A PC Based Virtual Reality Simulator for Forklift Safety Training

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Final Report

Submitted by:

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Abstract

The occupational safety and health issue addressed in this research dealt with the reduction of forklift injuries and fatalities through improved safety and injury prevention training technology by building a widely deployable, low cost, Virtual Reality forklift safety trainer (and similar powered industrial devices in the future). The specific goal is to significantly reduce the mortality and injury rate caused by forklift accidents by building an intuitive, low cost training platform that gives forklift operators the opportunity to study operating safety standards, rehearse them, and then be tested and evaluated on their understanding of them without the inherent risks of training on a real forklift, and with the benefit of getting the constructive and active cognitive experience of operating a forklift, which cannot be attained using video tapes or other training materials currently on the market.

The importance of the forklift safety problem cannot be overstated. Forklifts are by far the most dangerous industrial vehicles in operation based on the number of fatalities and injuries that occur every year in the United States. Annually, there are nearly 100,000 reported injuries and over 200 fatalities directly attributable to forklift accidents[1]. There are roughly 1 million forklifts in service in the United States and more than 1.5 million operators (closer to 6 million if you include occasional operators). This means that there is a roughly 10% chance that a given forklift will be involved in an injury annually. The ubiquity of the forklift in modern commerce combined with the faulty assumption of intuitive operability result in this astonishing level of danger to an equally astonishing segment of the population. The cost of such accidents involves more than just fatalities. It is estimated that at least 20,000 work days are lost each year due to these injuries[1], representing not just a major cost to the economy, but more importantly, a major public and occupational health concern.

The approach taken to address this occupational safety training issue involved 4 key elements namely, physically accurate forklift model creation, workplace environment development, training curriculum, and industry vetting. Three environments and three different style forklifts with real physical attributes were developed to show the breadth of applications possible with this technology. Educationally effective course curriculum was developed based on OSHA mandated training specifications as well as the universally accepted cognitive constructivism approach to developing teaching tools. The prototype Virtual Forklift Trainer (VFT) was then vetted by end users, trainers, and industrial users for feedback.

The responses received during the vetting stage as to the functionality and usability of the Virtual Forklift Trainer were overwhelmingly positive and have provided the Tactus team with great insight as to future, Phase II enhancements. Some of the specific comments received are shown in the next section regarding significant findings.

The Virtual Forklift Trainer will be used in the workplace for training forklift operators on proper handling and safety procedures as set forth by the Occupational Safety and Health Administration (OSHA). Potential users will range from small companies with only a few forklift operators to the largest of companies that have high employee turnover and a need for continuous forklift safety training. Our VFL product is also intended to be used by professional safety training centers in combination with their classroom and hands-on training environment.

Highlights/Significant Findings

The specific aims of this Phase I work were to develop a prototype virtual reality simulator and then establish its feasibility in terms of its potential to reduce injury and mortality through superior training, technical issues, and commercial success. All of these were achieved and each is highlighted in its own section below:

1) Developed a Prototype

A low cost PC based virtual reality forklift simulator was developed, which allows a user to drive a simulated forklift through a variety of environments, giving him or her a hands-on, active learning experience in safe forklift operations. The simulation provides superior training versus textbooks and videos, because it allows actual hands-on constructivist learning to take place. Figure 1 shows the prototype. The left pane shows a user operating a virtual forklift, the middle pane shows a sample forklift model (many were developed and each one has its own appearance and physical parameters to accurately portray the variety of behaviors of different models). The right pane shows an obstacle course the user drives through to learn how to steer a forklift safely.

Figure 1 - The Virtual Reality Forklift Safety Trainer prototype

2) Established Technical Feasibility

There were many difficult technical challenges to overcome in order to establish feasibility. They included the following:

- ability to process commodity PC gaming hardware to simulate forklift controls
- real time physics calculations to accurately portray forklift behavior
- ability to compute collisions between forklifts and pedestrians, forklifts and shelving, etc.
- ability to deliver content in a virtual environment
- ability to record and playback training sessions for review
- ability to quantify safety performance in virtual environment

All of these technical obstacles were overcome, and each is detailed in the scientific report.

3) Established Commercial Feasibility

Establishing commercial feasibility entailed conducting market research to determine whether there was support for the product as well as vetting the product with potential industry users. In addition to our market research and vetting the technology with industry, a formal market analysis was carried out by the Foresight Science and Technology Company, a market survey firm that was retained by NIH. They concluded that our technology was "revolutionary due its innovative component" and that end users will find "this technology very attractive". This was based on market survey and direct conversations with potential end users, safety experts and trainers from some of the largest forklift end users in the world such as Wal-Mart and Costco. Based on this market analysis, Foresight concluded that, once completed, VFL has the potential of generating revenue of $8 Million/year with in the next 5 years. The commercialization study concluded that VFL technology is a commercially viable and a timely safety product with tremendous demand.

