IoT Smart Home Using Eye Tracking and Voice Interfaces for Elderly and Special Needs People

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Abstract**—**Eye tracking has become increasingly important in many sectors because of its ability to facilitate day to day activities, especially for users with special needs, where tasks as simple as turning on a light require effort. To tackle similar issues, we propose a model that utilizes Video Oculography approach through Tobii technology with added voice interfaces using Azure cloud to help control home appliances. This model traces the user via reflected infrared light patterns and calculates the gaze position automatically. This method uses no wearable technology through Video Oculography with multiple cameras which deliver several advantages; it provides accurate gaze estimates, portability of the video recording system, and fully remote recordings. Eye tracking facilitates interactions to control home appliances when the user cannot or does not wish to use their hands by means of the IoT and cloud Technologies. Eye tracking has great impact in countless fields such as neurology, cognition, communication and security of different categories. Focus groups and usability tests show that many users were satisfied with the straightforward use of the model, flexibility and reliability in interacting with the system, and accuracy in the movement of the pointer, make this model a reliable solution to simplifying some daily tasks.

Index Terms**—**Azure cloud, eye tracking, IoT, smart home, tobii, video oculography, elderly and special needs people

I. Introduction

An eye gaze can be one of the most communicative features in the human body. Imagine that day to day tasks can be accomplished with a swift movement of an eye such as simply turning the light ON or OFF, and where appliances could be triggered remotely with a gaze.

Many around the world are unable to accomplish basic daily tasks due to numerous physical disabilities. They can't use home appliances by themselves, and therefore they rely on others for help. As an example, ALS patients who suffer from paralysis [1] can't move around to switch on a fan or a heater, users with hearing disabilities cannot hear the door bell and Alzheimer diseased users may forget the gas open in the kitchen.

Internet of Things (IoT) has come to describe numerous research disciplines and technologies that allow the internet to spread into the real-world objects [2]. “Things” in the IoT logic can cover any object or device you can think about it [3]. A wide variety of devices and objects exist in our life that can be sensed or controlled remotely across existing network infrastructure which improved efficiency, accuracy and profit of the IoT help to reduced human interventions [4]. Fig. 1 shows examples of different IoT devices and applications.

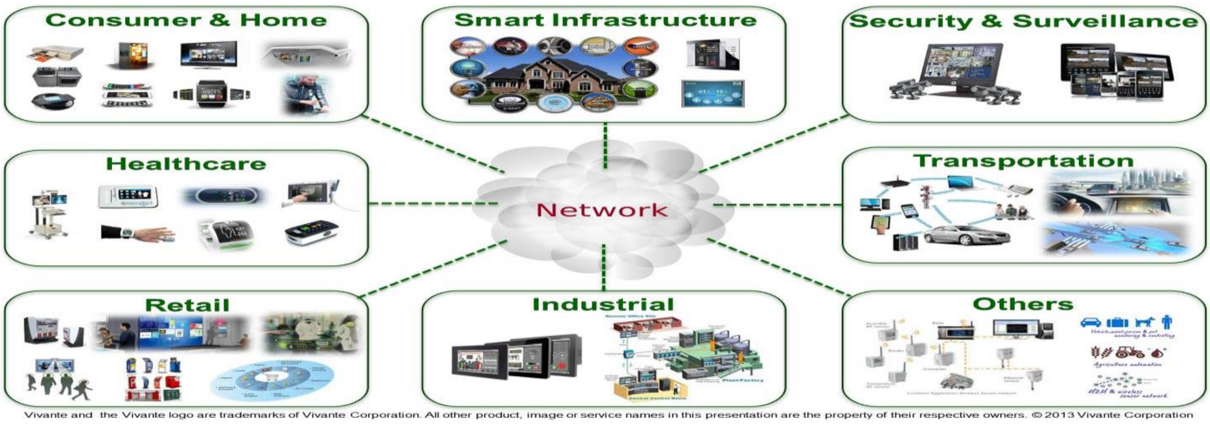

Figure 1. Examples of different IoT devices and applications [5]

Monitoring the activities of users and predicting their needs is possible with Smart technologies specifically Smart Home Wireless Sensor Networks, which offer elders and people with disabilities, personalized options in order to allow them to tune and adjust their environment to their specific needs from any smart phone, tablet, device or a computer application. Smart homes with hi-tech applications can be controlled remotely, are being heralded as the wave of the future.

