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(57) Abstract:

ABSTRACT MEDICATION DISPENSER WITH ON-DEVICE USER AUTHENTICATION AND MEDICATION VERIFICATION A medication dispenser device (100) includes a processing unit (10) configured to execute machine learning inference operations, a first image capture device (20) configured to capture facial images, a second image capture device (30) configured to capture medication images, a storage medium (40) storing face embeddings for enrolled users, user-medication assignment data, and a machine learning model trained to classify medications, and a dispensing mechanism (50). The processing unit (10) authenticates a user by comparing a facial embedding from a captured image against stored embeddings, actuates the dispensing mechanism (50) to release medication assigned to the authenticated user, classifies the released medication using the machine learning model, and verifies that the classified medication matches the assigned medication. Authentication, classification, and verification are performed on-device without external network connectivity. (FIG. 1)

FORM-2

THE PATENTS ACT, 1970

(39 of 1970)

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THE PATENTS RULES, 2003

COMPLETE

SPECIFICATION

(See section 10 and rule 13)

TITLE OF INVENTION

MEDICATION DISPENSER WITH ON-DEVICE USER AUTHENTICATION AND MEDICATION VERIFICATION

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THE FOLLOWING SPECIFICATION PARTICULARLY DESCRIBES THE INVENTION AND THE MANNER IN WHICH IT IS TO BE PERFORMED

CROSS-REFERENCE TO RELATED APPLICATIONS AND PRIORITY

[0001] The present application does not claim priority from any patent application.

PREAMBLE

[0002] The following specification particularly describes the invention and the manner in which it is to be performed.

FIELD OF INVENTION

[0003] The present disclosure relates to medication dispensing systems with integrated machine learning capabilities, and more particularly to a medication dispenser device that performs on-device user authentication via facial recognition and medication verification via image-based classification without requiring external network connectivity.

BACKGROUND

[0004] The following text of background art is provided for purposes of understanding and is not an admission that any cited document or technique forms part of the prior art under applicable law.

[0005] Medication adherence remains a persistent challenge in healthcare delivery, particularly for elderly patients and individuals managing multiple prescriptions. Automated medication dispensing systems have emerged to address missed doses through scheduling and reminder mechanisms. Prior approaches in this field include smart pill dispensers with consumption verification through movement analysis, as described by Minera et al. in "Smart Cup for Smart Pill Dispenser" (IEEE CCWC 2023), which utilized IMU sensors and ultrasonic detection to confirm pill consumption. Spectroscopic verification systems have been proposed, such as those disclosed in US Patent US10896752B2 (Woodyear et al., 2020) employing NIR spectroscopy and chemometrics for medication authenticity verification, and US Patent US10790052B2 (O'Brien et al., 2020) using Fabry-Perot interferometers for counterfeit detection. Biometric authentication approaches have been explored in systems targeting elderly and visually impaired users, as described by Al-Masri et al. in "Biometric-Sensor Smart Dispenser" (Computers & Electrical Engineering 2023). Automated pill identification using

rotation-independent surface features was disclosed in US Patent US10467477B2 (Gershtein et al., 2019). IoT-based dispensers with cloud connectivity and mobile application integration have been described in various publications including "IoT-Based Intelligent Pill Dispenser" (ICPCSN 2023) and by Abhijith M. et al. in "IoT-Based Smart Medicine Dispenser" (J. Neonatal Surgery 2025). AI-based pill detection for blister pack configurations was presented by Pinto et al. in "AI-Based Pill Detection" (IEEE SeGAH 2022).

[0006] Existing medication dispensing systems exhibit several limitations. First, verification mechanisms in current systems typically confirm consumption after delivery but do not validate pill identity prior to dispensation, creating a risk of administration errors even when timing and access control function correctly. Second, cloud-dependent architectures prevalent in IoT-based designs introduce privacy vulnerabilities and create single points of failure that may be unacceptable in healthcare settings, particularly for patients in locations with unreliable network connectivity. Third, existing solutions tend to address individual aspects of medication management in isolation—some prioritize access control through biometric authentication, others focus on mechanical dispensing simplicity, and still others emphasize AI-based identification—but do not integrate biometric authentication, scheduling, and local AI verification within a unified system. Fourth, patent-based solutions relying on proprietary spectroscopic sensors present cost barriers that limit accessibility and reproducibility in resource-constrained environments.

[0007] It has been appreciated that a medication dispensing device and method is needed that overcomes one or more of these problems.

[0008] The present invention addresses the above shortcomings of the prior art. However, the invention is entirely different from the prior art in terms of novelty and technological advancements.

OBJECT

[0009] In view of the foregoing, and without prejudice to the generality of the disclosure, it is an object of the present invention to provide. It is to be understood that the foregoing objects are illustrative and non-limiting; additional objects will

be apparent from the description, examples, and claims, and need not be achieved in every embodiment.

[0010] In view of the foregoing, and without prejudice to the generality of the disclosure, it is an object of the present invention to provide a medication dispenser device that integrates on-device user authentication via facial recognition with on-device medication verification via image-based classification, thereby ensuring that the correct medication is dispensed to the correct user without requiring external network connectivity. A further object is to provide a medication dispenser that performs pre-dispensation verification of pill identity using machine learning inference executed locally on the device, addressing the safety gap in existing systems where medication correctness is not validated prior to delivery. Another object is to provide a medication dispensing system that operates entirely offline, storing user face embeddings and medication assignment data locally, thereby eliminating privacy vulnerabilities and single points of failure associated with cloud-dependent architectures. Yet another object is to provide a medication dispenser employing a quantized machine learning model with temperature scaling calibration to produce reliable confidence scores for medication classification under variable environmental conditions. A still further object is to provide a medication dispensing device utilizing a dual-camera architecture for separate facial image capture and medication image capture, enabling independent optimization of each verification pathway. It is also an object to provide a medication dispenser with servo-actuated dispensing mechanisms controlled via pulse-width modulation signals, enabling precise mechanical release of specific medications assigned to authenticated users. It is to be understood that the foregoing objects are illustrative and non-limiting; additional objects will be apparent from the description, examples, and claims, and need not be achieved in every embodiment.

