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APPLICATIONS OF MULTI-TOUCH TABLETOP DISPLAYS AND THEIR CHALLENGING ISSUES: AN OVERVIEW

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Abstract- Multi-touch tabletop displays provide a co-located collaborative workspace for multiple users around a physical table. They sit together and perform collaborative interaction to select and manipulate digital contents using their bare fingers. However, these systems bring a new paradigm shift in user interaction and present various challenges to design natural user interfaces respectively. The growing popularity of tabletop displays and their related issues have gained a greater attention among researchers in academia and industry. It creates a need to present an overview of multi-touch tabletop displays. This review paper attempts to present the touch enabling technologies that support in the construction of multi-touch tabletop displays. It also presents the important applications of multi-touch tabletop displays in different domains and their challenging issues in different perspectives. Finally, this paper proposes the future work.

Index terms: user interfaces; touch enabling technologies; multi-touch tabletop displays; applications; challenging issues, collaborative multi-touch interaction; co-located collaborative work.

I. INTRODUCTION

Traditionally, the invention of the computer and its association with hardware interfaces (e.g. keyboard and mouse) and software interfaces (e.g. command line interface and graphical user interfaces) has assisted users for accessing digital information in many ways [1][2][3][4]. For example, command line interface (CLI) provided the unimodal interaction, where a user can give single input only through typing a command or text using a keyboard to access the digital information from computers. The Graphical User Interfaces (GUIs) facilitated the multimodal interaction where a user can give multiple inputs simultaneously using different input devices to access the information. It has been established that the quality of Human Computer Interaction (HCI) highly depends on the user interface design and interaction methods. Therefore, in the last few decades, the development in the field of HCI has not only produced the quality user interaction with computers using existing computer interfaces, but it has also focused on the developments of advanced computer interface technologies [3][4][5][6][7][8].

Despite the benefits of existing computer interfaces, it has been observed that the conventional input devices offer an indirect method of interaction to users [1][9][10]. The indirect method of interaction means, users use the intermediate input devices like keyboard and mouse to access the digital information from computers. This phenomenon of interaction with computers limits users to touch the digital contents directly. It does not provide a natural form of interaction while interacting with systems. These input devices support only single user interaction with computers. Therefore, graphical elements (e.g. icons, menus) or metaphors are designed and configured on displays in a unidirectional way [11]. Additionally, these conventional input devices limit user's natural capacity of interaction or the full use of interaction capabilities with the computers [4][5][12]. The association of these input devices with computers also restricts the simultaneous multi-user interaction in a collocated collaborative manner. The presence of these limitations in existing computer interfaces [13] and the continuous changes in user requirements have always demand for novel and intuitive user interfaces to be produced [3][4][5].

As a consequence, several attempts have been made by researchers to design and develop the multimodal, intelligent, direct and natural user interfaces using different technologies rather than the regular, unimodal and indirect user interfaces [3][4][5][7][8]. The research trend in the area of multi-touch displays started in the early 1980's at IBM, Bell Labs, University of Toronto. As reported in [14], the first multi-touch system called the flexible machine interface was developed by Mehta while studying for his master's degree at the University of Toronto. This system allowed users to perform a multi-point interaction simultaneously. Following this system, a Soft Machine was introduced by [14] and the properties of the touch screen based user interfaces were discussed comprehensively. Multi-touch sensitive displays have capability to detect user's multiple fingers directly as a multi-touch input [15][16][17][18][19]. The direct multi-touch input modality of interaction gives a natural feel to users [8].

Over the years, various types of multi-touch displays have been developed using the different technologies, i.e. resistive, Surface Acoustic Wave (SAW), capacitive, optical and computer vision [16][17][18][19][20]. Usually, the resistive and SAW based multi-touch displays are found in small sizes [19] whereas, the capacitive, optical and computer vision based displays are found in small [21][22] as well as large sizes [18][17][23][24]. The developments in multi-touch displays have laid the foundation and encouraged the researchers and designers to come up with the Natural User Interface (NUI) [8][20]. It is studied that NUI augments users to utilize their natural interaction capabilities to access the digital information as previously GUI facilitated the users to perform extraordinary interaction with computers as compared to CLI [25][26]. The NUI is considered as a next major development in computing and user interfaces [11][27]. The layout of main transition and developments in human computer interfaces, over the years, along with the methods of interaction is shown in Figure 1. It provides a brief overview of advancements in computer interfaces and methods of interaction. The detail description of the multi-touch tabletop displays is given in the following section.

