Final DREU Report

Blind people are more susceptible to being obese than sighted people [1,4,11], which increases risks of medical conditions like heart disease, high blood pressure, or diabetes [13]. Though physical activity is an effective way to prevent these medical conditions, blind people are less likely to exercise compared to their sighted peers [2,3,7]. Those mainstream exercise classes and exercise classes in school provide opportunities for physical activity, they are inaccessible to blind individuals. In prior work, Rector et al. utilized Microsoft Kinect's body tracking to produce and evaluate a personalized yoga system for blind people [8,10]. However, group-based aerobic exercise (AE) are still inaccessible for blind folks. Rector et al. discovered that blind people want technologies that assist in exercise classes [9], which should be portable and not intrude the exercise class as much as possible. It is essential to produce technological solutions that enable blind people to actively participate in AE classes.

Related Work

Exercise and Exergame Research for People with Visual Impairments

I cover three studies that have been conducted involving exergames (or exercise games) designed for people with visual impairments and they have determined to be a useful way to encourage physical activity; however, they have also indicated some shortcomings.

In VI-Tennis [5], participants played a virtual game of tennis based on Wii Sports Tennis with no display and sent input to the game by swinging a motion-sensing controller in tennis like manner. They evaluated two versions of VI-Tennis with children with visual impairments: (1) a game that implements only haptic cues and (2) a game that supplied both auditory and haptic cues. They found that VI-Tennis encouraged physical activity. The average energy expenditure (AEE) was determined to be 16.9 kJ/min ($s = 7.4$). According to the United States Center For Disease Control, participants in the study on average were able to achieve enough physical activity to be considered healthy for adults, but not enough to be considered healthy for children.

While the study was successful, the researchers uncovered limitations with VI-Tennis. Players were using their dominant arm, which leaves the possibility that more physical activity is possible if a player uses more of their body. Errors were also a major issue. The game did not penalize players for swinging too early so if a swing happened in the required period, the player would be able to hit the ball. For players who wished to do well but did not understand the required timing, this resulted in players just constantly swinging. Though this technique caused physical activity, it did not make the game enjoyable. People should engage in physical activity over an extended period to have it be meaningful. A game that players can win by swinging constantly would not have replay value and therefore may not be the best choice when advocating for physical activity.

In VI-Bowling [6], participants played a virtual game of bowling based on Wii Sports Bowling by sending input to the game via a motion-sensing controller. Players mimic a bowling motion and the game would certify the player's throw. When developing a game like this, a challenge was showing the player the location of the pins. To compensate for the lack of display, the researchers developed a technique called tactile dowsing to indicate where the pins were located so that a player could aim in the right direction. Tactile dowsing varied haptic pulses in a Geiger counter like manner to illustrate the location of the bowling pins. Players were able to use tactile dowsing successfully, which demonstrated the players' ability to adapt to various kinds of haptic cues. The researchers evaluated VI-Bowling with adults with visual impairments and produced an AEE of 4.61 kJ/min (s = 1.62).

One flaw with bowling was the self-paced nature of the game, which enabled players to take their time and aim correctly; however, it also affected their energy expenditure. Though this closely followed the real game of bowling where players can take as time as needed, it may have harmed the physical activity.

To promote physical activity for people with visual impairments (VI), researchers created a game called Pet-N-Punch, which is a VI accessible version of a game similar to the game Whack-A-Mole. There was no graphic interface and players interact with the game via sounds and vibrations. Two modes of play were available, one where a player holds a hammer in each hand, and another with one hammer held in the player's dominant hand. Players were instructed to help a farmer get rid of rodents in their farm by smacking them on the head with their hammer(s) which were motion-sensing controllers. Players were alerted to the presence of rodents in two ways: (1) vibrations in the controller, and (2) the sound of a rodent. To prevent players from swinging wildly, cats were also present in the playing fields and players were penalized if they hit cats on the head.

To determine the accuracy of a game using both arms when compared to a game using the dominant arm, researchers calculated the success rates. The success rate is the number of correct motions executed divided by the total number of required motions. The data (Figure 3) represents the difference between the success of the dominant arm versus the two-arm version of the game. A Wilcoxon signed-rank test indicates a significant difference (Z 2; 12 = 2.325 $p < 0.05$) in the decline between the two modes, which enables the researchers to accept the null hypothesis. The research team used a Wilcoxon signed-rank since it reflects that the average success for the two-arm version was lower consistently.

Research Group's Prior Work

We discuss the game of Virtual Showdown, Eyes-Free Yoga, and a study that explored the potential of technology to improve exercise for blind people or people with visual impairments by utilizing Value Sensitive Design (VSD).

Virtual Showdown

The objective of Virtual Showdown, which was modeled after Showdown, which is an accessible version of air hockey. It is a game for youth where participants use a Kinect to track their body movements. Rector et al. conducted a user study with 34 youth, and they played the game with verbal and verbal/vibration scaffolds. Participants had a higher overall score in the Verbal Scaffold than the Verbal/Vibration Scaffold ($t = 2.28$, $df = 33$, $p < 0.05$). The overall mean score in the Verbal Scaffold was 35.76 while the overall mean Verbal/Vibration Scaffold was 32.53. The participants who experienced Verbal/Vibration first improved the Final Score once the vibration hints were removed. The mean Verbal/Vibration overall score was 31.88 while the mean Verbal Final Score was 37.59.

