ESTIMATION OF ROCK GLACIER DYNAMICS BY ENVIRONMENTAL MODELLING AND AUTOMATIC PHOTOGRAMMETRIC TECHNICS

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ABSTRACT:

The development of this article follows the search for a technique that automates the modelling and dynamics of any natural (dunes, slipping of mountainsides, glaciers…) or artificial (collapsing of buildings…) structure. In this study, the dynamics of the Argualas rock glacier (Pyrenees-Spain) has been investigated since 1991.
A peculiarity of rocks glaciers is their sensitivity to environmental changes. For this reason, the influence of possible climatic terrestrial changes in the environment can be known by means of the analysis of their dynamics.
In general, the measurements of the dynamics of rocks glaciers have been studied with geodesic and aerial photogrammetric techniques. However, a close range photogrammetric technique is proposed here.
Through predictive statistics it is possible to correlate glacier dynamics with climatic information, and in this way, the mathematical function for each of the fixed points observed in rock glacier can be resolved. When a future photogrammetric observation is made, the process of "exterior orientation" in field can be avoided, assuming that the climatic conditions (rainfalls, temperatures and so on) are known, it will be possible to predict the position of the "control points".
The photographs are taken with a semimetric camera from a helicopter. The photogrammetric relation of the distance between the photographic base and the object isn't maintained as in aerial photogrammetry. Moreover, the photographic shots are convergent and tilted, and it makes matching strategies cumbersome. This paper makes some contributions in order to overcome the modelling and dynamic predictions of rock glacier.

1. INTRODUCTION

Nowadays, world's glaciers are disappearing and this fact could be derived due to climate change. Spain has glaciers (white and rocks) nearer to equator than any other country in Europe. Unfortunately, there are not any kind of studies about their dynamics, unlike it occurs with some Alpine glaciers (which have been studied since 1850).
Traditionally, glaciers' dynamic measuring has been done through techniques such as geodesy or aerial photogrammetry (Kaufmann and Ploesch, 2000). From our point of view, both techniques have drawbacks:

- Geodesy: Spatial determination (X, Y, Z) with little points in space.
- Aerial photogrammetry: It is very expensive for the study of small and far away areas.

To overcome these disadvantages, our photographs have been taken from an helicopter on the job.
The automatic analysis of the Argualas rock glacier was carried out as follows:

1. Geodesical data (six observations) studied since 1991. Climatical data taken from the Meteorology National Institute (I.N.M.) since 1991.
2. Correlation among of the information stated before and mathematical techniques (dynamic system), in order to obtain future geodesic mark targets or "control points".
3. Analogical photographies (Rollei semimetric camera 6008) and scanning (Vexcel, UltraScan, 5000) previous to running the C.D.W. "Workstation Digital Close Range" software.
4. "Foto-Cartógrafo" software, which employs filters to improve the quality of the images (elimination of noises) and detects the presigned photogrammetric targets.

2. DETAILS OF A PYRENEES ROCK GLACIER

To form a glacier, the snowed part must be bigger than the melted snow. This happens when it snows a lot and it is so cold that the snow is on the rocks. In addition, if there are stones fall down of the wall the permafrost is preserved, in this is a rock glacier (Figure 1).
The active rocks glaciers move very slowly because of the size of the blocks of stones, the slope of the glacier, the temperature, etc. Besides, the glacier dynamic is not the same in all of its surfaces (the front side is much more dynamic). Additionally, its dynamic depends on the season (for instance, in summer the dynamic is higher than in winter).
The Argualas rock glacier is orientated to the northwest part of Mountain Argualas (3032 m); it is 750 m long and 400 m wide. The geophysics studies have shown a layer of surface of 2 m and 4 m stones thickness, and a permafrost surface below ranging from 10 m (near the border) to 20 m (near the center) (Fabre et al., 1995).

Figure 1. Argualas rock glacier (Pyrenees-Spain).

3. WEATHER IN THE AREA OF THE ROCK GLACIER

The rocks glaciers move forward and backwards as an answer to the change of the weather; that is, if the temperatures increases, its dynamic also increases. These movements can not be appreciated at a simple glance, but they can be controlled with geodesic and photogrammetric methods. Because of the snow, photogrammetric and geodesic observations can only be carried out in September and exceptionally in August.