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According to users with neural and muscle disabilities, eyes could be the best solution to help them gain a better user experience [6]. Hence, an optimal solution for the elderly and special needs users may be an IoT eye tracking system which uses a device that tracks the eye movement to capture accurately where the user is looking and for how long. It also involves software algorithms for pupil detection, image processing, data filtering and recording eye movement by means of fixation point, fixation duration and saccade [7].

In this paper, a model of a smart home using eye tracking and voice interfaces is developed to help solving significant elderly needs and disabilities by giving them a chance to live more independently and have the ability to regulate different home appliances to their needs, such as unlocking doors, turning the TV ON or OFF as well as lights, air-condition, heater, fan, electric curtains, etc.

The rest of the paper is organized as follows: the related works is listed in Section 2. The eye tracking techniques is overviewed in Section 3. The research methodology is described in section 4. Finally, Section 5 presents the conclusion and future work of this paper.

II. RELATED WORKS

The exponential research in advanced technological methods, devices, and solutions delivers inexpensive and improved patient care. Where valuable insight can be uncovered and examined to improve the healthcare field. With IoT's great advances, this insight is easily attainable; making IoT thrive in the field of health care.

Smart healthcare is a widely discussed subject. From chronic disease to a minor illness, finding new ways to handle disease through IoT has become of major importance [8]. Researchers and physicians explore new technologies and methods that could make detection, handling and curing illness possible and cost-effective.

In the field of chronic and life-threatening illness the importance of early detection of the patients' state is a vital approach. Alhussein, *et al*., 2018, discusses how seizure prone patients using a device to measure the patient's movements and face gestures may provide signs related to their state, then sent to the cloud where real-time assistance is given from a physician. However, when using the cloud, issues of security and availability always arise [9]. As well as managing and tracking chronic disease, Klímová and Kuča, 2018, researched the importance of the application of wearable sensors to manage Parkinson's disease through detecting, controlling and treating the illness [10].

Eye tracking can be applied in many arenas. ADHD (Attention deficit hyperactivity disorder), autism in children, disabilities, and the aid of elders are just a few. Yaneva *et al*., 2018, uses eye tracking to specify users with autism through classification with features such as time viewed, fixations, and revisits. the ability of an eye gaze to be used to differentiate between those diagnosed with and without autism by activities on web pages through unusual visual-attention patterns. This experiment studied the effects on browse and search in web pages with 0.75 and 0.71 accuracy respectively [11].

Also, Vernetti *et al*., 2018, measured responses of children that have autism through the application of gaze-contingent eye-tracking, and identified the illness where weak social communication in autism was examined. Vernetti shows how there was a reduced initiative for autism diagnosed children with changing social incentives [12].

Similarly, the field of ADHD has been studied vastly, since 11% of children from ages 4-17 suffer from this disease. Garcia, *et al*., 2017 developed a .NET Framework, which uses a hand recognition sensor (Leap Motion) and eye tracking device (Tobii X1 Light Eye Tracker) shows positive results with good interfaces item - the system supports the rehabilitation of cognitive functions in children with ADHD [13].

More on the use of eye tracking in health care is in neural monitoring. Ettenhofer., 2018, Integrated eye tracking and neural monitoring to measure the TBI (traumatic brain injury) to estimate variations in behavioral performance, saccadic performance, pupil response, and brain activation that occur at different levels of cognitive load. And found that those with TBI a strain on their cognitive abilities and fluctuations in brain stimulation with increasing load [14].

