Approaches to Thermal Management in Handheld Devices: A Survey

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***Abstract*-Use of handheld devices like smart phones, tablets etc. have become a basic need for the generation. With advancements in IT technology, lots of applications are running on these devices. To support faster response, high-end processors which run on GHz clock are used in these devices. In addition, complex architectures with specialized processors are used to support video calling, streaming multimedia, gaming, multitasking etc. Because of this, high power consumption and heat generation is seen in handheld devices. With increase in temperature,users may find it inconvenient to use devices and temperature beyond certain limit may lead to breakdown of the devices. Hence there is a need to address this issue and many attempts have been made in this regard. This paper is a survey of the earlier works on thermal managementin handheld devices by passive as well as active cooling methods.**

***Keywords*- Thermal Management, Heat Dissipation, Cooling**

I. INTRODUCTION

Electronic devices generate heat during their operation. The generated heat gets accumulated and when it crosses certain threshold, the devices may break down. In order to make system reliable, it is necessary to remove the generated heat. Thermal management is the process of controlling temperature of the device to improve its stability and reliability. Simplest of these is seen in computers where heat dissipation is increased by using fans. But for handheld devices, it is difficult to install an active cooling device like a fan, inside its compact package. This limitation has led to a necessity for finding some passive approaches to thermal management incompact handheld devices. Some of the techniques include reducing the processor frequency, turning off unused applications, changing the display intensity. These are effective and simple passive cooling techniques but only these methods are not sufficient for different devices and sometimes these techniques come with a performance trade-off. Many researchers have done a lot of work in this area and still is an active area of research. The main objective here is tocontrol the temperature of the device without affecting the device performance or its durability oreven the user experience.

II. SURVEY

A. *Using Phase Change Material Inside the Device as a Cooling Agent*

Phase Change Material (PCM) is a substance which is used as heat sink to control the temperature. Working principle of this method is that PCM is coated on electronic device, when the device gets heated, the heat is absorbed by the material and it changes its state e.g. from solid to liquid state andthe liquid holds the latent heat. When the device is not working under heavy workload, heat is dissipated from the liquid material, gets cooled and it regains its solid state. RenCe C Estes [1] examined the use of PCM for heat storage, to protect the telephone optical network unit (which is used to convert optical signal to electrical signal) from varying ambient temperature. He analyzed two modes of the heat storage process one is Sensible mode- where the heat is absorbed by the material and it changes its phase, second is Latent mode- when the material absorbs the heat after phase change which results in the increasing of PCM temperature. Latent mode process can be continued till PCM reaches threshold- the maximum amount of heat it can store. Mark J Vesligaj et al. [2] worked on a thermal management method using PCM. This method includes a Thermal Control Unit (TCU) placed near the power supply of an electronic device. PCM and Thermal Conductivity Enhancer are included inside the TCU and this TCU is used to control and spread the heat. This work analyzed the heat storage as time variant power workloads and physical model-wearable electronic device is compared with numerical model for different boundary conditions of TCU. Esam M Alawadhi et al. [3] also worked on PCM usage for controlling heat. In this experiment they used Eicosane as the PCM based on its latent heat of fusion. Properties of a PCM are discussed, a PCM better be of high melting point, non-corrosive, of low density etc. and even the quantity of PCM to be used is commented. This experiment was done on two different arrangements of TCU, and improvement in TCU size was achieved. Esam M Alawadhi et al. [4] continued to work on [3] so as to have a correlated physical model for the numerical model and optimize the performance. In order to get better performance, TCU structure is modified along with some changes in Thermal Conductivity Enhancer. Factor causing PCM melting-time duration is analyzed. Close agreement between numerical model andexperimental results helped in finding effective heat transfer co-efficient and average material properties of TCU. F L Tan et al. [5] proposed a method for thermal management in mobile devices. In this model, PCM is placed inside a thin metal case called as Heat Storage Unit (HSU) and HSU is placed just inside the device cover so as to enclose all the heat sources. This work shows PCM with good properties in proper quantity as a sufficient material for thermal management in mobile phones, showing that reaching power dissipation that causes PCM melt is very rare case. F L Tan et al. [6] presented an experimental study of effect of PCM in the heat sink of mobile phones when the device is under different workloads. The n-eicosane with melting temperature of 36°C is chosen as the PCM and experimented with aluminum heat sinks of different structures. This study shows that the use of PCM is applicable only for intermittent usage of the device but not during continuous usage. Effects of placing fins in the heat sink and the orientation of phone, on cooling action are also explained. Oksen T Baris et al. [7] explained capacitive cooling system using PCM as the capacitive element with its ability to store heat during peak power spikes and heat release during idle stage. A micro fabricated calorimeter is described to measure temperature, heat capacity and enthalpy of phase transitions of PCM.