Eyes-Free Yoga

Yoga classes are generally inaccessible to people with visual disabilities. Eyes-Free Yoga teaches yoga to people with visual disabilities. Eyes-Free Yoga has four workouts of different lengths. All sequences and the verbal scripts describing every pose were produced with the help of one yoga instructor to ensure a proper workout [12]. Eyes-Free Yoga incorporates the work of several yoga instructors and motivates people with visual disabilities who are inexperienced with yoga to continue practicing yoga in the long-term. This resulted in positive experiences in both the learning phase and for the long-term according to the studies. The experimental design and qualitative data supported the positive impact of an improved version of Eyes-Free Yoga. Eyes-Free Yoga has shortcomings, such as not having the ability to track whether the person is experiencing pain or track the person's breathing. Since injury prevention was essential, the game had to remind throughout the gameplay about doing things Kinect could not detect.

Exploring the Opportunities and Challenges with Exercise Technologies who are Blind or Low Vision

People with visual impairments may have more difficulty participating in exercise due to lack of experience or inaccessibility. Rector et al. [9] utilized Value Sensitive Design (VSD) to explore the potential of technology to improve exercise for people with visual impairments. They conducted 20 semi-structured interviews about technology and exercise with 10 people with visual impairments and 10 people who facilitate fitness for people with visual impairments. Also, they conducted a survey with 76 people to learn about outside perceptions of exercise with people who are low vision or blind. Based on the survey and interviews, they discovered opportunities for development in technology in four key areas: 1) mainstream exercise classes, 2) exercise with sighted guides, 3) rigorous outdoor activity, and 4) navigation of exercise spaces. Design considerations must include how and when to deliver haptic or auditory information based on context and exercise, and whether it is acceptable to create fewer mainstream technologies if they improve mainstream exercise.

Developing an algorithm to help People with Visual Impairments in Aerobic Exercises using a Sensor Mat

The first step to developing an algorithm that gives feedback on aerobic exercises to people with visual impairments is to determine how to detect one's feet on a sensor mat. Our goal is to determine the best configurations for *template matching* to detect one's feet on a pressure sensor mat. I evaluated different template matching approaches to assess the accuracy, precision, and recall for:

1. different template matching methods
2. different types of shoes (athletic or not)
3. different types of datasets (whether they included contour edges or not)
4. different types of templates (whether the template was a single image or combined across multiple images).

Testing Methodology

I evaluated the effectiveness of identifying feet on a sensor mat using:

- Six template matching methods: TM_CCOEFF, TM_CCOEFF_NORMED, TM_CCORR, TM_CCORR_NORMED, TM_SQDIFF, and TM_SQDIFF_NORMED
- Three types of shoes – with 50 black and white photos for each dataset
  - "original" shoe template and dataset of 50 black and white photos
  - (fitness-related) "shoe 1" template and dataset of 50 black and white photos
  - (fitness-related) "shoe 2" template and dataset of 50 black and white photos
- Two types of footprint coloring
  - A template and dataset that had edge detection to highlight contours of 50 black and white photos
  - A template and dataset with fully colored footprints of 50 black and white photos
- Two types of templates
  - Single footprint image
  - Combined shoe template from 50 images

Quantitative Results

Overall Effectiveness of each Template Matching Method

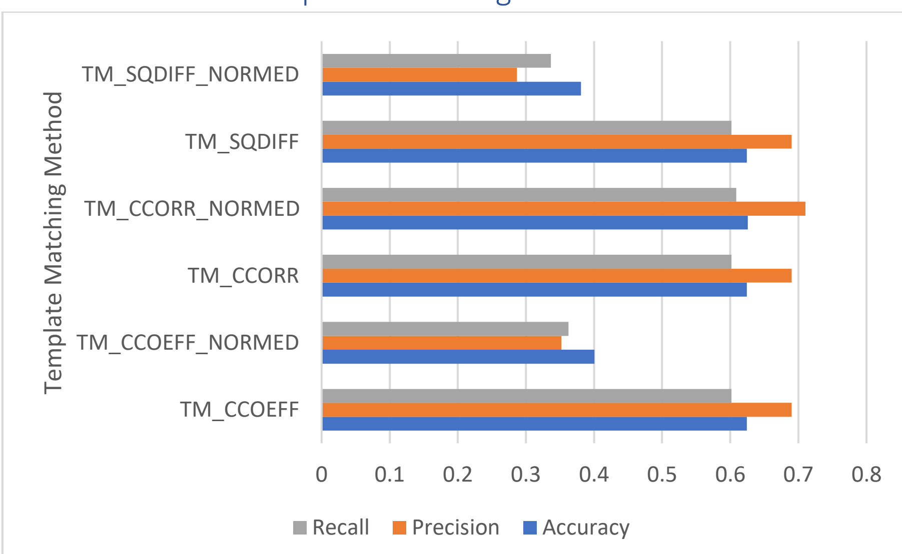

Figure 1: Overall Effectiveness of each Template Matching Method

Overall, using this template matching method, TM_CCORR_NORMED, produced the best results in terms of accuracy, precision, and recall. The accuracy, precision, and recall of TM_CCORR_NORMED averaged across all tests were 0.625964, 0.710163, and 0.608913, respectively.

