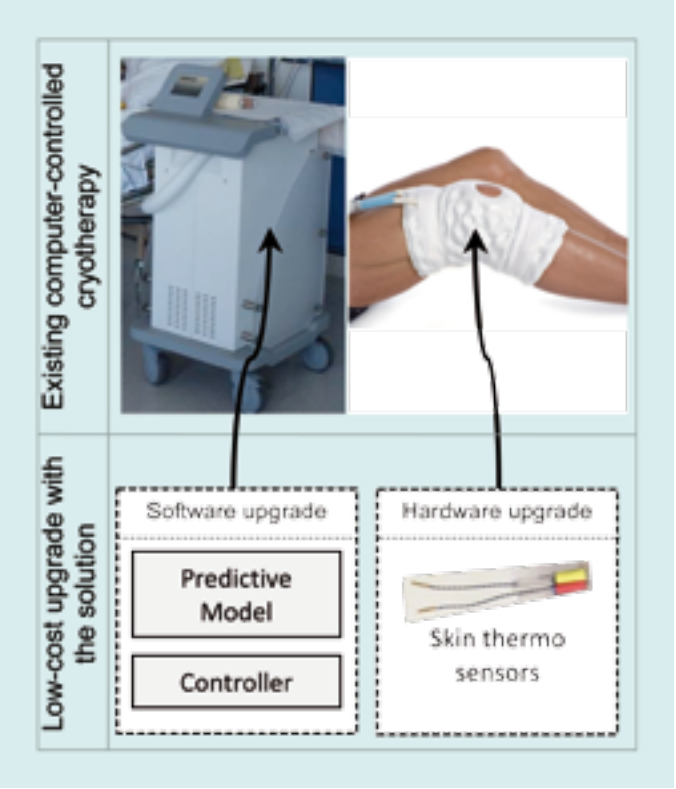
LEVERAGING HPC, MACHINE LEARNING AND CONTROL THEORY TO DESIGN EMBEDDED SYSTEM FOR SMART THERMAL THERAPY

Method and device for non-invasive real-time control of inner body temperature variables during therapeutic cooling or heating

Therapeutic cooling or heating of body parts is a medical treatment that adjusts patients' body part temperature to reduce the need for pain medications and enable faster rehabilitation after injury or surgery. Knee cooling is often performed using refrigerated gel-packs or computer-controlled cryotherapy (pad cooled by a liquid at a constant temperature maintained by an external cooling device).

Our previous clinical study showed that the cooling is significantly more effective by computer-controlled cryotherapy than with gel-packs. Moreover, another important finding was that patients' responses to cooling differ considerably. The average central knee temperature measured in vivo in 12 patients treated with computer-controlled cryotherapy after two hours of cooling was 34.6 °C, while with one patient it dropped to 27°C degrees. The result indicated that the cooling procedure has to be controlled by feedback information from the cooled region, which raised the need for "smart" or personalized thermal therapy.

To address this issue, we proposed an **embedded system for non-invasive real-time control of hidden inner body temperature variables** that are, for example, impossible to be measured non-invasively during therapeutic cooling or heating, based on the feedback for the individual patient's response provided by variables whose measurement is more feasible, i.e. temperatures on the body surface.



The solution is a cross-fertilization of three disciplines: **HPC** (computer simulations), artificial intelligence and control theory. Machine learning methods are used to construct a **predictive model** for estimation of the controlled inner temperature variable based on temperatures on the knee skin. The machine learning method uses data generated from **computer simulation** of the cooling or heating therapy for different input simulation parameters e.g. input signals, initial and boundary conditions, or any combination of them. A set of **fuzzy logic** rules constructs the **controller** that sets the temperature of the cooling liquid based on the error between the desired and predicted inner knee temperatures.

So, the solution involves a **low-cost upgrade** of existing computer-controlled therapeutical devices with:

- two thermistors placed anterior and posterior on the knee below the cooling pad,
- upgrade of the support mini on-board computer with software consisting of a lightweight predictive model and fuzzy logic controller.

The proposed system has been protected with a patent application at the Slovenian patent office from March 2013 with the intention to extend the IPR. The invention has been awarded with a special prize for innovations for economy at the 6th International Technology Transfer Conference and Innovation Day 2013.

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