Detection of Humans Carrying Concealed Objects

Jeremy Webb
Yang Ran
Dr. Rama Chellappa

Abstract:

Computer vision methods for detecting humans carrying concealed objects on an ankle or around the midsection were studied. Data was collected, tested and a computer vision system was developed to "see" changes in human gait as a result of concealed objects. It was determined that concealed objects that affect the geometric symmetry in human gait can be recognized by this computer vision system. This work has applications in video surveillance. In particular, the use of computers to recognize individuals carrying concealed objects.

Introduction

It is possible to detect individuals carrying concealed objects using computer vision techniques. This report will show that clues into the presence of concealed objects can be found by looking at the double helical signature of a human's gait. The concealed objects studied where placed on the ankle and around the midsection. An individual's double helical signature can be found from a video sequence using a technique explained in this report. It will be shown that concealed objects that create a geometric asymmetry in human gait can be universally detected. Other objects may be detected with the knowledge of the individual's normal gait but as data shows that this not reliable. This report will go though a process for detecting concealed objects, the results from data collected, and a conclusion based on the data.

There are several difficulties in detecting concealed objects from a person's gait. People do not always walk in the same way from day to day or throughout the day. Different footwear and other factors can affect a person's gait. Different individuals will compensate in different ways to loads. Furthermore, more athletic individuals often will have very little change in there gait for a given load compared to someone who lives a more sedentary lifestyle. Difficulties that are inherent to computer vision are the effects of background clutter and viewing angles. These difficulties must be overcome in order to detect concealed objects using computer vision and analysis of the human gait.

The ability to detect individuals carrying concealed objects would be valuable in security and video surveillance. It is possible to see small changes in human gait with computer vision that would otherwise go undetected. It is difficult for the human eye to detect small changes in the human gait. We have trouble seeing these changes because details from moments before are forgotten and therefore are not compared to present visual information. As a result small differences from one step to another go unnoticed by an observer. With computer vision it is relatively easy to compare different steps and see small gait changes. Security officials using video surveillance could use computer vision to see things that they would otherwise be unable to see. This would improve there effectiveness significantly. Computers have the benefit of doing things faster than humans which improves efficiency. This work has implications in the ongoing effort to develop computer vision, especially for use in the security and video surveillance fields.

Concealed Object Detection Methods

The problem of detecting concealed objects was tackled by creating techniques for analyzing data collected. The data collected consisted of many video sequences with the help of several individuals. For simplicity, the participants walked orthogonal to the camera for all the video sequences used in this study. Data was collected by having the participant first walk weightless back and forth in front of the camera. Then a load was attached to the individual and he/she would again walk back and forth in front of the camera. This would provide 2 weightless sequences and two loaded sequences. If many different loads were to be studied more weight would be attached to the individual and he/she would again walk back and forth in front of the camera. Only two weightless sequences where taken for an individual each time data and video was collected.

For the study of concealed objects on the ankle three participants where used to look into the effects of a five and ten pound load. This data was collected in front of the Computer Science Instructional Center on the University of Maryland Campus. Seven individuals participated in the 15 pound ankle load test. The data for a 15 pound load was collected on two different occasions. The three individuals who participated in the five and ten pound ankle load experiment also participated in the 15 pound experiment. The data from these three individuals was collected at the same time. The four other participants in the 15 pound ankle load experiment were filmed inside the lobby of the Jeong H. Kim Engineering building on the University of Maryland campus.

For the study of midsection concealed objects two participants were filmed outside in front of the Computer Science Instructional Center. Ten and 25 pound loads were attached around their waists with fanny packs. A common book bag with a 25 pound load was also used in this experiment. Two slow walk sequences were collected for each of the two participants in this experiment.

The only difficultly encountered in collecting data came with a series of video sequences collected in a new indoor location. The weightless sequences had significant geometric asymmetry in the gait of both participants. This data was thrown out and not considered for this project. When new data was collected it came out as expected with little geometric asymmetry in the weightless case.

A double helical pattern from the participants gait was found for each video sequence. The double helical pattern is a pictorial representation of the gait over time. Video is a collection of many images and frames displayed rapidly enough to trick the mind into thinking that there is motion. For every frame a horizontal line was taken out. All of the horizontal lines, or slices, from a video sequence were then placed one on top of the other to form an image of the double helical pattern. The slices were taken about knee level. It was determined that the lower on the leg the slice is taken the better because there is more displacement of the leg the farther from its pivot point, hip and knee. If the slice was taken too low the feet would clutter the double helical pattern. See Figure 1 for a pictorial explanation.

