Chapter 3: Research Method

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Like other projects, a high-quality research effort begins with a well-defined plan and stated outcomes. This chapter aims to meet these requirements by detailing the research methodology and its appropriateness. Next, it documents mechanisms for collecting data and analyzing that information. The chapter concludes by enumerating known assumptions, limitations, delimitations, and ethical assurances.

## Statement of the Problem

The problem to be addressed in this study is implementing a quality assurance process for an autonomous assistant to elderly and special needs care. Multiple industry-wide trends create the need for this technology. First, the number of practicing nurses has declined for several years (Kim & Kim, 2021). This labor shortage increases hiring and employee retention costs that the patients and welfare programs must cover. The funding gap is a global problem that does not impact all communities equally. For instance, in South Africa, rural special needs communities have 57% fewer nursing visits than their urban neighbors (Besada, 2020). Newly industrialized economies like Taiwan, South Korea, Thailand, and Malaysia are experiencing challenges maintaining their long-term care programs due to growing costs (Phua, 2021). Domestic programs like Veterans Health Administration (VHA) and Medicare are not immune to these economic limits (Lei et al., 2021). Businesses and governments must control these costs and replace human labor with less expensive automation.

Implementing and verifying those processes comes with a high barrier to entry, precisely due to personal privacy concerns, logistical complexity, ethical & cultural considerations, and procurement & configuration overhead. For example, a recent study shows that 95% of Pakistani versus 50% of New Zealand patients refuse to share a severe medical concern outside their primary care physician (Shirazi & Shekhani, 2021). Researchers create frameworks to mitigate these privacy concerns (e.g., redaction), though these procedures are challenging in practice (Blackhurn, 2021). Beyond human and process issues are technical complexities in configuring prototype autonomous assistants. It requires multiple domain specializations like computer networking, embedded technologies, AI/ML, and distributed computing (Tun, Madanian, & Mirza, 2021). Each cross-cutting concern adds complexity and reduces the probability that small teams can successfully provision their test environment. Furthermore, those difficulties limit other researchers from reproducing the results. These factors slow innovation and restrict the value researchers can contribute to the body of knowledge.

## Purpose of the Study

This constructive research design study aims to propose a research process that divorces privacy and safety concerns from investigating autonomous assistants in elderly and special needs care. It aims to deliver this capability by utilizing humanoid constructs within a realistic physics simulation process like PhysX or Gazebo (Bipin, 2018; Unreal, 2021). These engines support replaying specific MoCAP human behaviors under varying character properties such as weight, flexibility, and dexterity. Next, positioning virtual cameras, instruments, and devices within the virtual world enables researchers to collect their experimentation data. Lastly, the automation can modify the environment using programmable interfaces such as raising the alarm or applying other mitigations.

Hemodialysis (HD) patients have a high risk of falling and becoming injured (Shirai et al., 2021). This situation negatively impacts their quality of life by either remaining in bed or requiring more medical resources. The study explores this use case by virtualizing the HD patients and monitoring them with an AI/ML CV process to collect metadata and predict a fall in advance. Human trials prioritize safety, creating challenges to study metadata properties like floor slickness and character overexertion (Aihara et al., 2021). In contrast, humanoids are well-suited for these experiments. Furthermore, the lack of privacy concerns simplifies the video collection in bathrooms and showers.

Robot operating systems (ROS) and similar toolchains support generating dozens of floor plans and filling them with furniture (Bipin, 2018; A.W.S. RoboMaker, 2021). These services streamline experimentation, allowing the research to focus on the patient requirements versus simulation infrastructure. The study will use these capabilities to verify the AI/ML CV process across a reproducible gradient of character properties (e.g., weight from 80 to 500 lbs and age between 30 to 120 years).