Overall Effectiveness of each Shoe Type

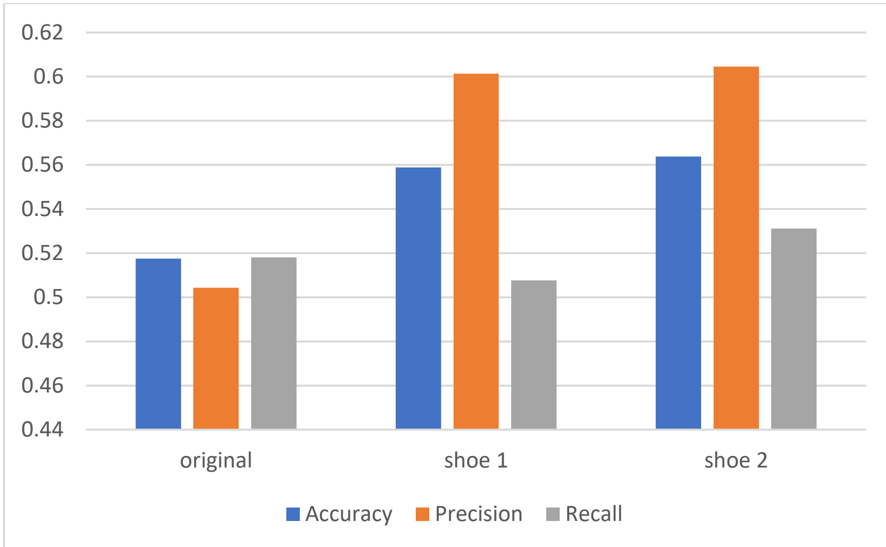

Figure 2: Overall Effectiveness of Every Shoe Type

Overall, shoe 2 performed the best regarding accuracy, precision, and recall. The accuracy, precision, and recall averaged across all tests of shoe 2 are 0.563726, 0.604575, and 0.531121, respectively. The original shoe overall performed the worst in terms of accuracy, precision, and recall. The accuracy, precision, and recall averaged across all tests of the original shoe template were 0.517516, 0.504314, and 0.518153, respectively. Shoe 1 overall performed the second strongest compared to shoe 2. The accuracy, precision, and recall averaged across all tests of shoe 1 were 0.558823, 0.601307, and 0.507675, respectively.

Overall Effectiveness of each Footprint Coloring

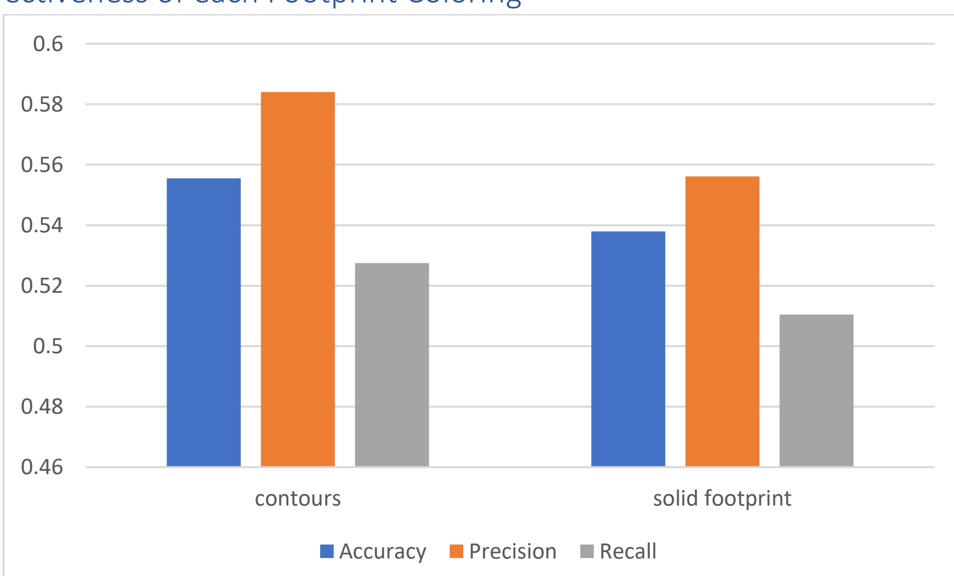

Figure 3: Overall Effectiveness of each Footprint Coloring

Overall, using edge detection was more beneficial than not using edge detection in all shoe templates since the accuracy, precision, and recall were higher for using edge detection. The accuracy, precision, and recall averaged across all tests using edge detection were 0.555474, 0.58403, and 0.52753, respectively. The accuracy, precision, and recall averaged across all tests using no edge detection 0.537903, 0.5561, and 0.510436, respectively.

