ARTIFICIAL INTELLIGENCE DRIVEN TILT SENSOR BASED SMART DRINKING DEVICE FOR STROKE SURVIVORS

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ABSTRACT

The proposed work introduces a tilt sensor device designed to monitor glass orientation during drinking activities in stroke survivors. Phase 1 of the study assessed the device's reliability in 96 normal individuals, achieving a correlation coefficient (r) of 0.99. In Phase 2, 96 stroke survivors were divided into six subgroups based on specific tilt orientations of the glass during activity. The device's concurrent validity, measured by Pearson's correlation, was 0.78 compared to motion analysis data from KINOVEA. Intraclass correlation (ICC) analysis demonstrated high agreement of 0.99 between the actual angle readings and the measurement angle from each trial. Results indicated that the device significantly reduced orientation range from 2.31 degrees without feedback to 0.85 degrees with feedback, highlighting its effectiveness in providing real-time feedback during drinking tasks. Additionally, the test-retest reliability (interclass correlation) was 0.99, supporting the device's consistency over time. Further work will involve the path for development of an AI-driven app using SQL files from data collected from stroke survivors, aiming to provide personalized rehabilitation strategies. The developed tilt sensor device shows promise as a reliable tool for monitoring glass orientation during drinking activities in stroke survivors, with potential implications for enhancing rehabilitation outcomes in this population.

Keywords – Tilt sensor, Smart Glass, Stroke, Kinovea, IoT, Artificial Intelligence

1. INTRODUCTION

Rehabilitation after a stroke is crucial for restoring motor and cognitive functions. Post stroke, various muscle deficit functions and muscle weakness, spasticity and different problems are observed. However, stroke monitoring and rehabilitation are expensive, requiring costly infrastructures and extensive medical staff involvement over prolonged periods [1]. Upper extremity dysfunction is a common challenge for stroke survivors, affecting their ability to perform daily tasks. Acute paresis of the hand or upper limb affects up to 87% of stroke patients, with 40-80% experiencing insufficient restoration of function. This underscores the need for effective rehabilitation strategies and assistive devices to improve independence and quality of life post-stroke [2]. Research indicates that stroke patients often encounter difficulties using everyday objects like cups, glasses, forks, and pens. Specifically, they struggle with maintaining the vertical orientation of handheld objects, particularly during transferring them to or from a table. These challenges stem from factors such as muscle weakness, coordination issues, and sensory deficits resulting from the stroke [3].

Presently, there are no standardized scales available for evaluating drinking task performance. A review of existing tools and smart objects that track the positioning of the glass during drinking activity in stroke survivors has been conducted as part of the literature review. However, no tool or device offers specific feedback on the orientation of the glass during drinking. Previous efforts have been made to develop a smart cup capable of monitoring the arm and hand activity of stroke patients while they drink. This cup would detect the amount of liquid in the cup, the force used to grip it, its orientation, and any tremors [4]. In other context Roby-Brami et al., conducted a study to quantify hand orientation and arm joint rotations during unconstrained reaching movements in healthy and hemiparetic individuals. Four electromagnetic sensors were used to measure hand orientation and compute wrist, elbow and shoulder joint angles. Hand azimuth is correlated to arm movement direction in both healthy and hemiparetic individuals [5]. Timmermans A A et al. conducted a study to find the skill preference of person with stroke regarding arm-hand training and examines the relationship between the use of patients affected arm and their training preferences. A list of 10 most preferred skills were found and analyzed between a group of sub-acute and chronic stroke population. They concluded that patient preferences related mostly to task involving 'manipulation in combination with positioning' and 'manipulation' which is more similar to the drinking task that involves grasping and manipulating the cup to the mouth with maintaining the stability of the cup position to avoid water spillage [6]. Nayeem et al., presented the "MAGIC TABLE," an uniquely designed tool that records the kinematics of stroke patients as they interact with things, specifically a “a cup of coffee,” in real time. Six stroke survivors and six healthy individuals manipulated a 3D printed cup with a ball moving inside that simulated sloshing coffee at three different levels of difficulty. Performance is assessed using both traditional kinematic measurements (movement time and smoothness) and new kinematic metrics that took object interaction into account (risk and predictability) [7]. In another work MA Murphy et al. proposed a study to determine the relationship between movement kinematics from the drinking task and the impairment or activity limitation level after stroke assessed with traditional clinical outcome measures. They concluded that kinematic movement performance measures obtained during the drinking task are strongly associated with activity capacity than with impairment [8]-[10].

