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Vision Based Assistive Technology for People with Dementia Performing Activities of Daily Living (ADLs) – an Overview

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ABSTRACT

The rapid development of intelligent assistive technology for replacing a human caregiver in assisting people with dementia performing activities of daily living (ADLs) promises in the reduction of care cost especially in training and hiring human caregiver. The main problem however, is the various kinds of sensing agents used in such system and is dependent on the intent (types of ADLs) and environment where the activity is performed. In this paper on overview of the potential of computer vision based sensing agent in assistive system and how it can be generalized and be invariant to various kind of ADLs and environment. We find that there exists a gap from the existing vision based human action recognition method in designing such system due to cognitive and physical impairment of people with dementia.

Keywords—activities of daily living; dementia; health care; caregiver

1. INTRODUCTION

The population of elderly people in many countries especially developed countries has increased due to the improvement of quality of living. Elderly people with the age over 65 have a higher risk of dementia [1] which has become a major impact [2] and incurs a huge increase in the care expenditure by either the family member or the health care organization. This huge care expenditure includes the training and hiring cost for the human caregiver that must have special knowledge and skill to care the people with dementia. They are required in assisting people with dementia performing activities of daily living (ADLs) such as bathing, toileting and eating due to the difficulty in completing such activities [9].

The intervention of the artificial intelligence in developing the assistive technology overcomes many problems especially reducing the care cost and burden of the human caregiver. In addition, the new intelligent assistive technology provides some additional useful information as well as second opinion (instead of caregiver opinion) and is able to provide patient health status which is difficult to be obtained solely based on current existing assistive technology. In other words, the new assistive technology manages to reduce the human error. Generally, the intelligent assistive technology consists of sensing element and decision making mechanism. Sensing element is used to obtain data from patient and environment before passing the data through the decision making mechanism to provide the meaningful output. Types of sensing elements in use depends on the intent (i.e. depends on the types of ADLs) and environment where the activity is performed. The computer vision intervention as a sensing element for intelligent assistive system is promising, as it has the potential to become a sensing element that is invariant to different ADLs and environment.

This paper presents an overview of vision-based assistive technologies for people with dementia where the computer vision is highlighted as the sensing element. In section II, we report the current existing assistive technologies for people with dementia consisting of several types of sensing elements and the purpose of those systems. Section III reviews the COACH (Cognitive Orthosis for Assisting aCtivities in the Home) assistive technology and the future directions of such system. Next, Section IV overviews the existing vision-based human action recognition method that can be used to develop vision based sensing element. Section V suggests future work for future assistive technologies.

2. EXISTING ASSITIVE TECHNOLOGY FOR DEMENTIA PATIENTS

Bharucha [3] managed to generalize the assistive technology tackling people with dementia into four types which are based on its primary purpose; (a) *cognitive aids*, (b) *environment sensor*, (c) *physiological sensors* and (d) *advanced integrated sensor*. Cognitive aids means that the system is solely aiding the patient's cognitive impairment when performing the ADLs. Such a system is the Memory Glasses Project [18] which cues memory through displaying the recorded information such as names, faces and place to the user. Environmental sensors are the environmental based sensing element

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such as acoustic, pressure and ultrasound for detecting the agitation movement of people with dementia. These kinds of conventional multiple sensors can be used to detect anomaly which might occur in people with dementia performing ADLs. For systems that consist of attached body sensing element for detecting any physiological abnormalities in a patient, they are categorized as physiological sensors. Advanced integrated sensor systems acquire multiple data from several sensors inferred by sophisticated artificial intelligence as the decision making mechanism to aid either the patient or the caregiver while performing ADLs.

The assistive technologies for people with dementia can be divided into three groups based on the intent; (a) "*assistive technology for single ADLs*", (b) "*assistive technology for multiple ADLs*" and (c) "*assistive technology for other purposes*". We define systems that are developed for aiding patient tangibly performing single ADLs as "*assistive technology for single ADLs*", assisting systems for tangibly performing multiple ADLs as "*assistive technology for multiple ADLs*" and systems that assist intangibly for either single or multiple ADLs as "*assistive technology for other purposes*".

2.1 Assistive Technology for Single ADLs

Hoey and Mihailidis [4-9] introduced an intelligent prompting system for people with dementia performing hand washing (COACH). The whole system consists of only camera mounted on top of a tub. The system will interpret the steps completed by the patient and cues when the patient makes an error or forgets any steps while performing hand washing. The detail description of this system will be mentioned in Section III as one of the well-established vision based assistive technology for people with dementia. Systems for ADLs such as cooking are proposed in [11-12]. For example, the Visual Enhanced Recipe Application (VERA) [11] was developed to guide aphasia patients in performing cooking through visual-text online recipe instead of conventional text based recipe book since aphasia patients (another symptom for dementia) suffer from language impairment. The subject will only follow the instructions until the task is complete. Another cooking based assistive technology called Cook's Collage [12] has a video reminder system that provides previous 6 steps performed by the subject in order to cue and guide the subject towards completing the cooking process. Both systems have been executed without any evaluation mechanism.