[0011] For the avoidance of doubt, the foregoing objects encompass compositions and manufacturing processes suitable for adoption in jurisdictions where claims to methods of treatment of animals may be restricted; corresponding "use" or "product" claim formats are contemplated without limitation.

SUMMARY

[0012] The following summary is intended to introduce aspects of the present invention in a simplified form and does not identify all the features or the scope of the claimed invention. The summary is provided to assist in understanding the invention and is to be read in conjunction with the detailed description and accompanying drawings, claims, and abstract. One or more embodiments of the present disclosure are set forth below solely for illustrative purposes and should not be construed as limiting.

[0013] In a first aspect, a medication dispenser device is provided. The medication dispenser device comprises a processing unit configured to execute machine learning inference operations; a first image capture device configured to capture facial images of a user; a second image capture device configured to capture images of medication; a storage medium storing user identification data comprising face embeddings for enrolled users, user-medication assignment data associating each enrolled user with at least one prescribed medication, and a machine learning model trained to classify medications; a dispensing mechanism configured to release medication from the device; wherein the processing unit is configured to authenticate a user by comparing a facial embedding generated from a captured facial image against the stored face embeddings, actuate the dispensing mechanism to release medication assigned to the authenticated user, classify the released medication by processing a captured medication image using the machine learning model, and verify that the classified medication matches the medication assigned to the authenticated user; and wherein the authentication, classification, and verification are performed on-device without requiring external network connectivity.

[0014] The medication dispenser device provides a technical advantage by integrating user authentication with medication verification in a single device that operates independently of external networks, thereby eliminating privacy vulnerabilities associated with cloud-dependent architectures and ensuring reliable operation in environments with limited or unreliable network connectivity. The on-device execution of machine learning inference for both facial recognition and medication classification enables the device to verify that the correct medication is

dispensed to the correct user without transmitting sensitive biometric or health data to external servers, addressing security concerns in healthcare applications.

[0015] The machine learning model may comprise a temperature scaling calibration layer configured to adjust output logits by a temperature parameter to produce calibrated probability scores.

[0016] The temperature scaling calibration layer provides a technical advantage by producing confidence scores that more accurately reflect the true probability of correct classification, enabling the device to distinguish between high-confidence predictions that can be trusted and low-confidence predictions that may require additional verification or manual intervention. This calibration addresses the tendency of neural networks to produce overconfident predictions, which is particularly beneficial in safety-sensitive medication dispensing applications where reliable uncertainty estimation supports appropriate decision-making.

[0017] The machine learning model may be a quantized model having integer-format weights.

[0018] The quantized model with integer-format weights provides a technical advantage by reducing the memory footprint and computational requirements of the machine learning model, enabling efficient execution on resource-constrained embedded processing units without requiring dedicated hardware accelerators. The reduced model size and faster inference times achieved through quantization allow the medication dispenser device to perform real-time medication classification within latency constraints suitable for interactive operation.

[0019] The dispensing mechanism may comprise at least one servo motor, and the processing unit may be configured to control the at least one servo motor via pulse-width modulation signals to release medication from a corresponding medication container.

[0020] The servo motor controlled via pulse-width modulation signals provides a technical advantage by enabling precise mechanical actuation of the dispensing mechanism with repeatable positioning accuracy, ensuring consistent and reliable release of individual medication doses. The direct control of servo

motors through pulse-width modulation allows the processing unit to map specific medications to corresponding actuators, enabling the device to dispense the correct medication type based on the authenticated user's prescription data.

[0021] The processing unit may be further configured to compare a confidence score associated with the classified medication against a predetermined confidence threshold, and to generate an error indication when the confidence score is below the predetermined confidence threshold.

[0022] The comparison of confidence scores against a predetermined threshold provides a technical advantage by enabling the device to identify uncertain classifications and alert users or caregivers when the medication verification result may be unreliable, thereby preventing potential medication errors in cases where the classification model cannot make a confident determination. This confidence-based filtering mechanism enhances the safety of the medication dispensing process by deferring ambiguous cases for manual verification rather than proceeding with potentially incorrect medication delivery.

[0023] In a second aspect, a method of operating the medication dispenser device is provided. The method comprises capturing a facial image of a user using the first image capture device; generating a facial embedding from the captured facial image; authenticating the user by comparing the generated facial embedding against the stored face embeddings; retrieving medication assignment data for the authenticated user from the storage medium; actuating the dispensing mechanism to release medication assigned to the authenticated user; capturing an image of the released medication using the second image capture device; classifying the released medication by processing the captured medication image using the machine learning model stored on the storage medium; and verifying that the classified medication matches the medication assigned to the authenticated user.

[0024] The method provides a technical advantage by establishing a sequential workflow that ensures medication is dispensed only to authenticated users and that the dispensed medication is verified against the user's prescription data before the dispensing transaction is considered complete. The dual verification approach, combining biometric user authentication with image-based medication

classification, addresses the safety gap in existing systems where medication correctness is not validated, reducing the risk of medication administration errors.

[0025] Authenticating the user may comprise computing a cosine similarity score between the generated facial embedding and each of the stored face embeddings, and determining that the user is authenticated when the cosine similarity score exceeds a predetermined authentication threshold.

