ABSTRACT

This paper describes the methods and results of a semester long senior project in which a team of four students successfully developed and tested the first phase of a protective garment for use with patients who have unsteady balance. A prototype was developed, and tested using a mannequin and a test stand. It was designed and built by the four member student team for their senior capstone project at Southeastern Louisiana University to fulfill requirements for their Computer Science/Information Technology degrees. The goal for this phase of the project was to create a prototype vest/garment, detect a fall using onboard sensors, and trigger the protective apparatus of the garment, before impact. To support the development various test stands/equipment were built so that consistent falling motions could be generated, and upon impact sensors and microprocessors would not be damaged.

Keywords: Fall detection, hip injury, unsteady balance

1. INTRODUCTION

The motivation behind the Protective Inflatable Garment System (PIGS) project was to develop a vest/garment for use with recovering/elderly/sick patients to protect them from injuries resulting falls due to loss of balance. The project had a secondary goal of providing an easy method of monitoring vital functions such as pulse, temperature, and breathing rate, with the ultimate goal of the project is to develop this garment so that if a patient falls, the vest will detect the fall, deploy its safety apparatus lessening impact related injuries, then monitor the patients vital signs, and if needed, automatically call a pre-set phone number for assistance.

Of primary importance is convenience and comfort. The garment itself needs to be non-intrusive, and any data collected by its sensors would ideally be available wirelessly. If the protective garment is ever to be used for more than a project, convenience, comfort, and simplicity of use are of primary concern, but for this phase the students concentrated on the nuts and bolts of getting the phase 1 prototype to work.

2. BACKGROUND

As previously mentioned, potentially injurious falls can be sustained for many reasons, including:

- Aging and its related effects.
- Weakness or diminished balance experienced during recovery from various health procedures.
- Illness/Dementia/Alzheimer's disease.

The website "about.com"[1] has published some data regarding fall rates and injuries. Based on a study done in 2003 by the Consumer Product Safety Commission (CPSC) regarding falling due to accidents involving consumer goods such as ladders, slips on bath tubs, tripping over electric cords etc. is common. Their data indicates that among people over 65 the leading cause of injury is falling. The Center for Disease Control (CDC) reported that in 2006 that the number one reason for that people over 45 visiting the emergency room was because of an unintentional fall. The National Safety Council (NSC) reports that, on average, 30,000 Americans over the age of 65 suffer injuries from falling per week, with about 250 of those resulting in death. Of the survivors, 20 to 30 percent sustain injuries that affect them for the rest of their lives. Furthermore, the NSC reports that 54 percent of all fall related deaths occur at home, with 20 percent occurring at institutions. The most common serious injury occurring from falling is hip fracture, with upwards of 24 percent of those people dying within a year, and 50 percent never regaining their mobility.

Some of the methods used to help prevent falls due to reduction of blood pressure upon standing include the following[2]:

- Behavioral modifications such as hand clenching, ankle pumps, and elevating/tilting of beds.
- Reduction of medications
- Pressure stockings.
- Modification/removal of environmental hazards, such as loose rugs, using safer furniture, installing grab bars in bathrooms, etc.
- Addressing gait impairment and loss of balancing skills. When a person's gait/balance is compromised, physical therapy can be used to help the person regain more effective mobility. Aids such as walkers and canes can also be introduced.
- Correcting loss of strength in muscles associated with mobility. Various exercises can mitigate the loss of strength and sometimes help the individual regain needed strength.

There exists a variety of technologies and services for helping people once a fall has occurred.[3] These include popular systems such as Life Alert, Medical Alert, and Mobile Help, and Walgreen's Ready Response. Typically these systems are implemented by
using a patient carried pendant that can be used to contact help.

As for systems that protect a person once the fall is initiated, there is an auto-deploying helmet for bicycle riders, the Hovding[4], see figure 1. This system appears to be fairly unobtrusive.