Overall Effectiveness of each Template Type

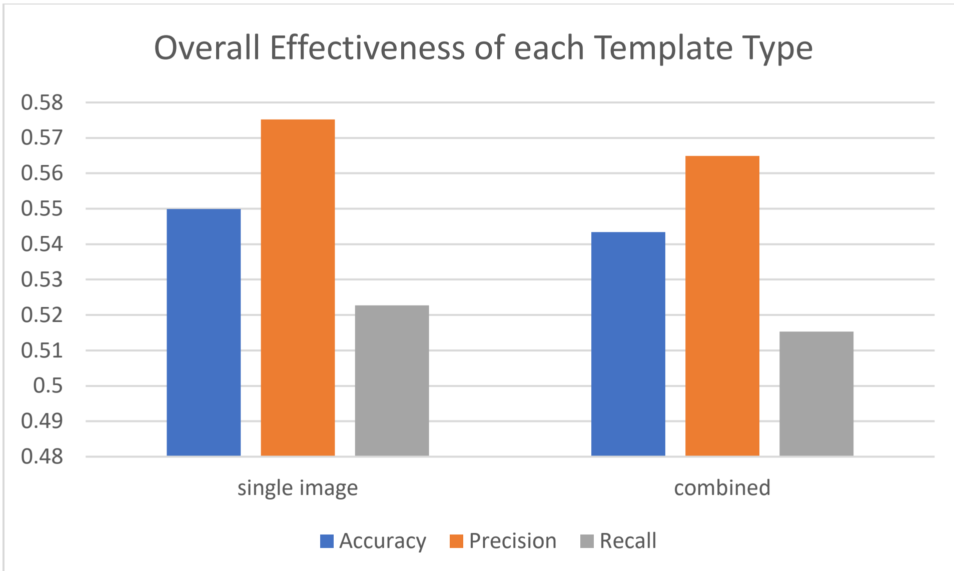

Figure 4: Overall Effectiveness of each Template Type

Overall, using a single image template was more beneficial than using a combined image template since the accuracy, precision, and recall was higher for using a single image template. The accuracy, precision, and recall averaged across all tests using a single image template were 0.549929, 0.57524, and 0.522687, respectively. The accuracy, precision, and recall averaged across all tests using a combined image template were 0.543448, 0.564891, and 0.515279, respectively.

Summary

Based on the test results, we recommend using the TM_CCORR_NORMED template matching method, athletic shoes with clearer arches, edge detection to highlight contours of the shoe, and use a single image as a template.

Software Development

The final portion of the DREU experience included developing software to analyze the footprints to indicate if someone was properly completing a step aerobics workout. I added these software features using an example of someone stepping onto the mat:

1. Printing whether the mat detected no feet, right foot, left foot, or both feet in near real-time
2. Importing the prescribed steps that someone takes to step on the mat

a. 1500ms, No feet
b. 3000ms, Right foot
c. 4500ms, Both feet

3. At the timestamps (e.g., following a music beat), determine whether the person's detected feet match the prescribed workout.

These software features will help the research team continue the system implementation and eventual user testing with people with visual disabilities.

References

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Appendix

Below are the results of each test conducted.