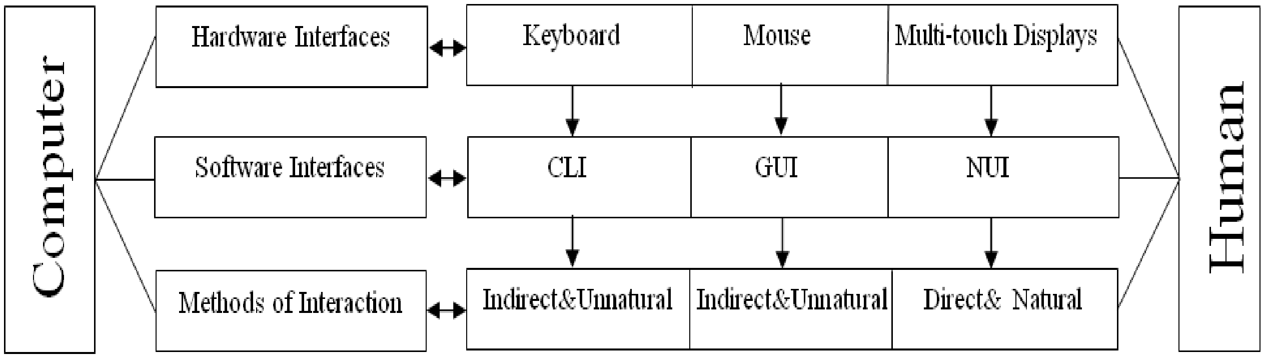

Fig.1. Layout of transition and developments in human computer interfaces along with methods of interaction

II. MULTI-TOUCH TABLETOP DISPLAY TECHNOLOGIES

Traditionally, humans use the traditional tables in homes, offices and design centers as well as many other places for different purposes. It is noticed that the tables are made from different materials (e.g. wooden table). The physical setting of tables provides a co-located collaborative workspace for multiple users. They sit together in front of each other around the physical table and perform different activities [28][29]. For example, the use of a table in an office provides a convenient physical setting for a single or multiple users to examine physical documents, to draw maps on a piece of papers and navigate the maps for different purposes and so forth. In addition, users are also used to place the desktop/laptop computers and many other computing devices on tables to access the digital information in offices, playing games and to perform many other useful activities. In many scenarios, it is also observed that the Digital Light Processing (DLP) projectors are connected with computers and mounted above the surface of physical tables to visualize and discuss the dense information [18]. It suggests that traditional tables play a vital role in our daily life activities either used in indoor or outdoor applications for different purposes.

The continuous research developments in touch-enabling and display technologies highly encouraged the researchers to construct the multi-touch tabletop displays. In recent years, several types of tabletop displays have been constructed that incorporate the advantage of physical tables [18][28][23]. These multi-touch displays/surfaces have capability to detect user's multi-point of interaction using his multiple bare fingers. It is observed that multi-touch tabletop displays are designed and constructed using different touch enabling technologies. For example, the DiamondTouch [18] and SmartSkin [23] systems are constructed using the capacitive technology. The matrix capacitive sensors have been used inside a medium of surfaces that enable system's surface to detect user's multi-touch input directly.

It is reported that the capacitance based multi-touch tabletop surfaces are opaque in nature. There is no embedded display unit inside the system surface for displaying the digital information. Thus, the DLP projector is always mounted and calibrated above system's surface for displaying the digital contents for users. They can select and manipulate the digital contents using the multiple fingers and hands gestures [18][23].

Furthermore, there are many multi-touch tabletop displays that use the optical and computer vision based technologies in their construction. They also depend on the use of infrared cameras to detect user's multi-touch input. The cameras are configured and calibrated in different ways according to the size and position of the display. There are two main types of vision based multi-touch displays, i.e. purely vision based and optical and vision based [11][28][30]. In purely vision based displays, cameras are employed for detecting the visual gesture of hands and fingers as multi-touch input and the computer vision techniques are used for tracking that input accordingly. The most common examples of purely vision based interactive displays are Everywhere [31] and PlayAnywhere [32]. These systems may also be called as visual tracking systems.