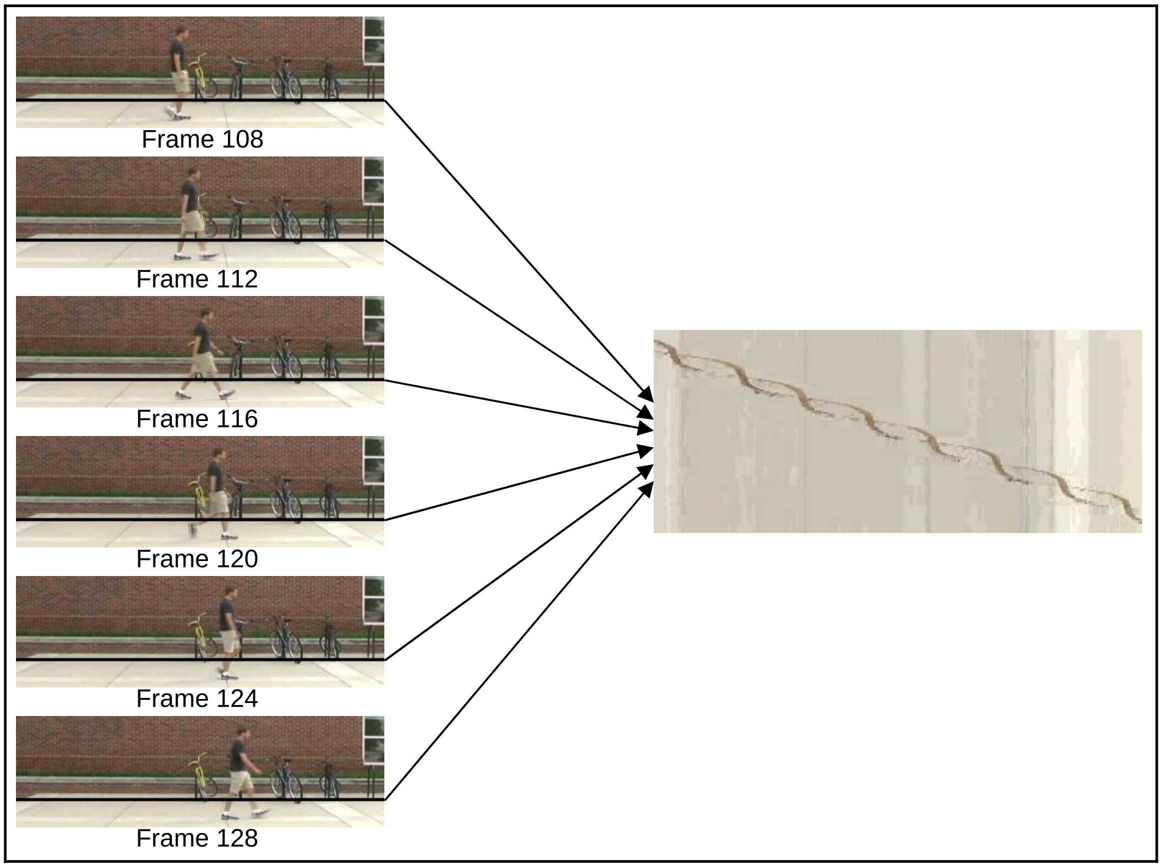

Figure 1. The building of a double helical pattern

In this study the image of the double helical pattern was the heart of the gait analysis. The double helical sequence is a representation of the gait in which time is represented on the y-axis. The top portion includes the first frames of the video sequence; therefore, if a time scale was implemented t = 0 would be on the top of the image. The x-axis is length. (See Figure 2.) The main interest of the double helical pattern was to measure the step time and step length of each step. This was done by measuring pixels in Microsoft Photoshop. As illustrated by Figure 2, the crossing of the curved lines in the double helical pattern was used as points of reference in making these measurements. Step length and step time were analyzed in the study of human gait for the purpose of detecting concealed objects.

