Proposition of an integrated geodetic monitoring system in the areas at risk of landslides

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The sense of security is being mentioned as one of the most essential human needs. By talking about safety, we understand a lot of factors and aspects that considered together prove its multidimensionality. E.g., you can refer safety to issues such as globalization, demographic changes or functioning of state services. These are examples of issues which, by virtue of the changing conditions of people's living in contemporary world, never lose their topicality.
One from crucial „dimensions" of safety aspect is the spatial information, which is functioning in the world of ICT and modern technologies and is often called geoinformation. Almost all aspects of life of the contemporary man depend on it. This is because almost every object or phenomenon has its location in space and time. Without adequate spatial information it is difficult to imagine a state security, industry or citizens. For example, appropriately presented road networks, power transmission lines, or actually conducted analyses of the transport efficiency or range of phenomena, have a substantial impact on the effectiveness of the public services and the economy. They constitute also a main component of strategic and crisis management. Very important is e.g. a proper coordination of services ensuring public and property safety, in emergency situations of natural phenomena danger (such as floods, landslides) or coordination of the units responsible for country's infrastructure.

Keywords: integrated geodetic monitoring system, landslides, geomatic, SOPO

Introduction

Geomatics

Contemporary geodesy is undoubtedly a field of knowledge integrating many others related disciplines, as well as extending to modern technologies. In order to achieve the most faithful presentation of the Earths shape and figure, to descript the dynamics of examined phenomena or to depict it in the credible way keeping the repetitiveness and explicitnesses - a knowledge of measurements integration, mathematical modelling, computer science, geology, construction and shaping the environment is being used. In recent years, more and more often, the term „geodesy", is replaced by a broader „geomatics". There are many definitions of this term, according to the perception of that new name in the world of spatial information. Including the subject in the most universal way, geomatics is the science of acquiring, processing and modelling spatial data also called „geodata". The range of geomatics therefore includes classical surveying as a medium for obtaining high distribution spatial data, as well as the processes of mathematical modelling, the visualization of results and the record to the database. Additionally, computer and tele-informatics issues are also associated with this subject - very common term in the literature is therefore „Geoinformatics" combining geodetic and cartographic issues with IT solutions. Consequently, many notions known so far underwent the alteration, inter alia, the concept of geodetic and geotechnical monitoring, which currently can provide information about the examined object or a phenomenon practically in the real time, in compliance with dynamics of changes and with taking into account the relations which so far have been very difficult to discover.

Schematic presentation of „geomatics" is shown in Figure 1. In the context of the subject elaborated in the article, the great significance can be attributed to geodetic monitoring of displacements and deformations [1], which allows among others predicting and preventing from accidents and disasters, giving relevant units a possibility to react before the occurrence endangers the stability of the examined object or the safety of its surrounding.

By analysing various aspects and challenges of the safety, it is impossible to omit the issue of the technical infrastructure protection against the effects of different phenomena, in particular landslides. Landslides are posing a great threat to people, of residential and industrial objects, constitute also a relevant problem for the economy. Forecasting such phenomena, although sometimes difficult, constitutes undoubtedly an important challenge given to services and specialists using geodetic, geological or geotechnical data. Extremely useful in such tasks is modern measuring technology and elaborated methods of numerical analyses, including the probability and considering data about so-called high (measurable values) and low level of the structuralization (mainly descriptive information) [3].

In the issues of the quality and timeliness of geodata, their standardization and normalization are undoubtedly important. The main purposes of both these branches of science and technology are to improve the process of collecting data about the objects (so-called *geodata*) and to enable a proper description of reality through modelling (so-called *conceptual modelling*) [9]. So-called supplementing the „knowledge base", i.e. the recursive recognition process of the examined object or phenomena are perform-