On the other hand, the construction of optical and vision based tabletop displays highly depends on computer vision techniques, infrared cameras and the optical phenomenon of infrared light. The infrared light sources i.e. Infra-Red Light Emitting Diodes (IR LEDs), are assembled in front of the edges of the system's surface. These light sources emit the light inside the surface medium into a pattern called the Total Internal Reflection (TIR). The sensitivity of the system's surface depends on the Frustrated Total Internal Reflection (FTIR) technique, and also on the optical surface architecture [17]. When a user interacts with the optical surface using his bare fingers, the infrared light frustrates and creates bright fingertip images called fingertip blobs. The configured and calibrated infrared cameras detect these fingertip blobs and send them to the computer system (processing unit) to be processed using computer vision techniques. The most common examples of these displays are the low cost multi-touch system [17] and interactive wall [24].

There are other optical and computer vision based systems [33][34][35] that use the Diffuse Illumination (DI) sensing technique in their construction. These systems also use an optical phenomenon of infrared light produced by infrared illuminators on system's surface. The cameras are configured and calibrated under the system's surface. When user interacts with multiple fingers on the optical surface then fingertip blobs are created and processed using computer vision techniques [16][19]. The one of most popular example of these systems is Microsoft Surface table [33]. Based on the literature review, it is noticed that the two main common approaches, i.e. bottom-up and top-down approaches have been used for design and implementation of the capacitance, optical and vision based tabletop displays. In the bottom-up approach, the cameras and projector are used beneath a multi-touch surface. Whereas, using the top-down approach, the cameras and projector are used above or in front of a multi-touch surface. It is also observed that the use of camera and projectors make these systems bulky and fixed in nature at particular place. Consequently, it introduces a thick form factor of displays and the portability issue [16][21].

It is noticed that some of these systems such as Microsoft Surface, DiamondTouch and Multi-touch Interactive wall have been commercialized in market. These systems have been used in academia and industry to explore and investigate the single user multi-touch and multi-user interaction in co-located collaborative work environment [36][37][38]. It is also aimed to identify best possible use for variety of purposes in different domains [39][40]. These systems are used to investigate the co-located collaborative work [41] and for visualization of 2D/3D digital information [42][43].

III. APPLICATIONS OF MULTI-TOUCH TABLETOP DISPLAYS

It is established that multi-touch tabletop display provides a co-located collaborative workspace for multiple users. They sit together in front of each other around the table and perform collaborative multi-touch interaction to share and examine the digital documents simultaneously [41][43][44][45][46]. It suggests that tabletop computers can better support the multiple users to carryout collaborative work on same or shared interactive display as previously supported by a physical table surface. There is no intermediate device between users and tabletop displays. Users can select and manipulate the digital contents using their bare fingers directly and in natural way [10][36][47][48]. It is expected that these displays will free us from conventional input devices, i.e. keyboard and mouse [49], in the near future, in the way that the mouse minimized the usage of the keyboard in the past [50]. In addition, it is reported that tabletop displays/surfaces bring the hands-on computing [50] that subsequently enrich the concept of surface computing [25][51][52][53].

Considering the potential of tabletop displays benefits, i.e. a co-located collaborative workspace, high visualization of 2D/3D digital information, direct and natural method of collaborative multi-touch interaction. They have been experimented for multi-purposes applications in different domains that include collaborative medical image analysis [42][54][55][56] in health care institutes, interactive collaborative learning [39][40][57][58][59][60][61] in education institutes. They have also been used for visualization of 2D and 3D information [43][62][63][64][65] to perform collaborative work. Recently, some studies introduce tabletop displays for oil and gas reservoir engineering. It is attempted to explore and test the potential of tabletop displays for visualization and monitoring the digital information of oil and gas reservoirs [66][67].

Furthermore, tabletop displays are used to navigate and visualize the dense geospatial data for urban planning and development [68][69][70]. They are used to investigate user experience while playing games in a collaborative manner [71][72][73][74][75]. In addition, the tabletop displays are used in restaurants to facilitate and enhance the customers in ordering their menu [76][77][78]. They are also potentially used for monitoring and managing the natural disasters (e.g. earthquake) [79][80] and military applications [81][82]. The potential use of tabletop displays in different domains clearly suggesting that these systems can also be practically used in offices and homes at regular basis to perform a co-located collaborative work and enhance social skills.

Based on literature review, it is observed that the accommodation of co-located collaborative workspace and collaborative multi-touch interaction around tabletop displays influence the collaboration among users [83] and support for mapping ideas [53][84]. These tabletop displays establish the suitable environment for important discussions, meetings, brainstorming, and decision making to solve the critical problems [44][82][85][86][83]. Furthermore, playing games using tabletop displays in a collaborative manner can boost the users enjoyment, engagement, emotions, and improve social skill developments [74][87][88][89]. Tabletop displays enrich the concept of social interaction and help in designing the better user experience [53].