B. Cooling by Altering Surface and Size of the Device

Experimenting with the surface and size of the device is another approach for thermal management in handheld electronic devices. This approach includes using devices of different sizes, increasing heat dissipating surface area, changing the material which is used as the device cover, coating the surface with other materials like PCM etc. Jaeho Lee et al. [8] studied the relationship between power dissipation and size of different handheld electronic devices. Devices of different sizes are testedunderthree conditions, in still ambient air, handheld and kept in pocket in order to find the effect of different values of heat transfer co-efficient. This work looked into the material properties and proposed different material combinations for covering the device components. Experiments showed that increasing the space inside the device for air circulation and increasing device surface areacan lower the device temperaturelargely. Increasing surface area by 4mm could reduce the temperature by around 5^0C-25^0C. If the material chosen for PCB and/or device case is a good thermal conductor like aluminum, surface temperature drops close to the ambient temperature. Xinsheng ZHANG et al. [9] proposed Biomimetic Transpiration Cooling Technique (BMTC) to overcome the bottleneck of passive heat dissipation in high end handheld devices.In this method biometric skin- made of temperature sensitive hydro gel is used to control the heat. Whenever the skin temperature crosses the hydro gel threshold, heat dissipation is boosted through its evaporation. Experiments done at a voltage of 110V showed that the temperature of the device which is coated with hydrogel is 10^0C less when compared with the device with natural convection cooling system.

C. Usage of Heat Sinks and Heat Spreaders as Cooling Elements

In this approach, the devices are cooled either by using heat sinks to absorb the generated heat or byusing heat spreaders to spread the generated heat over a large surface area, which in turn leads to fastercooling. Mingzong Wang et al. [10] worked on a Chip Scale Package (CSP) in which Die size is of 80% ormore of the package size. Since this package size is shrinking, heat spreading and dissipation is achallenge. To control the heat accumulation in package, a metal block or shield which works as heat spreader, is mounted on top of die. Analysis and the experiments were done on Hard Disk Drive atpackage level and at module level by embedding heat spreaders of different size, material and ofdifferent designs. It is shown that the improvement in heat dissipation after embedding heat spreader isaround 9% at package level and around 23% at module level. Hsien-Cheng TSENG et al. [11] proposed ahighly compact Heat Spreading Structures (HSS) simulated by Genetic Algorithm and demonstrated amulti-finger collector up Hetero-junction Bipolar Transistors (HBT) based Power Amplifiers. This workfocused on the thermal management of power HBT through unique HSS. Collector up HBT with HSSshowed 55% power added efficiency when compared with HBTs without HSS. Chien-Cheng Lee et al. [12]discussed a method, in which a metal coin is introduced inside PCB to dissipate the heat generated inPCB. Metal coin is mounted on PCB under some high power components like power transistor. Duringoperation, heat generated in these components is conducted to chassis or other heat sinks based on thedesign and connection of the coin. As part of this work, simulation of thermal performance of PCBs isdone and compared for four different types of coins. Yin Xiong et al. [13] explained the usage of very thin heat spreaders made of Graphite. Graphite is used because of its unique anisotropic properties of high in-plane thermal conductivity and low thru-thickness thermal conductivity. Application level thermal performance of handheld device packages is tested withgraphite heat spreaders of different thickness and thermal conductivity. Experiments showed that graphite can be a better heat spreader when compared to copper or aluminum.