2.2 Assistive Technology for Multiple ADLs

Smart home based assistive technology has been modeled [13-16] to monitor people with dementia performing multiple ADLs. Generally, it consists of multiple sensing elements from several types of sensor. These multiple information will be inferred by an intelligent decision making mechanism to recognize any deviation from the normal ADLs process. Nursebot [17] is a mobile robot which has the capability to interactively communicate with patients as well as recognize the physical condition of the patient such as the walking speed and the change of movement speed. The robot will remind the patient if he or she misses a step in a task or a task is not completed properly. One drawback of this robot is confirming the validity of the patient activities. The robot assumes task completion based on patient position. For instance, the patient is assumed has completed meal taking based on the time spent in the kitchen area. Besides that, there is no face recognition mechanism, thus making the system susceptible to miss identification of the subject of interest.

2.3 Assistive Technology for Other Purposes

Memory Glasses [18] is an assistive technology for the purpose of solely aiding the general cognitive impairment. The Memory Glasses identifies people interacting with the user, time and the location which is helpful in cueing memory through names, faces, time and place.Most assistive technologies related to this section take account patient security and safety as well. These systems not only monitor the patient but also intangibly guide the patient to perform proper ADLs without harming the patient's health. For example, the fall detection system [19-21] is used for detecting falling when the patient is performing ADLs. Many sensors were proposed for detecting falling such as camera or computer vision based sensor [21], infrared sensor [19] and piezoelectric sensor [20]. The security and safety of the patient should also be of concern especially at night. For this purpose, the system called CareWatch [22] was introduced. The system consists of multiple sensors such as door opening, bed occupancy sensor, motion detection and wireless receiver were used to monitor any anomaly behavior from the patient at night. Instead of external parameters, Medical Mood Ring [23] as an attached sensor will monitor the patient health status based on internal parameters such as pulse, blood pressure, oxygen saturation and blood glucose. This system will transmit all the information to the caregiver for monitoring purpose.

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3. COACH: RAPID DEVELOPMENT OF VISION BASED ASSISTIVE TECHNOLOGY FOR PEOPLE WITH DEMENTIA

Mihailidis [4] introduced COACH as the first prototype of such a device with artificial intelligence intervention to replace human caregiver in prompting person with dementia performing ADLs. We review this system because COACH is the most significant, rapid and well developed assistive technology that involves not only artificial intelligence in decision making mechanism but is also embedded with a computer vision as the sensing element. COACH only can model the hand washing operation as one of the ADLs. The author claims that the system can be expanded to other ADLs in the future [8].

COACH is divided into three main elements; (a) *sensing element*, (b) *decision making element* and the (c) *prompting element*. Computer vision is implemented from video input using a camera and the output of this element is the position of hand and towel as the objects of interest in the hand washing operation. This 2D hand and towel position is analyzed by decision making element to determine which step is being performed. Finally, the prompting element triggers verbal and/or visual cue if the user forgets to perform any steps in the process. The development of COACH has gone through three revisions. This is for the purpose of realizing the initial goal that is to generalize the COACH to other ADLs instead of limited to hand washing. Drastic changes has been made in all elements in the system, it still modeled solely on hand washing mechanism. However, significant improvements can be seen in the decision making element from supervised learning Neural Network [5] to reinforcement learning such as Markov Decision Process (MDP) [6] and finally to Partially Observable Markov Decision Process (POMDP) [9]. The inducement of changing from supervised learning to reinforcement learning is due to the activity task (hand washing) involves sequences of decision making, that is appropriate to be modeled using reinforcement learning.

In addition, the hand washing has been remodeled again from MDP to POMDP due to the feasibility of this technique which caters to the hidden variables such as user responsiveness. Hoey [10] again improved the POMDP by introducing the systematic procedure that automatically generates POMDP to model other ADLs based on knowledge driven method. The objective in [10] is still to generalize the prompting system for people with dementia performing other ADLs instead of hand washing. The systematic procedure involves the Human Factors Annotator and ubiquitous sensing technician in generating POMDP model for other ADLs. Computer vision is no longer implemented as the sensing element. In the prompting element, the prompting mechanism is improved to mimic human caregiver.