Major challenges faced by stroke patients are

- Difficulty to grasp the glass
- Challenges in positioning the glass upright and transferring to mouth
- Difficult to empty the glass without spill

The proposed work focuses on developing and validating a tilt sensor device designed to monitor the orientation of drinking glasses during activities involving stroke survivors. The study will also evaluate the device's reliability in a sample of healthy individuals by establishing its concurrent validity in stroke survivors. Additionally, the research aims to assess the effectiveness of the device in providing real-time feedback during drinking tasks and to explore its potential for enhancing rehabilitation outcomes in this population.

2. DESIGN AND WORKING PRINCIPLE

The tilt sensor device is attached to the glass is custom-fitted and developed using a Gyroscope and Accelerometer based sensor. The design of electronic enclosure carried out using the CAD tool CATIA as show in the Figure 3, with the resulting model converted to an STL file for 3D printing. The device is then 3D printed and integrated into an Internet of Things (IoT) based software for real-time monitoring as shown in the Figure 1.

Figure 1: Developed device with hook and loop fastener

The glass, equipped with the tilt sensor device, is placed on the table. The device is switched on. When the glass is lifted from the table, the sensor starts tracking the orientation of the glass with respect to the zenith angle. The device's functionality is programmed in Node MCU, a microcontroller with an inbuilt Wi-Fi module. LEDs illuminate based on predefined threshold values: green for 0 to 20 degrees, yellow for 21 to 30 degrees, orange for 31 to 50 degrees, and red for greater than 50 degrees. Continuous tracking of the glass's orientation and movement frequency readings is performed, and the data output is monitored in the serial monitor of the arduino software. This data is wirelessly transmitted to the cloud platform for further development of AI driven applications.

The tilt sensor device design consists of MPU6050, Node MCU, Lithium polymer battery, super debug TP4056, LEDs, and ON/OFF switch. The components are fixed in a 3D print fabricated cylindrical model and its sealed. Component design with LED is shown in Figure 2. Figure 4 shows the development flow chart of device development.

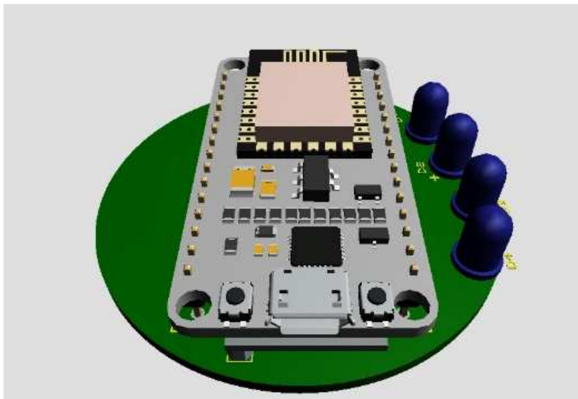

Figure 2: Component design with enclosure for Proposed Device

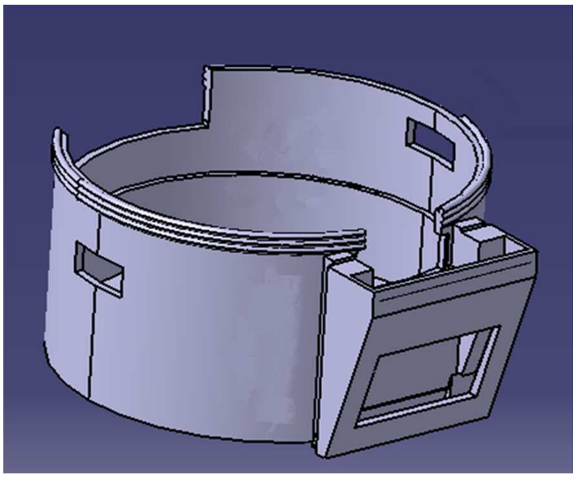

Figure 3: CAD Model of Electronics Enclosure

3. TESTING METHODOLOGY AND IMPLEMENTATION

The study has received approval from the Ethical Committee to conduct research. Participants from the normal population who fulfill the inclusion and exclusion criteria will be selected and provided with detailed explanations about the study. Each participant will receive an information sheet and a consent form for approval before the study begins. Data will be sourced from stroke rehabilitation centers, physiotherapy OPDs, and neuro-physiotherapy clinics in Bangalore.