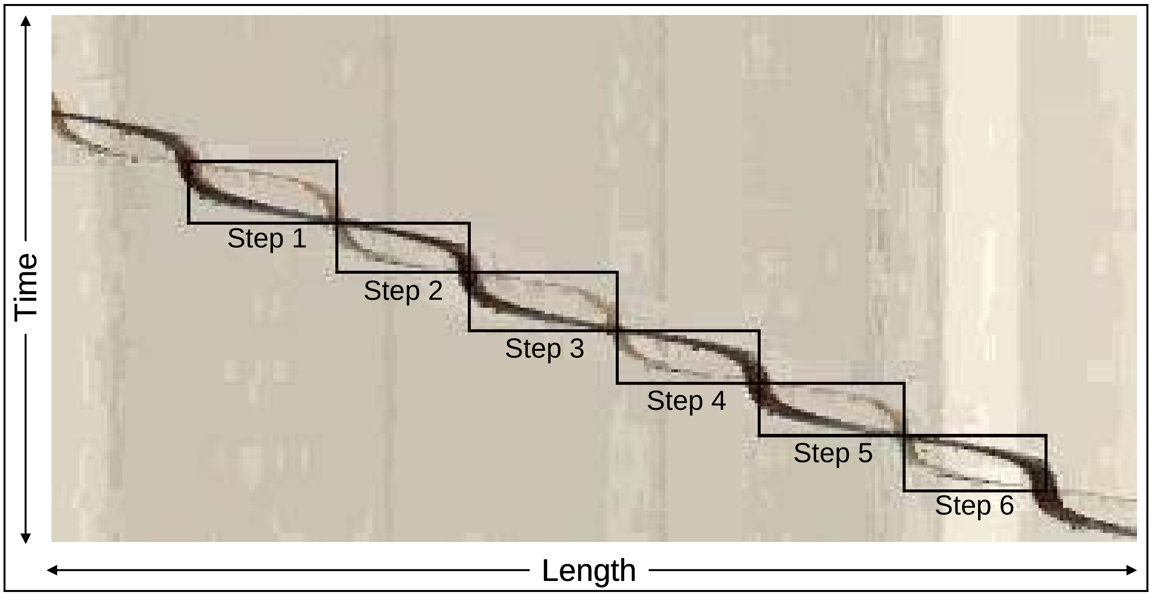

Figure 2. Double helical pattern created from a video sequence.

Geometric Asymmetry

In this study a sufficiently heavy ankle weight would result in an asymmetry of the human gait. This asymmetry is quantified by averaging the odd and even steps and then comparing them. The following equation is used in the comparison.

$$\text{Percent difference} = \left(\frac{odd - even}{odd + even}\right) * 100$$

Both the step length and the step time where compared. If the percent difference was significant it is reasonable to assume that some external force is altering the gait, a concealed object. It should be noted that since different steps were compared the scale used to measure step length and step time is not critical.

Geometric Symmetry

For objects that do not alter the geometric symmetry of the gait, detecting concealed objects is much more difficult. It becomes necessary to look at deviations from an individual's normal gait. For this the individual's identity and normal gait must be known. The step length and the step time of the individual's normal gait are compared to the step length and step time in the sequence in question. It is assumed that the normal gait does not change but remains constant. This assumption is the basis for human gait recognition.

Results

Concealed objects on the ankle, geometric asymmetry

It can be seen in Figure 3 that a 15 pound ankle load is enough to cause a significant geometric asymmetry in the gait. Figure 3 shows the 14 weightless and 14 loaded sequences from seven individuals. The sum of the asymmetry of the step time and step length for each data point averages to 3.3 percent in the weightless case and 11.7 percent with a 15 pound load. The difference is 55.6 percent. There is a distinct separation between the bulk of the weightless points and the 15 pound load points. It should be noted that the two closest loaded points, the points on the y-axis, did not come from the same individual. There are three weightless data points that should be questioned. A look at the data for each individual step reveals that for two of the points the first or last two steps in the sequence were unlike the steps in the middle of the sequence. This resulted in skewed data for the whole sequence.