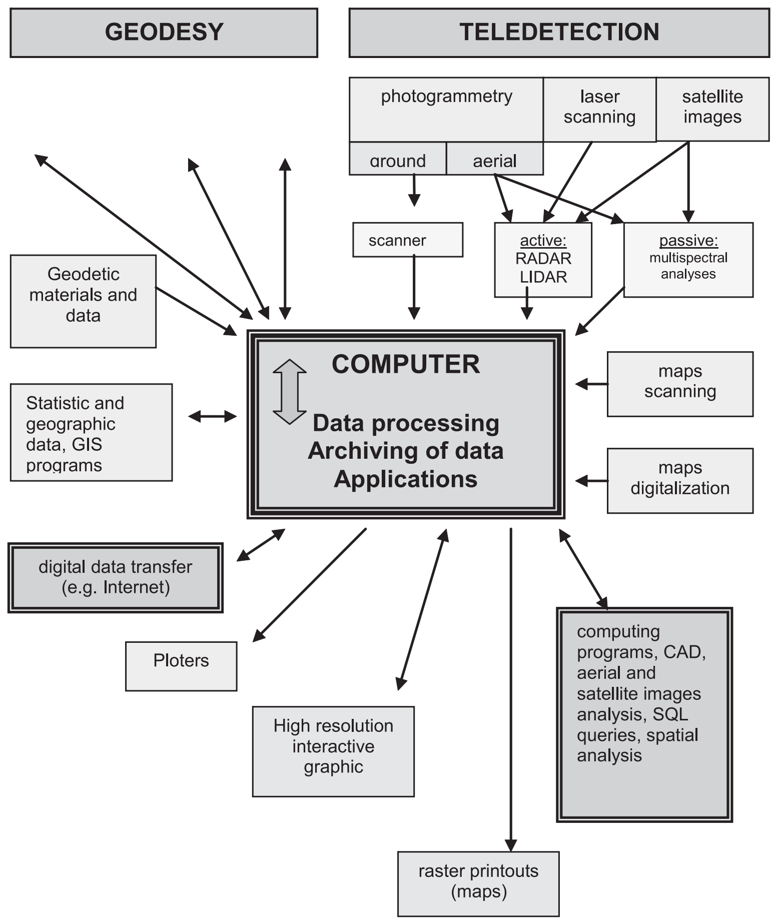

Fig. 1. Schematic geomatics presentation

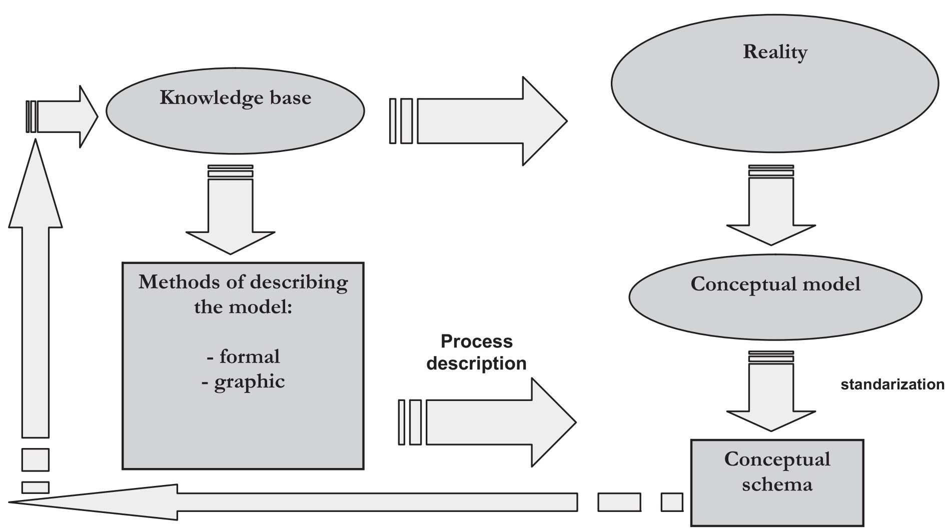

Fig. 2. Outline of the process of the modelling of phenomena (based on the [8], comp. K. Karsznia)

ing here the substantial role what in the schematic way is described on Figure 2.

Topicality of law regulation, norms and standards with the degree of their consistency with the current level of knowledge (in particular: the development of measurement technology) should be considered in terms of effectiveness, safety and efficiency of the geoinformation systems applied for instance in the monitoring of displacements and deformations of mining excavations [2].