Eye tracking is one of the main focuses in IoT. Many researchers studied and proved the effectiveness of utilizing eye tracking technology in the field of medical diagnosis. MarketsandMarkets., 2015 conveyed that the approximation of the eye tracking market is to reach USD 1028.1 Million by 2020, increasing at a percentage of 35.2% between 2015 and 2020 annually [15]. Moreover, diagnosing and monitoring patients with heart disease is vastly studied and researched. The design of an ECG monitoring system is a great advance in IoT. Implemented by Yang., *et al* 2016, through the use of a wearable node to monitor the patient, connected to three electrodes, where immediate accurate signals can be collected. This system eliminated the need of mobile applications [16].

Various studies focused on helping special needs people utilizing eye tracking by helping them to operate electric wheelchairs. Gautam, Taher, and Meena discussed this issue. Gautam *et al*., 2010, proposed a visual eye tracking system to support mechanical wheelchair using optical type eye tracking system. They translated user's eye movement based on the angle of rotation of pupil by using Daugman's segmentation algorithm [17]. Taher *et al*., 2016 have shown different techniques using the combination of Electro Encephalography and eye movement to control an electric powered wheelchair. They used a low-cost, non-invasive headset for Electro Encephalography [18]. Furthermore, Meena *et al*., 2016 developed a new assistive device to help special needs people to perform daily life activities called EMOHEX. It uses an eye tracking device with a wheelchair-mounted hand-exoskeleton that can assist people with disabilities pick things while moving around [19].

In addition, researchers have studied and developed methods to enable elders and special needs users to handle computer and devices through a specific gaze or an eye movement. Ghude *et al*., 2014, suggested a system that will allow people with multiple disabilities to use eye movement to handle the personal computer. They used facial recognition method, geometric feature extraction algorithm and K-mean clustering [20]. In the same way Deepika and Murugesan in 2015, aimed to improve disable people life by using image-based eye tracking technique to facilitate their interaction with computer. They focused on controlling the movements of cursor on the screen using eyes. The accuracy was affected by illumination and down movement that can't be detected [21]. Haritha *et al*., 2016, combined an effective method of eye tracking and blink detection to help physically special needs people to access computers very easily. They suggested eye detection and tracking camera that captured image against isophote center of eye tracking and eye blink detection method [22].

III. Eye Tracking Techniques

A large number of different techniques that track eye movements have been investigated previously; four eye tracking techniques have been shown to be the major methods and are commonly used in research and commercial applications today. Following, these techniques are described in details [23].

A. Scleral Search Coil Approach

In this method, eye trackers use a contact lens with mirrors. As soon as a coil of wire shifts in a magnetic field, a voltage induces in the coil. If the coil is attached to the eye, then a signal of eye position will be produced. To measure human eye shifts, compact coils of wire are inserted in an altered contact lens. An embedded mirror in the lens is used to measure the light replication. Alternatively, an injected coil in the lens will enable sensing the coil's location in a magnetic field [24]-[26].

B. Infrared Oculography Approach

This system measures the force of an infrared light which is replicated from the sclera of the eye. The sclera reflects infrared light and collecting information about the eye position, this information will vary reliant on the eye position. The light source and sensors can be positioned on spherical glasses. Infrared oculography has a lesser amount of noise than electrooculography. As this method rests on perceptible light and pupil tracing, head movement might be a delicate issue [24]-[26].

C. Electro-Oculography Approach

Electro-Oculography (EOG) is human-computer interaction method where sensors are connected at the skin that is around the eyes to measure an electric field that happens when the eyes rotate, by logging the small variations in the skin that surrounds the eye, the location of the eye can be predicted by cautiously inserting electrodes. Parallel and perpendicular shifting of the eyes is logged in disjointedly by the insertion of electrodes. However, the signal can vary when there is no shifting of the eye. This method is both practical and low cost [25], [26].