The few years back, a survey was conducted by [90] for identifying the importance of tabletop displays in the context of use pattern. It was reported that, 36% of the users utilized these displays for viewing entertainment media activities, 31% for collaborative activities, 17% for the visualization of applications and 5% for accomplishing productivity tasks. It was also reported that tabletop displays possessed the potential of facilitating novice users for accessing the digital information frequently in a collaborative manner. These enormous benefits of multi-touch tabletop displays support users to apply their natural style and capacity of interaction to access the digital contents. The potential applications of tabletop displays in different domain and their acceptance suggest that these systems can be incorporated for specific and general purposes in our daily life.

IV. CHALLENGING ISSUES USING MULTI-TOUCH TABLETOP DISPLAYS

Despite the potential benefits and growing popularity of multi-touch tabletop displays in different domains, they present some challenging issues for HCI researchers to be resolved. These issues include some basic research questions such as what are social and psychological effects, what kind of user interface design and interaction techniques can better support to perform collaborative work. In addition, how these systems lead to human tactile and perceptual implications [9] while interacting with systems. In general, these challenging issues can be related to two main areas, i.e. screen-based and user-based challenges. These challenging issues are described and discussed in following sub-sections.

A) Screen-based Challenges

The screen-based challenges pertain to size, shape and affordance of displays [91]. Relating to size, several different size of tabletop displays have been constructed using diverse touch enabling technologies [18][23][32][92][93]. However, it has been observed through some comparative studies that each touch enabling technology has its own advantages and disadvantages [30] [94][95] according to their functionality and cost. In this perspective, it is understood that some of touch enabling technologies (e.g. surface acoustic wave, resistive and capacitance) have limited potential to support the construction of large size tabletop displays. They also have high constructional complexity in terms of configuring the matrix of sensors inside the surface. In addition, it requires an extensive industrial and engineering work that leads to high cost. It is hard for researchers to construct tabletop displays in a normal environment at low cost [17][21][16].

There is some touch enabling technologies (e.g. optical and computer vision) that potentially support for the construction of large size tabletop displays and interactive walls at low cost. It is easy for researchers to construct the large size tabletop displays in a normal environment and even less industrial work is required. The potential of optical and computer vision technologies have encouraged researchers to build their own tabletop displays and explore the multi-touch interaction techniques [92][96][97][98]. However, it is unclear and less focus is given to study that which touch enabling technology is more suitable, scalable and flexible to construct different size, shape of tabletop displays. It creates a need to conduct a comparative study or a systematic review of touch enabling technologies in the aspect of architecture, functionality, scalability, flexibility, and cost.

In user's perspective, it is attempted to explore display factors (e.g. display size, display angle, user arrangement) that may influence the co-located collaboration. It is reported that these display factors have direct impact on the co-located collaboration [99]. In addition, the effect of user group size and table size on collaborative interaction is investigated on tabletop display. It is concluded that large group of users around a tabletop display highly impacts on user performance. It is suggested that there is a need to add or extend more vertical displays and shared displays for proper information sharing. It may assist and influence user's collaboration and communication [100]. It is also attempted to explore tabletop displays for visualization of information during co-located collaborative work. It is reported that tabletop displays still lead to technological, perceptual, and collaboration issues [101]. The screen size and its resolution are critical for high visualization. Users perceive that tabletop displays are unique in nature as compare to desktop computers [101]. It is studied that user perceive visual variables (e.g., angle, length, shape) differently on a horizontal surface [102].

It is reported that large size tabletop displays or surfaces introduces the physical restrictions for effectively interacting with digital contents. For example, it can be hard for users to reach the digital contents that are available another side of display. User's hand and fingers also introduces the occlusion problem while interacting tabletop displays. These limitations strongly affect the tabletop displays therefore the novel design considerations for user interfaces is required [11]. In addition, collaborative work environment around tabletop displays provides the limited awareness of information to users. It is reported that the visualizing the large and complex datasets increase users cognitive load [101]. Keeping in view the existing body of knowledge, it can be argued that tabletop displays size strongly affect co-located collaborative work and user performance. It seems that there is still unclear about the standard size of tabletop displays that can better support for multiple users to perform co-located collaborative work. It is also uncertain that which shape (e.g. square, rectangular, or circular) of tabletop display can better support to co-located collaborative work. Therefore, there is need to focus on providing a standard size and shape of tabletop displays. It may assist in designing the appropriate natural user interfaces. Consequently, the tabletop displays can be installed properly at public and private places for many purposes.

