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Multimodal assistive wheelchair system operated by finger movement and capable of keyword extraction from images for visually and physically challenged people

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Abstract:

The Assistive Technology (AT) is a boon for the physically, mentally challenged and aged people. There are various research projects conducted around the world to facilitate the disadvantaged people to lead a normal life. A team of researchers from the University of Technology and Applied Sciences of Salalah campus with the support of the Ministry of Higher Education, Research and Innovation's funding is working on a project on finger movement multimodal assistive system for the smart people (Disadvantaged people). The research team has identified people who have difficulty in speaking and locomotive disability. The team has designed a manual wheelchair with the visual and audio command options for the helper or the nearby people through the finger movement of the disabled people. The main objective is to convey the commands or instructions to others through simple finger movements which are not to be memorized. The machine learning component of this system will make the instruction personalized for the people and it will not be common for all.

Keywords: *Assistive technology, Finger movement multi modal system, Machine learning, Smart gloves, Wheel chair with AT*

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1. INTRODUCTION

The article number 19 of the United Nations Convention on the Rights of Persons with Disabilities (CRPD) [1] supports the community with disability. The endorsement and successive implementation of such international guidelines fortifies the individual countries drive for regularization [2].

The article 19 of the convention emphasizes the right to community living by all people with disabilities and a right to appropriate support to ensure inclusion [3]. There is always a gap between the living of the disabled and the normal people. The Assistive Technology is playing a major role for the benefit of the disable people. Due to wide nature of the Assistive Technology all cutting edge technologies plays a major role in its success.

The people who are having problem in communicating with people and also having locomotive limitation are not able to lead a normal life. This happens not only due to the physical disability, also due to intellectual disability (autism) and for the aged people [4]. Internet of Things (IoT) tools and sensors helps a lot in designing the Assistive Technology systems. For the normalized movement all the above-mentioned people are using manual wheelchair since it is more economical. Hence the Assistive Technology should be incorporated within the wheelchair and should convey the disabled people's instructions to the environment [5].

To allow to communicate maximum commands by the disabled people the research team preferred to get the smart gloves which are readily available in the market. The smart gloves with minimum number of sensors are also possible to be designed by the research team. But these self-designed gloves will reduce the number of instructions to be communicated by the disabled people.

The research team used the speakers for the better communication between the stakeholders [6][7]. All the components were connected together with the help of Raspberry pi system. This helps to run the machine learning algorithms like CNN for making the system personalized for the users [8][9]. The motion sensing sensors and tracking sensors can be used to make the wheelchairs semi-automated [10]. This paper will propose such a system which can give maximum benefit to the disabled people economically.

Ghorbel et al. were used ATMega328 Microcontroller. Joystick, 16X2 LCD for displaying the values received from the multiple sensors and made the smart wheelchair a more user-friendly. They have explained the importance and the functionality of the collaborative control in a smart wheelchair [20]. The same ATMega328 used by Sivakumar and Sudhagar [21] to demonstrates the arrangement and headway organize for wheelchair. They have emphasized that the Smart wheelchair can be used for innumerable applications. To avoid the obstacles detection and make the smart wheel chair a reliable one, the design was discussed by Malhotra et al. [22-26]. G. Bourhis et al., J.Connell and P. Viola [27][28]have highlighted that some of the smart wheelchairs were a mobile robots with a seats attached during early days. Whereas R. Simpson [29] mentioned that many smart wheelchairs are just a modified version of the commercial powered wheelchairs with a few of sensors and a computing component.

2. PROBLEM STATEMENT

The main objective of this research is to address the problems confronted by the people who have issue in communicating their daily needs to the environment easily. The patients can only move their hands or fingers to convey their needs. Hence the research team should design the system suitable for these people. The finger movements of the patients will be captured by the smart gloves and the gesture will be converted to the audio and given as an output through the speaker. The patients may have different speed and comfortable finger movements. The AI based application will detect the appropriate message to be conveyed by the patient by their finger movement, using the machine learning algorithms.

3. COMPONENTS USED

3.1. Wheelchair

The research team has opted for the wheelchair with a removable toilet seat. The team has chosen this so that the battery, raspberry pi, bread board and speakers can be fixed in the removable toilet seat and can be removed whenever required. The wheelchair should be operated manually. The instructions can be given by the patient without moving the body or orally. The gloves can be worn by the patient and fingers can be moved without much effort and convey whatever they want. This model wheelchair can be automated in the later stage of the project. The wheelchair is wide and comfortable so that sensors can be fixed without disturbing the patients [11][12]. Fig 1 represents the sample wheel chair has been used in this project.

