Week 8: Elderly Care 2.0 User Acceptance Test Plan

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# Elderly Care 2.0

Senior citizens live longer than ever and want to defer moving into nursing homes until later in life. This constructive research project examines industry trends and expands into the next iteration.

## Problem Statement

Senior citizens live longer than ever and want to defer moving into nursing homes until later in life. Transitioning into elderly care comes as a double edge sword. On the one hand, nurses can provide 24-hour care. This assistance could mean the difference between life and death (e.g., during a fall). However, on the other hand, the services are prohibitively expensive, nearing $90,000 annually (Tan et al., 2020). Additionally, these medical facilities lack the personalization available within one’s home. Further, specific individuals with diseases like dementia and Alzheimer’s require even greater levels of attention.

Traditionally, addressing the situation requires increasing human capital, such as adding more traveling nurses or family member oversight. However, this solution increases health care costs and collects limited patient health samples. In addition, these infrequent visits might miss critical issues, especially with those most reluctant to relocate. Alternatively, researchers are exploring wearable IoT devices. These sensors provide mechanisms for requesting assistance and receiving continuous monitoring. However, there are many limitations to wearable solutions. Most notably, the person must remember to wear them, which raises challenges for early-onset memory loss patients.

## Building the Business Case

Many senior citizens want to remain in their homes and still receive the attentiveness typically found in assisted living facilities (Tan et al., 2020). When this gap narrows, it enables the patient to remain in familiar settings for more prolonged periods. That situation has numerous benefits, both psychologically (e.g., higher morale) and economically (e.g., deferring private health care costs). Medical facilities can address these challenges through real-time video monitoring services that analyze patient actions and recommend care. For instance, patients with memory impairment might forget to empty the dishwasher, take medication, or bathe regularly. These scenarios are challenging to address through wearable devices. However, through computer vision, an in-home camera system transforms into a watchful eye that spots those missing actions. After detecting an issue, the system alerts the person using Text-to-Speech (TTS) services (e.g., Amazon Alexa or Google Home).

Medical facilities also benefit from massive deployments of in-home monitoring systems. First, the in-home camera system tracks patient movements enabling early behavioral regression detection (e.g., reduced mobility). Next, centralized teams can provide higher-quality care to more remote patients. This configuration increases profit margins by reducing operational overhead (e.g., excess staff and fewer physical beds). Finally, when patient care issues arise, the system can prioritize and audit its resolution. The business can leverage this competitive position to avoid cutting corners and providing world-class care.

Additionally, having the option to remain in-home expands the caregiver’s addressable market. These populations include healthy widows, lower-income families, and even younger children with disabilities. While adult children might stress over putting their mother in a facility, they are more willing to pay for a low-expense monthly service. Lower-income households cannot afford private health care and at the mercy of public options. Likewise, special education children need additional oversight, not removal from the home. The family in each situation gains peace of mind and improves their quality of life.

# Literature Review

## Just Walk-Out (2018)

Amazon Go enables customers to purchase goods from physical stores without requiring cashiers (Amazon, 2021). Their solution uses Deep Neural Network (DNN) algorithms that process real-time video streams. Wankdhede et al. (2018) assessed the system’s sophistication through a series of shoplifting test cases. Their malicious attempts to steal items failed, which provides evidence that real-time video monitoring is an effective real-world tool. However, before engineers can transpose the solution directly into a person’s home, several critical changes are necessary.

## Consumer RGB-D Cameras and Applications (2012)

Action tracking systems require sophisticated machine learning algorithms that classify spatiotemporally movements. They typically follow a process that collects RGB+D (Color and Depth) camera frames and decodes them into 3-D space (Litomisky, 2012). Next, a series of filters must crop, resize, and align the principal subject. This step is necessary because people can freely move around the room. Third, a feature extract process outputs matrices representing the body’s location, pose, and orientation. Finally, those tensors flow into Long-Term Short-Term (LTSM) algorithms that classify the movement into gestures.

## Toyota Smarthome (2019)

Many general-purpose gesture detection libraries already exist for behaviors such as sporting events other high-energy actions. However, daily indoor activity tends to be more subtle and nuanced (Das et al., 2019). This discrepancy limits reusability and creates the need for purpose-built training sets that sufficiently cover patient-specific actions. These custom datasets necessitate vast quantities of examples with accurate labels, or the machine learning model will produce unreliable results. As a general thumb rule, each model parameter needs at least ten examples to avoid overfitting (Snee, 2015). Mechanisms exist for accelerating the process of building custom datasets (e.g., transfer learning). However, this is still an open research topic.