The medium temperature per year of 0º C is in Pyrenees approximately in 2726 m, and the rock glacier of Argualas is between 2590 m and 2730 m, so that it is situated into the limit place where the ice appears. Therefore, the snow is supposed to be, theoretically, the whole year.

Glacier weather conditions (rainfalls and temperatures) are extrapolated from I.N.M. stations near the area.

- Rainfalls: The nearest station to the glacier is “Sallent de Gállego”, which is 5 km further from the glacier. There is a data complete of rainfalls taken from this station since 1990. Later on, these data have been given to the influential area of the glacier.
- Temperatures: There is not a continuous study of them in the nearest stations to the glacier, so that, a gradient termical in this area during August and September (-0,61 ºC/100 m). The data of Sallent de Gállego’s station has been finished taking into account that gradient termical, and with this gradient, the temperatures have been calculated in the area of the glacier.

The dependence of the I.N.M. stations makes mistakes, such as: do not have complete series of data, different altitudes among the high parts of the glacier-station, orientation of the stations... So that, the location of its own automatic stations has been asked. In these stations different parameters can be gathered: temperatures, rainfalls or snow. This kind of stations have been used in the station “Juan Carlos I” (Antarctica) and in rock glacier of Veleta (Sierra Nevada) by Spanish investigators with good results (Ramos et al., 2001).

4. GEODESIC STUDY OF THE GLACIER DYNAMIC

A geodesic study has been performed since 1991 to calculate and locate with high precision and accuracy specified targets (rods) in order to compare the movement in the course of time (X, Y, Z).

The geodesic studies have been done in the years: 1991, 1993, 1994, 1995, 1998 and 2000. The annual study would have been an ideal situation, but it has been impossible because there was not enough budget to do it and climatic in some observations was bad.

The topographic technique which has been developed to calculate the glacier dynamic is the direct intersection (angle and distance), but, in addition, the global positioning system (G.P.S.) was used in the year 2000. The G.P.S. in its R.T.K. (static) application has not shown good results because of the multipath effect of the satellites signals of the glacier walls.

In 1991, a lot of rods were put together to control the glacier geodesic and in 2000 another ones were put together to development the close range photogrammetric technique. The geodesic rods were distributed through the whole glacier area to study all the possible movements of the glacier, while the “control points” photogrammetric have only been used near to a big rock (8 meters of diameter). It has been studied in this way because it was impossible to realize a photogrammetric study of the whole glacier.

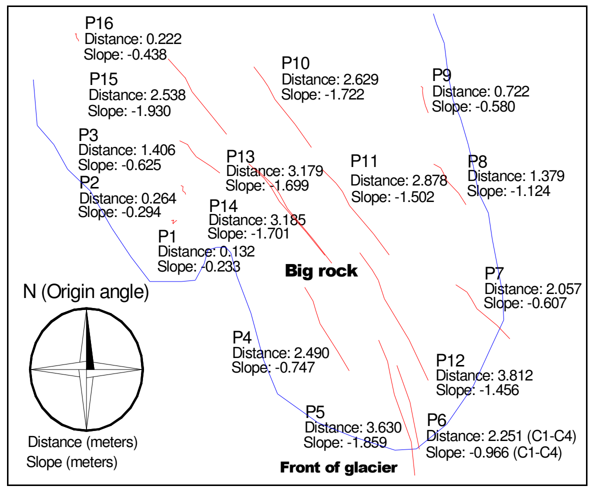

Figure 2. Dynamic of Argualas glacier (1991-2000).

To realize the geodesic study of the rods (1991 to 2000) the following elements were used:

- There are three firm stations (nails) put in the highest east wall of the glacier.
- There are three firm references (nails). From each station, three firm references are observed (nails).
- There are fourteen nails 1,20 cm high put on the glacier and two nails on the biggest rock. The rods movement is the same as the glacier’s dynamic.

The techniques used to study the glacier have been the following:

- Angles direct intersection.
- Distances direct intersection.
- Combination of angles and distances intersection.