Even though COACH is one of the latest computer vision based prompting system development, the improvement of the computer vision sensing element is still less drastic compared to its decision making element. It can be seen from the first to third version; the input of sensing element is still in 2D plane image and the output of the system is still in 2D position of hand and towel [5-9]. However, the developer [9] states that computer vision based sensing element can be further expanded to stereo vision to obtain 3D information especially the object of interest such as hand and towel in the future. The improvement on the back end of the system (decision making element) seems unbalanced with the front end of the system (sensing element) in achieving the dream of versatile prompting system implemented to several ADLs. Overall, the idea of implementing computer vision based sensing element in COACH shows the feasibility of this kind of sensing agent compared to other for achieving the dream of generalizing the system to several ADLs. This is due to the several advantages such as [5]; to track not only gross movement but also fine motor movements; rich of information representing human action such as positional data, user interest and anomaly action characteristic based solely on single sensing agent; easy to adapt or embed with various kinds of environment and different types of ADLs; accommodate multiple subject action interpretation using only a single sensing agent; and high user acceptance due to unobtrusive characteristics.

4. OVERVIEW OF CURRENT VISION BASED ACTION RECOGNITION METHOD

In order to realize the idea of generalized computer vision based sensing agent into prompting system as assistive tool for people with dementia performing other ADLs, the existing methods regarding the vision based human action or activity recognition needs to be reviewed. The purpose of this overview is to provide some exposure on current image and video processing methods that can be used for developing the vision based prompting system for people with dementia. Action and activity recognition is emphasized because it plays a major part in vision based sensing element to interpret people with dementia performing the ADLs. Several surveys on vision based human action and activity recognition have been recently presented [24-26]. The term human action recognition will be used in this paper to represent either the action or activity recognition. Typically, human recognition can be separated into three levels as human recognition taxonomies; (a) *low level*, (b) *middle level* and (c) *high level* action. These three levels action were defined using different terms according to different researchers [24-26]. All these levels determine the complexness of action from simple (low level) to complex (high

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level). High level action is produced by the sequences of middle and low level actions; and the middle level actions consist of sequenced low level actions.

In low level action, there are several modules such as background subtraction, segmentation, tracking and object detection that have been introduced to extract important primitive features for representing human action. The most popular methods [27] are optical flow, point trajectories, background subtracted blob and filter response. Different methods suffer from different problems. For instance, the optical flow is not invariant to noise and illumination changes. Point trajectories provide limited information and suffer from occlusion. Filter response was designed to overcome optical flow limitation that is the difficulty to extract features from low resolution or poor quality image. Table 1 and 2 summarizes the types of middle and high level action methods which were generalized according to Tugara [27] framework. Middle level actions are divided into Nonparametric, Volumetric and Parametric; while high level actions are categorized into Graphical Model, Syntactical Approaches and Knowledge/Logic-Based Approaches. Tables 1 and 2 shows the limitations and advantages of the methods described [26-28].

Table 1 Existing methods in middle level

Non-parametric	Volumetric	Parametric
2-D Templates • Motion Energy Image (MEI) • Motion History Image (MHI) **Limitation**: Difficult to obtain or model complex actions [27].	**Spatio-Temporal Filtering** • Consists of filter bank inspired from 2D filter e.g. Gaussian, Gabor filter **Limitation**: Feasible but variant to fixed spatial and temporal scales [27].	**HMM (Hidden Markov Model)** • Simple HMM and Multiple HMM to tackle multiple action **Limitation:** Less efficient to complex action due to difficult to model the behavior [26].
3-D Object Models • Based on spatio-temporal axis *(x,y,t)* space, obtain the geometry descriptor **Limitation**: Good segmentation is required to obtain the sequence of silhouette [27].	**Part-Based Approaches** • Separate the volume into several local parts • Harris interest point + classification such as SVM, K-means etc. **Limitation**: Distortion from data due to illumination changes leads to incorrect interpretation [27]	**Linear Dynamical System (LDS)** • Similar to HMM, but consists of infinite set of state space **Limitation**: Same as HMM
Manifold Learning Method • Method that reduces the dimension of multiple description data • PCA, Laplacian Eigen map **Advantage:** Efficient [27].	**Tensor-Based Approaches** • ST volume *(x,y,t)* can also become 3 independent dimension of a tensor • Human action, human identity and angle trajectories (three dimension)	**Conditional Random Field (CRF)** • Solves the limitations of HMM • A kind of deterministic process **Limitation:** suffers with high rates of learning time [26].