[0026] The cosine similarity computation provides a technical advantage by enabling efficient comparison of facial embeddings in a manner that is robust to variations in embedding magnitude, focusing instead on the directional similarity between feature vectors. The predetermined authentication threshold allows the system to balance between accepting legitimate users and rejecting unauthorized access attempts, with the threshold value being configurable to adjust the trade-off between true acceptance rate and false acceptance rate based on the security requirements of the deployment environment.

[0027] The method may further comprise logging a verification result indicating whether the classified medication matches the medication assigned to the authenticated user.

[0028] The logging of verification results provides a technical advantage by creating an audit trail of dispensing transactions that can be reviewed to identify patterns of medication errors, track adherence over time, and support troubleshooting of system performance. The stored verification logs enable caregivers and healthcare providers to monitor medication adherence and identify potential issues without requiring continuous real-time observation of the patient.

[0029] In a third aspect, a non-transitory computer-readable medium storing instructions is provided. The instructions, when executed by a processing unit of a medication dispenser device, cause the processing unit to perform operations comprising processing a captured facial image to generate a facial embedding; comparing the generated facial embedding against stored face embeddings to authenticate a user; retrieving medication assignment data associated with the authenticated user; executing a machine learning model to classify a captured image of medication released by a dispensing mechanism of the medication dispenser

device; verifying that the classified medication matches the medication assigned to the authenticated user; and generating a control signal based on the verification result.

[0030] The non-transitory computer-readable medium provides a technical advantage by enabling the medication dispenser device to be updated or reconfigured through software modifications without requiring hardware changes, allowing the system to be adapted to different medication types, user populations, or operational requirements. The software-based implementation of the authentication and verification logic facilitates deployment across different hardware platforms and enables iterative improvement of the machine learning models as additional training data becomes available.

[0031] The operations may further comprise applying temperature scaling calibration to output values of the machine learning model to produce calibrated confidence scores prior to classifying the medication.

[0032] The application of temperature scaling calibration to output values provides a technical advantage by transforming the raw output logits of the machine learning model into probability scores that are better calibrated to reflect actual classification accuracy, enabling more reliable decision-making based on the confidence scores. The calibrated confidence scores allow the system to implement confidence-based rejection mechanisms that can identify predictions with high uncertainty and flag them for additional verification, enhancing the overall safety and reliability of the medication verification process.

[0033] The foregoing general description of the illustrative embodiments and the following detailed description thereof are merely exemplary aspects of the teachings of this disclosure and are not restrictive.

BRIEF DESCRIPTION OF FIGURES

[0034] The drawings appended herein illustrate exemplary embodiments of the present invention and are provided to enhance understanding of the inventive features disclosed. These figures, when read in conjunction with the detailed description, depict the operational flow, component architecture, and other mechanisms.

[0035] The illustrations are schematic in nature and serve solely to clarify the principles and functionality of the present disclosure. While particular constructions and configurations are depicted for explanatory purposes, it will be understood that the invention is not limited to the precise implementations shown in the figures and may encompass variations without departing from the scope of protection.

[0036] FIG. 1 illustrates a flowchart for a method of operating a medication dispenser device with user authentication and medication verification, according to aspects of the present disclosure.

[0037] FIG. 2 illustrates a flowchart for a method of operating a medication dispenser device with facial embedding processing and control signal generation, according to an embodiment.

[0038] FIG. 3 illustrates a flowchart for a method of operating a medication dispenser device with cosine similarity computation and authentication threshold determination, according to aspects of the present disclosure.

[0039] FIG. 4 illustrates a flowchart for a method of operating a medication dispenser device with verification result logging, according to an embodiment.

[0040] FIG. 5 illustrates a confusion matrix displaying raw prediction counts for a medication classification system, according to aspects of the present disclosure.

[0041] FIG. 6 illustrates a normalized confusion matrix displaying classification performance percentages for a medication classification system, according to an embodiment.

[0042] FIG. 7 illustrates reliability diagrams for calibration evaluation of a medication classification model across multiple medication classes, according to aspects of the present disclosure.

[0043] Furthermore, in terms of the construction of the system, one or more components of the device may have been represented in the figures by conventional symbols, and the figures may show only those specific details that are pertinent to understanding the embodiments of the present invention so as not to obscure the figures with details that will be readily apparent to those of ordinary skill in the art having benefit of the description herein.

DETAILED DESCRIPTION

[0044] The following detailed description is intended to provide an in-depth understanding of the invention and its various components, configurations, and operational aspects. While specific embodiments are described with reference to the accompanying drawings, the invention is not limited to the particular forms disclosed herein. The scope of the invention shall be interpreted broadly and in accordance with the claims appended hereto.

[0045] The terms “comprises,” “comprising,” “includes,” “including,” and similar expressions used in this description are intended to be open-ended and should be interpreted to include, but not be limited to, the mentioned elements. Unless explicitly stated otherwise, singular terms may include their plural equivalents and vice versa, depending on the context in which they appear.

[0046] Reference is now made to the accompanying figures, which illustrate example embodiments of the present invention. It should be appreciated that the figures are intended for illustration and explanatory purposes only and do not limit the scope of the invention. Similar reference numerals have been used to denote functionally similar components throughout the figures.

[0047] The embodiments described herein are presented for illustrative purposes and are subject to variations, modifications, and adaptations by those skilled in the art. Any equivalent implementations that perform substantially the same function in substantially the same manner are intended to fall within the scope of this disclosure and the claims appended hereto.