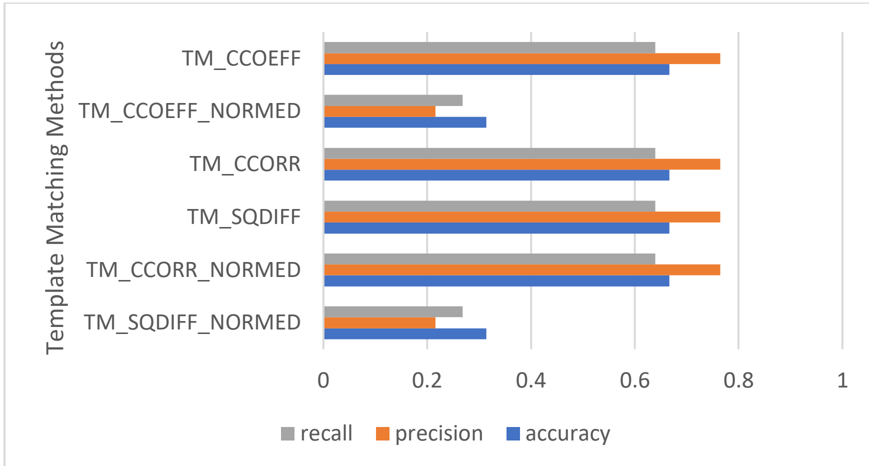

Figure 5: Edge Detection and Combined Shoe Template for Shoe 2

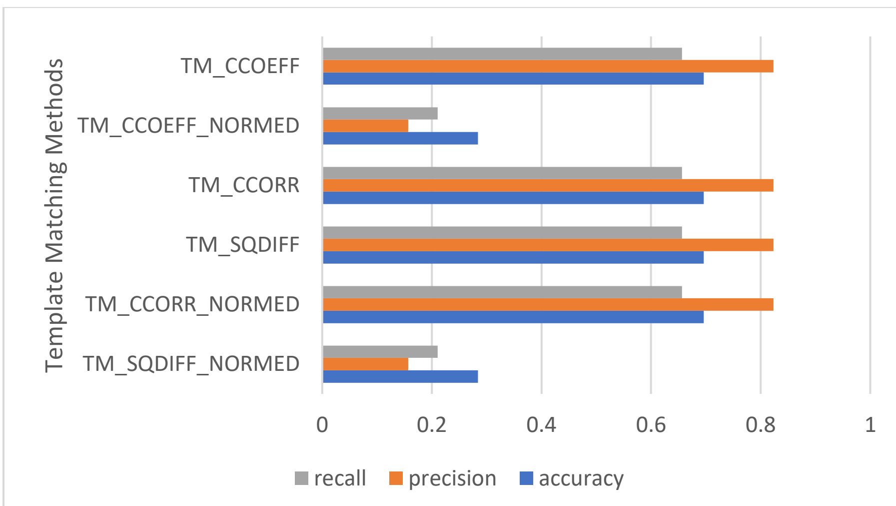

Figure 6: Edge Detection and Combined Shoe Template for Shoe 1

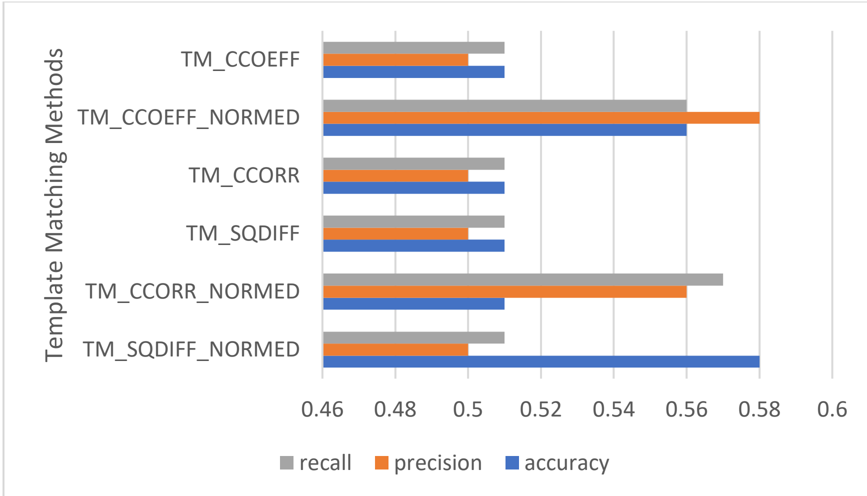

Figure 7: Edge Detection and Combined Shoe Template for Original Shoe

By using edge detection and a combined shoe template, shoe 1 overall produced better results for accuracy, precision, and recall. With shoe 1, the accuracy, precision, and recall using these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, were 0.696078, 0.823529, and 0.65625, respectively. Meanwhile, shoe 2 with these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, had an accuracy, precision, and recall of 0.666667, 0.764706, and 0.639344, respectively. Furthermore, the original shoe performed the worst in terms of accuracy, precision, and recall compared to shoe 1 and shoe 2. The accuracy of the original shoe with this template matching method, TM_SQDIFF_NORMED, was 0.58 while the precision of the original shoe with this template matching method, TM_CCOEFF_NORMED, was 0.58. However, the recall of the original shoe with this template matching method, TM_CCORR_NORMED, was 0.57.