The interactive tabletop displays allow users to perform multi-touch [26][37][38][92][103] and tangible interaction [104][105][106][107][108][109]. Both types of interaction modalities facilitate users to access digital information in different ways and user perceive them differently around tabletop displays [105][108]. It is also studied that tabletop display technology allows users to use digital pen to interact with digital information [110]. However, it is still indistinct that how many users simultaneously can perform collocated collaborative interaction on displays in an effective and accurate manner. It creates a need to study the group dynamics and user's taxonomy of collaborative interaction around tabletop displays extensively. The outcome of these studies may assist in proposing a consolidated solution for enhancing the co-located collaboration around tabletop displays.

B) User-based Challenges

User based challenges relates to ergonomics, individual differences, accessibility using tabletop displays. Although, it is discussed that tabletop displays provide promising co-located collaborative workspace for multiple users and influence the collaborative interaction as well [90]. At the same time, some studies report the ergonomic issues for users due to the horizontal orientation of interactive tabletop displays [11][28][90][99][111][112][113]. The working on large size displays also presents ergonomic issues such as reachability for users to desired artifact or contents. It forces users to stand-up for reaching up the artifacts to interact with [114]. The appropriate space for the user's feet under the table is very important in a sitting position. Otherwise, staying in an awkward position at the table for an extended period of time leaves the negative impact on user's comfort [11]. Users apply fingertip gestures like rubbing and taping continuously and stay focused to select and manipulate the digital contents during collaborative work. In long run, it lead to arm fatigue [96][99][115] issue, and it also may lead to user's fingertip tendon infection, body back and neck ache issues. In addition, little research studies conducted to investigate visibility and readability of the digital information around tabletop displays. The user's orientation towards the dense and complex digital information may increase the user's mental workload during the co-located collaborative work. It is also observed through literature that less focus is given to address the ergonomic issues. The availability of the ergonomic issues may increase user frustration while interacting with systems. Thus, it needs to pay more attention to construct tabletop displays that must be sound enough ergonomically.

Based on the general observation, it can be described that individual differences in HCI relate to user's culture, region, and age characteristics. It is studied that differences among the user have a wide impact on the performance level than the differences in system designs and training [116]. For avoiding this issue, the alternative approaches have been attempted to designing the interfaces such as deigning for one uniform user group, different user groups or an adaptive interface.

The variation in designing interfaces created a need to review the individual differences in HCI. Later on, a comprehensive review has been conducted in which user characteristics are classified into four main groups, i.e. level of experience, personality traits, demographic and other characteristics. It is concluded that few studies consider only one or two user characteristics, but more studies need to be conducted to investigate the individual differences in HCI [117]. It is observed that individual differences that collectively introduce the challenge for designing generic type of user interfaces to improve user performance. Similarly, in the context of multi-touch displays, it is reported that user's fingertips size varies from person to person [36][98][118]. The difference in fingertips size cause the imprecise target selection during direct multi-touch input [96][119][120]. Although, several precise selection techniques have been proposed [96][119][120], but still fat finger problem is reported [120]. Based on literature review, it is observed that there is need to investigate the finger input properties based on user characteristics. It may help in providing a consolidated solution against imprecision problem.

In addition, there is need to evaluate the user performance based on group dynamics theories around the tabletop display during co-located collaborative work. Because, there is still no consensus that how many users can be better supported by a tabletop display during collaborative work. It is not only to focus on the group dynamics but need to deal with age related issues in different settings. It can be possible that performance of an old age user group can be better than younger age group during co-located collaborative work. These all challenging issues in individual difference perspectives appeal to HCI researchers to provide them suitable interface as expected.

It is described earlier that tabletop displays facilitate multiple users to perform the direct collaborative interaction to access the digital contents using their bare fingers. This phenomenon of interaction influences the collaboration and communication among users. At the same time, it is reported that tabletop displays must support the multiple users to access multiple file systems to simultaneously [121]. However, the large size tabletop displays introduces the reachability and privacy issues to access and manipulate the digital contents [11][122]. If any user wants to open his/her separate application then he/she needs to define the specific territory on screen. It requires a virtual division of the large size screen then user would be able to access digital information. In order to deal these issues, a DiamondSpin toolkit system has been proposed by [123] that supports the public and private workspaces for users on a same display. Furthermore, it has been attempted to study the territory for users on tabletop display. It suggests that management of large and complex datasets is hard that leads to the effect of portioning on user's personal space [124]. It is noticed that visible boundaries on shared tabletop display might have a negative impact on overall collaborative work and users' collaboration.