Figure 1. Wheelchair With a Removable Toilet Seat

3.2. Raspberry Pi 4 System

Figure 2. Raspberry pi 4 with 8 GB RAM

The research team has purchased raspberry pi 4 system. The fig 2 shows the Raspberry pi 4 image. Arduino boards are much cheaper compared to it. But the capability and flexibility of raspberry pi is incomparable. The research team wants to run the machine learning algorithms to make the system more user friendly. The specification of the raspberry system is as given below:

- *Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz*
- *1GB, 2GB, 4GB or 8GB LPDDR4-3200 SDRAM (depending on model)*
- *2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE*
- *Gigabit Ethernet*
- *2 USB 3.0 ports; 2 USB 2.0 ports.*
- *Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards)*
- *2 × micro-HDMI ports (up to 4kp60 supported)*
- *2-lane MIPI DSI display port*
- *2-lane MIPI CSI camera port*
- *4-pole stereo audio and composite video port*
- *H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)*
- *OpenGL ES 3.1, Vulkan 1.0*
- *Micro-SD card slot for loading operating system and data storage*
- *5V DC via USB-C connector (minimum 3A*)*
- *5V DC via GPIO header (minimum 3A*)*
- *Power over Ethernet (PoE) enabled (requires separate PoE HAT)*
- *Operating temperature: 0 – 50 degrees C ambient*

The research team connects the raspberry pi with the bread board so that more sensors can be connected with the system easily. The speakers can be connected easily with the 4-pole stereo audio and composite video port. The sound clarity will be good with the speakers with 1W output. The research team has tried the audio output with the Bluetooth speakers. Separate power supply is required for the Bluetooth speakers and the connectivity is not stable always. Hence for the reliability of the system the research team has opted for the wired 1w speakers fixed under the wheelchair. All basic components can be comfortably fixed with the raspberry system. But for adding more sensors to the system, the research team used the breadboard. Anker power bank with 10k amps capability fixed to supply power to these devices. The power bank can be charged when power is low. The research team wants to fix a separate display unit to show the power level to the user. It is not added to the system at present.

3.3. Maintaining the Integrity of the Specifications

The research team has got a wireless smart glove named Nova from a Netherlands company named SenseGlove. The image of the right-hand glove is represented in fig 3. This glove is used for the Virtual Reality applications. It has 9-axis absolute orientation sensor in the wrist for a perfect motion capture. It has also 4 sensors to capture the flexion and extension of the thumb and the index-, middle- and ring-fingers. 1 sensor to capture the abduction and adduction of the thumb. SenseGlove proprietary Computer-Vision is used to determine hand location in Cartesian space to positional tracking.

Figure 3. Wireless Smart Glove

The power consumption of the gloves is 3450mAh Lithium-Ion Battery, good for an average of 2-3 hours of simulation time. It weighs 320 g only. Hence it is more convenient to be worn by the patients. The gloves can transfer the signals using 2.4GHz wireless serial communication and with 60Hz refresh rate. An extensive software development kit is provided by the company for Unity. The wireless capability of this gloves makes the data collection and storage easy in the raspberry pi system or the GPU connected thorough the mobile network [13][14].

3.4. Sensors

The research team has designed a glove with flex sensor. The number of instructions that are passed with the help of the signal received from the flex sensor will be very limited. The movement of the finger also to be memorized by the patients [15].

The automation of the wheelchair can be achieved by the track sensor. The track sensor has infrared reflection sensor which detects the edge and follow a line. The proximity sensor or the ultrasonic sensor helps to detect the presence of an object [16].

3.5. AI Based Applications and Tools

Assistive Technologies are now getting smarter with the use of AI-based algorithms. The major contribution of AI-based technologies such as machine learning, deep learning, and natural language processing (NLP) has been two-fold. Firstly, with the incorporation of AI in existing Assistive Technologies and devices have become smarter and more intelligent. For example, command-based speech recognition has been replaced by ordinary speech. The NLP algorithms are able to extract important contexts in a given spoken text and thus subsequent systems connected to NLP can act accordingly. This does not require memorization of commands as each time a differently spoken sentence may lead to the same action. Another example lies in the education sector where students having sensory or locomotor disabilities can study using speech-to-text translators powered by NLP. Navigation is a big issue for persons with visual disabilities. Even basic walking becomes a difficult chore. CaBot [17] an AI-powered suitcase robot provides effortless navigation options even in environments such as busy airports, and shopping malls. CaBot is fitted with sensors and a camera to help guide motion in a chaotic place. The robot has been tested with visually impaired subjects and has been evaluated high on its usability [18].