D. Video Oculography Approach

An eye tracking system that relies on video can be either applied remotely through positioning a camera ahead of the user or put up where the camera is located below in visual axis of the eye, usually on the frame of eyeglasses. Head-mounted systems regularly contain a scene camera for taking footage of the user's view. Through directing infrared light on the eye, in which the light makes a spark on the cornea of the eye. It can be applied to discover the user's gaze through using single or two cameras [26]. The problem with single camera models is that it can take images with restricted range in taking high resolution images. On the other hand, dual cameras are operated to gain wider view high-resolution images to offer precise gaze approximations. In this method, head moment is taken into perspective. by using one camera for the head location and another camera is used for the eye. Calculation of the pupil center is accomplished by 3D coordinates. The video cameras are placed on the monitor screen whereas the infrared light is situated before the other camera to capture the flash in the image [23]-[25].

E. Discussion of Eye Tracking Techniques

A brief description about the popular eye tracking techniques has been mentioned above. The following Table I illustrates the advantages, disadvantages and differences between them.

TABLE I. The Differences between Most used Eye Tracking Methods.

Method	Eye Status	Area	Advantages	Limitation	Example
Scleral Search Coil	open	Medical and psychology	High accuracy and unlimited resolution impact	Requiring something to be placed into the eyes. and difficulty in the implementation	Chronos vision system
Infrared Oculography	Open	Commercial	Ability to measure gaze interactions by using image processing, as well as shifting between eye blinks	Sensitive to light and axis degrees and does not have the ability to measure torsion movement. In addition, head movement may be a delicate issue which result in low accuracy	Eye Max System

Electro-Oculography	Can be used with closed eyes	Medical	Linear proportional to eye displacement and EOG signals are assessed with respect to the head.	Is not compatible for regular usage. Will not produce bioelectric amplitude that is proportional to eye position if their great eye movements - EOG signals are deterministic for similar users in diverse situation	Eagle eyes system
Video Oculography	Open	commercial	Clinical observation of eye movement disorders, Video recording system is easily handled, and it can allow head free movement and fully remote recording.	Head video recording system is expensive and it has limited spatial resolution	Tobii Eye Tracking system

F. *Selection of Tobii Tracking System*

According to the comparisons between the popular eye tracking techniques as shown in Table I, it is concluded that there is no optimum method that can resolve all the problems in different life sectors and environments; each method has its limitations and advantages based on the problem specification, environment, cost, usability and etc. But in general, it is noticed that the last technique, the video oculography has many advantages and fewer limitation comparing to other techniques and has been integrated into a variety of devices.

The tobii eye tracking system is an example of video Oculography that uses multi cameras to detect and collect eye gaze data [27]. It contains head movement compensation and low deflection effects, with dual-eye tracking, which gives higher resolution. In addition, if user keeps moving, especially the head, the system can continue tracking even if only one eye is tracked during the movement [28].

Tobii provides a natural eye gaze interface with objects and devices, where the user is not required to be constrained with wearables, or health care gadgets such as Head-Mounted Displays, smart jewelry, smart clothing, or smart glasses, that might limit the ease of movement for this segment of users [29]. Therefore, we have selected the Tobii tracking system to convert the user's eyes' gaze into a pointer in order to help the elderly and special needs people to control home appliances as explained in Section IV.

IV. METHODOLOGY

The multiple cameras of Tobii technology are adopted in this framework as they serve several advantages over other methods in delivering accurate gaze estimates, portability of the video recording system, and fully remote recordings. Thus, the video oculography approach is the ideal choice in this model. The following framework in Fig. 2 presents the proposed eye tracking system using IoT and cloud technologies.

