The Next Smart Move : Towards Smart Surfaces and Sensors

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Abstract

In this research paper we have tried to understand the different factors that are leading to development of smart surfaces and smart sensors that could revolutionize the way machines communicate and respond to the environment. The ultra convergence of machines with inbuilt high capacity sensors and intelligent surfaces equipped with software algorithms can transform the way we know and use machines. This research paper is an effort to identify the paradigms and facts associated with such development. The observation and summarization of facts can thus lead to better understanding of the concept of smart surfaces and sensors. Some of the major findings were smart surface applications in automobiles, urban planning, health monitoring devices, pollution control mechanisms, temperature control systems, and disaster alert systems were found to be related to smart sensors. This information can be of immense help for academicians, researchers, students, and scholars who may be interested in this domain of knowledge.

Keywords : **Automobiles, health monitoring, savings, smart sensors, smart surfaces**

I. INTRODUCTION

The Smart Surface

The concept of smart surfaces emerged from the concept of surface of the modern Smartphone that beholds the interacting touch displays with licensed Operating Systems with various controls segmented into menus and sub-menus. In the initial phase, such adoptions did not succeed for two main reasons for development of smart surfaces in automobile sector [13]. One of the reasons included the fact that the menus were comparatively very difficult to navigate in an automobile, the reason being a Smartphone being smaller in size has user's undivided attention, whereas in automobiles, the lack of a physical button leads to frustration among drivers as the ability to interact with automobile system for intent-driven tactile response is hindered. The other fact being existing display technology considered good for smartphones was still inadequate for existing automobiles. Although, there were resistive touch displays, these were found to be difficult to read in direct sunlight and this reduced system performance in those years. Other significant problems such as capacitive touch was found as unaccommodating by drivers as well. The HVAC could not be easily operated by taking off the driver's gloves in cold weather. Also, many other factors such as environmental conditions such as moisture and EMI hindered the system's capability to accurately identify the user's input, thereby affecting user experience. It is a known fact that technology in automobile must always continue to be responsive in any environment to avert being distracted during driving and staying away from hazards [13].

To answer such difficulties, many industrial designers tried to create new model concept of vehicles and used three dimensional effects from re-imagined dashboard. This included many stand-alone buttons for newly designed surfaces that had the almost same functionality as before, with hidden buttons that could be available on user's demand and could disappear again unless needed again. Such imagination included gapless, solid wood or

Manuscript Received : November 4, 2020 ; Revised : November 17, 2020 ; Accepted : November 21, 2020. Date of Publication : December 5, 2020

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Doi : 10.17010/ijcs/2020/v5/i6/157501

carbon fiber panels that would just emerge for those controls which are significant for the driver. The multi faceted interiors would not only be beautiful, but would be more practical in terms of actual usage [13]. The newly thought designs would also eliminate the mechanical button failure that has been considered as the number one warranty expense in the modern automobile. It has been observed that a usual mechanical switch can start giving problems after a few hundred thousand actuations. Other associated issues could be ingress from oil, dirt, and abuse, and the time to failure shortens.

It was also observed that strain gauges were of utility in concept vehicles that led to the emergence of gapless surfaces, although they lacked the features of sensitivity, repeatability, or automotive reliability to transform from concept to mass production. Lack of enabling technology couldn't make the concept possible in such times.

II. THE SMART SENSOR

A smart sensor can be considered as a device that receives input from the physical environment and make utilization of in-built components to compute resources to carry out predefined functions as needed. Some of these components can include transducers, amplifiers, excitation control, analog filters, and compensation.

These sensors upon detection of specific input, processes them with necessary functions and then process passes them to the next level for further processing if needed.

A smart sensor also integrates different software-defined elements that provide the necessary functions such as data conversion, digital processing and communication to external devices. These smart sensors can be combined with Smart Surfaces and can create new way of handling major applications in different sectors including automobiles, households surfaces, health monitoring systems etc.

III. LITERATURE REVIEW

S. Gong et al. [9] presented a literature review on modern applications and design features related to the Intelligent Reflecting Surface (IRS) for future wireless networks. Traditionally, network optimization has been restricted to transmission control at two endpoints namely, the end users and network controller. The limitations can be the fading wireless channel that is uncontrollable and it limits the overall performance improvement. According to the author, the IRS is mainly composed of a large range of scattering elements that may be possibly configured individually to create additional stage shifts to signal reflections. Klooster [6] discusses about the designs of smart surfaces being inspired by creative focus of planners and designers [6]. Moreover, this clear and intelligible way of conducting activities may lead to concrete possibilities for applications. Major improvements can be seen in terms of cost-benefit analysis that could possibly answer many queries related to building, including details of constructions. He also mentions how smart surfaces cannot only provide a good overview of the inter-related themes but can also be source of inspiration for making use of these new surfaces in construction and building sector.