## Research Methodology and Design

Design science is a research methodology that creates and uses purposeful artifacts to study a phenomenon (Hevner et al., 2004). Academic and business communities employ this method as a standard approach to Information Technology and Communication (IT&C) problems (Peffers et al., 2007; Bryar & Carr, 2021). It comes with well-defined guidelines to implement a three-phased procedure. First, the researcher(s) must identify a domain-specific challenge. Next, that researcher creates artifacts that study this phenomenon. Third, those artifacts assess the topic and communicate answers to the research questions.

### Study Appropriateness

It is challenging to study humans in privacy-sensitive situations like home monitoring situations. This study proposes a research method for simulating those humanoids and having them perform realistic behaviors. Within the simulation process, the humanoids will perform MoCAP sequences like falling, and virtual cameras can extract that metadata for an ML model. Using a design science research method is appropriate to explore this technique as it explores the phenomenon directly.

### Alternative Methodologies

Quality research begins with a well-defined set of questions, such as ‘can an autonomous vehicle safely navigate city streets?’ Next, the researcher needs a plan to answer the question by collecting evidence and observations. Executing that plan requires a collection of quantitive and qualitative methods. Each of these methods is a tool with its inherent strengths and weaknesses (Jason & Glenwick, 2016). These attributes necessitate researchers to understand when a hammer is more appropriate than a screwdriver (see Table 1). Many people erroneously believe that quantitative methods are superior to qualitative alternatives (McCusker & Gunaydin, 2015; Creswell, 2014; Jason & Glenwick, 2016). This naïve perspective incorrectly assumes that a hammer is always the right tool. When researchers treat screws like nails, it results in erroneous publication claims.

Table 1: Research Approaches

|  |  |  |
| --- | --- | --- |
| Approach | Description | Example Use Case |
| Quantitative | Statistical modeling of a scenario | * Estimate the probability of an event * Stating a broad generalization * Cause and effect analysis |
| Qualitative | Non-numerical representation of a scenario | * Open-ended surveys * Exploration of needs * Investigating a local issue |
| Mixed-Method | Combination of both quantitative and qualitative | * Examining the breadth and depth of a topic * Examining a scientific idea and then mapping it to use cases |

Consider the difference when the vehicle study’s objective is (a) to identify safety requirements versus (b) modeling the limitations of the braking system. Under (a), qualitative methods best support the open exploratory nature of the problem. With (b), the answer needs a quantitative approach that describes the relationship of multiple variables, such as the car’s speed and the number of objects on the road. However, a more comprehensive study could answer both (a) and (b) by uncovering the importance of braking enhancements and then describing the limitations in greater detail.

This study’s objective is to demonstrate a research method. It does not aim to prove that method is superior to existing techniques through quantitative or qualitative measurements. These design constraints make the constructive research approach more appropriate. Future research should expand on the study and assess optimizations and enhancements through quantitative and qualitative questions. For instance, an example-derived quantitative study could examine different ML algorithms and measure the accuracy against real humans. Meanwhile, another example-derived qualitative study might consider the influence of humanoid character properties (e.g., gender and weight).

## Population and Sample

For an experiment to be successful, it needs to have sufficient *power* to measure the *effect* in question. Several knobs feed into the power of an experiment, such as relaxing the confidence interval, using parametric statistics, converting to a one-tail model, increasing the samples, or adjusting the sensitivity (Donovan, 2016). Choosing which value to tweak and optimize is scenario-specific and can be somewhat of an art form.

### Determining Power

*Insert data about choosing the power level here*. Given the relatively small sample count, adjusting the confidence intervals to meet acceptable power requirements might be necessary. Another option might be to reduce the number of racial categories, from nationalities to three groups. These data tweaks might detect high-level trends that future research could tease further.

### Determining Effect

Effect size measures the strength of a phenomenon (Donovan, 2016). While calculating the difference between the two distributions is relatively straightforward, it can be difficult to predict ahead of time. This bittersweet relationship introduces challenges when determining the appropriate sample size. One potential solution is to use an iterative sequential sampling policy instead of a fixed size upfront (García-Pérez, 2012). In this situation, *insert data about what this means for this situation* and variable selection. While this small group would have a reasonably low confidence interval, it could qualitatively hint at the overall sample size needing to be minor, medium, or large. There are potential risks that the random-initial sample produces an invalid seed in the study.