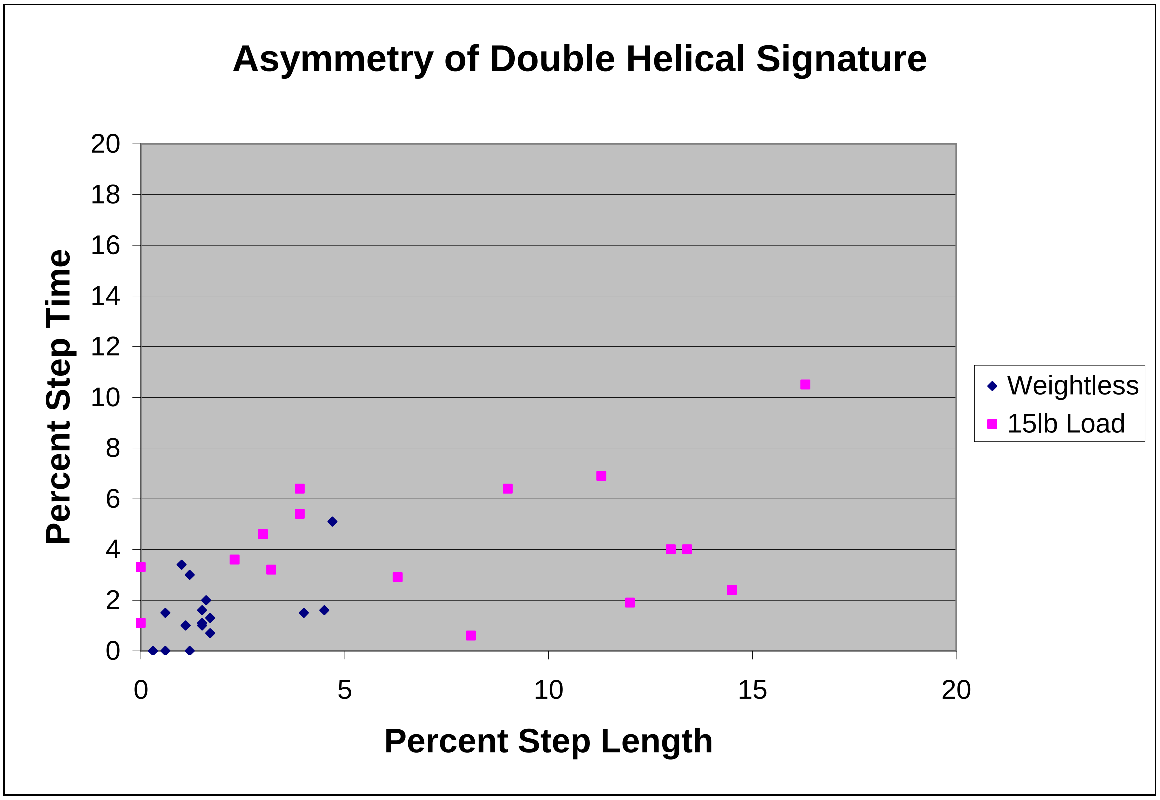

Figure 3. Asymmetry of Double Helical Signature for a 15 pound ankle load

Figure 4 is the result of excluding the first two steps from one of the questionable data points and the last two steps from another questionable data point. By excluding the bad data the average of the sum of the asymmetry of the step time and step length for each data point drops to 3.1 percent. The difference between the asymmetry of weightless and 15 pound load increases to 58.1 percent. One weightless data point corrupts this number. This data point was donated by an employee of the University of Maryland after a long day of standing and moving around. It can be seen that the difference in geometric symmetry for weightless individuals and individuals carrying a 15 pound ankle weight is explicit.

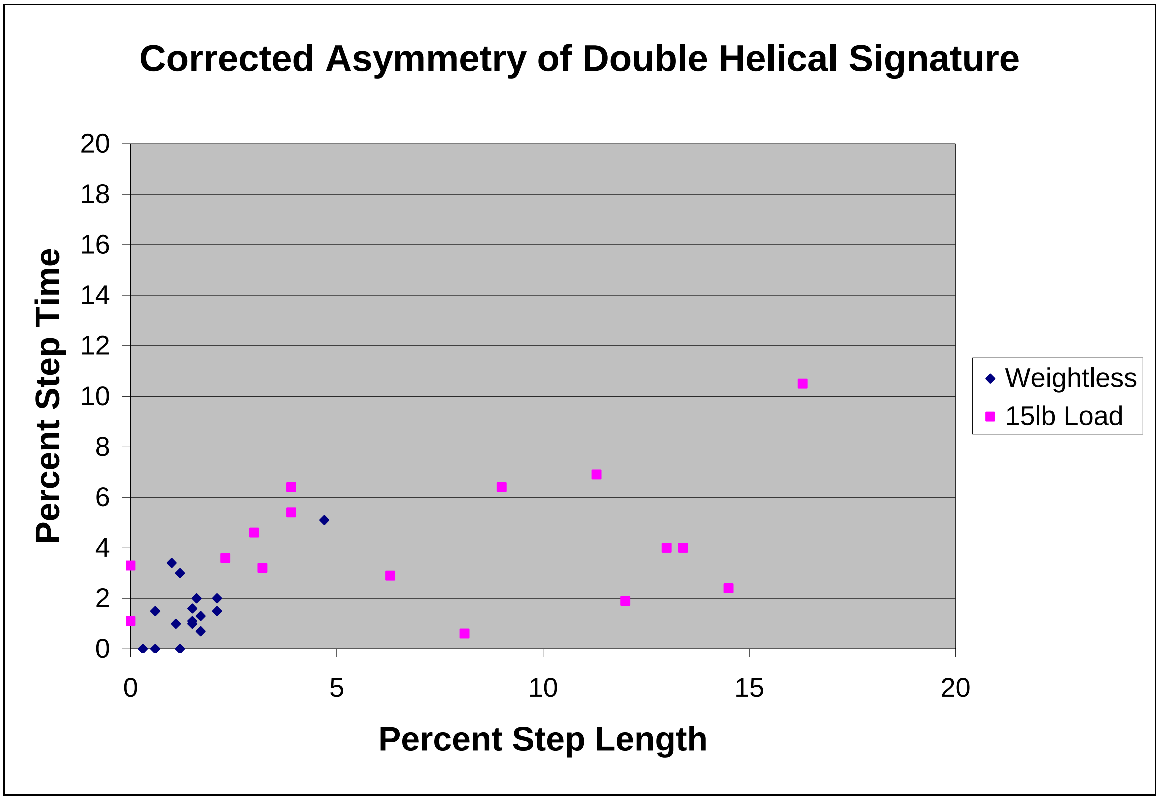

Figure 4. Corrected Asymmetry of Double Helical Signature for a 15 pound ankle load