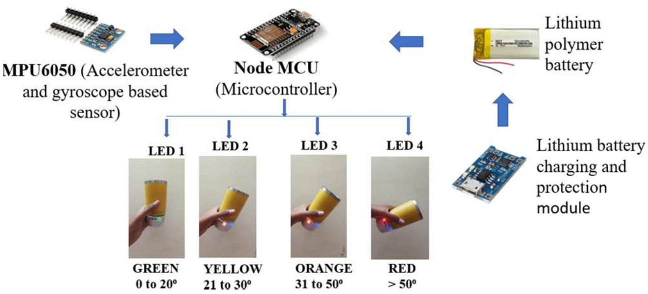

Figure 4: Development Work flow of Proposed Device

Figure 5: Device attached to glass/mug

For the normal population, inclusion criteria consist of individuals of both genders aged above 18 with full active range of motion (ROM) of the upper limb of the dominant arm. Exclusion criteria include participants with ROM restrictions of the wrist and hand, complaints of pain, injury, fracture, or dislocation in the dominant arm, and those unwilling to participate.

In the case of stroke survivors, inclusion criteria include confirmation of stroke diagnosis by a clinician and MRI/CT report, both genders aged above 18, and being in sub-acute (3-26 weeks) or chronic stage (>12 months) with various ranges of supination and pronation of the forearm. Additionally, participants should be able to sit independently in a supported chair. Exclusion criteria encompass other neurological disorders and musculoskeletal disorders, a Mini Mental State Examination (MMSE) score <24, visual impairments, passive restriction of ROM of the wrist and hand, complaints of pain, injury, fracture, or dislocation in the paretic arm, and unwillingness to participate.

4. RESULTS AND DISCUSSION

Current guidelines suggest task-oriented training to enhance drinking skills, but determining the appropriate dosage requires feedback on orientation magnitude.

Dosage = Intensity × Frequency

Our goal is to orient the glass vertically during the drinking task to prevent spills. However, there are no standardized scales to assess drinking task performance, and existing tools do not provide real-time feedback on glass orientation.

4.1 Reliability Testing of Prototype and Validation with KINOVEA Motion Analysis Tool

4.1.1 Reliability Testing

For the reliability analysis the data will be meticulously collected on baseline characteristics such as age, gender, and participation level of the subjects, as well as outcome measures. The intra-class correlation coefficient (ICC) will be calculated between 10 different measurement trials.

Reliability and Concurrent validity testing involved two phases such as;

Phase 1 consist of 96 normal individuals to establish the reliability of the tilt sensor device.

Phase 2 consist of 96 stroke survivors will be subdivided into 6 subgroups based on specific tilt orientation of the glass during activity.

Figure 6: Reliability Testing with wooden quadriceps board

In static reliability testing, some wooden quadriceps board capable of being positioned at 5 different angles is used as shown in Figure 6. The Tilt Sensor Device is placed over the wooden board at each of these angles, while goniometric angle measurements were taken simultaneously. The tilt sensor angle values were then correlated with the goniometric angle measurements. Intraclass correlation (ICC) was calculated between the actual angle readings and the measurement angle from each trial. The obtained interclass correlation coefficient (r) is 0.98. Eq. (1) and Eq. (2) considered for statistical analysis during reliability and concurrent validity testing of the device.

$$r = \frac{\sum xy - \frac{\sum x \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X^2)}{N})(\sum Y^2 - \frac{(\sum Y^2)}{N}}} \tag{1}$$

$$ICC = \frac{Subject\ Variability\ \ (\delta_S^2)}{Subejct\ Variability\ \ \ (\delta_S^2) + Subejct\ Variability\ \ \ (\delta_E^2)} \tag{2}$$

