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ORIGINAL ARTICLE

A kinect-based vocational task prompting system for individuals with cognitive impairments

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Abstract Difficulties in executing daily living tasks hamper the quality of life of many individuals with cognitive impairments who are otherwise physically mobile. With sufficient and appropriate support on the job, many people with developmental disabilities and cognitive impairments are capable of participating in the world of work to various levels. Kinect is used as assistive technology for individuals with cognitive impairments to achieve the goal of performing task steps independently. In a community-based rehabilitation program under the guidance of three job coaches, a task prompting system called Kinempt was designed to assist four participants involving pre-service food preparation training. The study assessed the effectiveness of Kinempt in terms of precision and recall. A follow-up comparative study then evaluated a baseline method and the system of least prompts against the Kinempt system. Results indicate that for participants with cognitive disabilities, acquisition of job skills may be facilitated by use of Kinempt in conjunction with operant conditioning strategies. Our findings suggest that the image recognition technology may be able to facilitate task prompts needed by people with cognitive impairments. Therefore, the system may be helpful for pre-service training while increasing independence in the process of community integration.

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1 Introduction

Cognitive impairments range from ones that are present at birth (such as Down's syndrome and intellectual and developmental disabilities, IDD), to ones that are acquired due to some form of traumatic brain injury or illness (such as aphasia, a speech and language disorder, or amnesia), to ones that emerge through the normal aging process (such as Alzheimer's disease), to ones that arise due to complicated causes such as schizophrenia. In the Unite States alone, an estimated 4.32 million people have intellectual and developmental disabilities [1]. Approximately 4.5 million individuals had Alzheimer's disease in 2006; this number is projected to grow to 14 millions by 2050. Aphasia impacts approximately 1.1 million individuals in North America [2]. In Taiwan, one million out of twenty-three millions of population are registered as disabled with thirty percent of them found cognitively impaired. Mentally/cognitively disabled individuals are still independently mobile, unless they are also mobility impaired.

Difficulties in executing daily living tasks hamper the quality of life of many individuals with cognitive impairments who are otherwise physically mobile. For example, an adult with a mental disability may want to lead a more independent life but he is not getting trained or remaining employed because he experiences difficulty in using public

transportation to and from the workplace. Strategies incorporating the use of various technologies for the cognitively impaired have been developed for skill training of activities of daily living (ADL) across numerous settings. Recently, supported employment programs targeted for people transitioning from institutional to community care have created more demand of cognitive aids to increase their workplace independence.

The research was started with an aim to use pervasive computing as a measure to increase autonomous functioning and improve the quality of life for the majority of otherwise-employable persons who remain unemployed, rarely access appropriate community services, and are socially isolated. Persons with cognitive impairments tend to be viewed as unemployable and systematically excluded from labor markets. However, this assumption has been challenged recently after the development of community-based rehabilitation (CBR) and supported employment services in particular. With sufficient and appropriate support on the job, many people with developmental disabilities and cognitive impairments are capable of participating in the world of work to various levels, which not only provides them with financial support but also opportunities for social connection. In other words, employment services for persons with mental disabilities play a key role in the process of social integration for them [3–5].

Job coaches at rehabilitation institutes serve as social workers and employment service providers. They work with individuals with cognitive impairments to support them in learning new job skills and maintaining paid employment. They may work for weeks helping a trainee learn how to improve work quality. Even so, the individual may still require assistance. While at the work, trainees often need to be reminded by job coaches from the supporting group in order to keep things in control. Without proper intervention, paid job offers for many individuals with cognitive impairments have been declined because they failed to meet task performance standards. For example, they may occasionally forget the procedures to make photocopies in an office setting or misplace salads when preparing food in kitchens. With proper prompts, the individuals may increase their effectiveness and efficiency in skill acquisition and task performance.