4) Established Potential Industry Adoption with Vetting and Feedback

The most important highlight of the research carried out was the feedback that was solicited from potential end users. The users that evaluated the Virtual Forklift Trainer prototype were overwhelming impressed with its visual and physical realism as well as its potential to improve the current state-of-art in forklift safety training. The following table lists the feedback obtained from potential customers, partners, and end users.

Partner/Customer/End User	Feedback on Virtual Forklift (VFL)
NCCC – Western New York Safety Resource & Training Center	Richard Gorco, Director of Corporate & Business Development for NCCC says VFL will greatly enhance current classroom training techniques. It will also provide trainees with an opportunity to practice while they wait for their turn to train on the actual forklift in class.
Emedco Inc.	Our distribution partner Kelly Cunningham, Product Manager for Emedco says End-users will flock to a forklift specific training package.
JLG Industries	Mike Popovich, Director of Safety, expressed interest in this technology for JLG's military group because this group needs to have a simulator before selling to the military.
Costco	Dale Anderson, Director of Safety, is interested in a new method for training forklift operators.
Sunbelt Rentals	Jeff Stachowiak, a Forklift Safety Trainer, stated that virtual reality simulation for forklift training is a great idea and that there is definitely a need for it, due to injuries and fatalities incurred in operation of forklifts.
Washington State Dept. of Labor	Lou Flores, a Forklift Safety Expert and Operation Trainer, stated that he believes a simulator could be very useful. As a comparable, he noted that aircraft simulators are used extensively for training pilots, and he saw no reason why this approach could not be successful. The need for this technology is apparent from the fact that there have been several fatalities in Washington state this year involving forklifts.
Sherman Safety Management	Larry Sherman, Safety Consultant, believes this could be a good training tool for people who are new to forklift operation. He also noted that OSHA legally requires forklift operators to receive re-training if the worker is involved in an accident or has to operate a new type of forklift. This product would be useful as a supplement to onsite training, but will not replace it.
Wal-Mart	Wal-Mart's training programs for forklift operators lack an interactive component. Jon Blevins, Risk Control Director, expressed interest in this product for this reason.
Nissan Forklift	Wayne Wilde, Director of Training, Ralph Petrek, Vice President for Customer Satisfaction, and John Kazmol, Manager of Customer Service Sales all saw potential to present many different safety concepts in this environment that are otherwise difficult to convey. They also saw a great potential for more efficient training, as every trainee has instant access to a virtual forklift.
Mitsubishi Forklift	Arnold Witt, Director of Dealer Training, and Bob Mundson, manager for safety training saw an opportunity to have drivers experience safe forklift operation firsthand.
AHOLD International	"Software must be comprehensive to replace existing training materials and must be OSHA compliant."
Erie Insurance	Mike Bova, Risk Management Director, John Maccario, Quinton Boroi, Rex Bennet, all regional Risk Managers, saw tremendous value in training with a virtual forklift. Rex Bennett, who described how the stability triangle concept is currently taught

	with a paper pyramid, saw a great opportunity for showing the trainee visual feedback that wouldn't be possible in real life (a virtual stability triangle, for example).

Table 1 - End User Feedback [2]

5) Developed Plan for Phase II

The process of completing the prototype, conducting market research, and vetting the technology with industry resulted in a solid plan for the Phase II research. Specifically, the following were developed:

- Technical blueprint and timeline
- Commercialization strategy and timeline
- Established industry partnerships for feedback and guidance (formal commitments)
- Established OSHA 1910.178 curriculum outline, covering every topic in the OSHA safety specification

Translation of Findings

Although this was a Phase I proof of concept project, the potential for virtual reality based safety training was clearly demonstrated by our own user observations, as well as industrial vetting. Every single industrial contact who was shown the demo or who had a chance to try the trainer supported the idea as both potentially highly effective as well as commercially feasible. Reviewers from industry included forklift operators, big box retail material handling managers, formal safety officers, small business, business insurance risk control officers, and many others. A formal scientific large sample efficacy study is planned in Phase II.

When the Virtual Forklift Trainer is adopted into the workplace, some of the ways employers and forklift trainees will potentially benefit from the use of this technology include:

- Hands-on active training
- Experience common mistakes and pitfalls
- Learn the concept of stability triangle and apply this knowledge while operating
- Trainees can progress at their own pace
- Ability to tailor training on an individual basis
- Performance metrics computed in real-time
- Ability to train on a specific type of forklift
- Record/Playback of training session from first and third person perspective
- Determine individual and group performance statistics
- Ability to tailor remedial training sessions based on an individuals performance
- Indefinitely save training sessions for future trend analysis and comparison

Finally, this project has the potential to raise the bar on safety training by finally applying a state of the art technology to what many consider to be a mundane task. Mass safety training today employs the same technology as it has for the past 10 years - multimedia, videos, workbooks, and classroom instruction - all passive learning technologies where the trainee is disengaged. Providing an active, hands on, simulation to a mass market such as forklift operation has the potential to be a high profile, highly visible innovation in the safety market place, inspiring other safety training domains to adopt similar technologies, and demand modernized training technologies for improved safety and in turn a significant reduction of injuries.

