**I period (1-6 months)**	**II period (7-12 months)**	**III period (13-18 months)**	**IV period (19-24 months)**
	List of countable indicatoes	**List of countable indicatoes**	**List of countable indicatoes**	**List of countable indicatoes**
1	Article	Sensor block-diagrams and functional schemes	Test bench	Article
2		Patent	Theses at conference	Final report
3		Test bench		

1.2. Novelty of research, scientific justification of methods and compliance with the goals of the project

Reasearch method in the proposed project consists of applied research and technology development. For realization of the project objectives the following works will be carried out:

Applied researches:

1. Comparative analysis of optical-fiber and intellectual sensors for realization of failure constant monitoring serving for estimation of sensor matching to the stated problem;
2. Determination of aggressive medium and alarming effect on sensor sensitivity and working out of deficiency algorithm;
3. Investigation of structure failure and deformation specifying information signals value in sensors;
4. Research of signal processing methods for structure condition monitoring.

Working out of technologies:

1. Creation of logical-mathematical criteria and substantiation of the possibility of deformation processes measuring with dynamic action optical-fiber sensors;
2. Making up of block-diagram of hardware-software monitoring complex, selection of units end elements, complex control software. Creation of signal detection program from sensors.

3. Checking of hardware-software complex operation with numerical tests with different problems simulation;
4. Working out of the method of data processing received from sensors, working out of the method of defective structures stiffness estimation;
5. Determination of failure criteria, determination of risk levels for accident prognosis.

Intellectual sensors (fiber-optical sensors), laser diodes, analog-digital converters, detectors, deflectometers, computers are used in the project. The project supposes to create such diagnostic system which will perform monitoring of buildings, machines and machine devices during the whole exploitation period continuously. Such software will make preliminary prognosis of any failures and deviations from working conditions.

2. Applied potential of the project

2.1. Research's expected product to meet the demands of the local and/or international markets

The proposed monitoring system will be of great use in industrial, social amd high-rise constructions, bridges, tunnels, flying vehicles, gas and oil terminals, pipelines, space technique and nuclear reactors.

In case of project realization a simple construction new system of continuous monitoring (diagnostics) will be created which will enable to solve, with high reliability and precision, structural integrity monitoring of the researched object and also to make prognosis about prospective accidents (catastrophes). In particular, it will become possible:

- To receive and process information about technical state of the researched object.
- To get information about prospective accident on the object.
- The proposed system will considerably increase the durability of different purpose objects, minimize prospective risk factor, and increase economical effectiveness.
- We have realized monitoring (diagnostic) system for separate simple elements which gave satisfactory results (see item 1.1)

2.2. Feasibility and sustainability of the research results application

In case of project realization we shall be able to make test device of monitoring system.

Project realization will help bisiness partners to avoid losses caused by accidents on their objects.

The uniqueness of the project: elaborated system of constructions and accidents prognosis which comprises intellectual sensors and automatic control hardware-software complex and enables remote (on hundreds of kilometers) continuous control of several objects.

Potential demand for project results: aeronautical companies (Tbilaviamsheni) building companies (Planeta, Horizonti, etc.), railway corporation (Georgian Railway), etc.

The expected gains: minimization of the expected accidents that will give great economy to building, aviation and railway companies. The reliability of their constructions will increase the popularity of the companies.

Intellectual property rights: Publication of scientific results in high impact-factor journals. Scientific ideas and know-how will be patented in Georgia. There are 5 acting patent.

Additional developments: New projects will be elaborated for realization of scientific results and practical implementation of know-how at engineering decisions.

Plan of practical implementation of project results: Selling of license and rights and implementation of the developed systems in interested companies.

Additional licenses and rights are not needed.