Table 2 Existing methods in high level

Graphical Models	Syntactic Approaches	Knowledge & Logic-Based Approaches
Bayesian network/Dynamic Belief • Bayesian Network (BN) • Petri Nets (PN) **Limitation**: BN- incapable to model temporal information [26] PN- difficult to map from low level info [26] PN - depend on the accuracy of the low level process, lack of uncertainty managing [27] **Advantage**: PN - Capable to determine the completeness of the event [26]	**Grammars** • Recognize the human activity by assessing using grammar in language model. e.g. context-free grammar (CFG) **Limitation**: Depends on high accuracy of low level processing Difficult to model activities involving parallel, overlap and synchrony actions [27] **Advantage**: Practical for real time because efficient [27]	**Logic-Based Approaches** • Based on common sense and logic thinking to model the human activities. e.g. Prolog(logic programming), Declarative model, markov logic network etc. **Limitation**: For Prolog and declarative model - incapable of handling uncertainty [27]
Other Graphical Models • Allen's interval algebra • Using Suffix-tree	**Stochastic Grammars** • e.g. Stochastic context-free grammars (SCFG) • Improvement over CFG which suffers from errors due to the low level processing dependency	**Ontologies [27,28]** • Most generalized to build human activities **Limitation**: Ambiguity in relating low level info [27, 28] **Advantages**: Fast in developing the activity models due to standard modelling procedure [27]

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From Tables 1 and 2, it seems that the significant problem faced by most middle level and high level methods is that the dependency on the appropriate method selected at the lower level in order to improve the accuracy of the implemented system. At the high level, the method based on stochastic manner is claimed to be able to deal with uncertainty at lower levels compared to the deterministic methods. On the other hand, methods based on deterministic process are preferred due to the strict procedure in decision making mechanism. Much study in recent years has focused on proposing methods that interpret human action based on the deviation between complete human action and correct human action model; meaning that the method only interprets the action after the action has been performed [26-28]. However, little research focused on human action interpretation in the perspective of incomplete task or action. This will contribute to two terms in human action recognition: action completeness [26] and action prediction or intention [27].

5. DIRECTION FOR FUTURE WORK AND CONCLUSION

This overview has identified the future feasibility of computer vision based assistive technology for people with dementia. Previously, several existing assistive technologies exist consisting of different kinds of sensing agent and different intentions either for people with dementia performing single ADLs, multiple ADLs or for other purposes. The current assistive technologies for multiple ADLs are irresolute due to the data obtained from multiple sensing agents in representing the behavior of the subject perform multiple ADLs. To validate the information and accuracy of the system is still an issue. One alternative way to overcome this problem is to use the assistive technology for single ADLs because validation of information is not an issue for these systems. Moreover, it has the potential to be expanded to several ADLs to become a huge assistive system consisting of several modules or subsystems that tackles different kinds of ADLs. However, in order to realize an assistive technology that is based on single ADLs and expanded for other ADLs, the generalization of such system should be made in order to reduce the system setup time. Sensing element in the system must be easily adapted and invariant to different kind of activities and environment.

The versatility and feasibility of computer vision based sensing element has the potential of being a generic sensing element for different kinds of ADLs. The COACH system shows that the computer vision as sensing element is feasible and can be easily adapting [5] to different kinds of ADLs. The practicality of this POMDP [9] as one of the reinforcement learning mechanism cannot be denied. This is due to the stochastic manner in dealing with uncertainty information from low level process. As a result, less emphasize given in improving the vision based sensing element due to dependency on high level process (the POMDP). Recently, the trend is to improve the low level method before performing improvements on the high level action recognition method. Otherwise, the system will suffer if the system needs to be implemented for different ADLs. Remodeling the high level method such as POMDP is required in order to apply the system to different applications or different ADLs. Thus, the improvement or generalization should be made at the lower level for action recognition in order to reduce the burden to the high level methods. Based on this argument, it seems that the computer vision based sensing element needs to improved. In section IV, we have highlighted two features that needs to be considered in order to design vision based assistive system for people with dementia performing activities of daily living (ADLs); i.e. the action completeness [26] and action prediction or intention [27]. These two features should be emphasized in designing assistive systems for elderly people due to their cognitive and physical impairment. In addition, most of the existing human action recognition methods are solely designed based on normal and unimpaired person.

In conclusion, computer vision based sensing element as a part in assistive technology for people with dementia promises many advantages compared to other sensing agents. Many recent research of such sensing element is rapidly going on. Recently, Microsoft® has introduced a new computer vision based fusion sensing device called Kinect. The combination between 2D information from camera and depth information from infrared component in the Kinect device not only provides new perspective on computer vision sensing but also provides multiple useful information (3D) to represent human action and reducing the computational time for such sensing modality compared to stereo vision (or multiple cameras). In future, Kinect maybe can be used to replace existing sensing agents for developing an intelligent assistive technology for people with dementia or other disabilities.

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