Outcomes/Relevance/Impact

An important outcome of this Phase I research was the overall acceptance of this training system and the technology as a whole by industry leaders such as AHOLD International, Nisan and Mitsubishi Forklift as well as large industrial users and training centers like Wal-Mart and the Western New York Safety Resource and Training Center. These potential adopters realize that the Virtual Forklift Trainer combines the best of both training worlds: the opportunity to do hands-on training that provides continuous feedback and instruction as well as take advantage of, and extend, the record keeping and reporting systems available to PC-based training and believe that the Virtual Forklift Trainer will lead to a reduction in mortality and injury rates caused by forklift accidents. The following list regarding the impact Virtual Forklift Trainer will have on Industry, end users, and society as a whole was adopted from conversations with these potential adopters:

- reduction in accidents, injuries and death
- simultaneously provides specific, visible training results and records
- reduced insurance costs for industrial users and health healthcare costs related to injuries
- reduced training time for trainees
- reduced training time for trainers
- reduced loss of work time due to accidents and injuries
- reduced lawsuits and litigation expenses
- reduced fines and other OSHA sanctions
- reduced product/equipment/work environment damage and loss
- opportunities for training on multiple occasions at no additional outside cost
- lean and faster training

Scientific Report

1) Background

The forklift is the most widely used industrial vehicle and is also by far, the most dangerous. In the United States, there are over 1 million forklifts in operation[3], and nearly 2 million operators[4] (nearly 6 million if you count part time and occasional operators[5]). Worldwide there are more than 20 million operators [4]. Each year, OSHA estimates that there are over 100,000 reported injuries and over 100 fatalities in the United States alone specifically involving forklifts[3]. The annual cost of property damage attributable to forklift accidents is 1 Billion,[6] and it is estimated that over 20,000 work days are lost each year from these accidents and injuries[3].

The danger of forklift operation has two primary causes. First, the sheer number of forklifts in operation in the United States alone tops 1.2 million [7]. This ubiquity reflects the utility of the forklift and its relatively low price. The second cause is that the forklift is an inherently difficult vehicle to operate, while appearing to be highly intuitive. A new forklift user believes he or she can operate a forklift much like he or she operates a car. Similarly, many operators believe that balancing loads and controlling the velocity, tilt, and other states of the forklift are intuitive. This false sense of security is a major contributor to forklift accidents and injuries. Exacerbating this problem is a relatively untrained pool of manpower from which retail giants and large companies hire coupled with a high turn over rate. It is reported that in some industries, such as retail shops, the annual turnover rate is as high as 500%[8].

As alarming as these numbers are, industrial trends indicate that the problem will only get worse. First, the number of forklifts being produced in the United States and worldwide is increasing (between 12 to 16 % in 2004[9]. The last year for which statistics are available, 2004, saw the most number of new forklifts put into production in history- 700,000[9]. Because of the rapid increase in the number of forklifts in use and high employee turnover in industry, forklift users are less willing to pay for extensive training for operators, and accordingly, forklift manufacturers are developing rapid training programs, which often consist of reading a safety manual and watching a video. Trainees are subsequently put on a forklift and are expected to be prepared to overcome many dangerous situations that occur in day-to-day operation (e.g. tipping over while going up or down a ramp with a load, improper placement of load, following traffic rules in a shop, including respecting other forklifts and pedestrian traffic, etc).

To address forklift safety, OSHA mandates that every forklift operator is trained prior to operating a forklift, but OSHA does not allow training on a forklift, which eliminates the opportunity for hands-on learning. Current training methodology is limited to videos and workbooks, thus, as already alluded to, operators are put into hazardous industrial environments with little or no hands on experience with safe forklift operation.

While the public is, in general, unaware of how serious a risk forklifts are for forklift operators and their co-workers in their daily working lives, large and small businesses that use forklifts, government agencies, insurance companies, and many others are intimately aware of the danger level. Further, the loss of life and limb, property damage, and increased insurance costs affect everyone, making forklift danger a serious public health and public policy issue.

Technical Problem

Virtual reality presents an excellent opportunity to deliver vastly superior training to forklift operators. Virtual reality has been extensively employed by the military and academia to provide highly effective state of the art training, and its sheer ubiquity in the military is testimony to how effective it is as a training tool. Intuitively, one would expect that practicing how to operate a machine as complicated as a jet on a simulation would result in superior learning versus reading a workbook on how to operate the same machine. The educational literature supports this assertion as well (see next section).

The problem with employing virtual reality as a training medium is it is prohibitively expensive for all but those with the deepest pockets, such as the United States military. Military grade flight simulators cost upwards of several million dollars, and other industrial virtual reality applications, such as school bus trainers, cost several hundred thousand dollars, including setup and installation.

The goal of this research then, was to establish the feasibility of a low cost, high fidelity (physically accurate) virtual reality forklift safety trainer that could be widely deployed.