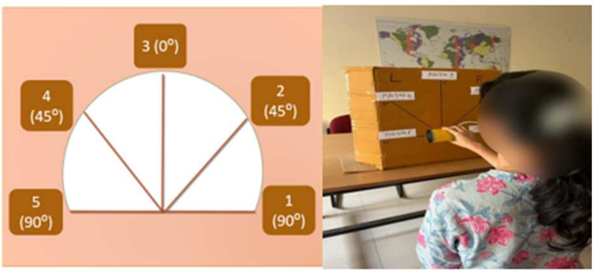

Figure 7: Reliability testing with Goniometer Setup

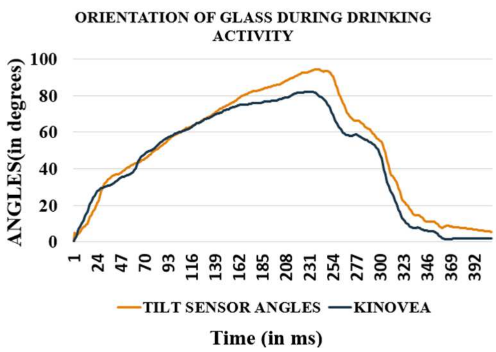

Figure 8: Variation of Tilt angle with time in Tilt sensor and Kinovea tool

4.1.2 Concurrent Validity Testing

Kinovea is a free 2D motion analysis software known for its capability to measure kinematic parameters. It is a reliable tool that produces valid data, offering an acceptable level of accuracy in angular and linear measurements obtained through the digitization of x- and y-axis coordinates. Participants are seated on a chair with back support in front of a table adjusted to chest level, allowing freedom of movement and compensatory adjustments if needed. A tilt sensor-fitted glass is placed on the table within easy reach. For normal individuals, a cardboard with marked lines indicating various angles is placed on the table, while for stroke survivors, two spherical markers are fixed in front of the glass, visible to the cameras. Water is filled in the glass to the maximum capacity without spillage. Figure 7 shows the goniometer setup for validity testing. Device attached to glass/mug used in the testing is shown in Figure 5. Figure 9 and Figure 10 shows the side view and top view setup scheme during concurrent validity testing.

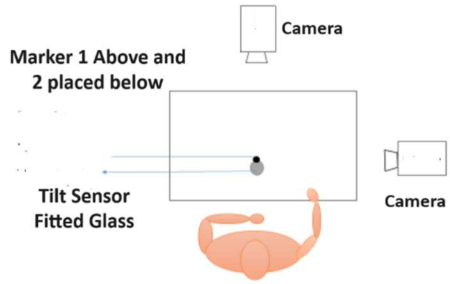

Figure 9: Top view of setup for drinking activity

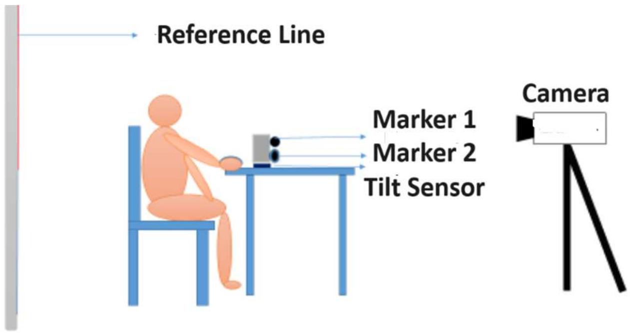

Figure 10: Side view of setup for drinking activity

Figure 11: Motion Analysis with Kinovea Tool with tilt angle of 8.4 degree

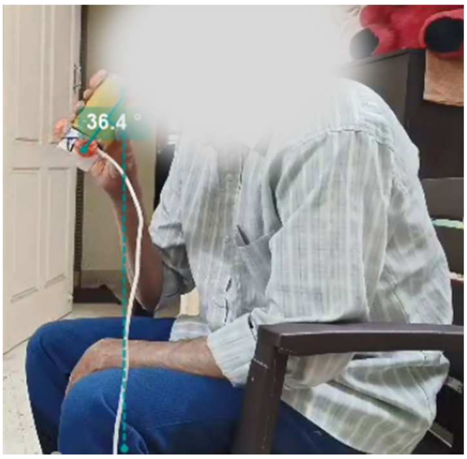

Figure 12: Motion Analysis with Kinovea Tool with tilt angle of 36.4 degree

Two cameras record the orientation of the glass during the drinking task: one placed in front and the other providing a side view of the arm performing the task. Reference lines of 1m height each are marked on the walls facing the camera. Participants are allowed to practice the drinking movement to find a comfortable sitting position. Once the glass is gripped, participants are instructed to begin the drinking activity at a comfortable self-paced speed after the command "start". Figure 11 and Figure 12 shows the motion analysis with Kinovea. Variation of angles obtained from tilt sensor and Kinovea tool shown in Figure 8.

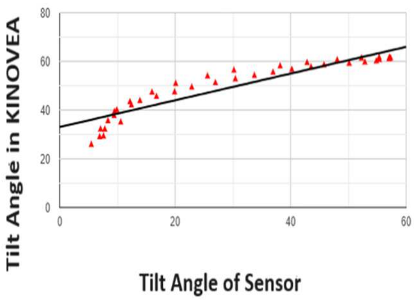

Figure 13: Data correlation between Tilt Angle Sensor and Tilt angle in Kinovea

Concurrent Validity shows the extent of agreement between two measures taken at the same time. It is used to prove that the tool measures what is supposed to by comparing results with other test that measures the same. So, here we are comparing the orientation of the tilt sensor fitted glass with the orientation tracked in kinovea software. Recorded videos of the drinking task from both the views are analyzed in kinovea software. A straight line is drawn connecting the two markers placed on the glass and orientation of the drinking glass is continuously tracked throughout the task. The angle of deviation of the straight line with respect to the reference vertical line on the wall will be analyzed throughout the drinking activity. The orientation values obtained from the Tilt sensor, and the values tracked in kinovea software are correlated and analyzed to establish the concurrent validity of the Tilt sensor in accurately monitoring the orientation of the glass while doing the drinking activity. Figure 13 shows the statistical correlation between data from tilt sensor and tilt angle obtained in Kinovea tool.

