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THERMAL FEEDBACK IN VIRTUAL REALITY AND TELEROBOTIC SYSTEMS

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ABSTRACT

A new concept has been developed that allows temperature to be part of the Virtual World. The Displaced Temperature Sensing System (DTSS) can "display" temperature in a virtual reality system. The DTSS can also serve as a feedback device for telerobotics.

For Virtual Reality applications the virtual world software would be required to have a temperature map of its world. By whatever means (magnetic tracker, ultrasound tracker, etc.) the hand and fingers, which have been instrumented with thermodes, would be tracked. The temperature associated with the current position would be transmitted to the DTSS via a serial data link. The DTSS would provide that temperature to the fingers[1].

For Telerobotic operation the function of the DTSS is to transmit a temperature from a remote location to the fingers where the temperature can be felt.

DISPLAY THEORY

By simply thinking of the many languages and forms of writing one comes to the inescapable conclusion that there are many way to present the same idea. The clarity of that presentation is a function of the individual; weather or not he knows the language, his background and so on. The display of a machine, be it as simple as the calibrated marks surrounding the volume knob of a radio or a Heads Up Display (HUD) of a fighter plane, is supposed to translate information into a form we can understand. Thus, *clarity* is still a function of the individual; weather or not he knows the language, his background (training), etc.

Information has 2 basic types, *inherent* and *abstract*. Inherent information is information that is common to all humans. For example, hot, cold, loud, rough, smooth are common to all humans, regardless of how they may be expressed. Abstract information is text, graphics and other things that require interpretation and prior knowledge.

[1]Obviously other parts of the body could be fitted with thermodes, but we don't talk about that.

From the above 4 laws are realized.

1) The usefulness of a machine is determined by the ability of the display of that machine to convey information within that machine.
2) Any display can do the job of any other display.
3) The ability of a display to reproduce the actual situation makes that display useful.
4) The perception of abstract information presented by a display is culturally determined.

PRESENTING TEMPERATURE INFORMATION.

The notion of temperature is implied in our language that describes reality: a summer day, a winter storm, a cup of coffee, or a drink at the water fountain. Thermal sensation gives other cues to the nature of things in the environment around us; for example, the average person can easily tell the difference between metal and wood because the difference in the thermal conductivitys is felt as apparent cold. Temperature is inherent information and therefore best displayed as hot and cold .i.e. felt as hot and cold. Reality is not complete without temperature. It fills in our picture of reality with the details that make everything seem correct.

The DTSS allows use of physiology deception to enhance realism of the virtual world. In addition to presenting thermal information **Weber's Deception** can be used to create the sensation of touching an object. Weber's Deception is the sensation of pressure or contact caused by slightly cooling the skin.[6]

THERMOELECTRIC HEAT PUMPS

A thermoelectric heat pump (sometimes called a Peltier Device or a thermoelectric cooler) is a solid state device that moves heat from its cold side to its hot side. Thermoelectric heat pumps are heat pumps just like the mechanical heat pumps used in refrigeration or air conditioning except they have no moving parts. All of the thermodynamic laws that govern conventional heat pumps also govern thermoelectric heat pumps.

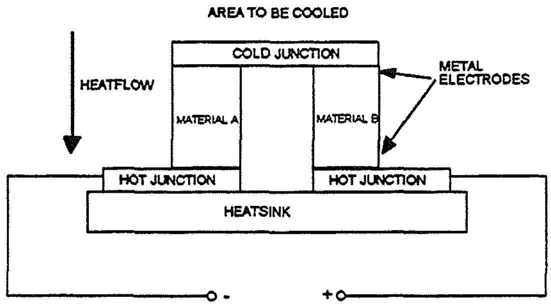

Figure 1.
A single element thermoelectric heat pump.

A thermoelectric heat pump can be thought of as a thermocouple being driven backwards. A thermocouple is a common temperature measurement device consisting of a junction of 2 dissimilar metals. When the junction is heated an electric current is produced. In a thermoelectric heat pump there are 2 junctions (see Figure 1). One junction is located in or on the space to be cooled; the other junction is located on the heat sink. When voltage is applied, the temperature of the junction in the space to be cooled will decrease and the temperature of the other junction will increase and heat will be transferred from one side to the other. The thermoelectric process is reversible. If the current through the heat pump is reversed the cold side becomes the hot side and heat flows in the opposite direction. A typical thermoelectric heat pump can generate up to a 67°C temperature difference from on side of the heat pump to the other[2]. Heat pumped is roughly proportional to the current through the heat pump[3].

THERMODES

A thermode is an assembly consisting of a thermoelectric heat pump, a temperature sensor, and a heat sink. The heat pump moves heat into or out of the heat sink to produce a temperature at the surface of the thermode. Using feedback from the sensor, the DTSS regulates the temperature of the surface of the thermode. A thermode can also serve as an input, sensing temperature and surface thermal conductivity.

The basic physical configuration of a thermode is shown in figure 2. A temperature sensor is mounted on top of the thermoelectric heat pump. The temperature sensor provides feedback to the control network. The heat sink is in contact with ambient temperature air.

[2]The 67°C temperature difference is for a no load condition.
[3]This is not strictly true; thermoelectric heat pumps are not linear, but do have regions where they are near linear. There is also a performance difference between heating and cooling.

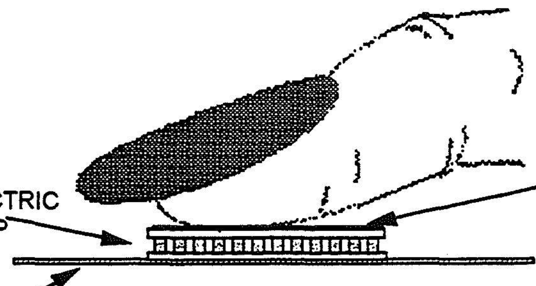

Figure 2.
Basic physical configuration of DTSS Thermode.

