Sensor fusion-based smart monitoring of sauna systems

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***Abstract*—An unexpected event, an error can endanger human life, the natural environment or cause significant material damage. [1] Safety-critical systems are IT systems that must be operated with the primary requirement that they do not endanger human life, health or cause economic or environmental damage. The aim of the research project is to develop a safe sauna control system, which, in addition to the functionality of traditional sauna control equipment, monitors and analyzes events in a sauna to achieve safe sauna use based on data from data collection sensors based on various technologies. Based on the detection, identification and behavioral analysis of sauna users, the system developed uses appropriate decision support algorithms to determine its current level of security risk during the operation of a sauna.**

I. Introduction

Sauna control equipment is an essential part of a sauna. The basic function of the controller is to operate the electronic equipment of the sauna. The safe sauna control system developed during the project contains, in addition to the basic functionality, important preventive safety functions. The new system continuously detects the internal sauna room, continuously monitors the events taking place in the sauna room, which is based on a sensor network based on modern technologies. By evaluating the events based on the data extracted by the sensors, the system is able to intervene automatically, if necessary, turn off the electrical equipment of the sauna, in case of an emergency, warn the user in the sauna room with various audible and visual warnings. The safe sauna control system is capable of react to events occurring in the sauna room in a timely and safe manner and implements the reliable operation of the saunas.

II. Methods and Tools

A. 3D imaging tools

3D imaging tools create a 3-dimensional model of the observed environment. Unlike traditional color (RGB) imaging devices, in a 3D imaging device, the value of each pixel in the output image contains the distance of that pixel instead of the color code of the pixel.

3D imaging devices work based on the following two principles:

Stereo image capture – 3D image reconstruction can be performed by analyzing images taken simultaneously by two known and fixed-distance color imaging devices. Then, the difference in the coordinates of the pixels belonging to the same object point in the resulting stereo image - the displacement belonging to a given object point - gives the distance of the given object point.

Infrared image – A 3D image can be captured using an infrared projector and an infrared sensor. In this case, 3D reconstruction based on the infrared sensor image is possible by analyzing the distortion of a well-known sample projected by the projector.

Infrared 3D cameras generally have the following components:

Infra-Red Projector – Projects a dot grid on the area in front of the camera.

Infra-Red camera – Its task is to detect this dot grid and then create a depth image from its distortions. The points of this can be exactly matched to the points of the image given by the RGB camera.

Figure 1 Colored depth image based on histogram

The figure shows a colorized image of the output image of a 3D imaging device based on a particular histogram. In the figure, the lighter pixels represent the closer pixels, while the darker ones represent the farther pixels.

B. RGB Imaging Devices

RGB imaging devices are widespread. All RGB imaging devices (USB webcams, IP cameras) meet the requirements of the camera-based sauna room analysis module for the RGB imaging device. There are 3D imaging devices that also have a built-in RGB sensor.

The camera-based sauna room analysis module has the following requirements for a color imaging device for close face and eye tracking [2]:

- Distance between 80cm and 150cm between the camera and the user's face.
- Within the given distance range, the user's upper body must fill at least 1/3 of the image.

- Within the given distance range, the eye and pupil in the camera image must be well separable for machine processing.

III. Results

The safe sauna control system developed during the project is a multi-component, modular system, which can be customized according to the needs of the users due to its flexibility and parameterizability. The main modules of the safe sauna controller:

sauna control electronics module, power supply and switching unit modules capable of controlling all types of sauna cabins,

the newly developed *camera-based sauna room analysis module*, which implements safe sauna use at a high level.

A. The camera-based sauna room analysis module

The camera-based sauna room analysis module is able to determine the level of operational safety risk by collecting the appropriate amount and quality of data on the current physical condition of the users, as well as their sauna conditions, and by processing and evaluating the data.

The operating logic of the camera-based sauna room analysis module

1) Data collection from sensors and imaging equipment.
2) Processing of extracted data.
3) The system evaluates the data using processing algorithms.
4) The system determines the level of operational safety risk.
5) The system intervenes if necessary. The intervention can be the simultaneous use of light and sound signals, switching off the electrical equipment of the sauna, possibly limiting boiler output, notifying an external or even remote supervisor by sharing video, and increasing ventilation or opening the door.

Module components:

- Central data collection module.
- RGB imaging sensors.
- 3D imaging sensors.