D. Heat Dissipation by Circulating Air Inside the Device

Earlier in this paper we have seen that larger air space in the device insulates the cover from the chip and diffuses the heat. In this section let us look into this method in detail by going through the research works and experiments which follow this approach. Philipp Bürmann et al. [14] did experiments to achieve thermal enhancement using Piezoelectric fans which are small, low noise and consume low power. These fans use peizoceramic patches bonded on their thin and flexible blades. Resonating, low frequency blades of the fan create airflow in the package. Material properties of a piezoelectric fan are given and experiments are conducted with piezoelectric fan made of stainless steel shim stock. In preliminary experiments, this method achieved 100% enhancement in heat transfer as compared to natural convection. Yoshiharu Iwata et al. [15] proposed a new outline design method for layout design of handheld device package. A modularized thermal model is designed with device modules, cooling structures and connectors. Thermal analysis is done on some boundary conditions of new model, for this model boundary conditions are taken to be the rate of heat flow from device module to board module and the position of device module. This paper explains the steps to converge the specification of air cooling and the optimization of layout design of corresponding device module. David B Go et al. [16] explained ionic air generation approach for thermal management in portable electronic device platforms. Ionic wind engines generate air flow without having any parts moving. Ionic wind is generated when positive air ions are accelerated in a direction by an electric field, and exchange momentum with natural air to gain body force on the air. In bulk flow, ionic air distorts the boundary layer and increases local cooling effect at a heated wall. This approach could cool the device surface by around 18^0C and local heat transfer coefficient was increased by more than 50% for bulk flow. E J Walsh et al. [17] worked on acoustic emissions and did experiment using small profile fans of rotor size 0.5 – 15mm in height and 15 – 32mm in diameter, as active cooling devices in mobile phones. Conventional fan scaling laws are verified for different ratios of rotor height to width. Ed Walsh at al. [18] implemented a centrifugal fan in a Nokia mobile phone and measured the thermal properties of the phone. A fan of dimensions 24x23x7mm and heater-to dissipate different amounts of heat, are placed on the PCM of the phone. In order to do this model’s performance characterization, the spot on the cover where the temperature is maximum, is chosen and temperature is measured at that point using thermocouples for different workloads. This experiment achieved around 40% to 75% increase in the heat dissipation from the device, depending on the type of blockage in the heat flow path.

E. Other Approaches

Usage of Synthetic Jet

Synthetic jet accelerates the heat transfer rate and there by achieve faster cooling. David B Go and Rajiv K Mongia [19] explained the usage of synthetic jets- diaphragm-induced flow devices, acting in cross-flow to a duct representing the confined space in a typical notebook, to accelerate heat transfer in location. The nature of jet and bulk flow interaction are studied and shown that bulk flow is slowed down and localized cooling is increased by 25%. Omidreza Ghaffari et al. [20] presented an experiment of finding jet-to-surface distance- the distance between synthetic jet and the hot surface, so the effect of jet can be maximized in terms of thermal performance. This experiment also showed that the mean surface heat transfer co-efficient is maximum at 300Hz jet frequency.

Changing Structure and Material of the Device Package

Designing suitable chip structure and modeling device layout is another method followed to dissipate heat. Jotaro Akiyama et al. [21] studied the factors which can be considered in thermal management of a stacked die package. This study showed that the die package (memory die, processor die etc.) structure and material properties affect hot spot and thermal performance. Sung-won Moon et al. [22] used a validated die package, a thermal module and a mock up test unit for their analysis. This mock up test unit included 8-layer board which has 11 thermal vehicles, and 2 heaters are mounted on the board. To enhance thermal performance, a direct heat conduction path from the package to the system enclosure is provided along with copper heat spreader and thermally conductive enclosure. This experiment showed that usage of copper heat spreader increased the heat dissipation capability by around 50%. Yifan Guo and Bhuvaneshwaran