The geometric asymmetry caused by a five pound load attached to the ankle is very slight. The geometric asymmetry is close to that of the weightless case. This is illustrated in Figure 5. It is interesting to note that the two points farthest from the origin are not from the same individual. The three 5 pound load sequences that are farthest from the origin are all from different individuals and it is their first sequence with the weight. The average of the sum of asymmetry from step time and step length is 2.8 for the weightless case and 3.9 for the loaded case. The difference is 16.3 percent. This number is misleading considering that each of the individuals had little gait geometric asymmetry on their last 5 pound load sequence. All of the data points are intermingled and there is not any clear separation between the gait geometric symmetry for the weightless and loaded sequences.

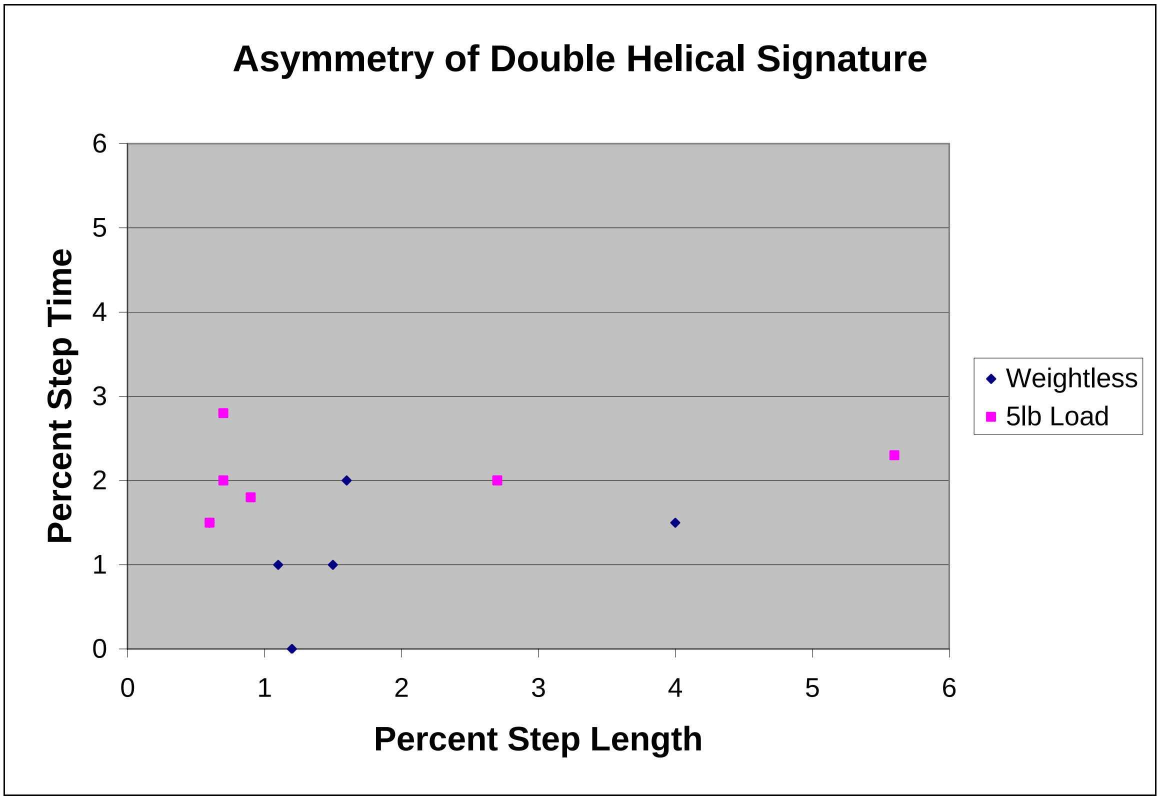

Figure 5. Asymmetry of Double Helical Signature for a 5 pound ankle load

The difference in geometric asymmetry between weightless individuals and individuals carrying a 10 pound ankle load is greater than it is for a 5 pound load. (See Figure 6.) The average sum of step time and step length for a 10 pound load increases to 7.1 percent. This gives a difference of 43 percent between weightless and loaded. This number seems significant but there are a significant number of 10 pound load sequences with gait geometric symmetries similar to the weightless case. It should be noted that for each 10 pound load point that lays a significant distance form the origin, it has a pair, data taken from the same individual, which is intermingled with the weightless points. The three points farthest from the origin are the second of the two 10 pound load sequences for each of the individuals.