[0048] The use of the term “exemplary” in the description shall be understood to mean “serving as an example or illustration” and shall not be construed as limiting the invention to the preferred embodiments disclosed. Various other embodiments may be developed without departing from the spirit or essential characteristics of the invention. The technical principles and advantages outlined in the foregoing description should be read in conjunction with the figures and claims. It is expressly understood that while the detailed description sets out specific structural and operational aspects, the scope of protection is governed by the claims and includes all legal equivalents of the claimed subject matter. Embodiments of

the disclosure are described in the following paragraphs with reference to Figures. In Figures, the same elements or elements that have the same functions are indicated by the same reference signs.

[0049] The present invention will now be described in detail with reference to the accompanying drawings illustrating exemplary embodiments.

[0050] FIG. 1 illustrates a method 100 for operating a medication dispenser device according to various embodiments. The method 100 comprises a sequence of steps for authenticating a user and verifying medication dispensed by the medication dispenser device.

[0051] The medication dispenser device 100 comprises a processing unit 10 configured to execute machine learning inference operations. The medication dispenser device 100 further comprises a first image capture device 20 configured to capture facial images of a user, and a second image capture device 30 configured to capture images of medication. The medication dispenser device 100 includes a storage medium 40 storing user identification data comprising face embeddings for enrolled users, user-medication assignment data associating each enrolled user with at least one prescribed medication, and a machine learning model trained to classify medications. The medication dispenser device 100 also comprises a dispensing mechanism 50 configured to release medication from the device.

[0052] The method 100 begins with a step 102, where a facial image of a user is captured using the first image capture device 20. The first image capture device 20 acquires a video stream or still image containing the face of the user positioned in front of the medication dispenser device 100.

[0053] The method 100 proceeds to a step 104, where a facial embedding is generated from the captured facial image. The processing unit 10 processes the captured facial image to extract a facial embedding, which is a numerical vector representation of the facial features of the user. The facial embedding is generated using a face recognition model that maps the facial image to a compact Euclidean space.

[0054] The method 100 continues to a step 106, where the user is authenticated by comparing the generated facial embedding against the stored face embeddings.

The processing unit 10 is configured to authenticate a user by comparing a facial embedding generated from a captured facial image against the stored face embeddings maintained in the storage medium 40. The authentication operation determines whether the generated facial embedding corresponds to an enrolled user.

[0055] Following successful authentication, the method 100 advances to a step 108, where medication assignment data for the authenticated user is retrieved from the storage medium 40. The processing unit 10 queries the user-medication assignment data to identify the medication prescribed to the authenticated user.

[0056] The method 100 then proceeds to a step 110, where the dispensing mechanism 50 is actuated to release medication assigned to the authenticated user. The processing unit 10 is configured to actuate the dispensing mechanism 50 to release medication assigned to the authenticated user. The dispensing mechanism 50 physically dispenses the prescribed medication into a dispensing area accessible to the user.

[0057] The method 100 continues to a step 112, where an image of the released medication is captured using the second image capture device 30. The second image capture device 30 acquires an image of the medication present in the dispensing area after actuation of the dispensing mechanism 50.

[0058] The method 100 advances to a step 114, where the released medication is classified by processing the captured medication image using the machine learning model stored on the storage medium 40. The processing unit 10 is configured to classify the released medication by processing a captured medication image using the machine learning model. The machine learning model is a quantized model having integer-format weights. The quantized model uses INT8 format and has a size of 627 KB, enabling deployment on resource-constrained edge devices.

[0059] The machine learning model is based on MobileNetV2 architecture with an alpha parameter of 0.35. The machine learning model has an input resolution of 224×224×3 pixels. The machine learning model is trained with ImageNet pre-trained weights using a two-phase transfer learning approach. In a first phase, head training is performed for 10 epochs with a learning rate of

1×10^{-3}. In a second phase, fine-tuning is performed for 30 epochs with a learning rate of 3×10^{-5}. A dropout rate of 0.5 is applied before the final classification layer to mitigate overfitting during training.

[0060] The method 100 concludes with a step 116, where the classified medication is verified to match the medication assigned to the authenticated user. The processing unit 10 is configured to verify that the classified medication matches the medication assigned to the authenticated user. The verification operation compares the classification output from the machine learning model against the medication assignment data retrieved for the authenticated user.

[0061] The authentication, classification, and verification are performed on-device without requiring external network connectivity. The processing unit 10 executes all machine learning inference operations locally using the models and data stored on the storage medium 40. This on-device processing ensures that the medication dispenser device 100 operates independently of cloud services or external servers, providing privacy-preserving operation and reliability in environments lacking internet infrastructure.

[0062] FIG. 2 illustrates a method 200 for operating a medication dispenser device according to various embodiments. The method 200 comprises a sequence of steps for authenticating a user and verifying medication prior to dispensing.

[0063] The method 200 begins with a step 202, where a captured facial image is processed to generate a facial embedding. The processing unit 10 receives the captured facial image from the first image capture device 20 and extracts a numerical vector representation of the facial features contained in the image. The facial embedding generation uses a face recognition model that maps the facial image to a compact Euclidean space where distances correspond to face similarity.

[0064] The method 200 proceeds to a step 204, where the generated facial embedding is compared against stored face embeddings. The processing unit 10 retrieves the stored face embeddings from the storage medium 40 and performs a comparison operation between the generated facial embedding and each of the stored face embeddings.

[0065] The method 200 continues to a step 206, where the user is authenticated based on the comparison result. The processing unit 10 determines whether the comparison result indicates a match between the generated facial embedding and one of the stored face embeddings. When the comparison result indicates a match, the user is authenticated and the method 200 proceeds to subsequent steps.