[23] discussed some issues and solutions for thermal management in plastic packages. They mentioned two thermal paths for heat dissipation, one is front side of the die and another is backside, whereas 90% of the heat (generated in die) dissipation is through backside in a plastic package. They also discussed about material and structure suitable for power amplifier module, with which the module generates comparatively less heat. Siva P Gurrum et al. [24] designed a thermal management model with a z-direction multi-component multi-stack device concept. Back plate stack, middle pate stack, display stack, PCB are some of the components. Thermal performance of a tablet of 7 inch diagonal display was tested altering back plate and middle plate thermal conductivity. This study showed that temperature of the device can be reduced up to 40^0C by using higher thermal conductivity middle plate and gap filler pads. Francesco Paterna et al. [25] studied and presented two aspects of thermal behavior in a smart phone. First is the thermal interaction between the different components of a PCB and second is the effect of ambient temperature of the phone. This study estimated back cover thermal increment and predicted the SoC temperature after a period of around 10 seconds, as a function of back cover temperature, current SoC temperature and CPU frequency. They also devised an ambient variation-tolerant, inter component aware thermal management technique. In this technique, rate of thermal increment of SoC is estimated and if it is estimated to exceed the threshold, computational speed of SoC is changed to the maximum allowable frequency in accordance with the thermal policy. As part of this work they tested the tradeoff between the thermal performance and processor performance, it was shown that the SoC temperature can be increased by 17^0C under some typical workloads and if the processor frequency is reduced to control this heat, performance is reduced by 27%. Inchoon Yeo and Eun Jung Kim [26] proposed a hybridmethod for thermal management in multimedia applications and systems. This model proactively estimates the thermal characteristics according to workload before running multimedia applications and at runtime reactively obtains the probability distribution of cycle demand to decode frames in various codecs. This scheme was implemented on Linux in a Pentium-M processor and the results showed that overall temperature of the device can be reduced by around 15^0C using this method.

III. THERMAL MANAGEMENT FRAMEWORK

Realizing thermal management framework is significant in perceiving when and how the above listed techniques are used in the devices. Thermal management framework consists of thermal sensors to read temperature at different parts of a device, a few cooling devices and/or cooling techniques and governors with thermal throttling and tripping policies, which monitors the temperature read by the sensors and starts cooling actions according to the policies. A section presented by Se-Hyun Yang et al. [27] described thermal management as a process. This model comprises of thermal sensors and a thermal management unit (TMU). Temperatures at various components are recorded using the thermal sensors and TMU monitors this temperature at every component so that it doesn't exceed the threshold called as throttling and tripping. If it finds that the some component has reached throttling point, it shuts off power supply to the related components till the temperature is settled down to an acceptable level. Jude Angelo Ambrose [28] proposed an interactive thermal management for multiprocessor system on chips (MPSoCs), this framework allows users to have some control on heat dissipation along with running the applications according to their will. A good example of usage of this framework is that if a browser is causing overheating of core, user can either stop the browser or start a single session of it or even indicate system to migrate to a different core in case of critical applications. A three layered model with MPSoc layer, OS later and Application layer is described. MPSoc layer consists of thermal sensors along with other hardware components. OS layer includes APIs to provide functionalities to the users to interact with the sensors. Application space takes care of providing the OS processed sensor data in user-friendly format. An additional application called HeatSmart is used for analyzing heat dissipation of an application and based on this analysis user can take the decisions to manage heat.

IV. CONCLUSIONS

This survey covers several studies revolving around the cooling techniques of Thermal Management in handheld electronic devices. These studies and experiments are classified into different sections of this survey depending on their approaches. A substance called PCM, which is capable of absorbing and releasing large amount of heat, is used as cooling agent in first approach. Experimenting with surface area and size of the device showed that increasing the space inside the device for air circulation and increasing device surface area can lower the device temperature largely. Heat sinks and heat spreaders are passive heat exchangers, used to facilitate faster heat dissipation bythermalconductionprocess. Cooling by circulating air inside the device is another method,in which active cooling device like a small fan in placed inside the device. Other approaches covered in this survey are, usage of synthetic jet to increase heat transfer rate and the experiments with structure and material of the device package. Description of generic thermal management framework is also given to interpret how the thermal management cooling techniques are incorporated in the device.

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