Undoubtedly, an important task is to assess the impact of threatening factors (eg. landslides) on the state of engineering objects such as the housing building, hydrotechnical facilities, bridges, roads and railways, power lines and technical infrastructure networks. Thanks to modern solutions from the scope of geodetic monitoring of displacements and deformations, as well as through the cooperation of specialists of various technical services, it is possible to conduct such an assessment in an ever more effective way. Again, shaping legislation and industry guidelines concerning, inter alia the need for (especially in areas at risk) check tests or - which gives much better results - the implementation of integrated measurement technologies, becomes an extremely important issue It is possible here to recall both the geodetic monitoring and wider environmental monitoring. Such integrated systems are an essential component of quality management [3], a comprehensive risk management [5], or even play a major role in crisis management [7].

Geodesy integrated in examining natural phenomena

In tasks of contemporary surveying engineering, whose aim is to determine a shape and a state of examined object, its static and dynamic state, a combination of different methods of measurement and an integrated work of many sensors are more often applied [12]. Actions of various specialists are affecting the quality of measurements conducted in this way – specialists from the field of geodesy, geotechnics, computer science or telecommunication. Both the spatial data concerning the geometry of the examined object and information about processes occurring in it, are contributing the database towards enabling their processing and visualisation. The data analysis as well as making based on that further decisions, is a domain of an expert system. If additionally such a system is equipped with the module of notifying users of appearing threats, we are talking about the system of the monitoring [11]. Depending on the size of the implementation of the monitoring system, we can talk about a global approach (large areas, for which one should take into account geodesic factors related to the curvature of the Earth, national spatial reference system, etc.), or engineering - that occurs during the execution of the construction process (in general a single engineering objects such as building structures, dams and bridges) [3]. It's necessary to add at this point, that the modern approach to ensuring the safety of buildings structures includes almost exclusively the use of remote monitoring (RM) [11]. This implies an interdisciplinary involvement of experts from the field of geodesy or the construction as well as ICT and electronics.

Since the geodetic monitoring is the activity of detecting changes and the resulting risks, it is essential to precisely determine earlier the type of the observed phenomenon or object and adjusting the designed system to it. Also necessary is the correct selection of expert tool (computer application) and determining the manner of notifying the existing threat (eg. in the form of an alarm, SMS messages, the e-mail or running a different application enabling appropriate services to take the remedial steps) [4]. Special importance, therefore, gets the issue of the integration of different surveying measuring techniques and already mentioned system interoperability.

Engineering monitoring systems and the problem of deformation of landslide areas

The engineering monitoring is finding its wide application in the safety assurance among i.e. the areas threatened with surface deformations. In the work [2], the authors pre-

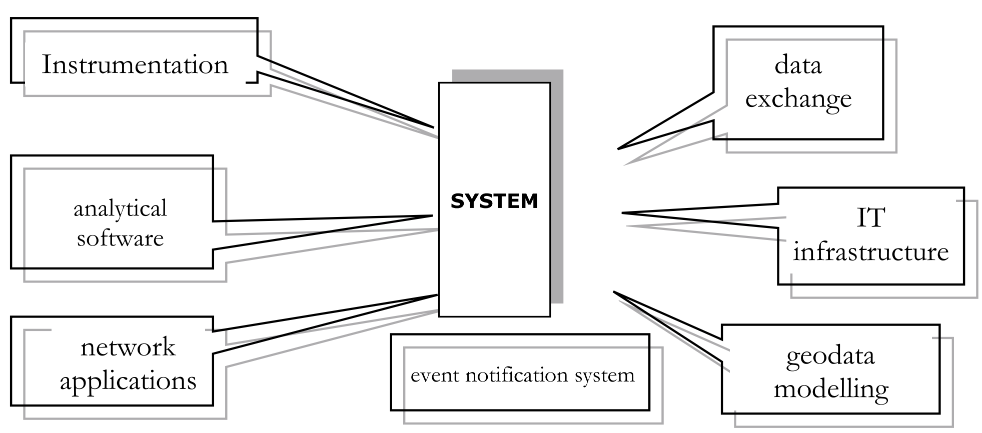

Fig. 3. Outline of functioning of the system of the engineering monitoring (comp. K. Karsznia)

sented performance of such an integrated system of the monitoring in the safety assurance of conducting mining works on the area of an open pit mine in Bełchatów, Central Poland. This object, by virtue of the intensive extracting lignite coal is, in the special way, exposed to danger of appearing of landslides, which in turn poses a threat to people working in the outcrop and mining machines. To counteract the effects of such occurrences, the integrated system of the geodetic monitoring is conducting constant observation of controlled points as well as is making calculations and analyses in order to inform the users of the occurrence of the even slightest trend of emerging landslide. Figure 3 shows an overview of the integrated geodetic monitoring system.