![Figure 1](image1.png)

**Fig 1:** The person in the image on the left is wearing an inflatable head protection system for bicycle riders. Note the black scarf-like garment around her neck. The person on the right's protection system has been deployed. It appears to provide good protection for the head and neck area.

Figure 2 shows another image of the same system. From the figure it can be seen that the developers have worked to make the system blend in with the user's apparel.

![Figure 2](image2.png)

**Fig 2:** This figure shows the auto-deploying bicycle helmet deployed, and blended with various styles of clothing.

Work done by Pennsylvania based Active Protective and Boston Device Development [5],[6] has a very similar goal and design as our system. They use a detection system that looks for "non-human natural" motion and deploy airbags to protect the hips in the event of a detection. Their literature says that they can deploy their airbags in 60 to 100 ms. The difference between this work and our work is that we want to combine this idea with that of the Hovding, and use a vital signs monitoring system to automatically call for help if needed. Figures 3 and 4, courtesy of the Boston Device Development website, show a human figure with their device, and a detail of the hip protection device.

![Figure 3](image3.png)

**Fig 3:** Here is a diagram of a female wearing the Active Protective device. On the left, un-deployed, center deployed, and to the right, it can be seen that the device protects the hip and femur area.

![Figure 4](image4.png)

**Fig 4:** This figure shows a close up of the Active Protective device un-deployed and deployed. Note that the air bags deploy to protect the pelvic region.

### 3. MOTIVATION AND APPROACH

As discussed earlier, injuries from unintentional falls are common. Preventative measures such as gait modifications, and physical therapy and beneficial, as is quick emergency like Life Alert, but neither of these can protect a person once the fall has begun. What is needed is a system similar to the Hovding auto-deploying bicycle helmet, but with modifications that protect the hip areas, as implemented by Active Protective. To further the utility of the system, it should be able to monitor the users vital signs and call for help if needed. The bullets below list the criteria for the system:

- The garment protects an elderly/sick or balance challenged person from a fall by sensing the fall and automatically deploying.
- The envisioned garment would be similar to an auto-inflating life vest worn by tournament fisherman. See figures 3 and 4.
- Another configuration could be similar to a belt and pair of suspenders.
- The shape of the garment when it was actuated would be such that it would protect the areas in which are most commonly injured from a fall.
  - Head
  - Hips
- The vest could be inflated by a CO2 cartridge or an Air soft CO2/green gas cartridge or compressed air cylinder.
When a person experiences a falling event, the system would rapidly auto-inflate, its shape that would protect their hips and torso. In order to protect a person from a fall the activation of the vest would rely on a combination of an accelerometer and distance sensors, to detect a sudden change in motion and the impending impact with the ground.

In order to accomplish the goal, a series of prototypes were planned. The first prototype was to be based on a commercially available auto inflating life jacket and an easy to use microprocessor such as an Arduino with the associated sensors. The goal of the first prototype was to integrate the fall detection system with the auto inflation mechanism. In the second prototype the garment is to be redesigned to protect the person's hips, torso, and head. In the second prototype, the software is to further developed to prevent false positive detections, and to integrate vital signs monitoring, so that once a fall event has happened, a call for help can be initiated. The third prototype is to refine the second in the areas of comfort and usability. Figures 5 and 6 show auto inflatable life jackets that are very common among sportsmen. They are presented here as a common example of auto-inflating protective gear, similar to what would be designed as part of the 2nd prototype.

3.1 Implementation

The system was broken down into 3 main components, the garment, the control system, and the monitoring/call for assistance portion. The student team concentrated on primarily the control system and a proof of concept garment.

3.1.1 Hardware

The control system consisted of an Arduino Uno USB Microcontroller Rev 3, paired with an Adafruit ±3g Triple Axis Accelerometer and Seed Studio Ultrasonic Range Finder. To help with debugging, a DF Robot LCD Keypad Shield for Arduino was also used. These components were attached to a suit vest and the whole assembly was placed on a mannequin (Marge) courtesy of the Southeastern Drama Department. Figure 6 shows the completed assembly on Marge.