### Potential Sample Sizes

Despite the effect size being unknown potential, it is possible to determine the range of sample sizes for the experiment (see Table 2). G\*Power version 3.1.9.7 projects that t-tests of the “difference between two independent means (two groups)” for a one-tail model will need somewhere to *insert actual values*. Since *insert available values* examples, there should be sufficient coverage assuming the specific measurements are kept simple.

Table 2: Sample Sizes

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Power | Effect Size | Confidence – 50% | Confidence – 80% | Confidence – 95% | Confidence – 99% |
| 70% Adequate | 0.20 – Small | 28 | 188 | 472 | 816 |
| 0.50 – Medium | 6 | 32 | 78 | 134 |
| 0.80 – Large | 4 | 14 | 32 | 54 |
| 95% Excellent | 0.20 – Small | 272 | 620 | 1084 | 1580 |
| 0.50 – Medium | 44 | 100 | 176 | 256 |
| 0.80 – Large | 18 | 40 | 70 | 102 |

### Acquiring the Sample

This study aims to demonstrate a research methodology for using humanoids in simulation processes to assess machine learning models. It presents an example of employing computer vision (CV) to detect falling patients. The research project will generate different humanoid configurations and have them perform MoCAP sequences. For instance, one experiment would provide a thirty-year-old actor that’s one hundred pounds (forty-five kilograms). Another one could have a sixty-year-old actor that weighs three hundred pounds. The simulation software will use these variables to influence movement speed and flexibility.

Using this approach is appropriate for the dissertation proposal methodology and design. It has several core strengths, such as avoiding a cumbersome human recruiting process and concerns that the selection procedure is unfair. This method examines the generalization and usefulness of the research technique. Furthermore, the experiments automated nature makes reproducing the results straightforward and economical. This design choice means that future researchers have sufficient information to replicate the study.

## Instrumentation

There are three aspects to the study that require data collection. These aspects include ML training performance, model accuracy, and inference performance. It is within the project’s scope to use instruments to confirm that correct procedures occur. However, this study does not aim to demonstrate extreme precision or the superiority of the research technique over existing patterns.

### ML Training Instruments

First, telemetry must report that the ML training process is performant and converging. This information is available through Amazon SageMaker and Tensorflow 2.0 metrics. The study does not plan to build custom metrics beyond the standard reports.

### ML Model Instruments

Next, the study must confirm that the ML model accurately predicts humanoid behaviors. In a physics simulation process, humanoid actors perform behaviors in a highly controlled environment. This feature allows the study always to know the current world state and quickly assess any CV model prediction’s accuracy.

### ML Inference Instruments

Third, an ML inference process will host the model and return predictions. Amazon SageMaker collects statistics regarding inference performance. The study will use this built-in information to confirm that the inference follows industry standards.

### Field Testing

The study will create a highly-simplified example to confirm that the instruments function expectedly. This stable configuration might consist of a 2-D humanoid performing two MoCAP sequences for a binary classification problem.

## Study Procedures

The research project aims to build a CV model that can accurately predict human activity recognition (HAR). Model training will initialize a random experiment configuration and perform an appropriate MoCAP sequence. During the performance, a virtual camera will collect changes in joint positionings. This delta stream will serve as input feature parameters to the classification process (e.g., sitting versus falling).

### Building the Model

A distributed training service can horizontally scale and assess these different humanoid permutations in isolation. Amazon SageMaker offers these capabilities through its “bring your own container” design. Researchers essentially bundle custom automation and open-source tooling into a virtualized process. SageMaker uses public cloud resources like compute and storage to execute the experiment hundreds or thousands of times. It also integrates into TensorFlow 2 for collecting accuracy and performance metrics. These features reduce the complexity of building boilerplate instruments for many standard requirements.