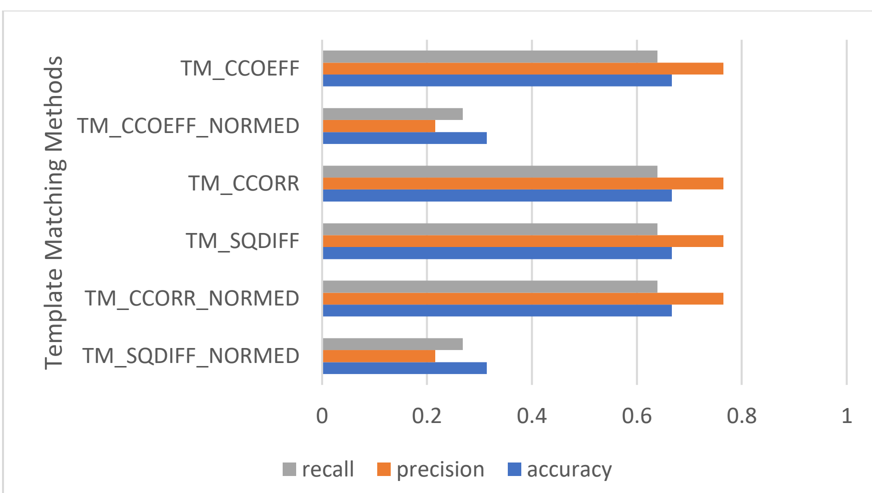

Figure 8: No Edge Detection and Combined Shoe Template for Shoe 2

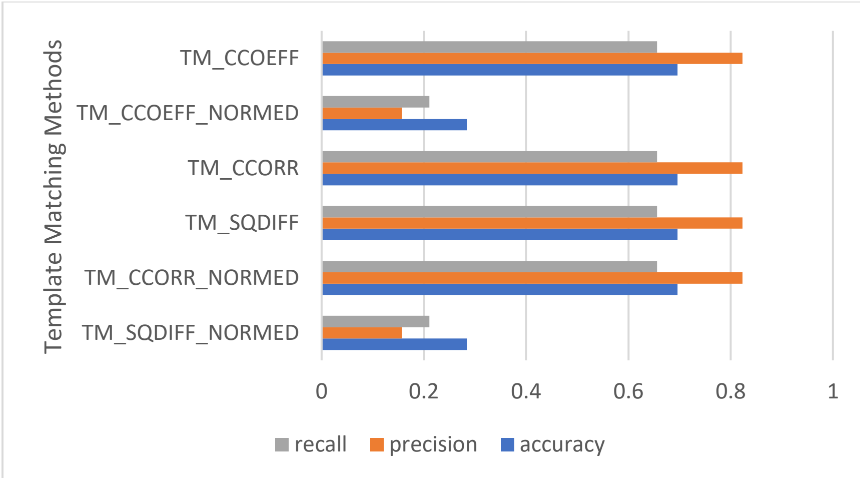

Figure 9: No Edge Detection and Combined Shoe Template for Shoe 1

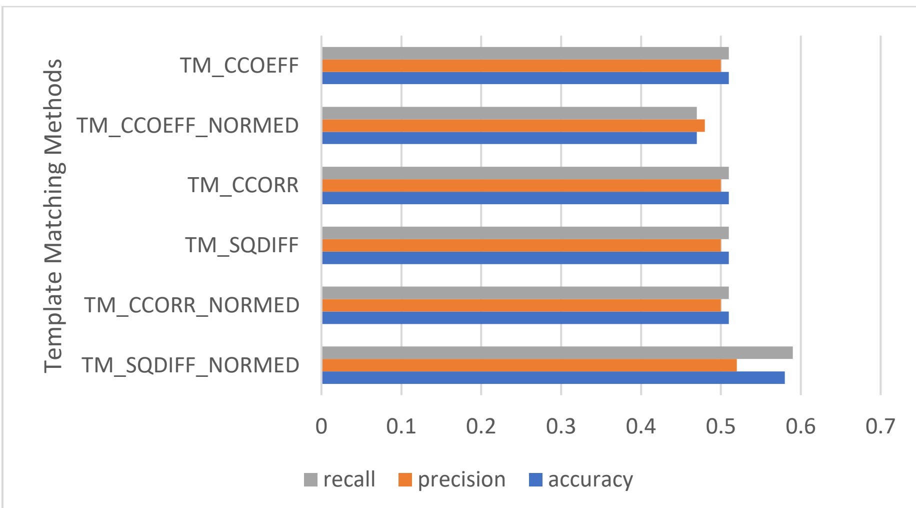

Figure 10: No Edge Detection and Combined Shoe Template for Original Shoe

By using no edge detection and a combined shoe template, shoe 1 overall produced better results for accuracy, precision, and recall. With shoe 1, the accuracy, precision, and recall using these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, were 0.696078, 0.823529, and 0.65625, respectively. Meanwhile, shoe 2 with these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, had an accuracy, precision, and recall of 0.666667, 0.764706, and 0.639344, respectively. Furthermore, the original shoe performed the worst in terms of accuracy, precision, and recall compared to shoe 1 and shoe 2. The accuracy, precision, and recall of the original shoe with this template matching method, TM_SQDIFF_NORMED, were 0.58, 0.52, and 0.59, respectively.