In order to have somewhat consistent fall events, a fall simulation/test rig was constructed. Its purpose is to hold the mannequin and upon release, let the mannequin fall through an arc, similar to that of a person tripping, and most importantly provide a safe area for the mannequin to impact so that the various electronics would not be harmed. Figures 7 and 8 show the mannequin on
the test rig in ready position and in resting position, the position it would in after a fall.

Fig 7: This figure shows the mannequin with the vest on ready to be tested.

Fig 8: This figure shows the mannequin with the vest in resting position after it has fallen.

For this phase, the protective garment inflation system consists of a compressed air vessel made from copper tubing pressurized to roughly 100 PSI. An electronic valve, Water Solenoid Valve by Adafruit, releases the pressure when triggered by the microprocessor. A Victor 884 Speed Controller is used to amplify the signal from the microprocessor to electronic valve. In the next prototype the Victor will be replaced by a solid state relay. Figure 9 below shows the garment inflation apparatus.

Fig 9: This figure shows the garment inflation apparatus.

The "w" shaped copper tubing holds air pressurized to about 100 PSI. The gauge to the left of the apparatus indicates the pressure and provides a valve to introduce pressurized air. The white piece attached to the middle of the "w" is the electronic valve. It is attached to the Victor speed controller which is in turn connected to the Arduino processor (not shown in this figure).

3.1.2 Software
The software was written in C/C++ using the Arduino IDE. The initial version of the algorithm for phase 1 uses a simple loop that monitors the output of the accelerometer's 3 axis. If the output of the accelerometer exceeds .1 g (an acceleration value of about 2.2 mph), then the fall is detected. To help prevent false positives work was done on some versions of the software to utilize the ultrasonic sensor in order to detect impending impact with the ground. The pseudo-code below shows the general structure of the monitor loop:

```c
falling = false;
deploy = false;
dist1 = dist2 = get Ultra Sonic Range ();

while (sensing) {
    get Accelerometer Values Raw(x, y, z);
    convet2Gs(x, y, z);
    /* Look for acceleration indicating a fall. */
    if ((x > .1) || (y > .1) || (z > .1)) {
        if (!falling) {
            falling = true;
        }
        /* If the ground is getting nearer, deploy. */
        dist2 = get Ultra sonic Range();
        if (dist2 < dist1) {
            deploy = true;
        } else {
            dist1 = dist2;
        }
    }
    if (deploy) {
        open Valve();
    }
}
```

4. RESULTS
The system successfully detected falls when released in the test stand. It was tested by lowering by hand in the stand slowly and by dropping and letting it hit. When lowered slowly, the system did not trigger the garment, which for these tests was a balloon. When dropped the valve opened and inflated the balloon well before the mannequin hit the landing area of the test stand. The sensitivity of the system was tuned by altering the constants in the "if" statement that detects the fall. For
the final demo, these contents were changed to values between 0.3 and 0.5. The values were arrived through experimentation. These tests were done successfully in the lab, videoed, and done for the class presentation.

5. CONCLUSIONS AND FURTHER WORK

This phase of development has accomplished the initial goals of the putting together a basic working prototype, a proof of concept. Phase 2, as discussed earlier, will concentrate on creating a system that can actually protect the mannequin, and successfully handle jostling and jolting events that are common when people are in social occasions and in everyday life settings.

In similar work both Jay Chen[7] et al. and Ning Jia[8] present methods with accelerometers that effectively filter false positives. One of the main differences between our system and theirs is that we use an ultrasonic sensor to actively look for the ground. Their methods, especially that of Jia, have direct application to our work in that he uses the same accelerometer that is used in phase 1. While these works are significant, their goal is one of detection and reporting.

The primary contribution of the work described in this paper is that it's goal is to not only detect a fall, but to help mitigate injury caused by the impact of a fall, like that of the Active Protective device and the Hovding device. This work's goal is to protect the user's hip and cranial area from injury due to an impact, and once an impact has occurred, Phase 3 work will work assess the condition of the user and call for help if needed.

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REFERENCES