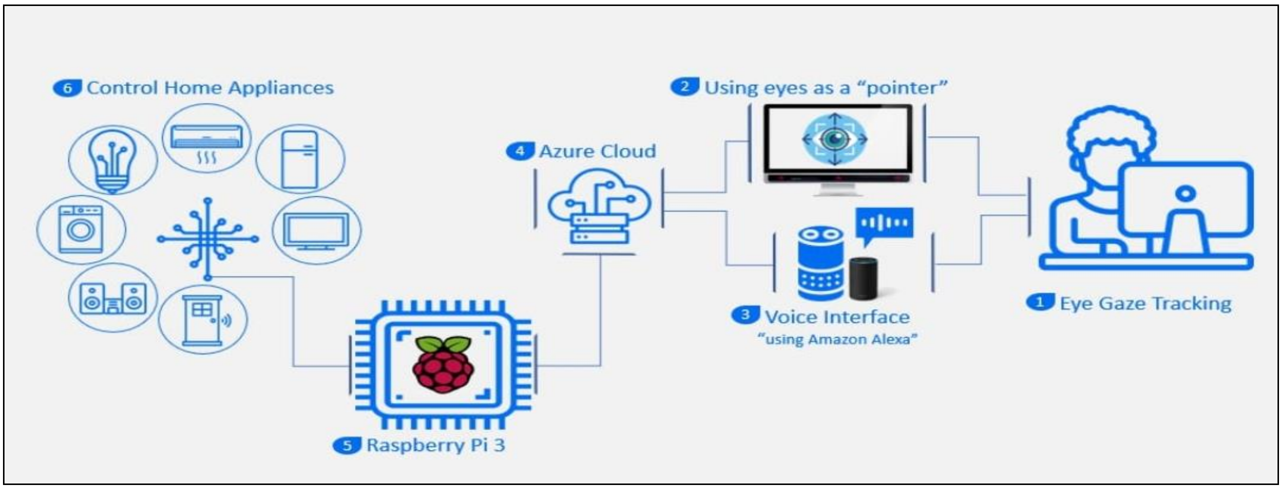

Figure 2. Proposed framework for eye tracking system using IoT and cloud technologies

A. *Tobii Eye Tracking*

The Tobii as shown in Fig. 3 is un-wearable eye tracking device includes sensors that consists of cameras that capture high-speed images to display the user's eye, and projectors that make a pattern of infrared light on the user's eyes [30].

The system tracks the user's eye gaze at a frequency of 50 observes each second. In combination of scene camera and advanced image processing algorithms the eye movement system monitors the person's eyes based on reflected infrared illumination patterns and calculates gaze conditions automatically. According to these mathematical algorithms, it figures out the eye's position (x and y) and gaze point for example on tablet, mobile or laptop's monitor [31]. Fig. 4 shows the Tobii eye tracking techniques.

B. *Website Interface*

Using eyes as a "pointer" on a screen, simplify communication with household appliances especially when the user can't or does not wish to use their hands.

The Tobii eye tracking techniques, converts user's eye gaze into pointer on a laptop's monitor that contains the developed website interface using HTML, JavaScript and PHP. It includes the household appliances as shown in Fig. 5. The user holds three seconds on requested appliance in order to send the request to Azure cloud.