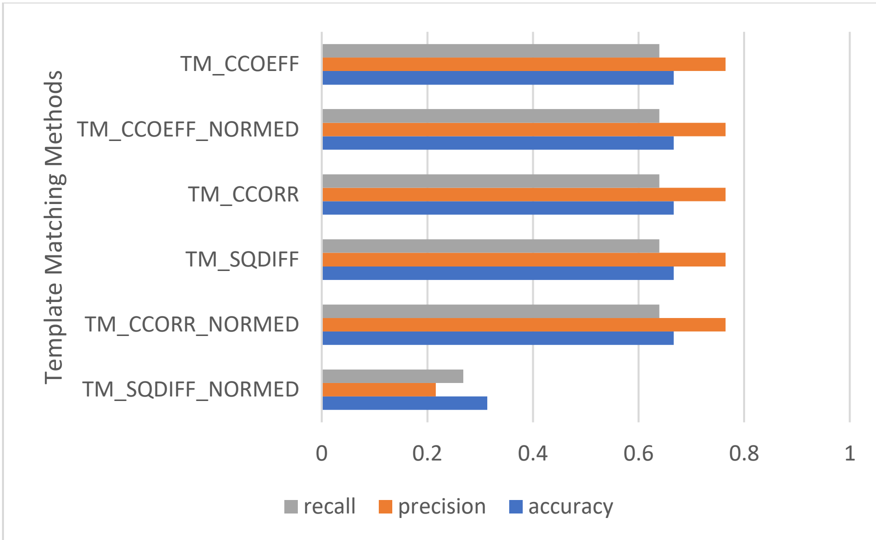

Figure 11: Edge Detection and Shoe 2 Template for Shoe 2

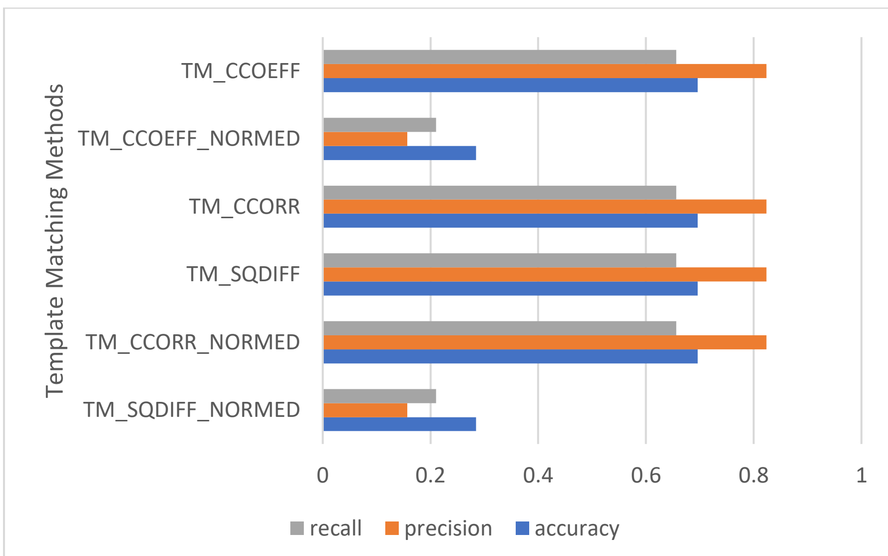

Figure 12: Edge Detection and Shoe 1 Template for Shoe 1

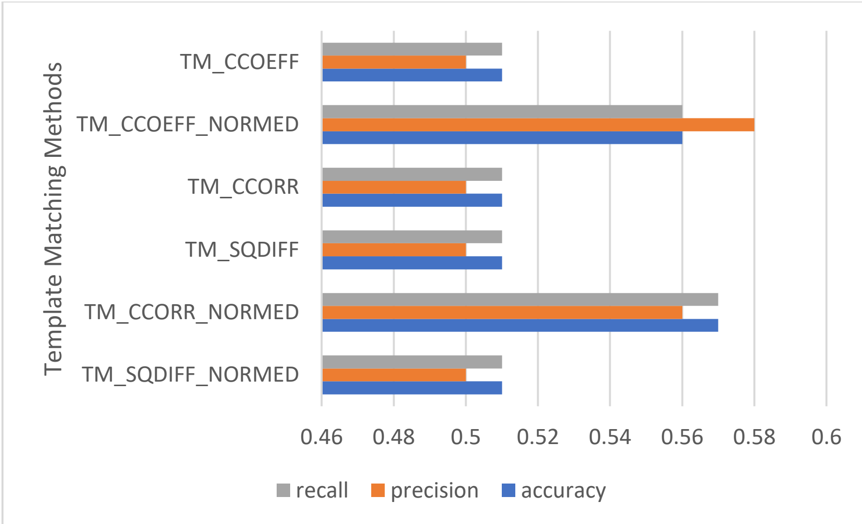

Figure 13: Edge Detection and Original Shoe Template for Original Shoe

By using edge detection and a single image template, shoe 1 overall produced better results for accuracy, precision, and recall. With shoe 1, the accuracy, precision, and recall using these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, were 0.696078, 0.823529, and 0.65625, respectively. Meanwhile, shoe 2 with these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, had an accuracy, precision, and recall of 0.666667, 0.764706, and 0.639344, respectively. Furthermore, the original shoe performed the worst in terms of accuracy, precision, and recall compared to shoe 1 and shoe 2. The accuracy and recall of the original shoe with this template matching method, TM_CCORR_NORMED, were 0.57 and 0.57, respectively. The precision of the original shoe with this template matching method, TM_CCOEFF_NORMED, was 0.58.