It should be added that the current speed of computer processors, as well as innovative solutions in the field of data transmission make it possible to develop the results of measurements in real time.

Landslide threat

Surface mass movements are one of the most common natural phenomena, resulting in natural disasters. They occur in all climatic conditions and depend on several factors ie. the slope, climate, hydrography and features of the internal structure of the slope (rock type, stacking pattern, saprolite amount, and the appearance of water in rocks). The predominant forms arising from these movements are landslides. Approx. 95% of the landslided area in Poland is located in the region of the Carpathian Mountains, only 5% is spread in the remaining area of the country. In addition to mountain landslides, there are also low-lying landslides: coastal, riverside and appearing in artificial excavations for the construction of roads, railways and opencast mines. Regardless to the place of occurrence, landslides often cause severe building damages, losses in tree stand, in agriculture, communication lines, may also threaten the opencast mines, water reservoirs and investments associated with them. It is therefore necessary to include threat of landslide processes at all new and existing investments.

Landslides are phenomena occurring most often on slopes, where the slope is up to 30 degrees, and their speed varies from a few meters to a few centimetres per second - may take a few seconds, minutes, hours or even several days. Sliding can be a violent and sudden process, but also can be slow, heralded with appearance in the hillside (in the area of later peak of the landslide) of scratches, cracks and crevices.

Slow slopes creep usually occur in areas with a slope of 5-30 degrees, but when the slope exceeds 30 degrees, mass movements are usually violent and lead to determine the new balance in the side.

The main causes of landslides include:

- strong soaking of the saprolite and rock masses with water, resulting from the natural factors (eg rainfall) or artificial (ex. breakdowns of the water supply or sewer system),
- raising the level of surface waters in the vicinity of the slope, for example, as a result of the river damming,
- suffosion processes (rinsing of small sedimentary fractions out from between coarse-grained fractions, occurring as a result of water flowing through the sediment) occurring in the lower part of the profile,

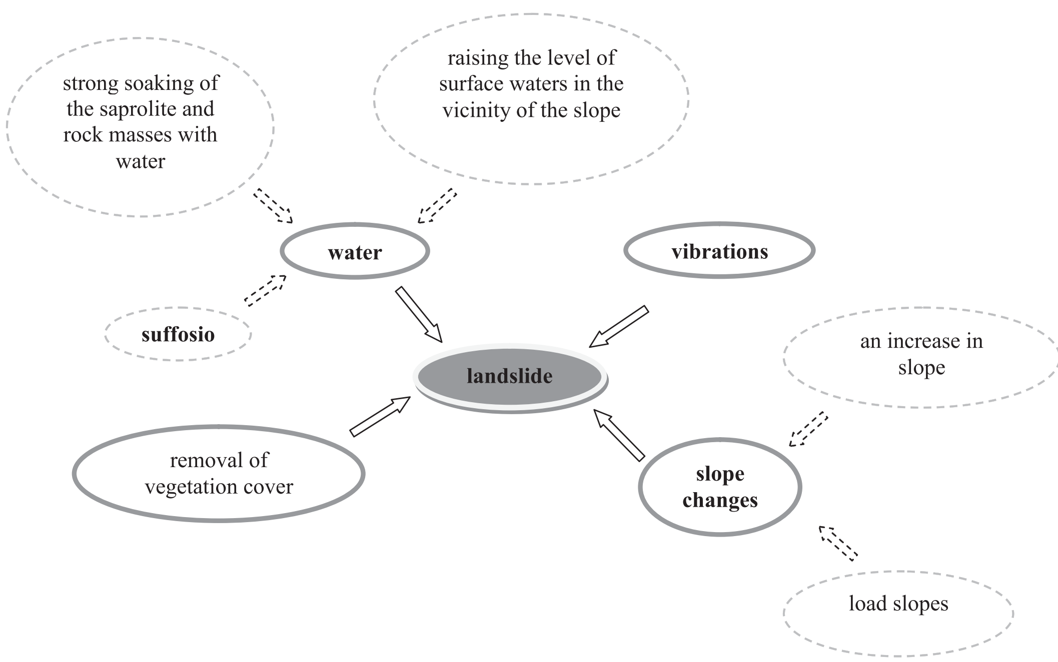

Fig. 4. Factors causing landslides (comp. A. Tarnowska)

- an increase in slope, e.g. as the effect of the undercut by the river,
- load slopes, e.g. by building or sand dune,
- vibrations, e.g. resulting from the impact of transport routes, earthquakes,
- removal of vegetation cover, which with the root system stabilized the slope.