Another important research of health monitoring using smart surfaces mentions the need for development and advancement of alternative methods for creating efficient sensing systems for next generation health monitoring systems. Sony, Laventure, and Sadhu [10] also reflect on the presence of abundance of programmable framework in smartphones that can be utilized for developing sensors that detects vibrations in health monitoring systems [10]. The use of UAVs, cameras, and robotic sensors for acquiring and analyzing the vibration data for structural condition monitoring and maintenance has also been discussed. Nath and Chilkoti [8] discuss about a new method known as thermodynamically reversible addressing of proteins (TRAP) that has the potential to distinguish solid and liquid elements on surfaces and thus, modulate and regulate their separation using protein based modulation. This method as suggested by the author can have varying future applications for bioanalytical applications.

Zhou and Huck [11] described the use of polymer brush system for controlling wet ability on smart surfaces. They also mention in their findings that polymer brushes with specifically controlled thickness and composition can reflect large conformational changes in varying solvents. This characteristic has been used in many 'smart' systems, where surface properties can change in anticipation of changes in environmental patterns. Therefore, a full control on surface initiated polymerization shall be needed for surface-initiated growth. This can also be related to growth in nanotechnology concept for polymer brushes.

Therefore, the studies discussed earlier reflect on the growing importance of smart surfaces, thus requiring more observations and discussions which have been dealt in section IV.

IV. OBSERVATIONS AND DISCUSSIONS

A. Technology Governing Smart Surfaces

'Smart Surfaces' can be understood as an expansive term that includes different technologies and other technological related approaches. These smart surfaces are material surfaces that reorganize their morphology or constitution or self-enhance their utility to the needed changes in the nearby dynamic environment. Such changes may include electronic, biological, or chemical functions that can drive these responses. In general, a smart surface exclusively refers to planar technologies that refers directly to multiple opportunities in industries that are previously producing surfaces at scale, such as automotive, aerospace, and construction [12].

For an extended usage, smart surface technologies may present a wide range of applications, but mostly focused on three areas, that is, transportation, buildings, and healthcare, and other technical functions shared across such areas.

B. Applications of Smart Surfaces

Some of the smart surface applications may thus include [12] :

(1) Self-cleaning surfaces for architecture, infrastructure, and vehicles

(2) Self-healing coatings for products and vehicles

(3) Self-healing concrete for buildings and infrastructure

(4) Building Integrated Photovoltaics (BIPV)

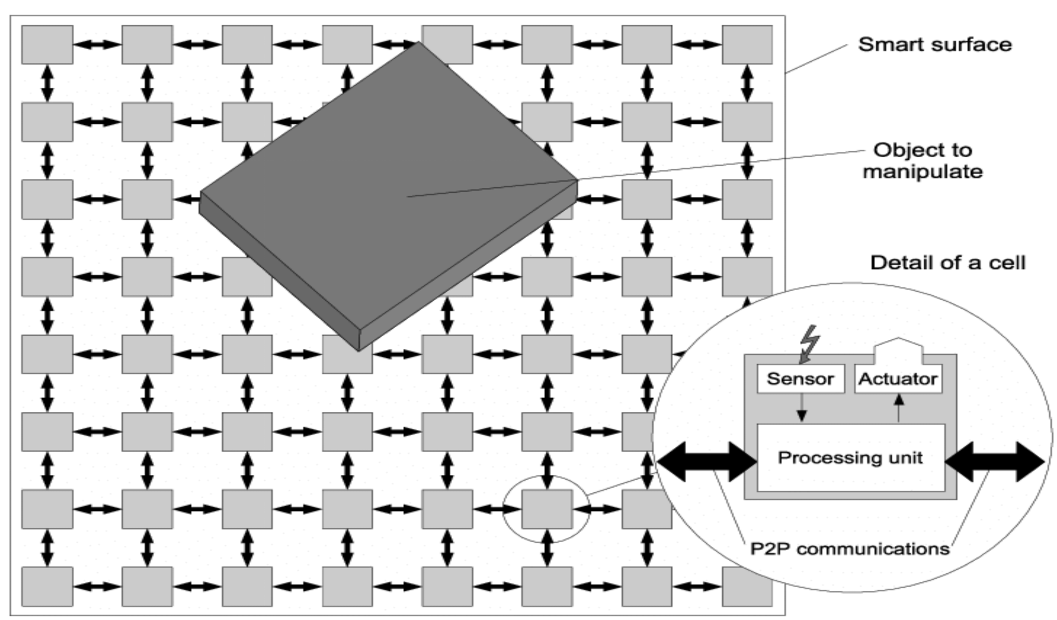
(5) Smart glass with integrated photovoltaics