4. PROPOSED DESIGN

The Primary objectives of the research project is to design Finger Movement Multimodal Assistive System (FMAS) for smart people / challenged people. The proposed system targets individuals with mobility limitations and limited speech capabilities, with the goal of enabling communication with the outside world through finger movements. The research team's main objective is to make the physically challenged people communicate with the real world just with their finger movements and aims to facilitate communication for individuals with physical disabilities by leveraging FMAS.

The second objective is to provide a solution which is technically and economically feasible for the end users. The last objective is to give maximum number of communicative commands with the finger movement of the physically challenged people. There are two systems proposed by the research team. The first system is using the readymade smart gloves with the raspberry pi system. The second system is to design a simple glove with the accelerometer sensor connected with the raspberry pi system. The block diagram of the first system is specified in Fig 4.

4.1. Block Diagram and Explanation

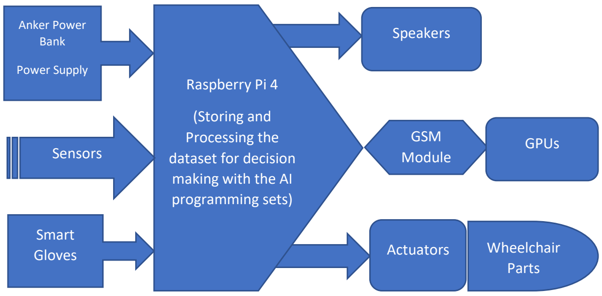

Figure 4. Block Diagram of FAMS

The smart gloves Nova has lot of sensors to capture the movement of the hands with high precision. The gloves, sensors and the raspberry pi system need power supply. The complete components are made to get the power supply from the anker power bank. The power bank can be charged when required. The basic system functionality starts only with the smart gloves movements. The movements of the parts of the gloves will send the value to the raspberry pi data set storage. The data set also is sent to the programming part of the system for the further action. In the advanced system more sensors can be added to the system for the data collection and further actions. The basic machine learning algorithm programs can be executed in the raspberry pi. The software can be developed using Python programming language or the Software Development Kit which came along with the wireless smart gloves. The advanced level deep learning programs which have difficulties in execution using raspberry pi can be sent to the GPUs which are connected using GSM module with the raspberry pi or through Bluetooth. The output of the programming unit is given through the speakers that are connected to the raspberry pi system. The visual output can be added if the user needs it. It can be done by adding a digital LED screen for a simple command. If the user wants a detailed instruction, then a small LCD monitor can be connected through the HDMI output of the raspberry pi system.

The programming part of this system will play a major role in making decisions based on the predictions. The data which is gathered through the sensors and the gloves will be fed to the neural networks (NN). The supervised learning technique will be used for training the NN. The unsupervised training will also be used wherever required. The convolution neural network and recurrent neural network (CNN or CNN-RNN) can be used to decipher the signs given by the glove movements. The execution should take negligible time since the system will be used to give instructions in real time. The output of the NN combined with the natural language process and convert to the sound. The sounds will be sent to the speaker connected with the system.

Our proposed approach utilizes transfer learning for image captioning. Specifically, we train a CNN model on the ImageNet dataset, which enables it to identify objects in different types of daily life images. Our image captioning model adopts a visual-space methodology in its encoder-decoder structure, rather than relying on modal representations as seen in some other models. The architecture of the model is a CNN-RNN combination [6] as shown in Figure 5.

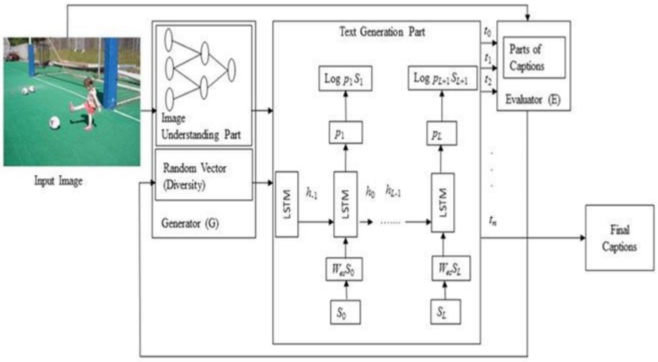

Figure 5: A CNN-RNN paired model for image captioning

In the proposed network, the second stage employs a Long Short-Term Memory (LSTM) Recurrent Neural Network (RNN) model for generating captions. Glove word embeddings are utilized for this purpose. Although the caption generation method is not highly robust, it can identify crucial objects in an image, which is adequate for our needs. The generated captions are then fed into the Rake NLP library to further narrow down on the most prominent keywords. Our overall model is depicted in Figure 6.