2) Specific Aims

The specific aims for Phase I of this project were:

- Develop Prototype

- Establish Technical Feasibility
- Establish Commercial Feasibility
- Potential Industry Adoption with Vetting and Feedback
- Developed Plan for Phase II

In summary, the specific aims for Phase I included designing the virtual reality forklift simulator, building an overall architecture, scoping the curriculum, and picking 2-3 modules from that curriculum and developing them to demonstrate overall feasibility. Extensive reviews were then conducted with many industrial end users and a solid plan for Phase II was developed consequently.

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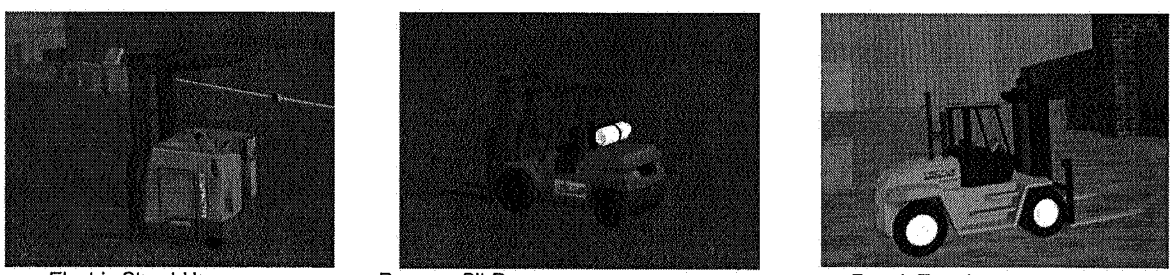
3) Results and Discussion

The work plan in Phase I was broken down into the following parts, the results for which are discussed accordingly.

Task 1 - Build Visual Models

Visual models were built for forklifts, work environments, pedestrians, and cargo. The first subtask was to build 3D models for 3 forklifts. Figure 2 shows each of the models that were completed. They include an electric standup forklift, a sit-down propane forklift, and a rough terrain forklift. All three models are fully functioning in the virtual environment, meaning, all three have mechanical moving parts, and physical parameters, including chassis length, axle width, steering limits, and all of the parameters necessary for accurate vehicle simulation, including center of gravity, and load physics. With these models, accurate simulation of how each truck behaves with and without cargo was achieved.



Electric Stand-Up   Propane Sit-Down   Rough Terrain

Figure 2 - Three completed forklift models

This subtask consisted of two stages- the visual creation of forklift models, and the mathematical modeling of degrees of freedom. A *degree of freedom* represents a discrete way in which a model can change. A typical forklift, for example, has 4 degrees of freedom, each of which was modeled for Phase I - steering angle, fork tilt, outer lift, and fork lift (a typical forklift lifts in two stages). A degree of freedom is modeled in the visual model as a matrix, and formula 1 shows a *translation* degree of freedom matrix - where part of the model simply moves linearly, where x, y and z represent the displacement in the three axes:

$$\begin{pmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & y \\ 0 & 0 & 0 & z \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{1}$$

Similarly, formula 2 shows a rotation matrix about a fixed point, where *x*, *y* and *z* represent the fixed point, and θ represents the angle of rotation:

$$\begin{pmatrix} \cos\theta & -\sin\theta & 0 & x - x\cos\theta + y\sin\theta \\ \sin\theta & \cos\theta & 0 & y - x\sin\theta - y\cos\theta \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{2}$$

A *scene graph* represents the visual model and the order in which it is drawn, including degrees of freedom. The scene graph for a forklift is shown in Figure 3:

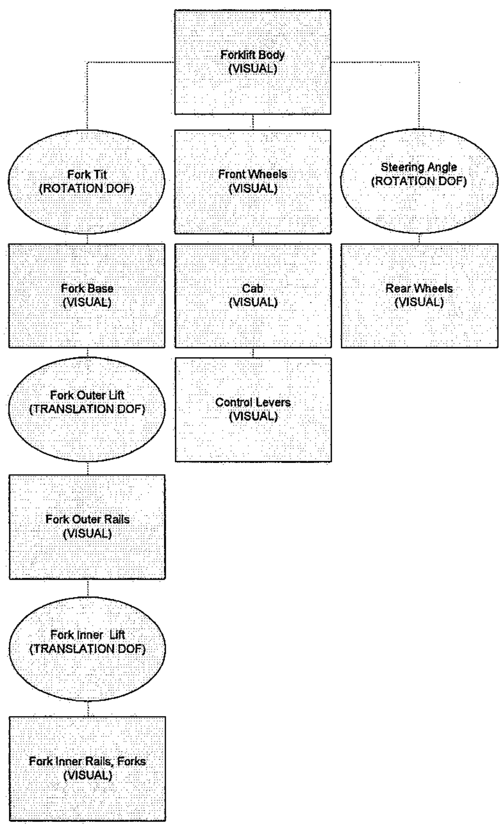


Figure 3 - The forklift scene graph

Visual components (the parts that are actually drawn on screen) are represented by rectangles, while degrees of freedom are represented by ellipses.