## Integration of SmartHome (2020)

After the system decodes the subject’s actions, it needs to act upon that information. While some responses are relatively trivial (e.g., dispatch an ambulance), other reactions must utilize Cyber-Physical Systems (CPS) to cross the digital boundary. Building these integrations is challenging as it draws upon knowledge spanning networking, sensors, embedded systems, and related concepts. Further, CPS devices lack standardization which impacts component reusability.

Elloumi et al. (2020) propose a Smarthouse Operating System (SOS) that provides core services such as identity management, system state, and message routing. Their blueprint also outlines several automation application profiles (e.g., heat management and fire detection). These capabilities enable developers to focus on their integrations value differentiation versus writing tedious generic code. The authors demonstrate the effectiveness of this approach using a CNC (Computer Numerical Control) machine to print a replica house (2 cubic feet).

## Privacy Enhanced Cloud-Based Facial Recognition (2021)

It can be helpful to think of identity within IoT as a profile of historical choices, stated preferences, user roles, and known associations (Wachter, 2018). When the device understands the user’s profile, the experience can be customized and produce more accurate predictions. However, t payment for access to these inferences and decision processes comes from personal information, such as calendars, contacts, and routines (Mickens, 2018). This trade creates privacy concerns that can be subtle and can go unnoticed for some time.

The monitoring system will collect intimate knowledge of its assigned patients and even capture private communications. Therefore, mechanisms must exist for protecting this information as it flows between different compute domains (e.g., local versus cloud providers). Yang et al. (2021) propose a Secure MultiParty Computation (SMC) model that locally encrypts sensitive images (e.g., faces). Afterward, they use Cheon-Kim-Kim-Song Homomorphic Encryption (CKKS HE) to predict details about the protected payload (e.g., Bob’s face). These efforts suggest that the system minimize the amount of information that must leave the patient’s private network.

## Healthcare Monitoring using IoT (2020)

Software that takes advantage of cloud resources gains agility, elasticity, instantaneous provisioning, and cost management constructs. However, some businesses are reluctant to trust these environments entirely due to security concerns (Ali et al., 2015). Alternatively, systems engineers can deploy hardware appliances that bring cloud aspects into the home or medical facility. For example, Abdulameer et al. (2020) propose implementing a small replica house similar to Elloumi. This solution uses various wearable device sensors, Arduino micro-controllers, and one Raspberry-PI. In addition, users can check their vitals and other health KPIs (Key Performance Indicators) through a web portal.

Provisioning small on-premise appliance makes sense and handles scenarios such as failures at the ISP (Internet Service Provider). In addition, some benefits come from standardizing the control-plane versus assuming the patient’s computer is compatible with the proposed monitoring system.

## Two-Way Video Healthcare System Design (2021)

Recently, Yi & Feng (2021) proposed a complete video-based injury rehabilitation solution that includes support for CPS and wearables. The authors leverage Carnegie Mellon University’s Open Pose library to map skeletal structures within images. Then, they publish this information and various sensor readings (e.g., smoke detectors) into a secure private cloud. Unlike Toyota (2019), the authors use Dynamic Time Warping (DTW) to compare and categorize the patient’s movements. Researchers use DTW to normalize time series and avoid discrepancies from action speeds (e.g., raising one’s hand within two versus four seconds).

# Examining the Competitive Landscape

Abdulameer et al.’s (2020) design fixate on collecting metadata from wearable IoT devices. Tun et al. (2021) surveyed fifty-five recent publications that discuss IoT use cases within elderly care. Their findings suggest that nearly all search focuses on wearable devices, mobility, and Personal Digital Assistants (PDA). Researchers focusing on these areas makes sense due to the low barrier to entry. Compare the effort necessary to clone a FITBIT mobile app versus transform 2-D images into spatiotemporal movements. Another set of challenges originate from insufficient training data. Aside from Toyota’s (2019) open-sourced data set, few repositories (e.g., YouTube) contain appropriate training data. Lastly, numerous areas across health care are improvable on a $25 RadioShake budget.