Figure 6: Keyword generator NN from images

To build our image captioning CNN model, we use transfer learning by training a pre-trained InceptionV3 CNN model on the ImageNet dataset. We modify the model by removing the top layer and integrating our own RNN (LSTM) model. Our goal is to capture the latent representation of image features and pass it on to the subsequent RNN network for caption generation.

For generating captions, we utilize a vocabulary provided by GloVe encodings, which offers access to a pre-trained unsupervised learning algorithm that represents words in vector form. This algorithm calculates vectors based on the nearest neighbor's principle, where words with similar meanings are closer in Euclidean distance (using vectors) than those with dissimilar meanings. We set the embedding dimensions to 200 to ensure fast convergence. The RNN network that processes word embedding's is depicted in Figure 7.

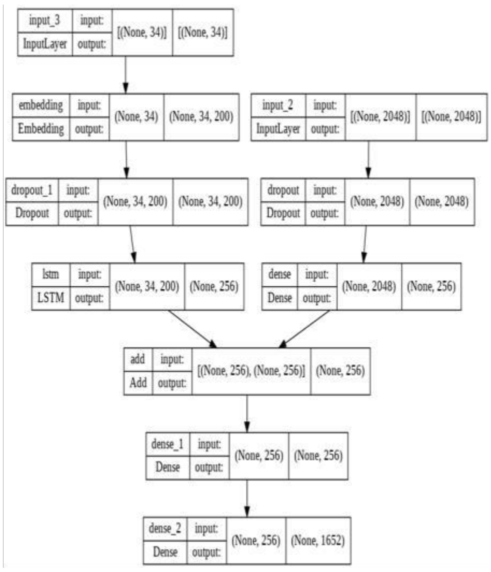

Figure 7: The caption generator RNN model

Some of the outputs of the generated captions are shown in Figure 8.

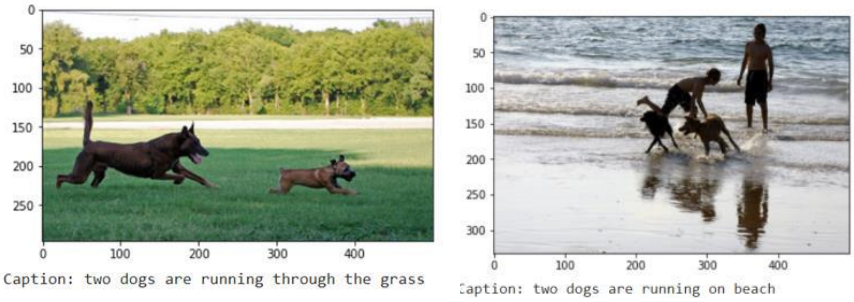

Figure 8: Generated captions

The generated captions are subsequently passed through the NLP Rake library, which produces the essential keywords. As previously stated, individuals who are visually impaired or have cognitive limitations can often comprehend the context and meaning of an image quite easily. Figure 9 illustrates the keywords generated from a particular image.

Figure 9: Caption with accompanying keywords generated by Rake

5. PERFORMANCE

To evaluate our generated captions against the provided training labels, we utilize the BLEU (Bilingual Evaluation Understudy) metric [19]. Since each training image comes with five descriptions, we assess our BLEU score against our generated caption. The BLEU score ranges from 0 to 1, with a score of 1 being considered an ideal match and a score of 0 indicating a complete mismatch. The score is calculated using different sizes of n-grams and is summarized using a geometric mean.

The general formula for calculating the BLEU score is presented below:

$$\exp\left(1 - \frac{length\ of\ reference}{length\ of\ hypothesis}\right)$$

Figure 10 depicts the BLEU score for each generated caption of a few samples. It is evident that, when tested over both the training and test data, our model achieves an average accuracy of 70% in most cases. However, during practical use, the accuracy may drop to an average of 20%.