The landslide movement initiated in one place of the slope can spread up and down the slope of this slope through widening of forms of destruction. The walls of the landslide niche can move back upwards hillsides (e.g. as a result of secondary landslide or flowing water), and also the balance in the slope below the area of the detachment can be violated (as an effect of sliding down and the surcharge of this slope with sliding masses).

What's more, the geological literature distinguishes landslides due to the frequency of their occurrence, highlighting:

- chronic landslides – in constant motion, until slope equilibrium is reached
- periodic landslides – are put in motion several times, usually after heavy rain
- landslides having any more activity after their occurence.

Landslides are a problem on a global scale, therefore an imperative is to take actions aimed at, in the first place, preventing their occurrence, and secondly: to assess their size, dynamics of changes, and - on the basis of acquired detailed data describing these dangerous phenomena - to make appropriate predictions of possible events.

Manners of the counteraction for landslides are closely connected with the causes of their formation. To prevent landslides, it is therefore necessary to use methods [10], which include:

1 Passive methods, such as:
    - a prohibition on the destruction of vegetation on the slope,
    - non-irrigation of crops on the slopes,
    - no undercutting of slopes showing displacement tendency,
    - ban on embankments and other structures aggravating slope,
    - ban on the use of explosives and causing vibration,
    - reduce runoffs in areas at risk of surface mass movements.
2. Active methods, namely:
    - a slope drainage covering surface water (drainage ditches-bands) and underground water (wells, tunnels),
    - removal of soil, which can be displaced, construction of retaining walls,
    - use stabilizing stakes (pin), grouting and anchoring rock fragments.

Monitoring landslide areas and areas at risk of the landslides occurrence in Poland

In order to achieve the second type of mentioned action, in 2006 the National Geological Institute - National Research Institute acting as the state geological survey, commissioned by the Minister of the Environment, launched the project Against Landslides Cover System (SOPO), whose primary purpose is to identify, document, and mark on the map in scale 1: 10 000 all landslides and areas potentially affected by mass movements in Poland and to establish a surface and a depth monitoring system on 100 selected landslides [6]. The database SOPO creates graphical resources of Map of Landslides and Threatened Areas (cartographic-geological documentation for landslides and areas at risk of mass movements that are or could be in the near future – for up to 50 years – a threat to human business and existence) and attribute-based resources (landslides characteristics). An integral part of the project is the monitoring, based on the selected surface and deep-seated methods, also including geodetic measurements methods.

Selection of a suitable technology of surface and deep measurement depends on the size and type of landslide and the degree of the threat or the accuracy of the required identification, and the scope and frequency of observations in all phases are determined individually for each landslide.

As stated in Regulation [10], *the surface monitoring is performed with classical surveying methods or with static method using GPS devices and led on the basis of stabilized grid of measurement points within a landslide (the number and location of measurement points forming a grid is determined by the project of geological works, prepared individually for each monitored object). Measuring points should be located in the areas of the greatest landslide activity and at the same time meet the condition of stability of foundation, which allows multiple measurement. The point of measurement for the surface monitoring should be located as to enable measurement of the X, Y, Z coordinates with methods determined in the project. Measurements should be made at least three times a year, and the results are presented in tabular form giving the coordinates X, Y and Z. Similarly, GPS measurements should be done at least three times a year, and the final report must include tabular results for each measurement session and a list of establishing points coordinates together wirh precise determining of the layout.*

The „Instructions to develop map of landslides and areas at risk of mass movements in a scale 1:10000" adopted a simplified, other than that described above, three-stage classification of landslides in terms of their activity:

a) still active landslide – landslide in constant motion or whose activity symptoms occurred during the registration or during the last five years
b) periodically active landslide – a landslide within which the activity symptoms occurred at irregular intervals over the last 50 years