These techniques have been done with a topographic computer’s program (TPC-IT), which has shown similar data. If it collecting information would be totally precise, these data would show a lot of results in common. But this does not occur and in the different studies, the difference has always been down the tolerance of ± 4 cm (Sanjosé, 2003).

The dynamic observance of all rods is not the same. This is logic because their spatial position depend on its situation on the glacier (Figure 2). In the future, instead of using geodesic technique, the position of these elements will be done with the development of the close range photogrammetric.

5. MATHEMATICAL PREDICTION OF GLACIER DYNAMIC

Some years after from the beginning of the dynamic study of the rock glacier of Argualas, it was seen that there was a relation between the climatic change and the movements of the glacier. For instance, this relation is more important in 1994, when the media temperatures were 3° C higher than the rest of the 90's in the Pyrenees. Obviously, there was an important glacier dynamic that year (Figure 3).

This correspondence gives us to a study line which try to foresee in a short period of time the movement of the glacier, through the climatic data and the geodesic measure.

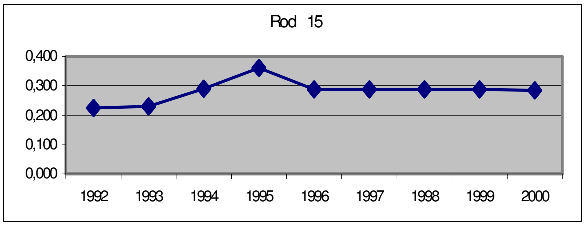

Figure 3. Glacier dynamic of rod number 15.

Through the employ of predictive processes, the future behavior of some targets (geodesic rods, presignaled control points) can be estimated.

The predictive study can be focused on "temporary sequences" and "dynamic systems". Concretely, a dynamic system has been developed because there are little data to be applied to temporary sequences.

The dynamic system shows the change of a system through the passing of time. This change can be described through a mathematical model, which can be a system of differential equations.

The needful information for the development of dynamic systems is:

- Geodesic coordinates (x, y, z) of the rods in different studies.
- Time of observations. This fact shows us of the period between campaigns.
- Weather information (rainfalls and temperature) between the studies.

The mathematical program "Mathematica" has been used to solve the dynamic system. With the weather and geodesic values of previous studies we can establish a second order polynomial for predicting weather conditions in future studies. The coordinates (x, y, z) are used in six geodesic studies, the first of them have not enough weather data and the sixth is used as test (López et al., 2002).

With these facts, 12 equations can be creates, and the system has 12 unknown $(a,b,c,d,e,j,g,h,k,l,o,p)$.

$$F_1(p,t) = \left(at^2 + btp + cp^2 + d,\quad et^2 + jtp + gp^2 + h,\quad kt^2 + ltp + op^2 + q\right)$$

With the value of these unknowns, the weather conditions for the sixth observation can be solved:

$$\left(p: 232.69\ dmm,\ t: 9.29\ °C\right)$$

The different positions of a rod through the effect of a deformation can be considered as the succession of a function about its initial function:

$$x_n = F \cdot x_{n-1} \quad \text{or} \quad x_n = F^n \cdot x_0$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_n = \begin{pmatrix} a & b & c \\ e & j & g \\ k & l & o \end{pmatrix}_{(p,t)} \begin{pmatrix} d(x) \\ h(y) \\ q(z) \end{pmatrix}_{n-1}$$

For example, the results of P1 rod coordinates obtained with the dynamic system are:

x: 1216,713 y: 1063,780 z: 847,909

The coordinates of the same rod P1 through the geodesic observation are:

x: 1216,753 y: 1063,818 z: 847,938

It can be seen that there is a difference of ± 4 cm among all the coordinates of the dynamic calculation system and the geodesic measures. So, the method is acceptable for the predictive determination of "control points". To the predictive system it can be imposed some conditions to make it better for future applications:

- Establishment of a minimal and maximal period of time among different observations.
- Minimal number of campaigns so that, the predictive system is acceptable.
- See if the given coordinates through the photogrammetric method are the ideal ones to develop this predictive technique. It has been shown than the geodesic method is acceptable.