(6) Anti-fouling coatings for ships

(7) Drag reducing coatings for ships

(8) Self-dimming windows for buildings

(9) Self-tinting windows for buildings and vehicles



Source : https://www.researchgate.net/publication/224199878_Distributed_control_architecture_for_smart_surfaces/figures?lo=1 [5]

Fig. 1. Smart Surface Concept

(10) Smart floors for office, home, and healthcare applications

(11) Air-purifying coatings for commercial and residential buildings

(12) Pollution-absorbing coatings for exterior surfaces in cities

(13) Large-scale printed sensors for occupancy sensing

(14) Touch-sensitive surfaces for control of smart building equipment and robots

According to a report, around 22 leading sustainability and urban organizations, that includes USGBC (U.S. Green Building Council), created the Smart Surfaces Coalition, a group that consisted of experts and organizations serving cities speedily adopting of cost-effective solutions that could reduce excess heat emission from buildings and surfaces, diminishing flood risk and thereby leading to better livability, health and equity along. These efforts could save billions of dollars and in the process also lead to creation of hundreds of thousands of new jobs [16].

According to Greg Kats, Smart Surfaces Coalition founder, the Smart Surfaces Coalition have shown societies the ability to improvise advanced surface technologies which could effectively reduce heat and thwart flooding. He also mentions the solutions creating enormous health and financial benefits including slowing down global warming, ornamental in better quality of life, thereby saving taxpayers billions of dollars in energy costs.

It is a well known fact that rapidly rising temperatures are by now costing consumers heavily and companies serving them are spending billions for creating higher energy and providing health care, thereby making communities less inhabitable and suffering in terms of health.

These smart surface solutions that includes reflective or green roofs in cities can minimize the amount of hot air being reflected back into the nearby environment, thereby minimizing temperatures of cities and communities, reduction in money spent by individuals and communities leading to better lives.

Some of the effective solutions that can be achieved by applications of smart services include :

- Installing cool roofs and pavements that reflect away (instead of absorbing) sunlight–reducing temperatures and smog in the environment.
- Use of green roofs and trees that provide shade and reduce flood risk
- Installation of solar PV that transforms sunshine into electricity and present shade to individuals and houses.
- Usage of porous pavements, sidewalks and roads that minimize water runoff and flooding, thus, cutting the expenses of managing storm water.

The USGBC also supervises the LEED (Leadership in Energy and Environmental Design) for green building rating system, integrates a lot of such methods that building owners can use to earn LEED certification which is the most extensively used green building rating system in the world [15].

This coalition has also been working with a dozen cities to build up tools and training to assist mayors, city managers, and other key officials in the U.S. to recognize and implement these amazing new opportunities to improve quality of life, health, and economic bottom line. According to recent projections, they also plan to partner with more than 250 cities to take on and commence deploying smart surfaces as normal standard city-wide policy by the year 2023 [15].

In terms of savings, smart surface technologies can generate savings in the form of lower energy, water bills, reduction in health costs, minimizing need of water treatment and vital infrastructural costs. The new set of activities shall also create more jobs in manufacturing, installation, and maintenance of these smart surfaces, which may be labor-intensive jobs and require more manpower [15].

It has also been seen that low-income urban areas are usually more susceptible to extreme heat as they tend to have fewer green spaces and more impermeable surfaces, thereby leading to higher temperatures and considerable poor air quality in the environment. All such facts tends to higher energy bills and more health risks. Smart surfaces can act as a deterrent in bringing optimum level of solutions to such structural inequalities.

Some of the Smart Surface Coalition members include the Amalgamated Bank, The American Institute of Architects, Atlantic Council, Capital E, Casey Trees, Chesapeake Bay Foundation, City of El Paso Office of Resilience and Sustainability, City of Philadelphia Office of Sustainability, City of Washington, D.C., Department of Energy and Environment, City of Washington, D.C. Department of General Services, DowntownDC, Eco Districts, Energy Coordinating Agency, Enterprise Community Partners, Global Cool Cities Alliance, The JPB Foundation, National Association of State Energy Officials, National Housing TrustNational League of Cities, Rock Creek Conservancy, Smart Growth America, Urban Sustainability Directors Network, U.S. Green Building Council etc. [15].

C. Algorithms for Smart Surfaces

Some of the well known algorithms as mentioned in [14] that are used for smart surface functional utilities are:

(1) Distributed Control Architecture for Smart Surfaces : In a distributed control architecture, part recognition is performed keeping an eye on the close-loop control of the Smart Surface. In this architecture, the decentralized cells can converse with their four neighbors with the help of peer-to-peer links. There are different types of original algorithms that have been deduced to recreate, distinguish, and convey the object floating or present on the Smart Surface. Some of the experimental results conducted showed that each algorithm performs a reasonable job and together these succeed in arranging and transmission of the desired objects to their final objective [5].