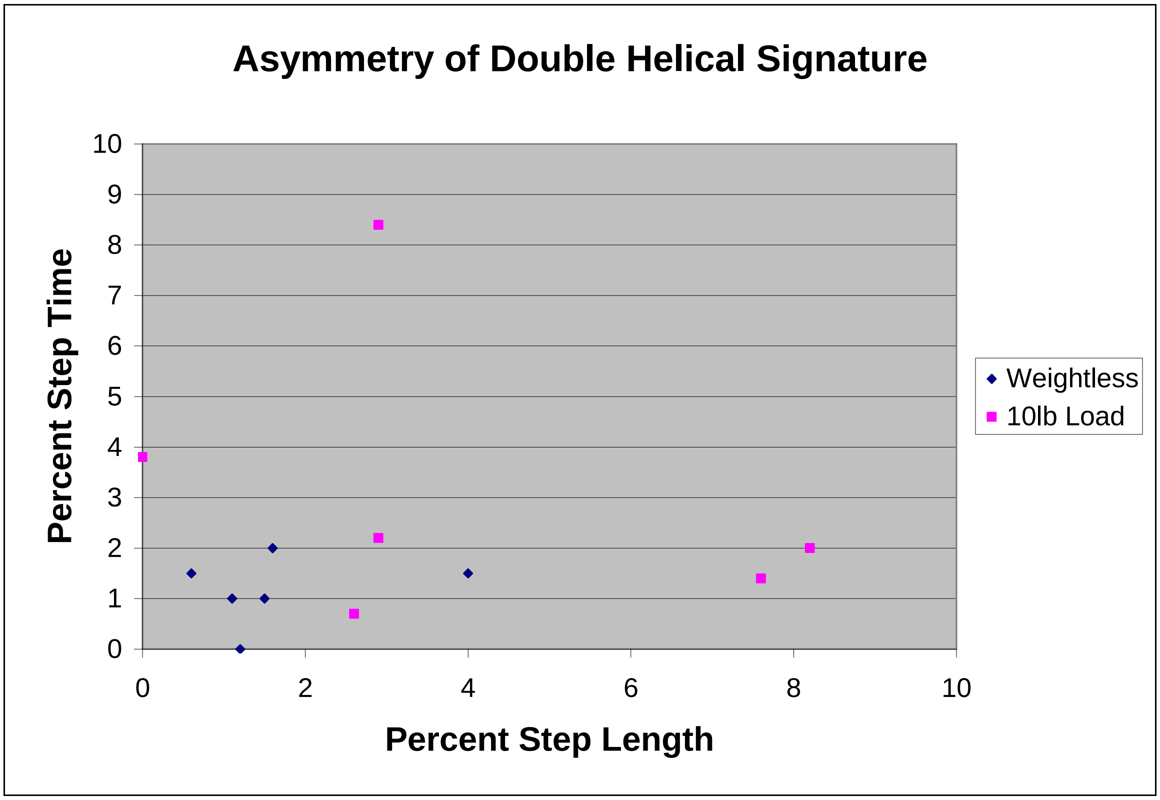

Figure 6. Asymmetry of Double Helical Signature for a 10 pound ankle load

Concealed objects around the midsection, geometric symmetry

Figure 7 is a plot of the step length and step time of an individual with a variety of loads attached to the midsection. The individuals weightless and slow walk step length and step time are also included in Figure 7. It should be noted that all of the weighted points are between the two points that represent normal gait. For the individual represented in Figure 7 there is no significant change in gait under the loads tested. In this case the slow walk sequence is of no consequence.