6. CLOSE RANGE PHOTOGRAMMETRY IN THE GLACIER DYNAMIC

6.1 Justification of close range photogrammetry technique

Different techniques can be employed to study any kind of rock glacier: Interferometry radar, geodesy (angle, distance), levelling (geometric, trigonometric), global positioning system, photogrammetry (aerial, terrestrial, close range).

Obviously, surveying around to Argualas glacier (walls of 300 metres) makes the employment of these techniques rather difficult. In the case of Argualas glacier, the geodesic techniques, G.P.S. and close range photogrammetry have been employed.

The geodesic techniques do not let us follow in a detail the movement of the glacier, because only some points can be measured. On the other hand, G.P.S. has given problems because of the multipath effect near glacier walls (Sanjosé, 2003). In addition, to obtain the geodesic dynamic the same points (rods) of the last campaign must be looked for in the land and these points can be hidden by of the movement of stones.

Aerial photogrammetry is very expensive just for analysing only one glacier; its employ could be more efficient to study all the rock glaciers of the Pyrenees (26 glaciers). Apart from that, the precision of the flights must be studied in relation with close range photogrammetry because the plane must not touch the walls of the glacier, so the plane should fly over them. This fact makes the photographic quality different. In any case, whatever kind of photogrammetric technique which is employed in the Argualas rock glacier must let smaller precisions than 6 cm in the displacement.

The advantage of photogrammetry (aerial, terrestrial) over the geodesy is than the photogrammetry can show the position of a lot of points (photographic information), and it can collect information in the country much faster than geodesy. The close range photogrammetry program "C.D.W." has shown excellent results in the study of the Argualas glacier.

6.2 Automatic Photogrammetric technique

In the last point "5. Mathematical prediction of glacier dynamic" we have solve the automatism of the "control points". The position of these points can be predicted through the previous knowledge of the climatic data and the dynamic of another campaigns. In doing so, for instance, the even years the traditional observation techniques can be employed (geodesy, G.P.S.) and in the odd years, the position of the points can be estimated with predictive calculations.
In addition, there has been a problem with photogrammetry because of the convergent geometry. In the near future, the "Foto-Cartógrafo" software, will be used for recovering the exterior geometry of the images.

6.3 Previous work to photogrammetric orientations

6.3.1 Taking photographs: In our case, the photographies of the glacier are convergent and sloping, and the relation base-distance is, in many cases of 1/1, that is to say, there is the same distance between the projection's centers and the object's distance. Great relations between the base and the distance to the object makes longer the intersection of the rays and this allows us to improve accuracy (Figure 4). By contrast, the conventional analytic and digital stereoplotters cannot perform the photogrammetric orientations.

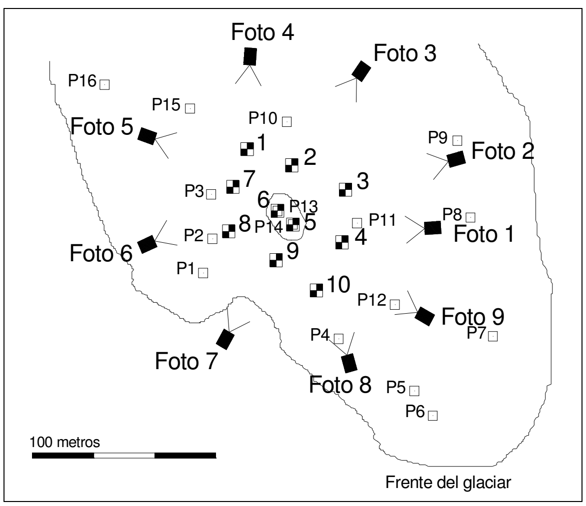

Figure 4. Scheme of the rods, control points or artificial signs of the photographics takings.

6.3.2 Premarking control points: In some places like deserts, beaches, forests and glacier, etc., the natural points could not be the most indicated targets to be controlled photogrammetrically. In these cases, the artificial points are located on land before taking the photographs. Their positions are specified through topographic measurements, although they can be foreseen statistically (Sanjosé y Lerma, 2001)**.**
To realize our study in different rocks glaciers (Argualas, Posets, Veleta) signals of different materials have been made; for instance, at the very beginning the signals were made of plastic, but their result was bad because they did not stay symmetrical from all the attitudes. Later, these signals were made of cardboard, which have been employed on the photographs, but their problem was related to traveling. During last years, the signals were made of cloth, which is very easy to transport, plus internal rods to give them a squared form.