Future researchers can replicate this experiment by deploying the same container images into their Amazon SageMaker and TensorFlow 2 environments. The humanoid automation will be versioned using GitHub. GitHub simplifies sharing open-source code and identifying specific point-in-time versions (called a commit SHA). Since those researchers can synchronize the repository to a particular commit and rerun the automation using industry-standard tooling, they have sufficient capabilities to reproduce the experiment.

### Implementing the Simulation Process

A critical component of the design is the simulation environment. This research project uses Unity 4 for modeling physical interactions and humanoid behaviors. Unity 5 is generally available (GA) but does not yet support Linux, a requirement for model training with Amazon SageMaker. The world and relevant artifacts will publish to Amazon Elastic Compute Cloud (EC2) resources. While Unity offers numerous features for modeling incredibly realistic and complex situations, many of those capabilities are outside this project’s scope.

## Data Analysis

There are two phases to implementing an AI/ML process: training the model and operationalizing the capability. The analysis must confirm that these phases meet acceptable quality standards. Additionally, it must succinctly address the research questions from chapter 1.

### Addressing the research questions

This research project attempts to demonstrate extracting *intents* from dynamic and noisy video streams (see RQ1). There must exist measurements of the inference accuracy and the extent to which the scene contains noise. Unity offers several rendering effects for smoke, fog, reflections, and lighting. Controls exist for adjusting these effects and their enablement strength between zero to one hundred percent.

### Model Training Analysis

Tensor Flow 2 generates statistical information regarding the model training performance. These Key Performance Indicators (KPIs) describe gradient convergence, model accuracy, and various troubleshooting metrics. An analysis must confirm that the training configuration occurs efficiently. Suppose the performance is substandard. In that case, this research plans to investigate the defects and reconfigure the training service (e.g., Amazon SageMaker). It is beyond this study’s scope to create “a perfect model” and only seeks to demonstrate the research technique’s viability. However, this study will validate that training is reliable and reproducible across positive and negative test cases.

### Model Inference Analysis

An analysis of the model inference must confirm that it is usable. This phase requires provisioning a model endpoint and posting experimental data. A simple approach could be using RGB+D cameras to record a small human group repeating the humanoid behaviors. There are several core advantages to this solution. First, it demonstrates bringing the simulation process into the real world. Next, these volunteers are readily available through work and social gatherings. It is beyond this study’s scope to “perfectly predict” every behavior. Instead, the goal is to collect and evaluate operationalizing the research technique.

## Assumptions

Research projects must be cognizant of the internal and external factors influencing their research. Making an assumptions inventory is essential to quality research because it communicates the implicit drivers in the design.

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### Quality Tooling Exists

This study makes several assumptions about the current industry state. It assumes that mainstream solutions like Amazon SageMaker, Robotic Operating System, Docker, OpenAI’s Gym, and Unity’s PhysX deliver the capabilities necessary to build the core artifacts. This situation would allow the experiment to focus on the AI/ML components, not rewriting boilerplate infrastructure. Suppose the toolsets haven’t matured to an acceptable level. In that case, the study will simplify the training subsystem.

### Adequate Funding Exists

The current plan also assumes access to a highly discounted rate for cloud computing resources. Amazon Web Services (AWS) has several programs for aiding researchers, like AWS Cloud Credit for Research and AWS Educate. Presently this study has funding through one or more of these programs and can pursue the entire project’s scope. Suppose that Amazon discontinued funding. In that case, the study would reduce the scale and focus on fewer test cases and humanoid configuration combinations.

## Limitations

Limitations are internal and external factors that *implicitly* restrict the study from exploring all aspects of the problem.

### Range of Motion

This study aims to build a HAR classification model that supports a predefined set of activities. These limitations exist due to challenges in finding sufficient example data. In this case, expanding the sample to contain open-source repositories will become necessary. These repositories could include YouTube, among other sites.