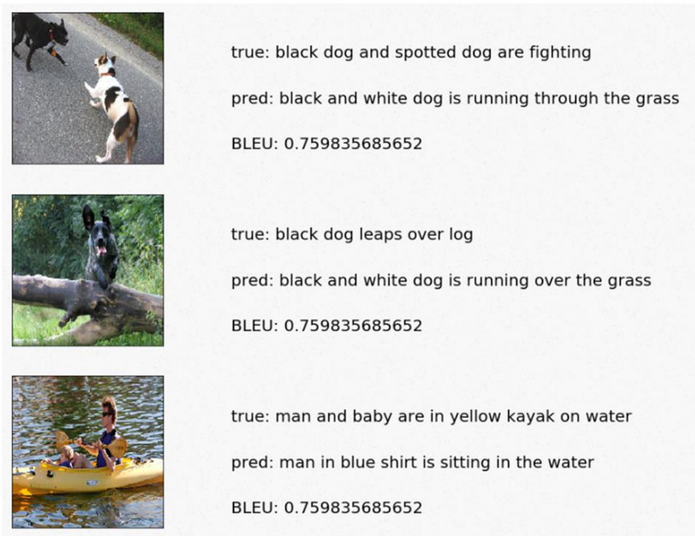

Figure 10: Examples with captions and corresponding BLEU scores

Addition of the eye tracker will allow the end user to give the output through the eye movement and blinks towards the screen added as input device. This will be an added advantage to the system but makes it more complicated.

6. DISCUSSIONS

Faria et al [30] has rightly pointed out that most of the smart wheel chair research projects around the world have given least priority to the interface to the patients. The proposed system aims to cater the needs of the individuals with locomotive disability who face challenges in communicating their instructions effectively. The research team has identified the major mode of communication done by the locomotive disabled people and tried to address it in this project. One of the major advantages of this system is its cost-effectiveness, as it employs readily available and affordable components in Oman. Furthermore, the system can be tailored to meet the specific requirements of patients and their budget constraints. With its high-end components, the wheelchair can be easily upgraded with additional sensors and programming components to make it fully automated. The components will help to make the wheelchair an automated one with additional sensors and programming components. Tyagi et al. [31] designed a system with less complexity and cost using cheaper and imprecise sensors and fuzzy control. The research team has used CNN and RNN and achieved the same. While the system currently lacks a visual display unit, it provides clear audio output that can be beneficial for patients with hearing impairment. But the system can also have a visual output for the deaf patients. Moreover, by integrating the system with a GPU via mobile networks, its capabilities can be exponentially enhanced, further enhancing its compatibility with the diverse needs of patients. Reddy and Kumar [32] proposed a smart wheelchair which can be connected to the mobile phone of the assistant or care taker as well as the social media. Whereas the researchers of this project have kept a tab and speaker for the nearby communication. The GSM technology used for the mobile communication when required. The smart devices like smart watch can prompt the health care people about the critical health status of the patients directly and make this project an economical and efficient.

7. CONCLUSION

The wheelchair is composed of a Raspberry Pi connected to smart gloves, sensors, a display unit, and a speaker, enabling individuals with disabilities to communicate with minimal finger movements. Machine learning algorithms personalize the signals received through finger movement. Smart gloves facilitate communication of a larger number of commands. The use of locally designed gloves with a reduced number of sensors helps lower the system's cost. Cloud and GSM systems connected to the Raspberry Pi can further bridge the gap between the lives of individuals with disabilities and those without. The system simplifies communication and can be personalized with an untrained dataset collected through the machine learning component. Incorporating an eye tracker can enhance the system's sophistication. Internet of Things assistive technology tools render the system more dependable and comfortable. The system can also be linked to Google Mini to provide users with necessary information, and Google can be used to make calls or send messages.

The assistive systems for the physically challenged people which are available in the market are more costly and not much personalized systems. The system which is depicted by the researchers is more economical and can be personalized based on the need of the user. Many research projects are either focusing in improvising a specific area of the smart wheelchair or the project concentrates on the technical aspect and ignoring the adaptability and cost of the system for the users immediately. The research project under taken by the researchers have accomplished the objective that delivering a smart wheelchair which is easily adaptable and economical.

The future prospectus of the system will be adding more appropriate sensors and improvising of the software component. The AI tools and apps are becoming a trend setter and make influence in all the domains. The AI tools can be used for the machine learning part of this project and make the system more personalized to the users in near future. The inclusion of the AI tools will make the system economical and most advanced one. The atomization of the hardware component will be a challenging one for the improvisation of this system. The atomization will affect the budget of the system. The research team may need to work in atomization part with reliable but cheaper components.

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