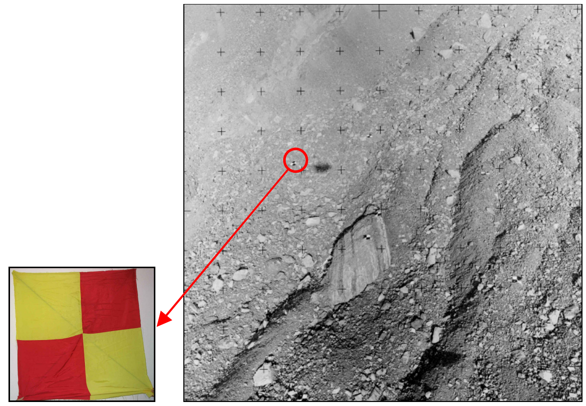

Figure 5. Design of a signal and its position on a photography.

In order to automate the calculation of the glacier's dynamic, permanent artificial signals can be left on the glacier (Figure 5). These signals are made of metal and they are put on the ground. Following this way, the signal's movement is the same as the glacier.

7. RECOMENDATIONS FOR FUTURE WORK BASED UPON EXPERIENCE

Project results have been analysed taking into account the position and attitude of shorts, quantity of control point and their distribution:

- Geometry: It is preferred convergent photographs than normal ones. It should be avoided narrow parallax angles.
- Number of photographs: It is important to take care upon the distribution of photographs, rather than on the number. Minimum number: three; recommended: four o five maximum.
- Number of control points: To the orientation, apart from the control points, another kinds of points can be observed. In relation with these points:
  1. Employ great quantity of control points does not imply get better results. The program needs more than ten similar points, and the system will be more consistent if all of them are points of object coordinates.
  2. To obtain the same number of photographs, the variation of control points imply errors, although they are better if there is a greater number of points.
  3. The medial quadratic error is, in general, smaller if we only take into account the calculation of the residual of the referential system of the control points.

8. CONCLUSIONS

As the geodetic methods only allow us to measure a small number of control points (targets) on site, and aerial photogrammetry is too expensive and not ideal for this kind of projects, close range photogrammetric techniques appears as an complementary method ideal for the 3D reconstruction and analyses of rock glaciers (Figure 6). Furthermore, the combination of multidisciplinary data and methods seems promising in order to analyse glaciers movements, as well as global weather changes.

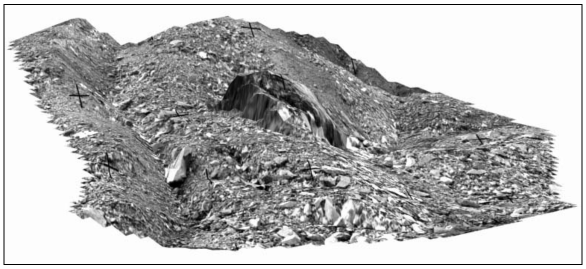

Figure 6. Three-dimension sight of Argualas rock glacier.

The relationship between the weather and the movement of the geomorphological structure can be shown with the use of predictive statistic tools. In this way, a polynomial function has been computed for each one of the targets with a accuracy of ± 4 cm.
This predictive technique allowed us to estimate:

- The position of a control point linked a specified campaing in the job.
- The determination of the moment in which the structure began to take shape or the future prediction in which ther will be a moment without activity.

Actually, in our case, the predictive techniques are applied on fixed and visible predictive targets prepared to take photographs from helicopters. Following this way, in the near future, the photogrammetric study can be supervised with geodetic campaigns after two years; the positions can be computed because of the predictive theoretical application of temporary series. Therefore, it can be summarise that ground control points are not always needed, and it is possible to reduce the amount of money for ground surveying, if and only if, statistical procedures are considered and used.
Actually, the techniques which have been developed in this project have been applied in the following glaciers: rock glacier of Posets (Pyrenees-Spain), rock glacier of Corral del Veleta (Sierra Nevada-Spain) and white glacier Ventorrillo in the volcano Popocatepelt (México).

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