In contrast, video-centric systems are still novel inventions and full of green-field opportunities. Therefore, there need to be new approaches that simplify the technology requirements, promote extensibility, and maintain customer privacy. While each Lego block exists today, they are standalone components, not a holistic solution. Researchers need to mitigate this issue by building a purpose-built Elderly Care SOS (ECSOS).

# Artifacts and Contributions

Constructive design is one of the most common research methods for information systems and technology (Silvestrini & Sammito, 2012). These studies identify a problem, build solution artifacts, and communicate the implementation’s unique value (Hevner et al., 2004). In addition, many researchers follow this process to build proofs-of-concept and execute case studies. Therefore, this methodology is appropriate for examining the effectiveness of the ECSOS solution and its abilities to improve elderly care.

## Artifacts

This research project has three core components which collectively form a proof-of-concept implementation and mechanism to measure results.

First, the team installs WiFi-enabled Eufycam 2C cameras to collect short recordings. These cameras use motion-sensing to trigger short Audio/Video (A/V) recordings (fifteen to sixty seconds). After the filming completes, its controller (Eufy Homebase) automatically uploads the file to Network Attached Storage (NAS). The file creation event triggers an analysis workflow that extracts and publishes metadata to message buses. Developers can author extensions using Function as a Service (FaaS) constructs that subscribe to the notifications.

Second, a machine learning algorithm will classify and annotate the behavior. There are several potential implementations (e.g., Open Pose versus Toyota’s approach). The performance and resource requirements between these strategies must exist. Ideally, the model can run in an edge appliance versus uploading into a Public Cloud Service (PCS). However, this raises concerns that the device has sufficient computing capabilities (e.g., parallel processing dozens of cameras). If analysis occurs within PCS, then it introduces security and privacy concerns. The artificial intelligence algorithm would require additional complexity to address these risks (e.g., supporting CKKS HE encryption).

Third, the ECSOS solution routes the metadata into monitoring and response extensions. These extensions include central services (e.g., identity and state management) and auditing capabilities (e.g., inputs, predictions, and recommendations). One crucial extension is the central audit log. These tables are queryable within a NoSQL time-series database (e.g., Influx). This technology provides two essential capabilities, native support for tracking system performance across time and Schema-at-Read versus Schema-at-Write (SAR versus SAW) semantics. Datastores that support SAR are more flexible and can quickly adapt to future enhancements (e.g., extending data contracts).

## Contributions

The core contribution to the body of knowledge is the case study using the proof-of-concept design. Existing research reviews each component in a silo or distinctly different use cases (e.g., sports injuries). Das et al. (2019) explain that those resources are not directly reusable, and implementations must use domain-specific labeled content. This design requirement necessitates compositing a new solution from custom and open-source software.

Second, the research produces a purpose-built machine learning algorithm made available for elderly care action recognition. This deliverable also includes quantitative metrics that describe the algorithm’s resource utilization and F-measure accuracy. Data scientists use F-measurements as a “way of combining the precision and recall of the model, and [defines] the harmonic mean of the model’s precision and recall (Wood, n.d.).” Researchers can trade-off in their solution to optimize this value for their specific scenario. For instance, a critical health extension system might enforce higher penalties on false negatives over positives.

# User Acceptance Test Plan

## Addresses Business Case

The system’s primary purpose is to increase the patients’ quality of life by remaining within their residency longer. Therefore, this mission statement obliges the solution to detect human activity and respond reliably. Also, patients will only use a continuous video recording solution if they trust its security and privacy controls. There must be explicit and deliberate decisions regarding how information is stored or transferred.

## System Architecture

Elderly Care SOS requires cameras, network storage, and a custom-built appliance (see Figure 1). Optionally patients can extend the system with various CPS device integrations (e.g., remote smoke detector). The appliance must have enough computing and storage resources to perform model predictions, persist state, and execute several micro-services. Periodically, the on-premise system needs to synchronize with an external cloud component. These operations include sending status reports, downloading updates, and issuing assistance requests.

Figure 1: Abstract Design

Diagram

Description automatically generated

There are three external user persona’s that require patient information: nurses and healthcare providers, family members, and administrators. These users can use a mobile app or web portal to access the relevant data. All operations from either UI (User Interface) require Authentication, Authorization, and Auditing (AAA). When systems mandate AAA enforcement, it prevents negligence or malicious actions while increasing transparency. It is also critical that the patient maintains control of their privacy. For example, they might want to share a weekly aggregate health report with family members, not verbose details.

## Reliability and Validity

## Security and Integrity