[0066] Following successful authentication, the method 200 advances to a step 208, where medication assignment data for the authenticated user is retrieved. The processing unit 10 queries the user-medication assignment data stored on the storage medium 40 to identify the medication prescribed to the authenticated user.

[0067] The method 200 then proceeds to a step 210, where a machine learning model is executed to classify a captured medication image. The processing unit 10 executes the machine learning model stored on the storage medium 40 to process an image of medication captured by the second image capture device 30. The machine learning model comprises a temperature scaling calibration layer configured to adjust output logits by a temperature parameter to produce calibrated probability scores. The temperature parameter T is loaded from a T_val.json configuration file with a value of 0.334. The temperature scaling calibration layer divides the raw output logits by the temperature parameter T before applying a softmax function, producing calibrated probability scores that correlate with the empirical accuracy of predictions.

[0068] The method 200 includes preprocessing pill images prior to classification. The preprocessing pipeline resizes raw BGR images from 640×480 resolution to the model's native input resolution using INTER_AREA interpolation to preserve edge details. The preprocessing pipeline further applies mobilenet style normalization that scales pixel values to the range [-1,1] via the formula $\text{pixel} = (\text{pixel}/127.5) - 1.0$. The classification achieves mean inference time of 2.97 milliseconds on CPU. The classification requires calibrated confidence scores above 85% under variable lighting conditions.

[0069] The method 200 subsequently proceeds to a step 212, where the classified medication is verified to match the medication assigned to the authenticated user. The processing unit 10 compares the classification output from

the machine learning model against the medication assignment data retrieved for the authenticated user. The verification operation determines whether the classified medication corresponds to the prescribed medication.

[0070] The method 200 concludes with a step 214, where a control signal is generated based on the verification result. The processing unit 10 generates a control signal that indicates whether the verification was successful or unsuccessful. The control signal is used to control subsequent operations of the medication dispenser device 100, such as logging the verification result or generating an error indication.

[0071] A non-transitory computer-readable medium stores instructions that, when executed by the processing unit 10 of the medication dispenser device 100, cause the processing unit 10 to perform operations comprising: processing a captured facial image to generate a facial embedding; comparing the generated facial embedding against stored face embeddings to authenticate a user; retrieving medication assignment data associated with the authenticated user; executing a machine learning model to classify a captured image of medication released by the dispensing mechanism 50 of the medication dispenser device 100; verifying that the classified medication matches the medication assigned to the authenticated user; and generating a control signal based on the verification result.

[0072] The operations stored on the non-transitory computer-readable medium further comprise applying temperature scaling calibration to output values of the machine learning model to produce calibrated confidence scores prior to classifying the medication. The temperature scaling calibration adjusts the output logits by dividing by the temperature parameter T=0.334 to produce calibrated probability scores that reflect the true likelihood of prediction correctness.

[0073] FIG. 3 illustrates a method 300 for operating a medication dispenser device according to various embodiments. The method 300 comprises a sequence of steps for authenticating a user based on facial recognition and subsequently dispensing and verifying medication.

[0074] The method 300 begins with a step 302, where a facial image of a user is captured using the first image capture device 20. The first image capture device

20 acquires a video stream containing the face of the user positioned in front of the medication dispenser device 100.

[0075] The method 300 proceeds to a step 304, where a facial embedding is generated from the captured facial image. The processing unit 10 processes the captured facial image to extract a 128-dimensional embedding vector representing the facial features of the user. The facial embedding generation uses MobileFaceNet architecture, which is a convolutional neural network optimized for mobile inference. MobileFaceNet maps the facial image to a compact Euclidean space where distances correspond to face similarity. The processing unit 10 uses MediaPipe for face detection to localize the face within the video frame and crop the region of interest prior to embedding generation.

[0076] The method 300 continues to a step 306, where a cosine similarity score is computed by comparing the generated facial embedding against stored embeddings. The processing unit 10 retrieves the stored face embeddings from the storage medium 40 and computes a cosine similarity score between the generated facial embedding and each of the stored face embeddings. The cosine similarity score is calculated using the formula $\frac{A \cdot B}{\|A\| \cdot \|B\|}$, where A represents the generated facial embedding and B represents a stored face embedding.

[0077] The method 300 reaches a step 308, which represents a decision point that determines whether the similarity score exceeds an authentication threshold. The processing unit 10 determines that the user is authenticated when the cosine similarity score exceeds a predetermined authentication threshold. The predetermined authentication threshold is set to 0.4 for determining a match between live embeddings and stored templates. The authentication achieves accuracy exceeding 90% with a false acceptance rate of 5% or less. The authentication latency is less than 200 milliseconds.

[0078] If the similarity score exceeds the authentication threshold (Yes branch), the method 300 proceeds to a step 310, where medication assignment data is retrieved for the authenticated user and the dispensing mechanism 50 is actuated to release the assigned medication. The processing unit 10 queries the user-medication assignment data stored on the storage medium 40 to identify the

medication prescribed to the authenticated user. The processing unit 10 then actuates the dispensing mechanism 50 to physically dispense the prescribed medication into a dispensing area accessible to the user.

[0079] If the similarity score does not exceed the authentication threshold (No branch), the method 300 proceeds to a step 312, where access is denied and an authentication failure is displayed to the user. The processing unit 10 generates an error indication and prevents actuation of the dispensing mechanism 50.

[0080] Following successful authentication and dispensing at step 310, the method 300 continues to a step 314, where the released medication is classified and verified to confirm that the released medication matches the medication assigned to the authenticated user. The processing unit 10 captures an image of the released medication using the second image capture device 30, classifies the medication using the machine learning model, and verifies that the classified medication corresponds to the prescribed medication.