## Delimitations

Deliminiations are internal and external factors that *explicitly* restrict the study from exploring all aspects of the problem.

### Humanoid Constraints

Humanoid actors initialize with a configuration that controls their mechanical movement. There are virtually unlimited permutations for these characters and their weight, height, dexterity, and flexibility, among other properties. The distributed training process must set value bounds to learn the problem space efficiently. For instance, there’s only one person over a 635KG weight (Guinness World Records, 2022). Therefore, it does not make sense for test cases to exceed this extreme limit. Similar practical constraints also exist for other properties. It is beyond the scope and budget of this study to examine outliers.

## Ethical Assurances

Northcentral University’s Institutional Review Board (IRB) must issue a statement covering ethical concerns, privacy violations, or undue harm risks.

### Human Subject Concerns

This study uses humanoids in a physics simulation process as a research technique that mitigates ethical concerns and personal privacy risks. Since a humanoid is a virtual construct, it intentionally and explicitly divorces any moral hazards. Furthermore, the simulation has no right or assumption to privacy, as it does not exist in the real world. To verify the model training, a small cohort of volunteers will re-enact safe behaviors that do not risk personal privacy or harm. For instance, the falling behavior can be onto a padded surface.

### Secure Data Storage

Medical facilities have a business requirement to collect private information from patients. While building a system that stores and retrieves this data is relatively trivial, several specific considerations influence the final implementation. Which users can issue queries against the datastore? What maintains the confidentiality of these records? How will auditing and compliance reporting work? Does this data have legal or regulatory implications? Answering these questions produces a model of acceptable risks and identifies business policies requiring cybersecurity enforcement. These enforcements protect the business against negligent and malicious attacks that could harm the integrity or reputation of the brand.

The principal objective of any business is to execute its mission in the most efficient manner possible. Delivering on that mission requires choosing between acceptable risks and desirable conveniences (Mickens, 2018; Dai Zovi, 2019). For instance, many small to midsized business owners lack the expertise to run a domain controller or email service. Employing dedicated staff retracts from resources that could provide value differentiation towards its core competencies. Contracting a consulting firm would be less expensive but lacks the deep economy of scale discounts available from Microsoft Office365. While financial factors influence many decisions, the security and compliance teams need to assess the risks to privacy and availability. Not all decisions originate from the leadership and often come from internal department requests. For instance, a data science team might require a Juypter Notebook server with access to a production database. While that team has enough knowledge to be dangerous and deploy an operational instance, they might lack a broader understanding of business continuity requirements (Brown, 2015). What physical host controls this instance? Does the database connection use encryption? How are backup and restore scenarios handled? Until understanding these subtle decisions, it is impossible to determine if a failed server hard drive will lose three minutes or years of productivity.

These decisions must influence the study’s data storage design to be secure, reliable, and durable. In this context, the *seed* data is not confidential and comes from public repositories. However, there are risks that the *result* data can become corrupted or destroyed. That situation would risk the dissertation process completing on time. This constructive research project mitigates those scenarios using automated backup into Amazon Simple Scalable Storage (S3) storage and frequent commits to GitHub. Both services offer industry-standard durability, versioning capabilities, encryption at rest, and authentication controls.

### Researchers Role

The researcher is responsible for building the artifacts, measuring their accuracy, and reporting the results. There is the potential for biases impacting the study due to resource constraints. For instance, the project might plan four different MoCAP sequences but only three work successfully. In that case, the results should not ignore the failure and instead discuss potential reasons for the issue. It is beyond this project's scope to validate every possible situation though it should make reasonable attempts too. Additionally, controls are in place to limit cheating or deceiving the results. For example, the result data originates through an automated process.

## Summary

This chapter documents the research methodology and the study design. These steps are crucial as it outlines the research plan.

Checklist:

Summarize the key points presented in the chapter.

Logically lead the reader to the next chapter on the study's findings.

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