Three complete work environments were also completed in Phase I. They are a warehouse with industrial shelving, an airplane hangar for driving practice, and an outdoor storage yard, complete with loading dock, and cargo train. Figure 4 shows these environments.

Figure 4 - Three completed work environments

Additionally, pedestrians were modeled to allow for practicing forklift/pedestrian protocols. Pedestrians can be placed anywhere in the work environments and corresponding curricula can be developed for learning these safety protocols. Figure 5 shows pedestrians in a warehouse environment.

All the important goals of the Task were achieved.

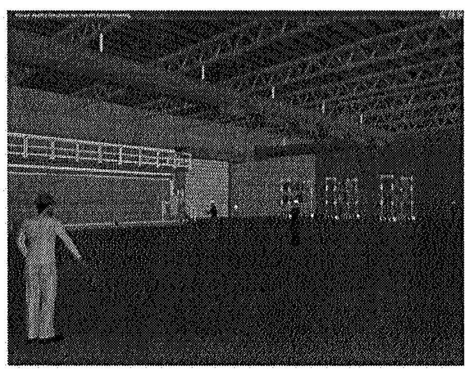


Figure 5 - Pedestrians in a warehouse environment

Task 2 - Build Vehicle Kinematics/Dynamics/Mechanisms

As alluded to, this task entailed building a parameterized forklift model that takes into account the specifications of a forklift, as well as its interaction with the environment. This design allows for any forklift for which the design parameters are known (most are published in sales literature) to be easily entered into the simulation. The simulation can then readily simulate that particular forklift's physical behavior. Additionally, as mentioned, all forklifts developed in Phase I are articulated, so that the forks can be tilted and raised and lowered in accordance with each model's specifications.

Specifically, the forklift parameters that were incorporated into the simulation are weight, chassis length, axle width, track width, wheelbase, fork width, fork length, center of gravity, mast height, mast width, load capacity, and tire diameter. The specific physics and dynamics that are simulated and there associated mathematical equations are shown in Table 2. Many of these equations have been adapted and modified from accepted vehicle dynamics theory[10, 11] to work on a forklift. The mathematical algorithms developed in Phase I allow these equations to be computed in real-time.

One of the main safety goals for forklift operation is *static stability,* which is computed in the Phase I prototype. Static stability is measured by continuously calculating moments around the center of gravity of the forklift-load-driver system. Calculation of a moment about a point is merely a force multiplied by its distance from that point. Summing the moments due to all the active forces on this system provides a constant check on stability. To display the stability to the user, the *stability triangle* - a mental model of stability for forklift operators designed by OSHA, is actually visualized on screen (see Figure 9 and 10, upper right hand corner). Changes in the stability triangle graphic, which is shown in the upper right hand corner of the display, are based on these continuous calculations. This task was completed successfully.

Kinematic/Dynamic Parameter	Formula	Nomenclature
Acceleration	$a_x = 550\left(\frac{g}{V}\right)\left(\frac{HP}{W}\right)$	g = Gravity V = velocity HP = Horse Power W = Weight of Forklift, Driver, & Load
Turning Radius	$R = \frac{L}{Tan\theta}$	R = Turn Radius L = Wheelbase θ = Steer Angle
Critical Velocity for Impending Rollover	$V_C = \sqrt{\frac{t \cdot R \cdot g}{2 \cdot h}}$	t = Track Width h = Height of Center of Gravity
Deceleration	$D_x = \left(\frac{F_{Brake} + F_{Rolling}}{W}\right)g$	F_{Brake} = Force applied to brakes $F_{Rolling}$ = Force due to rolling motion
Stopping Distance	$SD = \frac{V^2}{254 \cdot (F_{Friction} \pm G)}$	f_r = Kinetic Friction G = % grade/100
Stopping Time	$t_s = \frac{V_0}{D_x}$	α_t = Tire Angle T = time V_t = Initial Velocity
Static Friction	$F_{Static} = \mu(mg) \pm G$	
Rolling Friction	$F_{Rolling} = f_r \cdot W \pm G$	
X coordinate of steering	$X_{t+1} = X_t + \frac{L}{Tan(\alpha_t)}\left[Sin\left(\theta_t + \frac{V_t Sin(\alpha_t)}{L}T\right) - Sin(\theta_t)\right]$	

Y coordinate of steering	$Y_{t+1} = Y_t + \frac{L}{Tan(\alpha_t)}\left[-Cos\left(\theta_t + \frac{V_t Sin(\alpha_t)}{L}T\right) + Cos(\theta_t)\right]$	

Table 2 - Physical Equations of Forklift Motion

Task 3 - Build Object Model

This task entailed creating the algorithms and data structures necessary for the interaction between the forklift itself and the rest of the environment. Each item in the simulation was built as its own data construct (known as an "object" in object-oriented programming circles). The simulation consists of 5 specific objects- forklifts, pallets, shelves, floors and pedestrians. Objects for each of these were designed and built in Phase I. Figure 6 shows a forklift on a slanted floor, holding a pallet near a pedestrian. This figure shows the visual representation of many of the objects that were built for Phase I. This task was completed successfully.