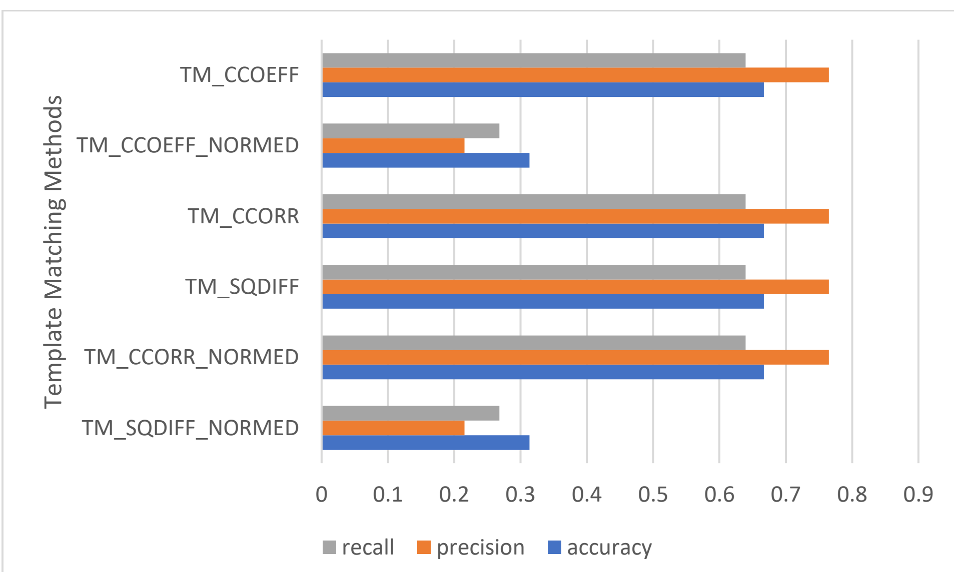

Figure 14: No Edge Detection and Shoe 2 Template for Shoe 2

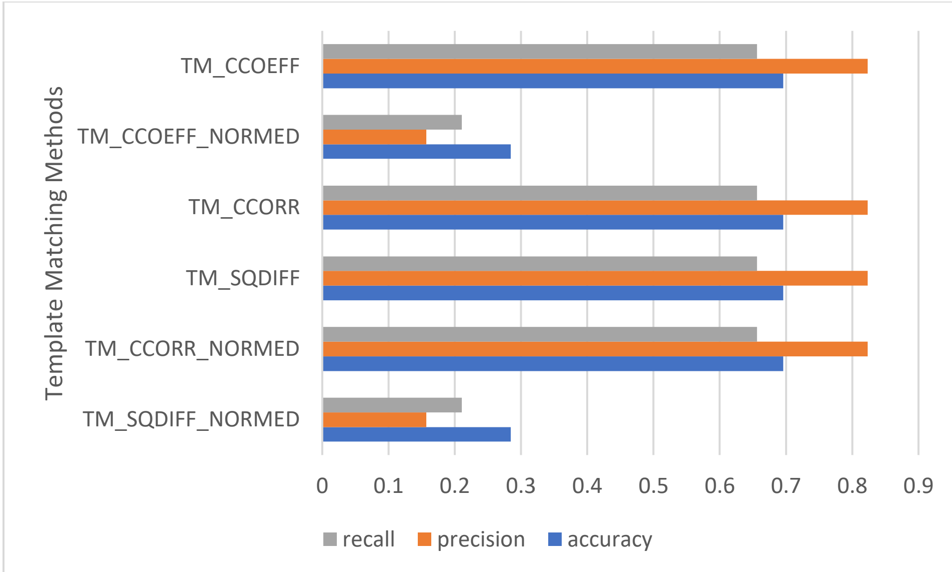

Figure 15: No Edge Detection and Shoe 1 Template for Shoe 1

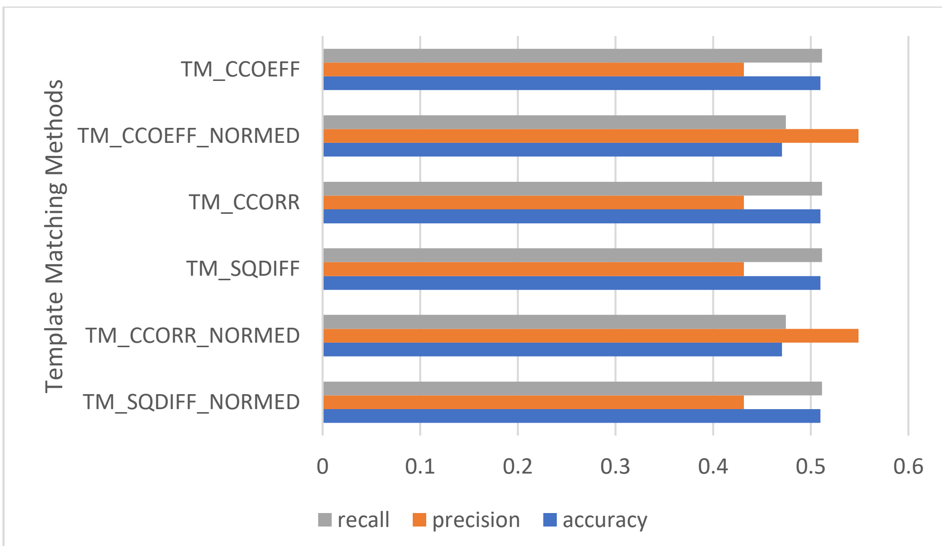

Figure 16: No Edge Detection and Original Shoe Template for Original Shoe

By using no edge detection and a single image template, shoe 1 overall produced better results for accuracy, precision, and recall. With shoe 1, the accuracy, precision, and recall using these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, were 0.696078, 0.823529, and 0.65625, respectively. Meanwhile, shoe 2 with these template matching methods: TM_CCOEFF, TM_CCORR, TM_CCORR_NORMED, and TM_SQDIFF, had an accuracy, precision, and recall of 0.666667, 0.764706, and 0.639344, respectively. Furthermore, the original shoe performed the worst in terms of accuracy, precision, and recall compared to shoe 1 and shoe 2. The accuracy and recall of the original shoe with these template matching methods, TM_CCOEFF, TM_CCORR, TM_SQDIFF, and TM_SQDIFF_NORMED, were 0.509804 and 0.511628, respectively. The precision of the original shoe with these template matching methods, TM_CCOEFF_NORMED and TM_CCORR_NORMED, was 0.54902.