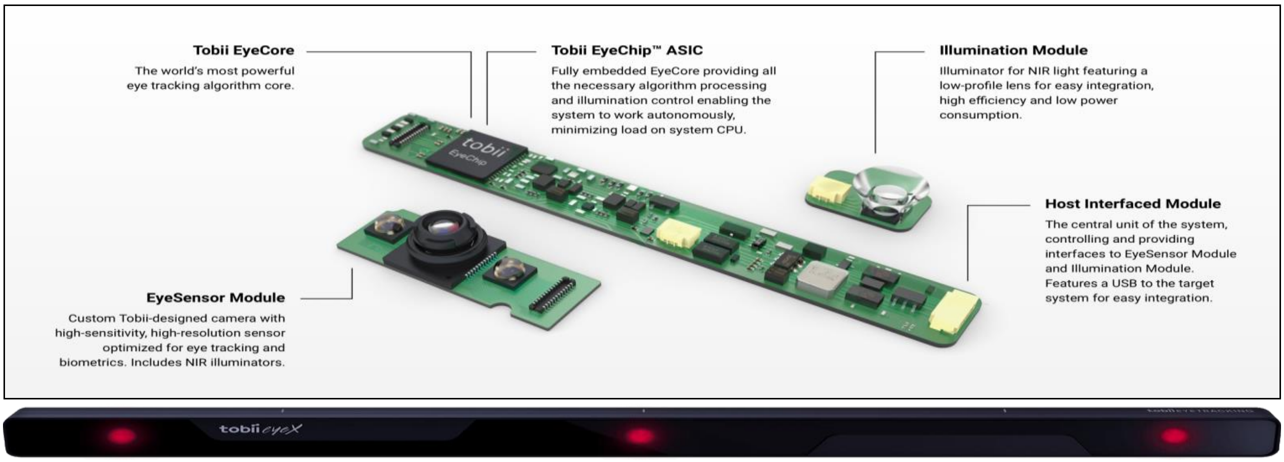

Figure 3. The un-wearable Tobii eye tracking device [30]

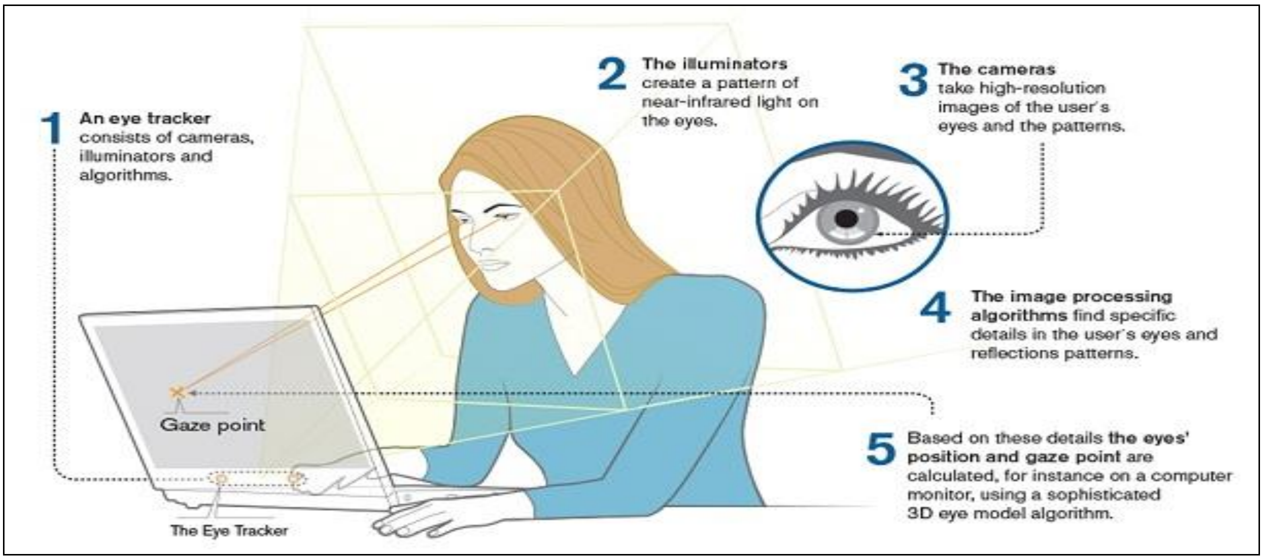

Figure 4. The Tobii eye tracking techniques [31]

C. Voice Interface

Moreover, a voice interface is presented to help users with special needs and disabilities who find it difficult to use the interface of the website. Voice assistants, for example Microsoft's Cortana, Google's Assistant, or Amazon's Alexa are software's that have the ability to understand human speech as well as reply through synthesized speech [32]. Amazon's Alexa is a smart speaker which supports smart home devices, its configurability and personalized aspects allow it to be personalized to users' specific requirements. Machine learning is the basis of Amazon Alexa's rising success; it is the reason behind the fast improvement in the abilities of voice-activated user interface and continuously working on resolving mistakes and decreasing the error rates. It has been used in the proposed system to receive user's verbal commands as shown in Fig. 6 and then send the request to Azure cloud to help them control home appliances.