As investigators identify the importance of independent functioning of individuals with cognitive impairments, prompting systems that incorporate the use of various technologies are emerging. Prompting systems provide antecedent cue regulation procedures that facilitate a shift in stimulus control from an individual to the system itself allowing the user more autonomous functioning. For example, picture prompts facilitate user performance by sequentially introducing visual depictions of task steps. Auditory prompts are recorded audio cues that facilitate user performance in completing targeted tasks and are typically delivered via portable devices.

The proposed system for vocational task prompting, called the Kinempt (a portmanteau of the words "kinetic" and "prompt"), is based on Microsoft Kinect as a natural user interface using gestures. Figure 1 shows Microsoft Kinect. Using Kinect means that the users need not be bothered with sensors that can be intrusive and that the prompting system can save the user from carrying a handheld device. The contributions of the paper include the following: (1) both exploratory and comparative study of a task prompting system for participants with cognitive impairments; (2) use of cognitive support to enable autonomous task switching; and (3) adaptation of a simplified task load index (TLX) for subjective assessment of user experiences. The rest of the paper is organized as follows. In the following section, we survey existing research literature on task prompting for persons with cognitive disabilities. Then we describe the design and main components of the proposed system. Experimental results and discussions in the context of occupational rehabilitation are presented next. Conclusions are in the last section.

2 Related work

The growing recognition that assistive technology can be developed for cognitive as well as physical impairments has led several research groups to prototype task prompting systems. Personal computers including laptops, tablet PCs and special purpose communicators [6–8] have been integrated with various assistive technology to provide task prompting. The proliferation of mobile compact computing devices such as palm size PDAs enables a new option for personal prompting and cognitive aides [9–13]. Due to highly variable cognitive deficits, there are still arguments with regard to the percentage of cognitive-impaired persons able to handle and use properly a handheld device such as PDA, even with proper training. In laboratory settings [14], field trials [11, 15] and community-based experiments [16],

Fig. 1 Microsoft Kinect

PDAs have been used as cognitive aids for the participating individuals with cognitive impairments.

Prompting is especially useful for task engagements such as mail couriers, janitors, kitchen helpers and parking patrollers. Previous work on task prompting using PDAs relied on "Wizard of Oz" approaches [9, 17], user self-conscience [10, 13, 18], or constant time delay (CTD) [8, 16] in order to trigger the prompts for planned task steps. For example, a handheld prompting system [13] with a hardware button to move forward to the next step was employed to transition independently through vocational tasks for individuals with intellectual disabilities. In this case, if a student forgot to press the button after finishing an assigned task, human intervention had to be provided. A handheld electronic device [16] was used as a reminder alarm for individuals with severe traumatic brain injury. It was found to be useful in taking medication or making appointments.

There is an increasing trend of studies [11, 19] that take context and situations into account for task prompting. The Clever project [11] uses on-bus GPS devices to send prompts to PDAs carried by cognitively impaired people to remind them to get off buses at right stops. Previous context aware prototypes have relied on visual tags [15] and passive RFID tags [20] just to name a few. However, some cognitively impaired users reported difficulties in using PDA cameras to capture visual codes and paying attention to looking for RFID tags in order to receive prompts.

3 A design based on Kinect

The proposed system for vocational task prompting, called the Kinempt, is based on Kinect, which is a webcam-style add-on peripheral intended for the Xbox 360 console. Kinect enables users to control and interact with the Xbox 360 without the need to touch a game controller, through a natural user interface using gestures. The device comes with an RGB camera and a depth sensor, which provide full-body 3D motion capture capabilities. Going beyond the system's intended purpose of playing games, we leveraged the human gesture recognition capabilities of Kinect for task prompting in rehabilitation settings. The design draws upon the usability studies of interfaces by people with cognitive impairments and the requirements based on interviews with job coaches at rehabilitation institutes. In the Kinempt system, open-source PC drivers were used to identify human gestures. A PC running, an in-house developed task prompting software is set up to work with Kinect. The sequence of user gestures is compared step by step to the routine sequence of vocational task analysis. If steps in the task analysis are not followed, the Kinempt system will raise an alert in text, sound, picture or a combination of the above. If a gesture is recognized as a correct task step, the cue for the next task step will be prompted. Use of this technology can free a job coach or trainer from the burden of having to constantly stay with users for pre-service vocational training.