In addition, there is possibility that users hands and fingers may collide during collaborative work. It might also be harder for a user to access the digital contents that are available at other side of display. In order to enrich the collaborative access of digital contents on tabletop displays, a theory of tabletop territoriality has been presented that includes personal, group and storage territories. It helps in utilizing the shared workspace properly but lacks in assessing the user performance in shared and individual accessibility on same tabletop displays [125]. Users possess the dynamic interaction capabilities to access the digital information, therefore there is need to understand the users working style on traditional table and tabletop displays extensively.

It is described earlier that advancement in tabletop displays technologies support users to perform multi-touch and tangible interaction in a collaborative manner. Therefore, some studies [83][126][127][128][129][130] have been conducted to explore and assess the impact of these interaction techniques on user's collaboration. It is observed that simultaneous multi-touch input gestures improve the user performance but their hands and fingers lead to occlusion and imprecise target selection problem [97][112][118][131][120]. The pen input is also implemented to select and manipulate the digital contents on multi-touch displays. It resolves the issue of imprecision at certain level, but limits the naturalness of interaction and some occlusion still remains due to user's hands [11][81][110]. The tabletop displays technologies assist in utilizing the potential of both finger and pen touch input separately but restricts their simultaneous use for selection and manipulation of digital contents. There is also difference in user's performance while using finger gesture and pen touch input [81].

In the perspective of tangible interaction around tabletop displays, users place and use the physical metaphors or objects on system's surface. They can select and manipulate the digital contents but these physical objects obstruct the view of digital information and restrict user's natural interaction on displays [132]. To avoid these issues, the transparent tangible artifacts or objects have been proposed [129][132][133]. These transparent artifacts assist in selecting and manipulation of the digital contents precisely. However, there is lack of mental model that guide users to interact with digital information and direct connection visual information [129]. In addition, there is lack of tactile feedback, collision response and grasping the physical artifacts is difficult for users during interaction. There is also presence of mismatch between input and output fidelity [134]. These interaction limitations using tabletop suggests there is still unclear that to what extent these tabletop display s can support for multi-user multi-touch and tangible input simultaneously in effective and accurate manner. It is also questionable that which user interaction strategy (e.g. symmetric or asymmetric multi-touch interaction) or taxonomy can better support for co-located collaborative work around tabletop displays.

VI. CONCLUSION AND FUTURE WORK

This paper presents an overview that informs about the state-of-the-art developments in the area of tabletop displays. This review paper materializes the references that informs about the touch enabling technologies, applications and related issues. It is observed that capacitance and FTIR based touch enabling technologies show a greater potential to construct both small and large size multi-touch tabletop displays. The embedded touch enabling capabilities in these systems promise to contribute in designing the next generation user interfaces. These systems enrich the concept of direct and natural form of multi-user multi-touch interaction to access digital contents around tabletop displays. It is observed that these systems are taking places in different domains for variety of work and leisure based applications. The available evidences in related literature suggest that tabletop displays can take place very soon everywhere due to support of high visualization of 2D/3D digital information and multi-user multi-touch interaction simultaneously.

Despite the potential benefits, these displays present the many challenging issues for HCI researchers into two different areas, i.e. screen-based and user-based issues. These issues lead practical implication on design and success of tabletop displays. There is need to further explore the potential utilization of tabletop displays for standalone and real time co-located collaborative applications. The tabletop displays are still in maturing stage and it still unclear that how multi-user multi-touch interaction is supported extensively and effectively. There is extensive need to assess usability and user experience of tabletop systems. Based on literature review, it is observed that there is much need to present the systematic literature review of touch enabling technologies for the tabletop displays and their technical limitations. It is also important to present a systematic review on applications of tabletop displays in different domains. It may open the window for design and evaluation of tabletop systems. These systematic literature reviews may help in proposing the consolidated solutions against the existing challenges of tabletop displays. Meanwhile, the further research may help to improve the quality of user interaction as well as to contribute in standardizing tabletop display interfaces for their success.

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