SAFETY

Thermoelectric heat pumps in contact with human skin can cause burns. Any experimentation with thermoelectric heat pumps should provide a way of preventing burns.

The comfort zone for humans is from 13°C to 46°C, with pain below and above these limits. The average human can feel a temperature change as little as 0.1°C over the entire body, however, at the finger tip a sensitivity of 1°C is typical. Exact numbers vary from person to person. [7]

A Thermal Electric Heat Pump used to stimulate thermai sensation to fingertips has several inherent safety problems.

The finger contains heat which must be dissipated in order for a person to feel cool. Because heat is convected to air (through the heat sink) slower than heat conducted from the finger, the heat sink size for the thermoelectric heat pump has to be large enough and have enough surface area so that the heat sink is not overwhelmed. If the heat sink is overcome (usually because the heat pump was operated in cooling mode for an extended period of time), the heat pump can not maintain the temperature difference. The heat in the heat sink will come back through the heat pump and burn the finger.

Another potential safety problem occurs if the heat pump is operated in a cooling mode for an extended period of time and the power to the unit fails. In such a situation the unpowered heat pump becomes a sandwich of ceramic and metal (with good heat conductivity), and once again, the heat in the heat sink flows back through the heat pump and burns the finger.

CONTROL SYSTEM

Figure 3 shows a block diagram of the control system used for the DTSS. The goal of the control system is to have the temperature at the finger tip follow the temperature command.

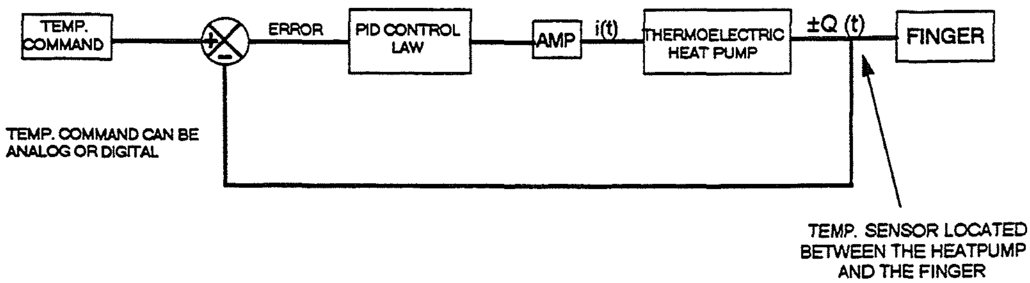

Figure 3.
Block diagram of the DTSS control system.

An early DTSS prototype used a proportional control law. It was found that in order to have an effective response time the gain had to be very high, but this caused temperature ringing at the fingertip (a very weird physical sensation). The DTSS uses a **Proportional Integral Derivative** (**PID**) control law for closed loop control of thermode temperature. A PID control law allows gross temperature error, cumulative error and oscillation to all be controlled. The control law is implemented in the software.

FEATURES

CM Research's first DTSS product is the model X/10. The X/10 is designed as a research unit for those who want to add temperature to their work.

- The X/10 has eight thermode channels. Each channel is software programmable as an input or an output. The inputs can be "mapped" to outputs, such that the output temperature tracks the input temperature; this is called analog track mode. Any input can be mapped to any output or group of outputs.
- The DTSS can be operated from the front panel or remotely via an RS-232. A front panel is provided so the unit can be used in a stand alone configuration. The front panel also makes troubleshooting easier in situations where the X/10 is part of a larger system.
- Differential analog inputs are provided so the X/10 can track an analog signal from some external device.
- The gains of each part of the PID control law (P, I, and D) are software adjustable via the front panel or the serial communications port.
- Demonstration software (with source code) is included to provide examples for interfacing the X/10 to other systems.

DTSS X/10 Safety Features
CM Research has elected to develop an intrinsically safe thermode. The temperature of the heat sink is never allowed to go beyond 45°C. This results in some degraded long term performance, but provides a simple way to overcome the safety problems mentioned above.

- The DTSS X/10 temperature reproduction range is 10°C to 45°C, with an ambient temperature operating range from 10°C to 35°C. By operating within the comfort zone for humans, the temperature differences are kept small, which allows for better use of energy.
- The size of the heat sinks are designed for maximum surface area.
- Power to the thermode has to be actively engaged by the computer after computer power up.
- Thermostats on the thermode cut power to the thermode if the heat sink or the surface of the thermode exceed 45°C.
- Redundant safety software zeros the input to the thermode if the operating range is exceeded.

APPLICATIONS
In a telerobotics application, temperature sensors could be placed in the fingers of remote manipulators. Temperature signals would be sent to the DTSS and drive thermodes on the fingers of the operator. The DTSS X/10 can accept analog input as well as serial digital input.

A virtual reality application would not require a temperature sensor input; the DTSS would take serial digital commands from the computer controlling the simulation. For example, thermodes would be placed on the fingers of the virtual explorer and a temperature value would be assigned to objects or locations in the virtual world. As the hand moved near these objects, commands would be sent via digital serial communications to the DTSS to change the temperature of the thermodes.

Prosthetics research applications; the DTSS X/10 can be used by researchers to explore application of displaced sensing to prosthetics. Temperature sensors could be placed in the fingers of the prosthetic limb and the displaced sensing system would be used to transmit the temperature felt by the prosthetic fingers to some point on the body, where the temperature could be felt.

CONCLUSION.

Another building block for the virtual world has been developed, thus another aspect of reality can be simulated.

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