The Kinempt system was designed to show step-by-step instructions of routine task steps in a vocational job. The Kinect sensor keeps track of the hand and wrist joints and checks whether they move in and out the designated position required by a task step. Both correct and incorrect task steps are identified and logged by the Kinempt system for immediate task prompting and post-task performance quantitative analysis. In the beginning, the users were assigned the tasks by the job coaches. The descriptions of the task steps were input to the PC and stored as routines. A computer screen showed the just-in-time instructions in text and picture, for example "Get a cup of pineapples." and "Get half a cup of shrimps." Each task instruction is matched with a task step so that it can be followed to fulfill an order. "Hands busy, eyes busy" users during task engagement alternatively rely on voice instructions as task prompts.

4 Experimental results

4.1 Settings

The Kinempt system was deployed in a way that mimicked a local pizza chain store that spared non-business hours for the short order food preparation training of adults with cognitive impairments, as in Fig. 2. Kinect transmitted the target response signal to a low-end Asus EeePC notebook computer, a mini host installed with Kinempt software and built-in Microsoft Windows XP Home Edition. Benefiting

Fig. 2 The main table in a pizza store that participated in the community-based rehabilitation program

Fig. 3 The experiment design that mimicked the main table in a pizza store

Table 1 Profiles of four volunteers

Subjects	Sex	Age	Syndromes
Al	M	35	Paranoid schizophrenia, hearing impairments, insomnia
Ben	M	29	Substance abuse
Cathy	F	39	Brain injury, paranoid schizophrenia
Doug	M	31	Dementia, paranoid schizophrenia

from its low power consumption (saving up to 60% in energy consumption), small size and low price, it is convenient to develop as the computer for the disabled. The computer sent video signals to a 42″ LCD screen to display vocational task steps. The Kinempt system checked task steps according to tray positions that the hand reached, as in Fig. 3.

4.2 Volunteer recruitment

Individuals of disabilities and ages in various ranges were recommended by the participating rehabilitation institutes that we have been partnering with and screened according to degrees of cognitive impairments, the ability to achieve daily living tasks, and severity of loss in short-term memory. Priorities were given to medium and low functioning patients as opposed to high functioning and very low functioning ones. Moreover, assessment on individual capabilities also took into account the ability to read the computer screen and understand its feedback. With long-term observation, three job coaches decided that Al, Ben, Cathy, and Doug were more ready to participate in experiments than the other trainees were. Table 1 lists the basic profiles of four volunteers with sensitive and irrelevant data omitted. None of the participants had previous experience with Microsoft Kinect.

Table 2 Task steps for preparing a vegan pizza

Number of steps	Task analysis
5	Get a cup of base cheese
	Get a cup of broccoli
	Get half a cup of mushroom
	Get half a cup of bell pepper
	Get a quarter cup of green beans

Al was diagnosed as having paranoid schizophrenia when he was a high school student. He has received very good rehabilitation and has been able to remain employed on a paid job as a janitor. Al has been looking for but not yet found a more demanding job with higher pay such as kitchen assistance and gas station management. Ben was diagnosed as having substance abuse and he has mild difficulties in memorizing routine procedures in his workplace. Cathy was diagnosed as having schizophrenia and brain injury after receiving a brain surgery. She is currently unemployed although she really wants a job. Doug was diagnosed as having dementia and paranoid schizophrenia. He was forgetful about the routines of work procedures. He has been unemployed since he lost his floor clerk job some years ago. However, he has been trying very hard in the occupational rehabilitation program to become employed in the future. The participants were receiving pre-training programs in community-based employment projects.