Software architecture of the camera-based sauna room analysis module:

- an embedded computer that provides resources to run camera-based sauna room analysis software.
- embedded operating system that provides the software platform for camera-based sauna room analysis software
- RGB and 3D sensor adapters, which are low-level, vendor-specific sensor interface modules.
- camera-based sauna room analysis software that implements sensor data collection, evaluation and decision making.

The camera-based sauna room analysis software component represents the implementation of the full functionality of the camera sauna room analysis software. The component contains software modules that make up the camera sauna analysis software. The software modules that implement the full functionality of the camera sauna area analysis software are the following:

Data collection layer – reads the data of the sensor of the camera-based sauna room analysis module and performs pre-processing on the data.

3D reconstruction layer – a software module for post-processing, merging the sensor data presented by the data collection layer and generating the virtual 3D room based on the sensor data.

Identification layer – a software module for identifying users and other static objects in the virtual 3D room generated during 3D reconstruction.

Decision support layer – the software module that derives the current risk level based on the instantaneous parameters of the users identified in the virtual 3D sauna room during the identification and the instantaneous parameters of the static objects.

B. Monitoring the sauna room with modern technological solutions

The sauna room is monitored with sensors based on modern technology and visual imaging devices.

The sensors can be used to monitor the operation and power consumption of the boiler in the sauna room, the air quality of the sauna (temperature, humidity, O2, CO2, CO, alcohol content), the condition of ventilation, lighting and doors. [3] Data collection sensors capable of detecting user presence, status and movement have also been integrated into the system:

- Radar sensor: One of the intelligent, energy-saving, compact solutions for sensing sensors is the use of radar sensors. With the device, small movements such as human breathing can be detected in the sauna room. From the change of the rhythm of breathing, the condition of the user can be deduced, if necessary, a signal can be given, and the user should be warned to leave the sauna cabin.
- Ultrasound sensor: we can detect the user's presence and certain movements with it.
- Infrared sensor: we can also detect and track the presence and movements with it.

A higher level of security is achieved using visual imaging devices in the sauna room. Using visual tools, the user's presence, the time spent in the sauna, and the possible glow of the users can be determined more precisely. By continuously tracking the movements of the sauna user over time, movement patterns can be identified, such as falling asleep, malaise, fainting, falling, the user in a forbidden place e.g. staying near a hot stove.

C. Method of identifying objects and people

In the sauna room, static and dynamic objects identified by the safe sauna control system:

Static objects – Static objects can be objects belonging to the interior of the sauna (stove, bench, etc.), but can also be objects brought into the sauna room by users (towels, slippers). Static objects may or may not be allowed. Allowed objects can also have allowed positions or non-allowed positions that the system can monitor.

User's movement and behavior – When identifying sauna users, the data to be collected is the user's presence in the sauna cabin, the user's movement, and behavior (falling asleep, malaise, loss of consciousness). The system monitors the static parameters of the users as well as the dynamic (behavioral) parameters. [4], [5]

The decision support layer of the system can determine the parameters related to the current operational safety risk of the sauna based on the detected parameters. During operation, the system derives and uses the following parameters for decision support:

- Static user parameters:
  - Physical parameters relevant to sauna use (e.g. physique).
  - Determining the context of sauna use using partial identification (e.g. identification of a known user, unknown user, identification of a known sauna use model in the case of a known user).
- Dynamic user parameters:
  - Location and position of the sauna user in the sauna room. Identification of location and position patterns:
    - normal position (e.g. standing on the floor, lying on a bench, sitting).
    - abnormal position (e.g. lying on the floor, standing on a bench, leaning on a stove).
  - Time tracking of sauna user movement, analysis of movement patterns. Identification of known patterns of behavior
    - normal sauna use,
    - excessive activity,
    - decreased activity.
- The environmental parameters monitored by the camera-based sauna room analysis module are as follows:
  - air pressure,
  - temperature,
  - humidity,
  - air quality (CO_2 concentration).

D. Data processing

The data collection layer of the camera-based sauna room analysis module provides the sensor data to the data processing layer. Prior to this, the task of the data collection layer is to convert the collected raw sensor data into a uniform form - in the form of a data descriptor independent of the sensor supplier. During the conversion, the manufacturer- or sensor-dependent data must be converted into a uniform, well-defined form.

The data processing layer of the camera-based sauna room analysis module performs post-processing on the unified sensor data received from the data collection layer. The required post-processing steps are recorded by the layer sensor configuration descriptor for each sensor available in that configuration. The means of post-processing are as follows:

- Filtering algorithms.
- Image enhancement, edge enhancement algorithms.
- Statistical algorithms (e.g. histogram making algorithms).
- Edge search algorithms.