4.1.3 AI Driven App Development

Artificial Intelligence (AI) utilizes SQL files by analyzing the data within them to extract insights and make informed decisions. In our research, the AI-driven app will use SQL files from data collected from stroke survivors to develop personalized rehabilitation strategies. The app will parse the SQL files to access relevant data points, such as demographics and outcome measures, and analyze them using machine learning techniques. Based on this analysis, the app will generate tailored rehabilitation strategies aimed at improving motor function and independence. It will continuously learn and adapt from user data to refine its recommendations over time. This approach aims to provide effective and personalized rehabilitation guidance to stroke survivors, enhancing their functional outcomes and quality of life.

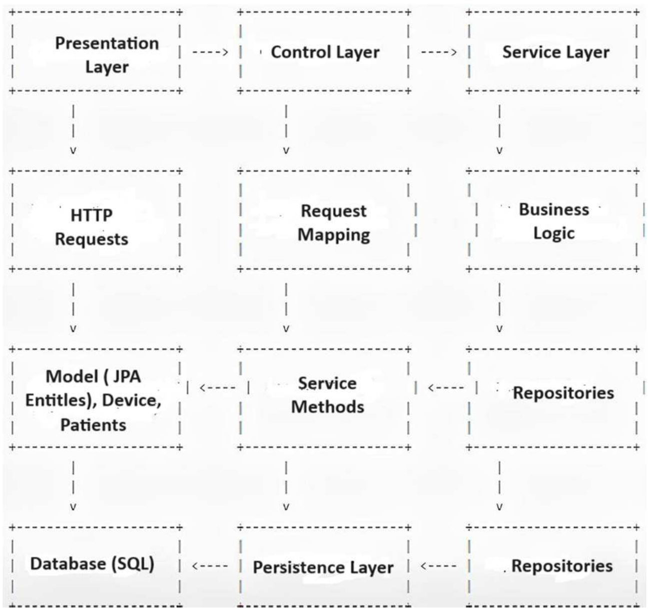

Figure 14: Work flow of java backend and sql database and their interconnection

The smart drinking device represents a breakthrough in patient monitoring, enabling precise tracking of hand activity crucial for rehabilitation. By capturing deflection angles along the X, Y, and Z axes, along with count data, this innovative device records invaluable metrics. Leveraging Java backend and API Postman, this data seamlessly flows into an SQL database, forming a comprehensive repository. This integration not only facilitates data retrieval but also empowers clinicians to assess patient recovery with unparalleled accuracy. Through SQL operations, including identifying maximum and average deflection, clinicians can swiftly analyze trends and tailor rehabilitation strategies. This holistic approach, driven by robust database management, streamlines patient care, ensuring optimized recovery pathways Figure 14 shows the Work flow of java backend and sql database and their interconnection.

CONCLUSION

In conclusion, our study developed and validated a tilt sensor device for monitoring glass orientation during drinking activities in both normal individuals and stroke survivors. The device exhibited high reliability in normal individuals with an intra-class correlation coefficient (ICC) of 0.95 and showed effectiveness in stroke survivors with an ICC of 0.93. Additionally, the device can be used for evaluating the magnitude of orientation to set the desired threshold level for drinking task training. The real-time feedback of the tilt angle of the glass could aid patients in maintaining glass stability, preventing water spills, and motivating consistent practice, delivering insights into progress, all of which are crucial for therapy adherence. The setup, including cameras and markers, ensured accurate recording and analysis of drinking movements, making the tilt sensor device a promising tool for improving rehabilitation outcomes in stroke survivors and enhancing long-term functional recovery. Ongoing work includes the development of an AI-driven app to utilize data collected from the tilt sensor device and provide personalized rehabilitation strategies for stroke survivors, aiming to optimize therapy outcomes and promote sustained recovery. The study successfully demonstrates the tilt sensor device's potential in aiding stroke survivors, though it recognizes the need for larger, more diverse samples and long-term evaluations to enhance the generalizability and durability of the findings. Future research aims to address these areas, ensuring broader applicability and sustained effectiveness across varied populations.

ACKNOWLEDGEMENT

We extend our sincere thanks to all the participants who contributed to this study. We also appreciate the support of the staff and clinicians involved. Lastly, we acknowledge the dedication of our research team members of The Oxford College of Engineering and The Oxford College of Physiotherapy.

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