4.3 Experiments

There were 100 occurrences of task steps performed by the four participants, each participant with five orders and each order with five task steps. Orders include vegan, steak, combo, pepperoni and country pizzas. Participants were prompted to get toppings one at a time from their trays. Task steps for preparing a short order vegan pizza is shown in Table 2. The sequence of task steps has to be strictly followed according to the standard training procedure. Each participant began the experiment sessions by waving hands for the Kinect sensor to capture initial joint locations.

Performance of the Kinempt system was measured in terms of the extent of exactness and completeness. A measure of exactness or fidelity is precision, whereas a measure of completeness is recall. In our scenarios, what matters is whether a subject follows routine sequences of task steps. Four possible scenarios were analyzed. A true positive is a task step correctly executed by the human and captured as correct by the machine. A true negative is a task step incorrectly executed by the human and captured as incorrect by the machine. A false negative is a task step incorrectly executed by the human but captured as correct

Table 3 Experimental result

Subjects	True cases[a]	False alarms	False negatives	Recall (%)	Precision (%)
Alan	25	0	0	100	100
Ben	25	0	0	100	100
Cathy	24	1	0	100	96
Doug	25	0	0	100	100

[a] The number of true cases is the sum of true positives and true negatives

by the machine. A false positive or false alarm is a task step correctly executed by the human but captured as incorrect by the machine. Based on the definitions of the four scenarios, recall = (True Positives + True Negatives)/(True Positives + True Negatives + False Negatives) and precision = (True Positives + True Negatives)/(True Positives + True Negatives + False Positives). The results are summarized in Table 3. The Kinempt system successfully identified correct and incorrect task sequences with only one exception out of 100 trials. A false alarm occurred because the Kinect sensor lost track of the user. On average, the precision is 96%, and the recall is 100%. It helped participants learn to perform the task steps in preparing short order pizzas.

4.4 Task load measurement

Besides technical evaluation, subjective workload measurement is also important. To evaluate the task load subjects may have experienced during device use, we adopt Hart and Staveland's NASA Task Load Index (TLX) method [21] which assesses work load on 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales. NASA TLX includes six indices: mental demand, physical demand, temporal demand, effort, frustration and performance. Considering the reading and verbal limitations with our subjects, TLX assessment was conducted in the form of oral interview. In the meantime, 21 gradations were simplified and reduced to only 5, i.e. 1–5 representing very low, somewhat low, neutral, somewhat high and very high, respectively. The survey results are summarized in Fig. 4.

4.5 Comparative study

After the exploratory study was concluded, we invited our test subjects for a comparative study to validate robustness of the proposed method against other methods. A prompting strategy frequently used by job coaches is the system of least prompts (SLP) [22]. This prompting strategy allows for independent responses by beginning with the presentation of a discriminative stimulus (a verbal

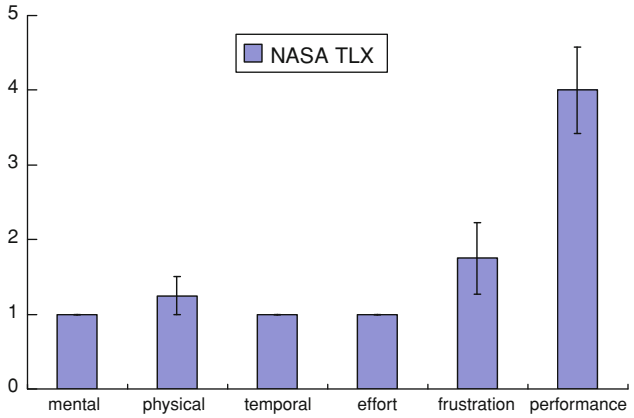

Fig. 4 Subjective assessment of user experience through oral interviews

instruction). If a subject does not respond or is unable to do so, the job coach uses the least intrusive prompt available (a verbal prompt) and waits for a subject's response. Gradually, more intrusive prompts (e.g., gesture, model, physical) are introduced if the subject continues to experience difficulty in responding or doing so incorrectly.