Some of the tools used in post-processing (e.g. histograms, edge search) produce new products that appear as virtual sensor data at the higher levels of the data processing layer.

Based on the different real and virtual sensor products generated in the data processing layer of the camera-based sauna room analysis module, an aggregated product must be created that contains the data of each sensor. This derived product will be the basis for the 3D room reconstruction process.

E. 3D model of the sauna room

The 3D model of the sauna room is generated based on aggregated sensor data generated by combining the dedicated sensor data obtained from the sensors by the data acquisition layer. During the 3D reconstruction, the module creates an internal 3D model of the sauna room from the aggregated sensor data.

The camera-based sauna room analysis module identifies dynamic objects (users in the sauna room) in a 3D model created based on the data of the connected sensors. Dynamic objects are objects within the sauna room that can change position and position on their own. Sauna users are always handled as dynamic objects by the module. Components of dynamic object identification: user position definition, user static parameters, user dynamic parameters.

After successful identification of the users, the camera-based sauna room analysis module represents the user with its wireframe model in the virtual 3D sauna room. The wireframe model contains the 3D coordinates of the representative points of the user's body (wireframe node). The camera sauna room analysis module must register the movement of the nodes of the user's wireframe model in time. Based on this, the user's behavior pattern and the intensity of the movement can be determined.

F. Safe operation by setting risk levels

An interface must be established between the secure sauna control system and the camera sauna room analysis module, through which the camera sauna room analysis module sends the monitored data to the control system and receives the intervention signals. The sauna room analysis module derives a safety risk factor based on the monitoring of events in the sauna room during its operation, which is sent to the safe sauna control system. Based on this level of risk, the safe sauna controller makes further decisions. The camera sauna room analysis module derives and sends the following data to the secure sauna controller:

- Current security risk level, which represents the events in the sauna area - mandatory data, monitored value in all cases. Basically, the risk values can be divided into 3 groups:
  - normal level of risk - does not require intervention by the safe sauna controller.
  - warning level - events in the sauna area show an increased risk, but do not require direct intervention, only a warning.
  - level of intervention - critical events in the sauna area (e.g. loss of consciousness of the user, contact with the stove, prohibited objects in the

sauna area, near the stove) require intervention by the safe controller.

- Number of users in the sauna room - optional parameter, if the sensor can be determined from the data.
- Individual sauna usage time for users in the sauna area - optional parameter if it can be determined from the sensor data.
- Event descriptor - a mandatory parameter that specifies the current level of risk generated by the event in the sauna room.

The decision support algorithms implemented by the sauna room analysis module derive the following primary parameters based on the data of the sensors located in the sauna room:

- The safety risk factor of sauna use, which determines the level of safety risk that is currently predicted by the events taking place in the sauna room. The system distinguishes the following 3 basic levels of risk:
  - Normal sauna use level.
  - Notification level, where immediate notification of the sauna user is required.
  - Critical, intervention level, where the sauna must be switched off immediately and the operator must be notified.
- Convenience features related to sauna use. Setting sauna parameters available with gesture control.

A further function of the secure sauna control system is to implement a well-defined open interface, through which the system status, operating parameters and derived parameters are presented to external systems, possibly from third parties. Intervention signals from external systems can also be transmitted on this open interface.

IV. Conclusions and Further Work

As a result of our work, an event recognition and risk assessment method has been developed, which is suitable for continuously determining the current risk level of sauna use based on the data collected during the monitoring of the sauna interior and for signaling or intervening in unsafe situations. To determine the level of risk, we have developed a method for identifying and tracking objects, among other things. Using the developed method, it is possible to operate a sauna with a higher level of security than before.

The developed method processes data streams continuously collected by several conventional sensors as well as 2D and 3D imaging devices. Based on the simultaneous processing of these signals, it identifies the objects and people located in the sauna room, determines the measurable parameters of them and the devices operating the sauna. Based on these, it monitors the processes taking place in the sauna and assesses their level of risk according to the built-in set of rules. Based on the risk level of the events associated with each process, the system intervenes with commands sent to the sauna controller or other direct alarms.

In addition to the implementation of security functions, the developed complex event recognition methods have made it possible to implement a number of useful functions and services, such as the creation of gesture-controlled sauna management functions, which significantly increase the comfort level of sauna use.

In addition to the developed methods, the most important software and hardware elements of the technical environment suitable for the implementation of the methods were presented in the article.

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