[0081] The method 300 includes a user enrollment phase where the system captures multiple distinct frames of the user's face and computes a 128-dimensional embedding vector for storage rather than storing raw images. During enrollment, the system captures 5 distinct frames of the user's face to generate face embeddings. The face embeddings are stored locally in pickle format, and user-pill assignments are maintained in JSON format. This storage approach enables dynamic configuration without database servers while ensuring privacy-preserving verification.

[0082] The method 300 includes saving debug frames during enrollment and authentication for system auditing and performance analysis. The debug frames provide a record of the facial images processed during each authentication attempt, enabling review and troubleshooting of the authentication system.

[0083] The method 300 includes automatic detection of rpicam-still or libcamera-jpeg tools to ensure cross-platform compatibility across Raspberry Pi variants. The processing unit 10 detects which camera capture tool is available on the system and configures the first image capture device 20 accordingly, enabling deployment on different hardware configurations without manual reconfiguration.

[0084] FIG. 4 illustrates a method 400 for operating a medication dispenser device according to various embodiments. The method 400 comprises a sequence of steps for authenticating a user, dispensing medication, and verifying that the correct medication has been released with appropriate logging of verification outcomes.

[0085] The method 400 begins with a step 402, where the processing unit 10 authenticates a user via facial recognition. The authentication at step 402 proceeds as described previously with respect to the method 100, the method 200, and the method 300, where the processing unit 10 captures a facial image using the first image capture device 20, generates a facial embedding, and compares the generated facial embedding against stored face embeddings to authenticate the user.

[0086] Following successful authentication, the method 400 proceeds to a step 404, where medication assigned to the authenticated user is dispensed. The dispensing mechanism 50 comprises at least one servo motor 52. The processing unit 10 is configured to control the at least one servo motor 52 via pulse-width modulation signals to release medication from a corresponding medication container 54. The pulse-width modulation signals are in the range of 500-2500 microseconds to control servo positioning. The processing unit 10 controls the at least one servo motor 52 to achieve 45 degree rotation for pill release. The dispensing mechanism 50 achieves 95% success rate over 100 consecutive dispensing cycles.

[0087] The method 400 then moves to a step 406, where the released medication image is captured and classified using a machine learning model. The second image capture device 30 is positioned at a fixed working distance of 10 cm from the medication. Internal surfaces of a verification chamber are painted matte black to reduce reflections. The processing unit 10 executes the machine learning model stored on the storage medium 40 to classify the captured medication image.

[0088] The method 400 continues to a step 408, which represents a decision point where the processing unit 10 determines whether the classified medication matches the medication assigned to the authenticated user. The processing unit 10 is configured to compare a confidence score associated with the classified

medication against a predetermined confidence threshold. The predetermined confidence threshold is set to 0.45, achieving 100% accuracy on accepted predictions while retaining 88% coverage of the test set. The processing unit 10 is configured to generate an error indication when the confidence score is below the predetermined confidence threshold.

[0089] If the classified medication matches the assigned medication (Yes branch), the method 400 proceeds to a step 410, where a successful verification result is logged. The method 400 includes logging a verification result indicating whether the classified medication matches the medication assigned to the authenticated user. The processing unit 10 records the successful verification in a transaction log stored on the storage medium 40.

[0090] If the classified medication does not match the assigned medication (No branch), the method 400 proceeds to a step 412, where a failed verification result is logged and an error indication is generated. The processing unit 10 records the failed verification in the transaction log and generates an error indication to alert the user or a caregiver of the mismatch between the dispensed medication and the prescribed medication.

[0091] End-to-end operation from facial detection to servo actuation and AI verification completes within 5 seconds on a Raspberry Pi 4 platform. This latency performance enables real-time operation of the medication dispenser device 100 for practical medication adherence applications.

[0092] FIG. 5 illustrates a confusion matrix displaying raw prediction counts for a four-class pill classification system according to various embodiments. The confusion matrix evaluates classifier performance across four medication categories: Aspirin, Cetirizine, Ibuprofen, and Paracetamol. True labels are arranged along the vertical axis and predicted labels are arranged along the horizontal axis. The step of classifying the released medication classifies medications into the four classes: Aspirin, Cetirizine, Ibuprofen, and Paracetamol.

[0093] The confusion matrix displays prediction counts for each combination of true label and predicted label. For Aspirin, the classifier achieves correct classification with all 15 samples correctly identified and zero misclassifications to

other categories. Cetirizine shows 12 correct predictions, with 1 sample misclassified as Aspirin and 2 samples misclassified as Paracetamol. Ibuprofen demonstrates 14 correct classifications with 1 sample incorrectly predicted as Paracetamol. Paracetamol achieves 14 correct predictions with 1 sample misclassified as Cetirizine. The diagonal elements representing correct classifications display higher count values, indicating the model's discriminative capability across the four medication classes.

[0094] FIG. 6 illustrates a normalized confusion matrix showing percentage distributions according to various embodiments. The normalized confusion matrix displays percentage values indicating the proportion of predictions for each true label category. Aspirin demonstrates 100.0% correct classification, showing no confusion with other pill classes. Cetirizine exhibits 80.0% correct classification, with 6.7% of samples misclassified as Aspirin and 13.3% misclassified as Paracetamol. Ibuprofen achieves 93.3% correct classification accuracy, with 6.7% of samples incorrectly predicted as Paracetamol. Paracetamol attains 93.3% correct classification, with 6.7% of samples erroneously classified as Cetirizine. The diagonal pattern of higher percentage values confirms strong overall classification performance of the quantized machine learning model deployed on the processing unit 10 for medication verification.