Ben and Doug agreed to participate in a three-week experiment. A session included five orders to be completed by an individual. The order was generated randomly from the menu. For each session, all the task steps were evaluated and statistical results in terms of success rates were collected. During the 1 week, a baseline measurement was accomplished with a subject attempting the same task sets given oral instructions. During the 2 weeks, the SLP method was used. Subjects independently performed task steps. Job coaches intervened and gave oral corrective instructions if task steps were not followed properly. In the last week, our proposed method of autonomous task prompting was used and subjects performed task steps according to cues prompted by the Kinempt system.

The experiments resulted in a total of 30 sessions in 3 different prompting strategies with 15 sessions for a subject. The statistics is depicted in Figs. 5 and 6. For the two subjects, the baseline achievements varied from 20 to 40% for Ben and from 40 to 80% for Doug. The performance difference between the baseline and the SLP method is statistically significant (Ben: $p = 0.0001$, $t = 12.4150$, $df = 8$; Doug: $p = 0.0004$, $t = 5.8797$, $df = 8$). The performance of the SLP method in terms of success rates improved significantly for the two subjects. The performance difference between the Kinempt method and the baseline is statistically significant (Ben: $p = 0.0001$, $t = 12.4150$, $df = 8$; Doug: $p = 0.0004$, $t = 5.8797$, $df = 8$). The high success rates validate the effectiveness of the Kinempt system. The results in the autonomous task prompting indicate that the performance is as good as the SLP method.

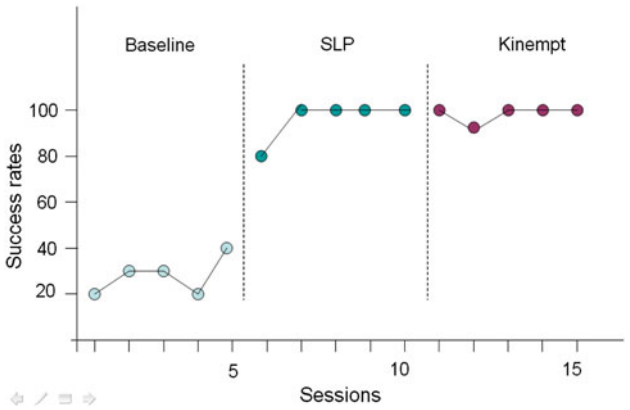

Fig. 5 The comparative study of Ben in three methods

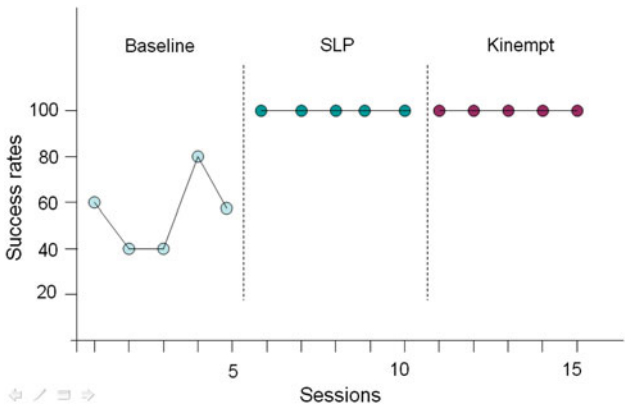

Fig. 6 The comparative study of Doug in three methods

4.6 Discussions and implications

This study assessed the effectiveness of the Kinempt system for vocational task prompting in a community-based rehabilitation program that involved four individuals with cognitive impairments. Results indicate that the system in conjunction with operant conditioning strategies may alleviate the problem of missing and mistaking task steps in routine sequences of vocational jobs.