Figure 6 - Forklift on slanted floor holding a pallet near a pedestrian

Task 4 - Build Object Interactions

In this task, the interaction between these objects was designed and built. This interaction consists of algorithms that detect and respond to various conditions that occur between two objects. For example, when the forks of a forklift enter the cavity of a pallet, and the forks are then raised, the software has to detect this so that it knows that the pallet must now be lifted with the forks, the center of gravity must be adjusted, and the load stability must be computed taking into account the slant of the floor as well as the position and weight distribution of the cargo.

This example highlights the various interactions that are necessary for the simulation to behave realistically. Table 3 describes the object interactions that were completed for Phase I. Figure 7 (left pane) shows a forklift holding cargo which is about to be loaded onto a shelf. This figure illustrates forklift-pallet, pallet-shelf, and pallet-pallet interaction.

Object Interaction	Description
Forklift-Pallet	Simulation detects when a forklift's forks have penetrated the pallets cavities, when the top of the forks have hit the bottom of the pallets top planks, and when the forks have released from these planks by virtue of the user having placed the pallet on the floor or a shelf.
Forklift-Forklift	Simulation detects when one forklift has collided with another forklift.
Forklift-Shelf	Simulation detects if a forklift has collided with the post of a shelf or the

	shelf itself or if the forks have penetrated the cavity of a shelf.
Pallet-Shelf	Simulation detects if a pallet has collided with a post or the shelf itself, and when a pallet has been lowered onto a shelf.
Pallet-Pallet	Simulation detects if one load of cargo has collided with another load.
Pallet-Floor	Simulation detects when a pallet has been lowered to or lifted from the floor.
Forklift-Pedestrian	Simulation detects when a pedestrian is near or if the forklift has collided with the pedestrian.
Pallet-Pedestrian	Simulation detects if a pallet or its cargo have collided with a pedestrian.

Table 3 - Object interactions completed for Phase I

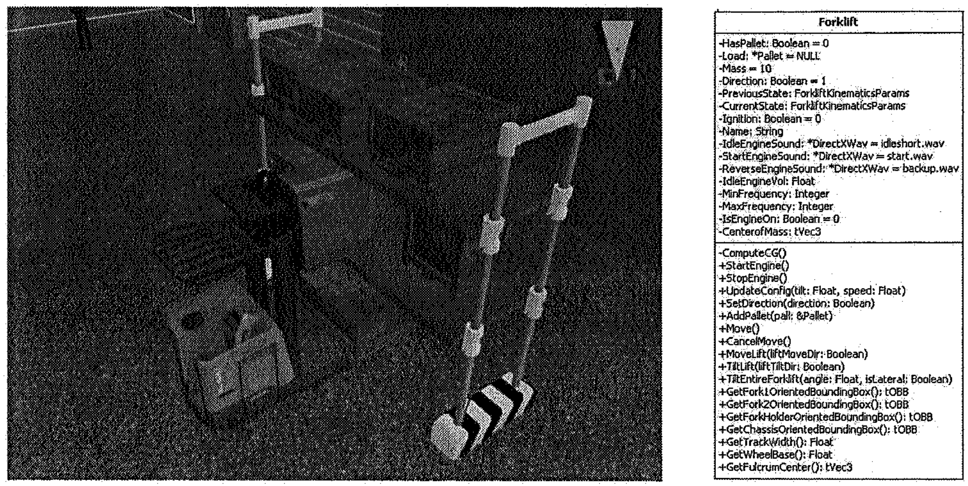


Figure 7 - Forklift holding cargo to unload onto a shelf and a UML model of a forklift

A C++ class was designed and built for each object in the simulation so that functional behavior was encapsulated into a single logical entity. For example, the forklift was designed so that it could update its position and compute its stability, determine its center of gravity, etc. Figure 10 (right pane) shows a UML (unified modeling language, the industry standard for object modeling) diagram of the forklift object. This task was completed successfully.

Task 5 - Build Educational Curriculum

This task entailed reviewing the entire 1910.178 OSHA forklift safety specification, and for each section or paragraph, describing a module that will be built into the final product. This curriculum was completed in Phase I, resulting in a table with 1,400 entries. The entire table can be reviewed in the appendix. This task was completed successfully.

Task 6 - Build Recording/Playback Capabilities

In Phase I, a Microsoft Access (note, the user does not need to own Microsoft Access, the Microsoft Access database engine ships free with every Windows installation) record and playback module was developed, allowing any exercise to be recorded and played back for review by either the trainee or the instructor. The state of the forklift every 1/30th of a second is captured, and stored in this database. Figure 8 shows the playback of a module the user has just completed. Once the user completes a module, his or her actions can be played back from any viewpoint, including first person (driving the forklift), passenger (as if the user were standing outside the forklift and riding along with it), or security camera or bird's eye view (as if a camera in a fixed location were filming the forklift).