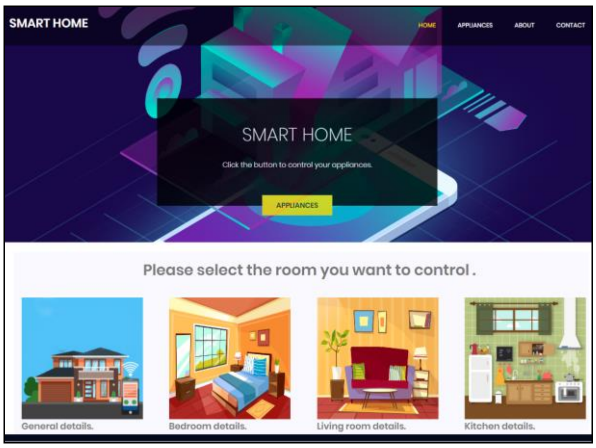

Figure 5. Website interface includes household appliances

D. Azure Function and Raspberry Pi

After receiving the users' request from API gateway to control a certain appliance by either turning it ON or OFF as described in 4.3 the Azure function reflect the request on SQL database. Then the Raspberry Pi microcomputer reads from SQL database and controls the appliance as shown in Fig. 7.

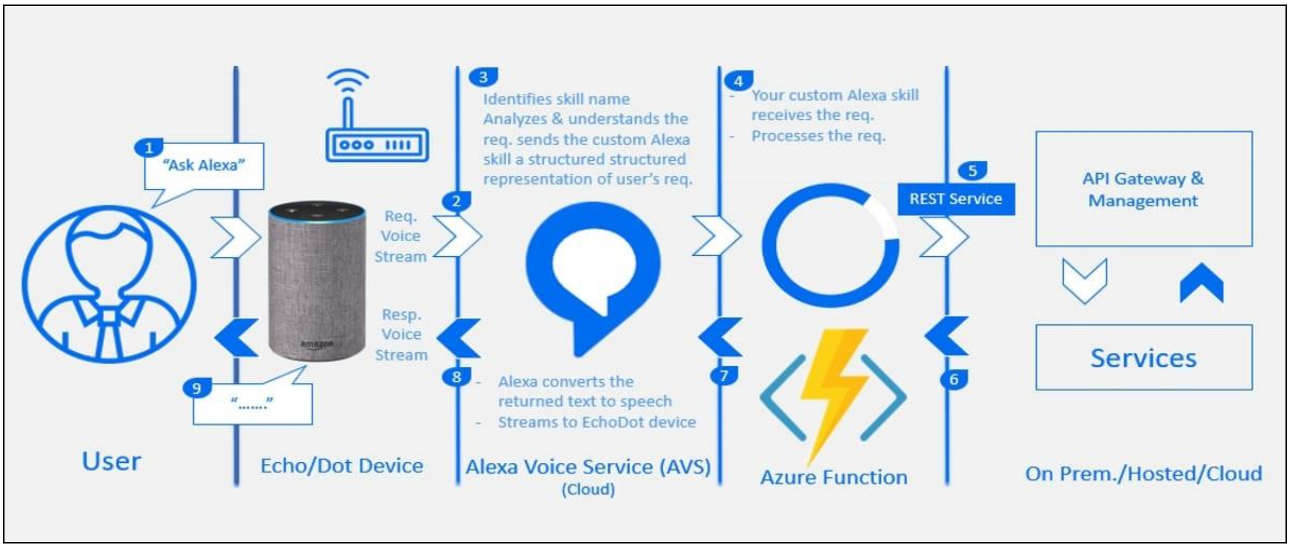

Figure 6. Amazon's alexa system.

