5th Dolomites Workshop on Constructive Approximation and Applications - 6-10 September 2021

A SPLINE-BASED METHOD TO ASSESS THE SUDDEN OCCURRENCE OF UNFORESEEN EVENTS

ALESSANDRO PERLO, EZIO VENTURINO

Department of Mathematics, University of Torino, Italy.

ABSTRACT

In this poster we present the experience gained during a stage activity in an industrial framework, aimed at the redaction of a Master thesis. The goal is the detection of unforeseeable events that disrupt the normal functioning of a device. Using suitable approximation theoretic tools, it is possible, by constant monitoring of the device output, to assess the sudden and abrupt change of the environmental conditions.

We propose a technique based on splines to suitably locate the occurrence of such unexpected behaviors, to follow them to determine their duration and intensities, and ultimately to restore the device to its normal functioning.

THESIS BACKGROUND

The stage is taking place in a firm in the province of Turin, which produces components for home heating systems.

The thermostat produced by this company allows the user to set a temperature (threshold) that he wants to maintain throughout the day. This thermostat, then, manages the heating system in this way: when the temperature falls below the threshold, the heating system is turned on; when it returns above the threshold, the heating system is turned off.
This method of control is extremely simple and intuitive, but it has some obvious disadvantages, in particular some heating systems (e.g. underfloor heating) start heating the house quite a long time after they are switched on. In this period of time, the internal temperature can fall far below the desired threshold, and therefore user comfort can be poor.

This is where our work fits in. The problem can be faced with different approaches, such as with a neural network, or by performing statistics on the historical data.
Instead, we chose to develop a differential equation model that describes home heating. This model allows to predict the temperature trend during the day knowing only the weather forecast and the physical characteristics of the house (energy class) and of the heating system (underfloor/radiators/...).
Thanks to these predictions, the thermostat software can always keep the internal temperature above the threshold, anticipating the switching on of the heating system.

However, we encountered the presence of unpredictable events, such as a family member opening the windows, which break the normal temperature behavior and make the predictions ineffective.
Therefore, we had to develop a method of detecting such events.

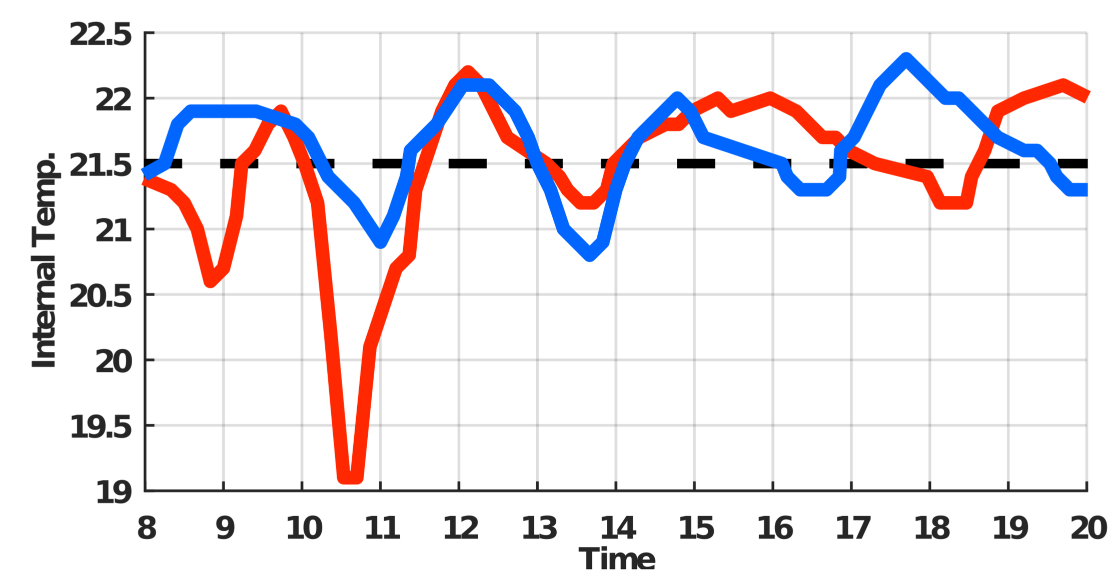
THE PROBLEM

Let's suppose to have a physical quantity, and to have a mathematical model that describe the evolution of this quantity through the time in "normal" conditions. If the model is sufficiently accurate, it can be used to make very precise predictions.

These assumptions are often made when we approach the study of physical phenomena. However in the reality it can happen that at times there are unexpected events, which are not foreseeble neither in their occurrence, nor in their duration, nor in their intensity, which disrupt the normal behavior of the physical quantity. So the prediction made with the model becomes useless, and there is no more information about the future evolution of the quantity.

During the stage activity, we were confronted with this type of problem. In our case, the physical quantity is the internal temperature of a house, the model describes the evolution of this temperature, and sudden events can be, for example, a family member who opens the windows.

In the following Figure you can observe the normal behavior of the temperature (blue line) oscillating around a target setpoint (black dashed line) set by the user, and its trend when a sudden event occurs (red line).