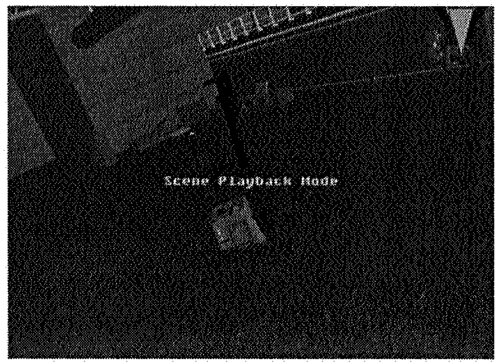


Figure 8 - Playback of a completed module

Task 7 - Build Database Module

As already alluded to, a database module was developed which, in addition to being able to record and playback a training session, can also store forklift parameters as well as trainee information. This allows a particular forklift model to be quickly loaded, and allows for historical playback for training. For example, a manager can load up a training session from several years ago, and watch the trainee's session using the same forklift the trainee originally trained on. A 3 tiered module was developed at the prototype stage, as depicted in Figure 9. Here, the software talks to the generic Microsoft Windows middle database broker layer (which ships free of charge with all Windows installations), unburdening the software (client) from running on a particular database. The software can be configured to allow for any database connectivity after it has been installed.

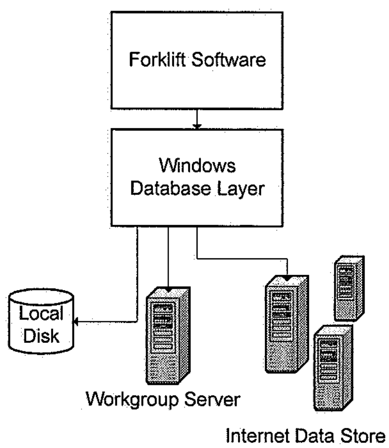


Figure 9 - 3 tiered database model

Task 8 - Construct Prototype

These building blocks were incorporated into a fully functioning prototype. The prototype consists of modules, each of which serves as practice or testing for one of the OSHA 1910.178 specifications. For Phase I, 21 individual exercises or assessments were built, which roughly correspond to 3 complete modules as discussed in the original proposal (1 complete module was promised in the proposal, however time allowed for additional work to be completed). These exercises include:

- studying the controls of a forklift
- practicing driving the forklift
- practice driving a car
- following a simple line path drawn on a hangar floor with a forklift
- following a simple line path drawn on a hangar floor with a car
- following a complicated line path drawn on a hangar floor with a forklift
- following a complicated line path drawn on a hangar floor with a car
- completing a simple cone obstacle course with the forklift
- picking up pallets of cargo from a warehouse floor and loading them onto shelves

Between exercises, the user navigates through a transitional tunnel, where lesson summaries are shown by hanging traffic signs (see Figure 10). At the end of each module, some type of assessment is given to the trainee, where either the trainee is asked to complete some forklift operation, or, where appropriate some form of traditional assessment such as a multiple choice quiz (Figure 14, left pane, shows a sample quiz). Each module has the ability to present the trainee with a playback of his or her actions for review. Upon completing each module, a performance report is generated to give the trainee (and management) a summary of his or her performance (Figure 11, right pane).

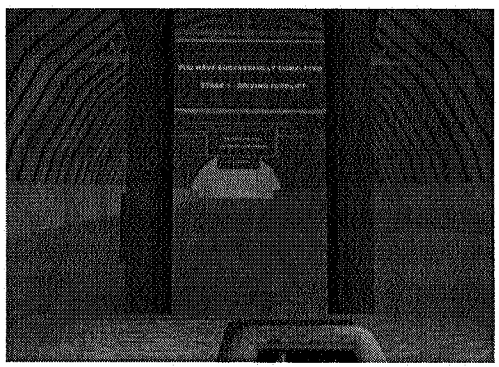
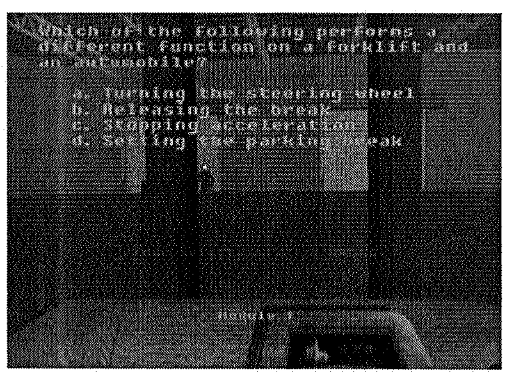