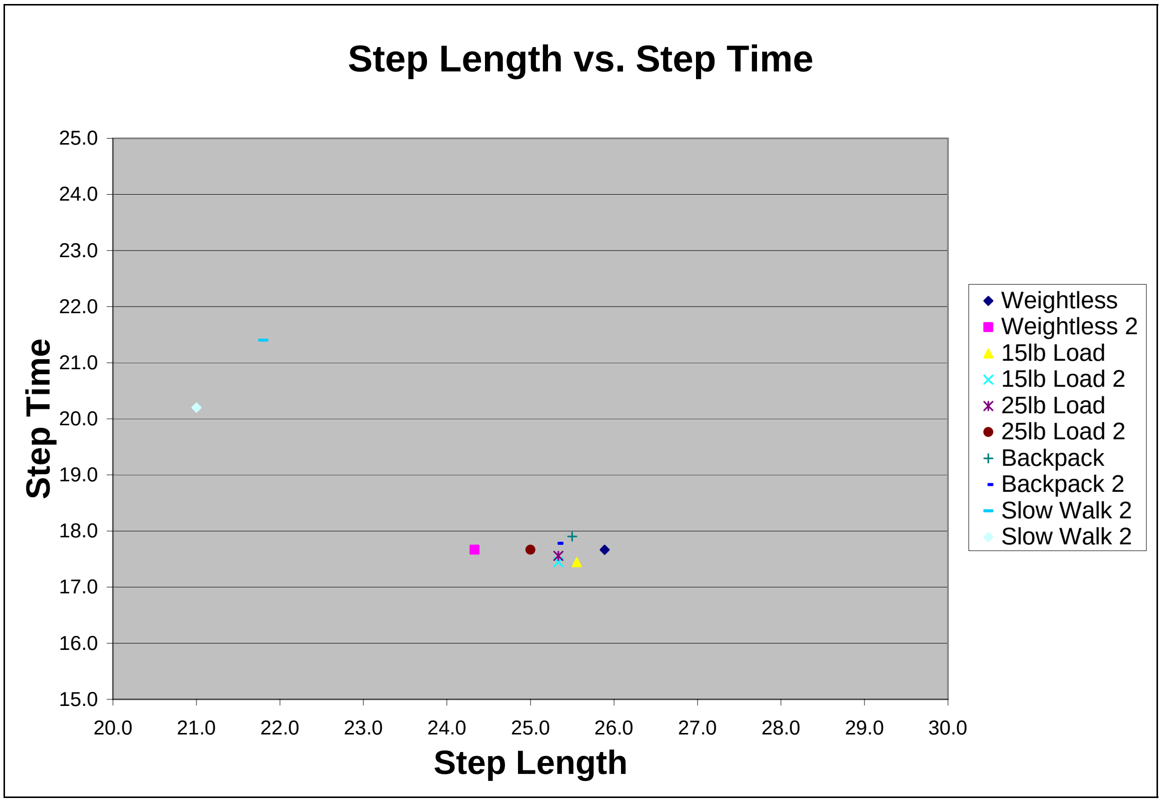

Figure 7. Weight Secured Around the Midsection for One Participant

Figure 8 is a representation if a second individual's gait. This gait is shown with the individual weightless, slow walking, and under different loads. The step time and step length are again plotted. The load that had the greatest effect is the 25 pound load suspended on the midsection by fanny packs. The 25 pound backpack produces the least impact on the individual's gait. It should be noted that the step length and step time of the slow walk sequence and the 25 pound fanny pack load are similar. For this individual all of his loaded data roughly falls on a line from the weightless case to the slow walk case.