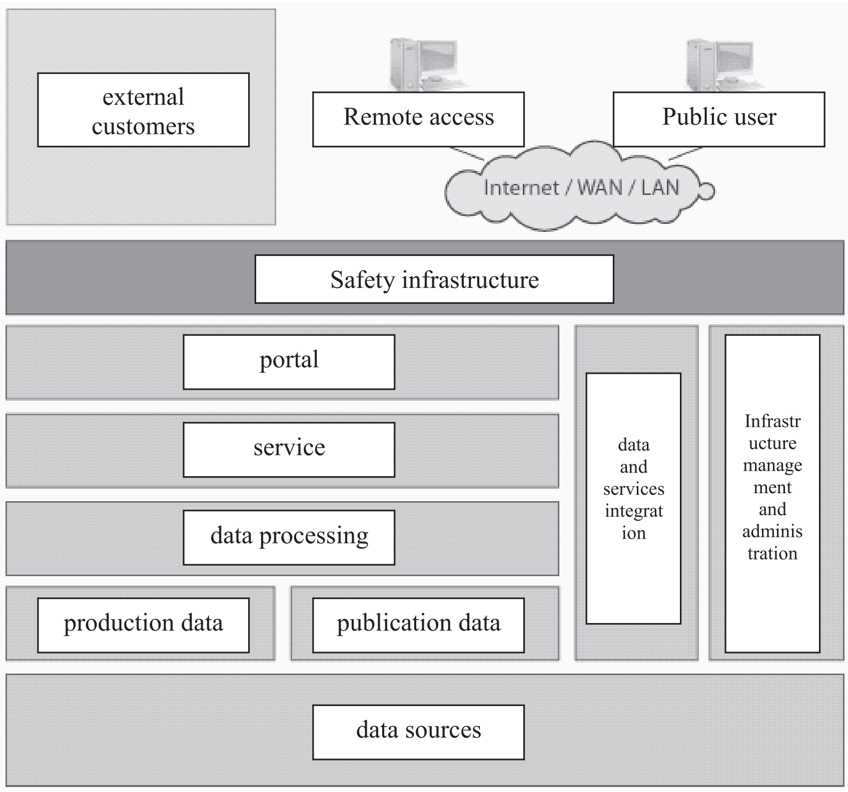

Fig. 5. The general architecture of the central node of the ISOK system (source: http://isok.imgw.pl/produkty-projektu-isok/ platforma-informatyczna-isok)

c) inactive landslide, landslide stabilized – landslide, within which weren't observed and documented any signs of activity since at least 50 years.

The assessment of the degree of landslides activity are:

a) the external symptoms on the surface of the landslide:
   - cracks and crevices of land,
   - slot above the main slope,
   - fresh bumps of the area,
   - appearance of „drunk forest"
   - tightening streams channels by landslides tongues,
   - deformation of the infrastructure (buildings cracks, damaged road surfaces, tilting linear structures)
   - prevalence of newly formed reservoirs in landslides areas;
b) community interview;
c) the analysis of changes in topography and extent of landslide based on a comparison of topographic maps and aerial photographs dating from different years;
d) the results of monitoring.

Undoubtedly, in addition to geological works, surveying is also necessary - not only in areas where landslide activity was stated, but also in areas suspected of landslide phenomena occurrence in the future.

Forecasting of landslide phenomena, though sometimes very difficult, is constitutes certainly a very important challenge given to services and professionals using geodetic, geological and geotechnical data.

According to information included in [7], among modern geoinformation methods enabling measurement of the deformations of the entire surface of the landslide are: the methods of laser scanning, ground and air, GNSS and interferrometric methods, using satellite radar imaging. In addition, the industry and scientific studies - for example, [2,8,9], often also recommend the use of automated and continuous (or quasi-continuous) methods of measurement.

In many cases, depending mainly on the size of the observed object and on the dynamics of geometry changes, the use of continuous metrological monitoring provides the most reliable picture of occurring geological processes. So structured monitoring system, with analytical module (evaluating occurring phenomenon in terms of achieving critical size) can also send a warning of detected danger as well as capture the trend of changes before they become emergencies (in extreme cases – geotechnical or construction catastrophes).