Figure 10 - Summary signs from operator's perspective in transition tunnel




```
----- Cone Course Performance Details ------
          07/10/06  12:46:30

Time Taken                 : 8.906 seconds
Average Speed              : 17.6526 m/s

Maximum Steering Angle     : 16.92 Deg
Minimum Steering Angle     : -11.9467 Deg

Total Number of Cones      : 32
Number of Cones Collided   : 0

----- Cone Course Performance Details ------
          07/18/06  09:48:08

Time Taken                 : 30.469 seconds
Average Speed              : 12.205 m/s

Maximum Steering Angle     : 22.7022 Deg
Minimum Steering Angle     : -36.4078 Deg

Total Number of Cones      : 32
Number of Cones Collided   : 1
```

Figure 11 - Trainee assessment item and performance report

In addition to the tasks specified in the Phase I proposal, two additional tasks were completed- building the baseline simulation infrastructure, and conducting preliminary feedback with industry. The simulation infrastructure consists of the basic building blocks that needed to be built in order for the simulation to run. Specifically, three functionalities were completed- rendering, collision detection, and input processing. Building a basic rendering engine consisted of creating a library that allowed loading of the 3D models, and an efficient manner for displaying them. In Phase I, we have completed the prototype of this functionality, which renders on a polygon-by-polygon basis, organized by polygon groups.

Collision detection was built to allow for determination of when objects intersect each other (for example, when the forks of a forklift enter the cavity of a pallet). Here, we built a prototype *oriented bounding box* (OBB)[12, 13] engine. OBB takes a complex object, and builds a rectangular volume around it, and then computes whether this volume intersects with another volume. The methodology relies on the *separating axis* theorem which states that two polytopes are disjoint (non-intersection) if and only if there exists a separating axis which is either perpendicular to the face of one of the polytopes, or is perpendicular to an edge taken from each. In Phase I, we have implemented a prototype separating axis test, which detects collision efficiently. In Phase II, a more efficient implementation will be designed as more objects are introduced into the simulation. Figure 12 shows a forklift and a pedestrian with their respective bounding boxes shown in green before collision (left pane) and in red after collision (right pane).

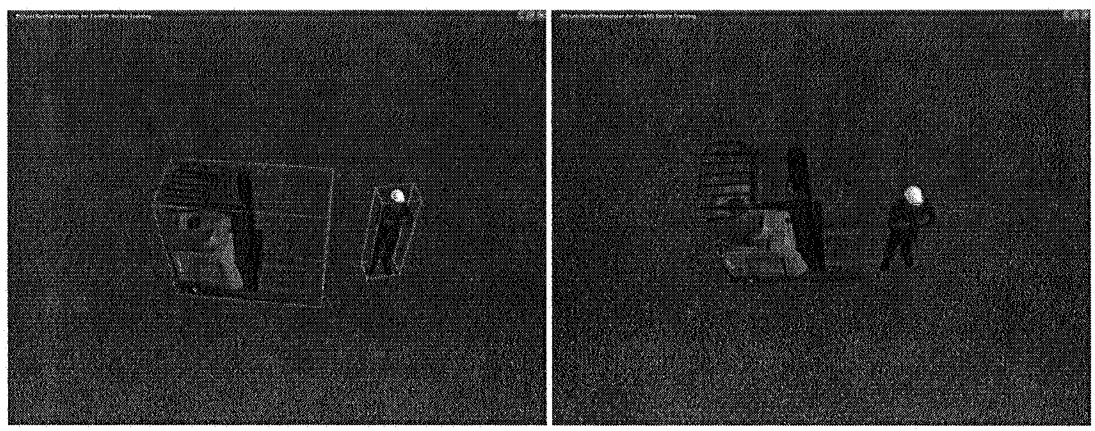


Figure 12 - OBB Collision

The technology was vetted to a number of forklift manufacturers, end users, distributors, training companies, and insurance companies. Most of the companies contacted for reviewing the technology have formally agreed to participate in Phase II of the project, and those who haven't agreed formally, have informally agreed to review the technology.

4) Conclusions

All of the aims and specific goals were achieved in Phase I of the project. A readily deployable, low cost high fidelity virtual reality based forklift safety simulator was shown to be feasible and there was unanimous industry support for the potential product.

The major weakness with current forklift training programs is the passive nature of these training environments. Currently available training methods and devices are limited to multimedia CDs, printed text and/or videos and are relatively costly in terms materials provided. Current training products cannot provide tailored instruction to the individual. The VFL training environment is a revolutionary product that allows for learning and objective assessment on an individual basis. Trainees can progress through the training modules at their own pace and practice until they are personally comfortable with their training before moving on to the next module. With the VFL training system, trainees are able to practice with the same forklift they will use in the real work environment. With the management tools incorporated into the VFL software, supervisors will have the ability to record and playback an operator's training experience, which allows for individualized objective assessment. Based on this assessment, a supervisor will have the ability to tailor a remedial instruction program if needed. VFL will revolutionize forklift safety training, and will raise the bar in safety training in general when expanded to other vehicles and procedures, by introducing a product that is interactive, dynamic and comprehensive.

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