[0095] FIG. 7 illustrates reliability diagrams for each pill class according to various embodiments. The reliability diagrams comprise four diagrams arranged in a grid, each corresponding to one of the four pill classes: Aspirin, Cetirizine, Ibuprofen, and Paracetamol. Each diagram plots Fraction of Positives on the vertical axis against Mean Predicted Probability on the horizontal axis, with both axes ranging from 0.0 to 1.0. A diagonal dashed line in each diagram represents perfect calibration, indicating the ideal scenario where predicted probabilities exactly match the observed frequencies of correct predictions.

[0096] The reliability diagram for Aspirin shows an Expected Calibration Error (ECE) of 0.109. The reliability diagram for Cetirizine shows an ECE of 0.110. The reliability diagram for Ibuprofen shows an ECE of 0.123. The reliability diagram for Paracetamol shows an ECE of 0.101. The ECE values quantify the

deviation between predicted confidence scores and actual accuracy, with lower values indicating better calibration. Paracetamol achieves the best calibration among the four classes, and Ibuprofen shows the largest deviation from perfect calibration. The calibration curves demonstrate that the temperature-scaled classification model exhibits reasonable calibration across all four pill classes, validating the trustworthiness of the confidence scores produced by the on-device pill verification system.

[0097] The dataset used for training and evaluating the machine learning model comprises 400 images with 100 images per pill class. The dataset is partitioned into 69% training (276 images), 16% validation (64 images), and 15% test (60 images) sets with balanced class distribution across the four medication categories. Data augmentation techniques are applied to enhance model robustness against variations encountered during operation of the medication dispenser device 100. The data augmentation techniques include rotation, brightness adjustment, contrast variation, and noise injection. The rotation augmentation improves robustness to different pill orientations in the dispensing area. The brightness adjustment and contrast variation augmentations improve robustness to lighting variations in the verification chamber. The noise injection augmentation improves robustness to image noise introduced by the second image capture device 30.

[0098] There are several technical advantages of the medication dispenser device of the present disclosure. First, the integration of on-device facial recognition with on-device medication classification enables the device to verify that the correct medication is dispensed to the correct user without requiring external network connectivity, thereby eliminating privacy vulnerabilities associated with cloud-dependent architectures and ensuring reliable operation in environments with limited or unreliable internet infrastructure. Second, the use of a quantized machine learning model with integer-format weights reduces the memory footprint and computational requirements, enabling efficient execution on resource-constrained embedded processing units without requiring dedicated hardware accelerators, while achieving mean inference time of 2.97 milliseconds on CPU. Third, the temperature scaling calibration layer produces confidence

scores that more accurately reflect the true probability of correct classification, enabling the device to distinguish between high-confidence predictions that can be trusted and low-confidence predictions that may require additional verification or manual intervention, which is particularly beneficial in safety-sensitive medication dispensing applications. Fourth, the dual-camera architecture with separate image capture devices for facial authentication and medication verification enables independent optimization of each verification pathway, with the first image capture device positioned for user interaction and the second image capture device positioned at a fixed working distance within a controlled verification chamber. Fifth, the servo motor controlled via pulse-width modulation signals enables precise mechanical actuation of the dispensing mechanism with repeatable positioning accuracy, achieving 95% success rate over 100 consecutive dispensing cycles. Sixth, the local storage of face embeddings and medication assignment data in pickle and JSON formats respectively enables dynamic configuration without database servers while ensuring privacy-preserving verification where zero data transmission to external servers occurs during operation. These technical advantages collectively contribute to a medication dispensing solution that addresses the safety gap in existing systems where medication correctness is not validated prior to delivery, while providing reliable operation suitable for privacy-sensitive and offline scenarios.

[0099] It will be appreciated that the above-detailed description, along with FIGs, is provided to illustrate the architecture and operation of exemplary embodiments of the present invention. Various modifications and enhancements can be made without departing from the scope of the invention. All such variations, as would be recognized by those skilled in the art, are intended to be within the scope of the present disclosure, which is defined by the claims that follow.

[0100] It will be appreciated by persons skilled in the art that while the invention has been described with reference to specific embodiments and accompanying drawings, numerous modifications, substitutions, variations, and equivalents are possible without departing from the spirit or scope of the present invention. The use of singular terms such as “a,” “an,” and “the” is not intended to

limit the disclosed elements to a single instance unless explicitly stated, and such terms should be interpreted to include plural forms as applicable. Likewise, the terms “comprises,” “comprising,” “includes,” “including,” “has,” “having,” and their grammatical variants are intended to be open-ended and non-limiting, and should be interpreted as meaning “including but not limited to.” Any enumerated listing of components, features, or elements does not imply that the items are mutually exclusive unless expressly stated.

[0101] It is further understood that where features, characteristics, or elements are described in connection with a Markush group or a disjunctive phrase (e.g., “A or B”), the invention includes all possible combinations and sub-combinations thereof unless explicitly excluded. Thus, a statement referring to “at least one of A, B, and C” should be interpreted to mean any one or more of A, B, and C, individually or in any combination. The language used in this specification is selected primarily for clarity and illustrative purposes and should not be construed to limit the inventive scope unless specifically recited in the claims. Accordingly, the foregoing description of embodiments should be regarded as illustrative and not restrictive, with the scope of the invention being defined solely by the appended claims and their legal equivalents

[0102] It will be recognized that various features, elements, and combinations thereof described herein may be desirably adapted for alternative implementations or other applications. Many such modifications, substitutions, enhancements, or equivalents may become apparent to those skilled in the art upon reading this disclosure and are considered to fall within the scope and spirit of the present invention. The invention is not limited to the precise configurations or exemplary embodiments set forth in this specification, and various alternatives may be used without departing from the intended objectives. The claims, and not the detailed description, shall define the legal scope of protection afforded by the present disclosure.