THE PROPOSED SOLUTION

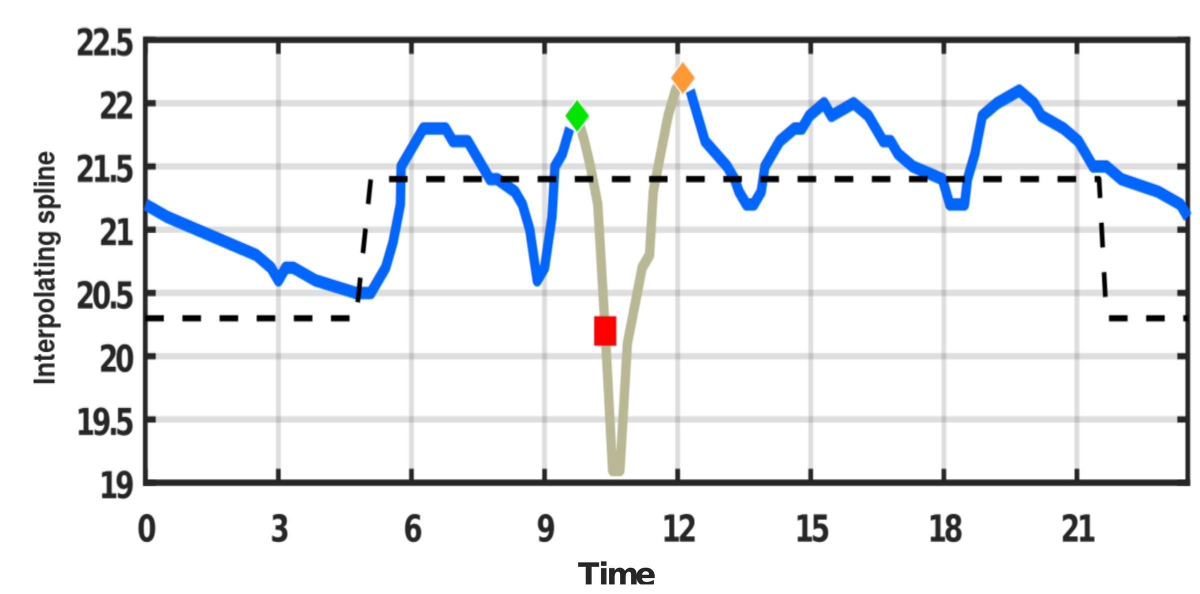
First, it is necessary that the observed physical quantity be measured periodically. Only in this way we have data on the real evolution of the quantity.

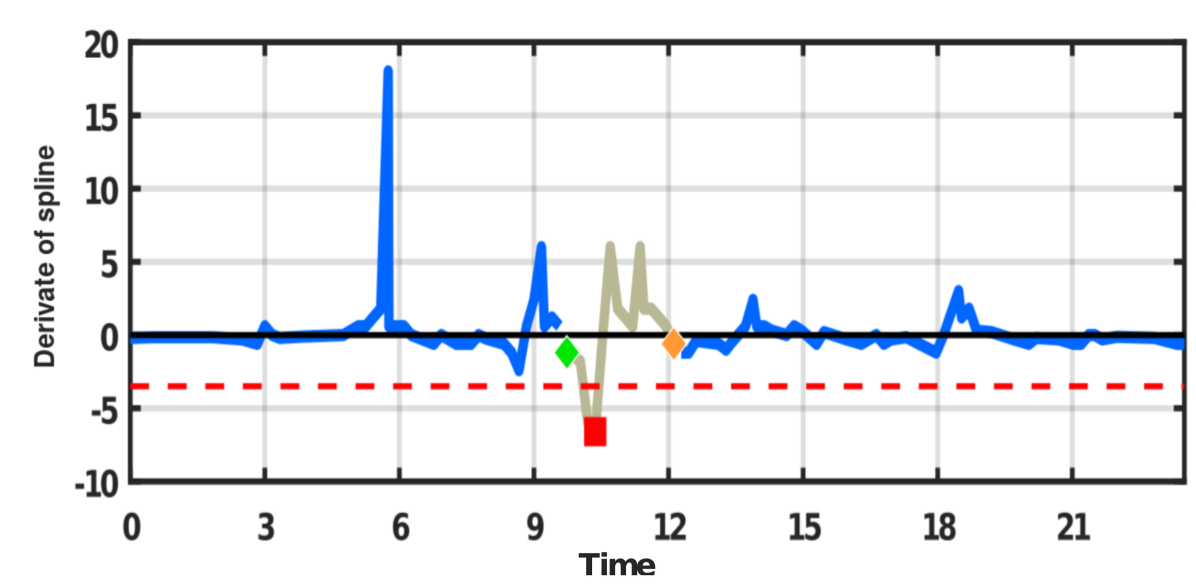
After that, we propose to interpolate this data with spline curves. The use of spline curves allows to calculate in a faster and easier way the geometric characteristics of the data (e.g. the norm of the derivative, the normal versor,...).
Now, to detect sudden events, we need only to geometrically characterize such events, i.e., to identify those features that characterize the spline when one of these events occurs.

For example, in our case the opening of the windows causes a sudden drop in the internal temperature of the house. So we can identify the sudden event simply by checking the derivative of the spline: if this derivative falls below a certain threshold, then the point in question is a flag of the sudden event.
The first Figure shows the spline that interpolates the internal temperature detected during a day (blue and gray line) and the threshold temperature set (dashed black line). The second Figure, on the other hand, shows the derivative of the spline (blue and gray line) and the threshold that allows to identify the opening of the windows (dashed red line). The red square is the opening window flag, indeed the derivative at that point is less than the threshold.

Then, to properly identify the phenomenon, we need to define other two geometric features, one for the start and one for the end of that event. In our case, we assume that the opening windows event starts at the last peak before the flag, and stops at the first one immediately following it.

In the two Figures the green and the orange diamond are the delimiters of the event, and the gray line represent the spline section affected by the phenomenon.





Therefore, the forecast made at the beginning can provide information until the beginning of the event, then it has no more value because an unexpected event has intervened. But when the event reaches the end, it is sufficient to calculate a new forecast through the model, which will be valid until a new unexpected event.

To conclude, the identification of an unpredictable event is reduced to the simple control of some geometric characteristics on a spline.