In this study, the subjects unanimously found mental and physical demands and efforts to operate the device low or very low. In addition, no individual felt rushed to accomplish the expected level of performance. The pace of the task was not hurried either. No significant frustration was experienced by the participating users except that Al considered the system neutral in the frustration index. In the beginning of experiments, the Kinect sensor lost track of Al's hand twice. The Kinempt system reminded Al to wave at Kinect to restart the tracking process. Although the situations improved as more task steps were performed, Al already experienced frustration. The performance of the proposed system was considered high or very high. Although no ergonomics test was considered, the users remarked on the ease and the speed of use. During the interviews, all the participants felt comfortable recommending the system to their friends. In addition to task load tests, the users, including Al, reported having had fun during the experiment and it felt like playing games. This made it possible to have the participants concentrate on most of the session.

One of the key research issues in task prompting is the timing of serving prompts. Researchers are faced with challenges of when, where and how the prompts are delivered to the users. The state of the art includes self-operated prompting, reminder alarms, countdown timers and shadow team approaches. The shadow team approach is a practice followed by some caregivers or instructors when interventions are implemented. It is effective but labor intensive and costly. Reminder alarms or countdown timers have proved to be useful in situations such as taking medication or fixing coffee. However, for tasks that take an indefinite amount of time or require different amounts of time depending on different individuals, setting the timers will not be quite helpful if possible at all. Self-operated prompting systems require extensive training so that individuals acquire skills to identify when to invoke the prompts they happen to need. The study in [22] also reported that the students in some cases did not like having to continuously press the buttons to get prompts or they simply got messed up when using a self-operated prompting system. In contrast, the Kinempt system is an intelligent prompting system that requires fewer manual interventions and causes less inconvenience while enhancing automatic response and independent functioning.

Specialized assistive devices, either ready-made or developed in-house, are designed to provide additional accessibility, and increase, maintain or improve functional capabilities of persons who have physical or cognitive impairments and disabilities [23, 24]. However, such specially made devices are often expensive and difficult to obtain or maintain compared to commercial off-the-shelf devices [25]. Commercial off-the-shelf products have many advantages, such as affordability, availability, good after-care service, good technical support and low concern about social stigma [26]. Enhanced hardware or software assistive technology can repurpose many commercial high-technology products, turning them into high performance assistive devices to match the special needs of persons with disabilities [26, 27]. However, this is rarely proposed by researchers due to technology complexity. As demonstrated in this study, a commercial off-the-shelf gaming device in connection with software enhancement technology turned into a viable anomaly detection device. This device enabled the subject to improve his daily living skill, and possessed the merits of an off-the-shelf product. This

achievement enhances a sense of self-determination, a feeling of independence, and improves the quality of life for individuals with disabilities.

4.7 Limitations and future directions

Interpretations of the results should be taken carefully considering the characteristics of our sample. The heterogeneous nature of cognitive impairments is one limitation of the study. Another limitation to this study was the small number of participants. Therefore, replication studies are needed to confirm the findings provided here when used with increasing numbers of users with moderate and severe cognitive disabilities.

The Kinempt system checked task steps according to tray positions that the working hand reached. The system did not examine the exactness of the number or amount fetched. A more accurate prompting system may need to address this problem.

5 Conclusions

Based on Microsoft Kinect, the Kinempt system is a novel application of gesture recognition in the field of occupational rehabilitation. Combining the task analysis method with human joint tracking technology, routine step sequences of vocational jobs were field tested by four users in a community-based employment program. The result indicates good performance in terms of satisfactory precision and recall. Despite a small number of subjects, such evaluation is valuable and hard to conduct. Our data provide preliminary evidence that the image recognition technology may be able to facilitate task prompts needed by people with cognitive impairments. Therefore, the system may be helpful for pre-service training while increasing independence in the process of community integration. As a token of their satisfaction, the job coaches now plan using the Kinempt system on a daily basis for the occupational rehabilitation of their users and have encouraged us to add new types of vocational jobs focusing on new issues. Currently, a second stage of the Kinempt system is being designed to incorporate all of their suggestions.

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