[0103] In interpreting the specification and claims, all terms should be construed in the broadest reasonable manner consistent with the context and the understanding of those skilled in the art. The use of terms such as “comprises,”

"comprising," "includes," "including," or "has" should be interpreted to be non-exclusive and not limited to the stated elements alone. Moreover, references to "one embodiment," "an embodiment," or "in certain embodiments" are not meant to imply that such features are required or exclusive, and any feature described in connection with one embodiment may be used in combination with other features or embodiments unless clearly prohibited or contextually inconsistent.

[0104] It should be further appreciated that reference throughout the specification to features, operations, or components using singular terms should not be construed as excluding a plurality thereof unless the context expressly indicates otherwise. Similarly, features described in the context of grouped or listed elements (e.g., A, B, and C) should be understood to encompass individual, multiple, or all combinations of said elements. Where ranges are given, all intermediate values and subranges are understood to be disclosed as if specifically recited. The scope of the invention should therefore be construed as inclusive of all such combinations and logical extensions as would be appreciated by a person of ordinary skill in the relevant technical field

[0105] In another embodiment, the above disclosure is a description of the invention and is not intended to limit the scope of the invention. Other variations and modifications of the above-described embodiment shall be apparent to those skilled in the art and are intended to fall within the scope of the invention as defined in the following claims.

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CLAIMS

WE CLAIM:

1. A medication dispenser device (100) comprising:

a processing unit (10) configured to execute machine learning inference operations;

a first image capture device (20) configured to capture facial images of a user;

a second image capture device (30) configured to capture images of medication;

a storage medium (40) storing:

user identification data comprising face embeddings for enrolled users,

user-medication assignment data associating each enrolled user with at least one prescribed medication, and

a machine learning model trained to classify medications;

a dispensing mechanism (50) configured to release medication from the device;

wherein the processing unit (10) is configured to:

authenticate a user by comparing a facial embedding generated from a captured facial image against the stored face embeddings,

actuate the dispensing mechanism (50) to release medication assigned to the authenticated user,

classify the released medication by processing a captured medication image using the machine learning model, and

verify that the classified medication matches the medication assigned to the authenticated user; and

wherein the authentication, classification, and verification are performed on-device without requiring external network connectivity.

2. The medication dispenser device (100) of claim 1, wherein the machine learning model comprises a temperature scaling calibration layer configured to adjust output logits by a temperature parameter to produce calibrated probability scores.

3. The medication dispenser device (100) of claims 1 or 2, wherein the machine learning model is a quantized model having integer-format weights.

4. The medication dispenser device (100) of any of claims 1 to 3, wherein the dispensing mechanism (50) comprises at least one servo motor (52), and wherein the processing unit (10) is configured to control the at least one servo motor (52) via pulse-width modulation signals to release medication from a corresponding medication container (54).

5. The medication dispenser device (100) of any of claims 1 to 4, wherein the processing unit (10) is further configured to compare a confidence score associated with the classified medication against a predetermined confidence threshold, and to generate an error indication when the confidence score is below the predetermined confidence threshold.

6. A method of operating the medication dispenser device (100) of any of claims 1 to 5, the method comprising:

capturing a facial image of a user using the first image capture device (20);

generating a facial embedding from the captured facial image;

authenticating the user by comparing the generated facial embedding against the stored face embeddings;

retrieving medication assignment data for the authenticated user from the storage medium (40);

actuating the dispensing mechanism (50) to release medication assigned to the authenticated user;

capturing an image of the released medication using the second image capture device (30);

classifying the released medication by processing the captured medication image using the machine learning model stored on the storage medium (40); and

verifying that the classified medication matches the medication assigned to the authenticated user.

7. The method of claim 6, wherein authenticating the user comprises computing a cosine similarity score between the generated facial embedding and

each of the stored face embeddings, and determining that the user is authenticated when the cosine similarity score exceeds a predetermined authentication threshold.

8. The method of claims 6 or 7, further comprising logging a verification result indicating whether the classified medication matches the medication assigned to the authenticated user.

9. A non-transitory computer-readable medium storing instructions that, when executed by a processing unit (10) of a medication dispenser device (100), cause the processing unit (10) to perform operations comprising:

processing a captured facial image to generate a facial embedding;

comparing the generated facial embedding against stored face embeddings to authenticate a user;

retrieving medication assignment data associated with the authenticated user;

executing a machine learning model to classify a captured image of medication released by a dispensing mechanism (50) of the medication dispenser device (100);

verifying that the classified medication matches the medication assigned to the authenticated user; and

generating a control signal based on the verification result.

10. The non-transitory computer-readable medium of claim 9, wherein the operations further comprise applying temperature scaling calibration to output values of the machine learning model to produce calibrated confidence scores prior to classifying the medication.

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ABSTRACT

MEDICATION DISPENSER WITH ON-DEVICE USER AUTHENTICATION AND MEDICATION VERIFICATION

A medication dispenser device (100) includes a processing unit (10) configured to execute machine learning inference operations, a first image capture device (20) configured to capture facial images, a second image capture device (30) configured to capture medication images, a storage medium (40) storing face embeddings for enrolled users, user-medication assignment data, and a machine learning model trained to classify medications, and a dispensing mechanism (50). The processing unit (10) authenticates a user by comparing a facial embedding from a captured image against stored embeddings, actuates the dispensing mechanism (50) to release medication assigned to the authenticated user, classifies the released medication using the machine learning model, and verifies that the classified medication matches the assigned medication. Authentication, classification, and verification are performed on-device without external network connectivity.

(FIG. 1)

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