(2) Distributed Discrete State Acquisition and Concurrent Pattern Recognition : Another algorithm mentioned that had been designed to perform the process of differentiation for parts put on top of the Smart Surface utilizes the concept of distributed state acquisition and followed by concurrent pattern recognition has been developed [2]. Algorithms of such type have been tested through a multithreaded Java Smart Surface Simulator, SSS, that can run on multicore machines [2].

(3) Decentralized Reinforcement Learning : This type of algorithm includes a distributed-air-jet MEMS-based systems that can maneuver small parts with high velocities and reduces any friction problems. Although the control of distributed-air-jet systems is itself very tricky and most of the techniques used for contact arrangement systems don't deliver adequate outcome [7]. Therefore, several techniques for reinforcement learning control had been proposed in order to locate and express an object. This popular approach enables to find controllers that are customized exactly to the system without any prior model, thus encouraging a global-local trade-off [7].

(4) Calibration of the Smart Surface : This algorithm depends on the number of sensors that have to be embedded using different hardware in the design on the Smart Surface. This model utilizes the Sensor Network Calibrator (SNC) which is a simulation framework that permits the parameterization of the Smart Surface and thereby determines the frequency of sensors that are required on top of the Smart Surface [4].

(5) Distributed Shape Differentiation : Another way of looking at the smart surface is the ability to reorganize the shape of the surface of the processing unit embedded in each cell of the parts that is put on the top of the smart. A method of distributed algorithm known as criterion separates and distinguishes non required substances. A software framework, called ECO (Exhaustive Comparison Framework) has been developed which has enabled successful testing of the method of differentiation criteria in terms of differentiation efficiency, memory and processing power needed [3].

V. SMART SENSORS AND THEIR FUNCTIONS

According to an article published online (Smart sensors: Applications, benefits, and working, 2019). the working of sensors have been discussed based on different requirements and their development [17]. Some of them are :

(1) Light Sensors : These sensors can tune light to the time of day, month, or year. This is the prime functionality of light sensors. It automates the luminaries operation in smart buildings along with function of providing human-centric lighting, daylight harvesting, and light scheduling that can lead to more energy savings, performance efficiency, and better atmosphere [1].

(2) Thermal Sensors : Room temperature automation in smart buildings and offices can be achieved by usage of thermal sensors. These sensors can maintain a steady internal temperature, minimizing the effect of the external temperature variation within the room. They can not only balance existing temperature but also cut down major costs on energy utilization [1].

(3) Wind Sensors : Wind sensors can also be used in Smart buildings that can react to nature smartly. Wind sensors automate the closing down of dust skirts, storm shutters, or lock retractable awnings if strong winds are spotted or detected [1].

(4) Smoke Sensors : One of the most essential developments has been the creation of smoke sensors that ensure home or building safety. These sensors can provide instant alerts and activate alarms in situations of fire bursts. Therefore, they can severely increase the possibility for smart escape from accident scenes for individuals in homes or buildings [1].

(5) Apart from the sensors mentioned there are lots of other sensors in use in the industry, like time sensors, location sensors, sound sensors, matter sensors, and many more.

VI. MAJOR FINDINGS

On the basis of the discussion on smart surfaces, we can draw these conclusions :

(1) Smart surfaces can be used in automobile sector, providing more ease and convenience to drivers or users of automobiles in future.

(2) The formation of USGBC that supervises the Leadership in Energy and Environmental Design (LEED) for using smart surfaces in cities can become an essential and non avoidable deployment for individual households and other major structures in cities in the near future.

(3) Usage of Smart Surface technologies in urban installations, buildings, and other structures can lead to savings in the form of lower energy, water bills, reduction in health costs, minimizing need of water treatment, and vital infrastructural costs.

(4) Research and development in the form of major algorithms such as Distributed Control Architecture for smart surfaces, Distributed Discrete State Acquisition and Concurrent Pattern Recognition, Decentralized Reinforcement Learning, Calibration of the Smart Surface, Distributed Shape Differentiation etc. can pave the way for smarter applications of Smart surfaces.

(5) The usage of Smart Surfaces and Smart sensors together can be considered as major breakthrough for Smart city development and brings smarter concepts into practice.

VII. FUTURE WORK

We know that this present work on Smart Surface and Smart Sensors applications is limited to some of the aspects of these concepts put together. In future, we shall try to incorporate more details and dig deeper into the other developments in usage and applications of these concepts.

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