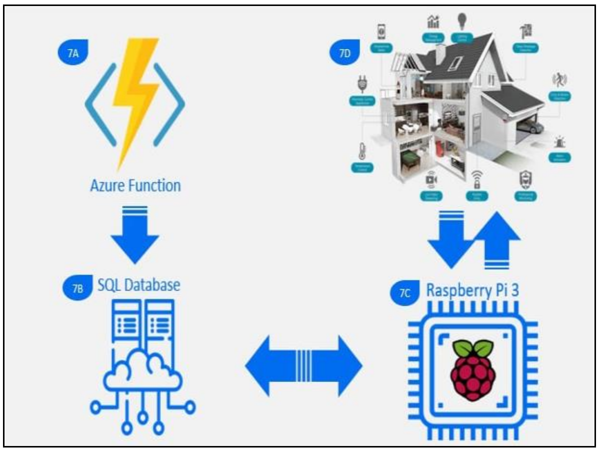

Figure 7. Azure Function and raspberry pi2

V. Evaluation and Testing

An evaluation was performed to confirm and validate the execution and performance of our system. We have tested the proposed system with the help of 20 volunteers of elders (age between 55 and 70) and special needs users. We distributed a sheet to each volunteer contains four questions as shown in Table I. We allowed each volunteer to interface with the system and use it to control all the appliances for at least two times for each appliance. Then, each volunteer filled the sheet with a satisfaction rate (i.e., a number between 0 and 100, the higher is better). We collected these rates and calculated the average as shown in Table II. Based on the evaluation results, we can conclude the followings:

1. The eye gaze was very accurate and can track the eye movement efficiently.
2. The pointer on the interface was easily controlled, where users could select what they require in a straightforward manner.
3. The response time had an acceptable delay.
4. The speech commands to control home appliances were simple and effective.
5. Generally, our initial system achieves high satisfaction rate.

TABLE II. Questions with the Average of Response of the Users

Question	Average Response
Was the eye tracking accurate?	93.2%
Was the interface easy to control?	91.7%
Was the response time having an acceptable delay?	90.3%
Was the speech command simple and effective?	91.5%

VI. Conclusion and Future Work

We described a method of smart home for elderly and special we described a method of smart home for elderly and special needs users through the Internet of Things technology (IoT) to control the home appliances by using either a web page, mobile application. as well as using the added voice and eye tracking interfaces that accept voice commands and eye movement tracking sent to Azure cloud where Raspberry Pi microcomputer reads from SQL database to help control the appliance. A comparison was performed describing the four major techniques used in eye tracking methodologies: Electro-Oculography, Scleral Search Coil, Infrared Oculography, and Video Oculography. Moreover, studying the advantages and disadvantages of each technique to find the optimal method for this study.

In this paper Tobii eye tracking system was chosen to develop the prototype due to the use of multiple cameras which capture high-speed images to display the user's eye, and projectors that make a pattern of infrared light on the user's eyes. Also, this system delivers higher resolution as it contains head movement compensation and low deflection effects, with dual-eye tracking.

Results shows how users found accuracy in tracking the eye gaze and movement through how responsive the pointer on the interface was. The response time of the system had an acceptable delay. Furthermore, the model shows simplicity of the voice interface option which shows that speech commands to regulate home appliances.

Although multiple camera eye trackers are rather costly and lack capability to measure with eye torsion. It provides the ability to clinically observe and measure eye movement disorders, they can allow head free movement and fully remote recording. The goal is to make the system as reliable and useful as elders and users with special needs require in accomplishing their tasks.

For future studies in this field, the prototype can be added as a new feature in any existing system in homes for the elders and hospitals, as required for users with special needs. Different techniques and comparisons between Tobii system and other eye tracking techniques could be performed to see if development is possible on the algorithm with Artificial Intelligence. As well as integrating the ability to track the user's behavioral aspects and patterns automatically to the system.

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