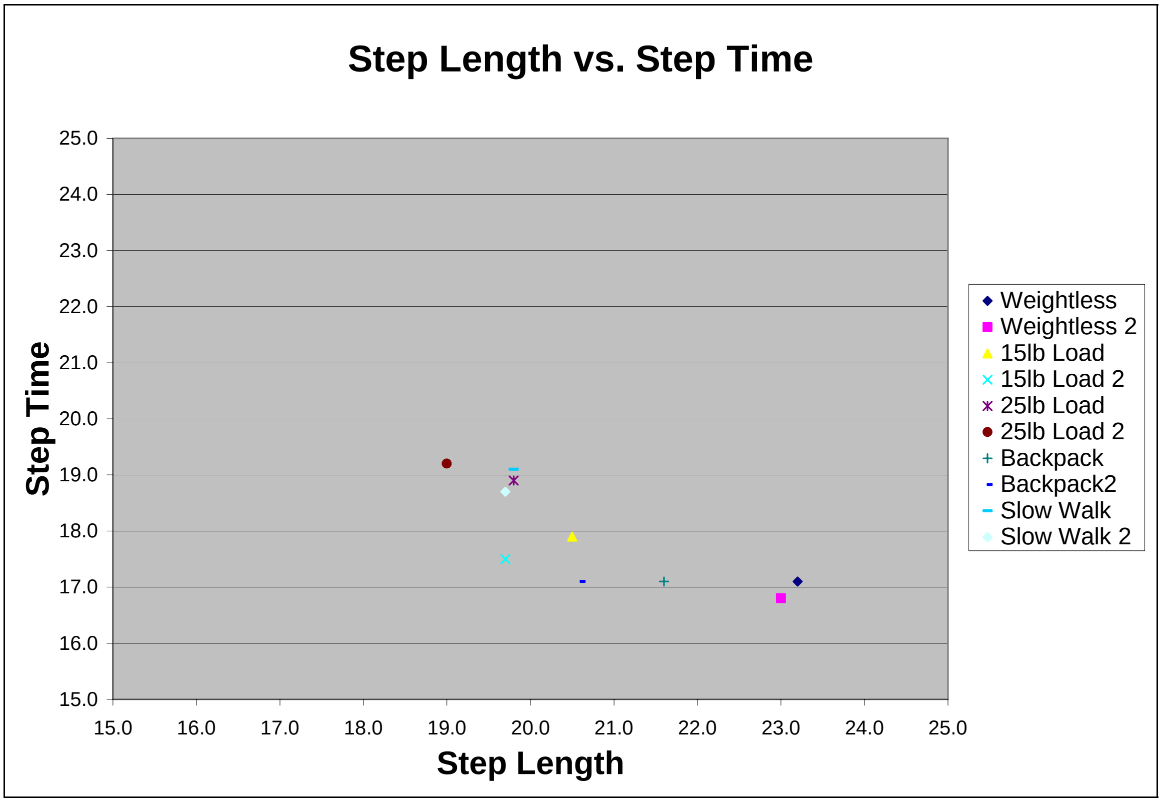

Figure 8. Weight Secured Around the Midsection for a Second Participant

Discussion

Concealed objects on the ankle

Detection of concealed objects on an individual's ankle has proven to be a simple task after building a double helical pattern and measuring the step time and step length. Since gait geometric symmetry is used to detect concealed objects this process applies for all individuals. One of the initial assumptions was that different individuals would respond to loads in different ways and this proved to be correct. It can be seen that some individuals respond to loads differently than others, but if the load is sufficiently heavy the geometric symmetry of the gait is lost and this can be detected. It is shown that for a load of at lest 15 pounds all of the individuals who participated in this study where unable to maintain geometric symmetry of there gait. For a load of 10 pounds reliable detection proves to be difficult. It is interesting that for all the individuals who participated in the 10 pound ankle load test displayed more geometric asymmetry of there gait on the second sequence than the first. Perhaps after an individual carries this load long enough to fatigue reliable detection would be possible. It can be seen from the data that for a load less than 10 pounds, 5 pounds was tested, the normal gait is not altered in any significant way. In fact, the data shows that the gait geometric symmetry of the individuals studied improved after carrying a 5 pound load for one sequence.

Concealed objects around the midsection

Detecting concealed objects around the midsection from the gait has proven very difficult. For one individual there is no change in normal gait when a load is attached the midsection area. For the second individual there are clear changes in normal step time and step length when carrying concealed objects on the midsection. Perhaps the loads used in the test are not sufficiently heavy for the first individual. Any of the changes in gait as a result of the midsection loads used are very similar to the changes in gait resulting from deliberately walking slowly. With the assumption that normal gait will not change this is not a problem. The main difficultly in detecting concealed objects in the midsection area is the need to have prior information on the individual's normal gait.

Conclusion

Through this study it can be seen that concealed objects that result in a change in the geometric symmetry of the human gait can be reliably detected. Changes in geometric symmetry are a result of imbalances in the legs caused by objects attached to the ankle. This would also apply to concealed objects attached to the foot. The data shows that a load of 15 pounds causes a disturbance in the geometric symmetry that can be easily seen with computer vision techniques. These disturbances however are often times very difficult for an observer to see. The human eye lacks the ability to remember images from moments before and compare them to new images. As a result small changes in step length and step time from one step to the other are often invisible to the unassisted eye. Using the computer vision technique from this study it is possible to create a picture that clearly illustrates geometric symmetry in the human gait. The technique has the benefit of working with most subjects without having to identify them or knowing anything about their gait.

Reliable detection of concealed objects around the midsection of individuals proves very difficult because there is no change in the geometric symmetry of the human gait. This was expected, but even the step length and step time of the gait was not reliably altered with loads up to 25 pounds. Perhaps with heaver loads detection of these concealed objects could be reliable, but knowledge of the individual's normal gait is still needed. Because of this easily implementation is lost.

With the knowledge gained from this study it can be seen that detection of concealed objects which result in geometric asymmetry of the human gait can be reliably detected. The implications of this in video surveillance and security are significant. Video surveillance and security efforts can be made more efficient and effective. Computer vision has the ability to detect things that an observer would miss. Further work should be done into automating the process by which the double helical pattern is built and then measured. Algorithms for building the double helical pattern on individuals walking at angles relative to the camera should be studied. With further work on this problem a system could be created that would reliably detect the variety of concealed objects that alter the geometric symmetry of the human gait. These concealed objects could include shoe bombs and other deadly objects.

References

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