Monitoring of natural phenomena can also apply to flood risk (Fig. 5).

In the ISOK project, the Institute of Meteorology and Water Management predicted involvement of geospatial techniques that thanks to the integrated acquisition, processing and analysis of geodata let in the interactive exploration of the changing hydrological conditions, and as a result, to effectively manage risk.

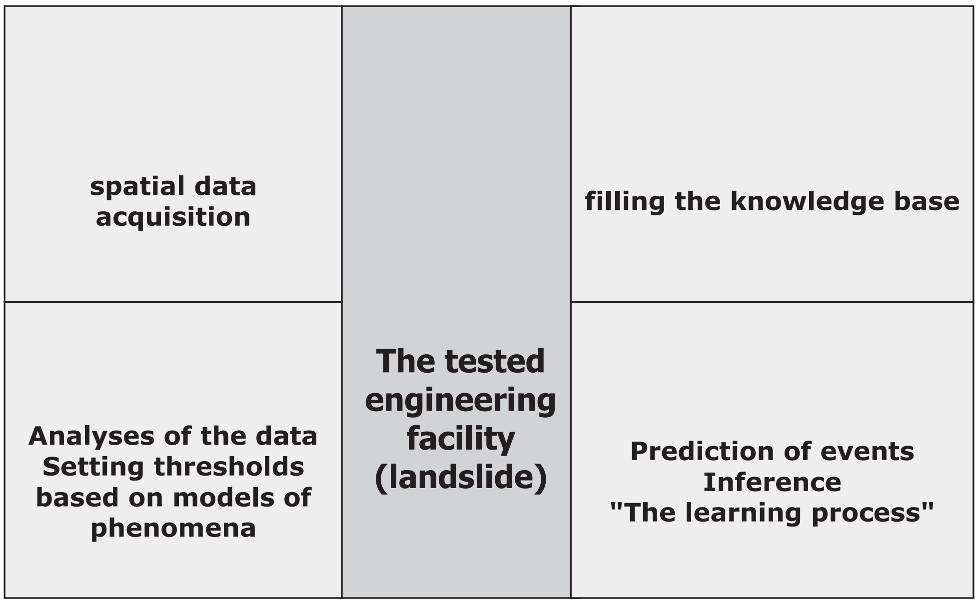

Fig. 6. Outline of system recognition including the examined engineering object – e.g. landslides (own comp. of authors)

Completion of preventive actions

Based on the dissertations discussed above, the authors propose to systematize the process of acquiring, processing and analyzing of spatial data for monitoring landslides. Such a process diagram is shown on Fig. 6.

The examined object is located at a focal point, and each of the task blocks has equal importance in the process of conducted monitoring. This approach therefore requires a thorough object recognition (studies of geological and geotechnical conditions, weather conditions), proper selection of technology (depending on values raised to endow the database), the adoption of optimal kinematic model (determination of critical values, tolerance and the level of confidence), and configuration of the database. On this occasion, to recall also belongs the need to maintain standardization procedures and quality assurance issues. These elements are extremely important due to the safety and the reliability of the conducted works.

Conclusions

In conclusion, the geodetic monitoring of displacements and deformations of surface objects, allows the prevention of accidents and disasters by giving the proper services the opportunity to respond in a proper way in advance, before the phenomenon threatens the life of people and the stability of the object and the safety of its surrounding. In many cases, the use of continuous metrological monitoring provides the most reliable and accurate view of the geological processes actually occurring in the given area. A well designed monitoring system, equipped with an analytical module (evaluating occurred phenomenon in terms of achieving critical size) allows to send a warning about detected danger as well as to identify the trend of changes before they become emergencies (in extreme cases – geotechnical or construction catastrophes).

Implementation of integrated engineering monitoring systems (surveying, construction and geotechnical), especially in the remote version, gives the opportunity to correct diagnosis and prediction of landslides, as well as making preventing decision before emerging trigger trends will lead to consequences difficult to control. Observing the dynamic development of technology, as well as trends in the construction of laws, regulations and industry standards, one should expect and aspire for further intensifying the works on the development of these systems and the growing share of their use in engineering practice.

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