Instrumented Activity Dice for Assessing Throwing Performance: A Pilot Study

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***Abstract*—Assessment tests are crucial but often viewed as tedious work by the participants and the experimentalists. Consequently, research has been done to integrate assessments into serious games and to automate observations using computer vision or wearable sensors. However, the use of camera generates privacy concerns. Moreover, the behavior of a person can change when the person feels being recorded or when the person has to wear sensors. Hence, we investigate a different methodology to assess the physical status of a person – by integrating sensors into a tangible toy commonly used by the participants – an activity dice that can be embedded in serious games. We demonstrate that with this instrumented activity dice, limitations of throwing performance of a person can be assessed purely based on the recording taken from the activity dice when the person throws the activity dice. We further demonstrate that variables extracted from the dice are similar to the variables extracted from a video.**

Keywords— assessments, serious games, intelligent toys, physical interaction, ubiquitous device, smart health.

I. Introduction

The continuous assessment of the physical capabilities of the elderly has the potential to assess their well-being and to react early if their physical strength is decreasing. Continuous assessments thus can contribute to maintaining the quality of life of a person. With the demographic transition to increasingly older populations in developed countries and a continuously increasing lack of caregivers [1], it has hence become crucial to develop inexpensive methods of measuring the physical status of elderly on an ongoing basis and to large numbers of people with less involvement of caregivers.

Consequently, technology assisted assessments are increasingly common in the field of health care, often with the added advantage of improving the cost-effectiveness of the care. Past research for technology assisted assessments of physical capabilities can be categorized into three major assessment approaches. The first category focuses on substituting the observations by a caregiver with a video camera, which is later automatically annotated with image/video processing software [2-7]. The second category focuses on attaching sensors to the elderlies' bodies [8-21]. Our work falls into a third category, i.e., the integration of sensors into everyday devices that the elderly handle, for which so far only little literature can be found [22-24]. We integrate sensors into an activity dice commonly used by elderly for throwing and social games.

Ball handling skills [25] are one of the most important motor skills that are assessed during physical assessment tests. The propulsion [25-29] category of the physical assessment tests are measured by the ball-handling skills, including throwing. There are also seated throwing activities that measure the upper body performance in older adults [30-34]. During these tests, the participants are asked to throw a medicine ball or a shot put as far as possible and the researcher manually measures the distance using a tape.

In this paper we study how the physical status of a person might be assessed by integrating an inertial measurement unit into an activity dice, forming the Instrumented Activity Dice. Our long-term goal is to incorporate the dice in serious games [35], where the physical status and well-being of players is continuously and automatically assessed. For now, in this work, we explore the data that can be obtained from the dice and compare it to the data obtained from an external camera for validation. We show that, from the features extracted purely from the activity dice, we can differentiate between the types of throw performed by the individual and obtain an indication of the initial velocity and energy used to throw the dice as well as of the distance the dice has been thrown. When combined with targets at known distances, this distance information might also be usable to estimate throwing precision. Research shows that the outcomes of throwing activities like precision or being able to hit a target and velocity are good indicators of physical performance in a throwing activity [29, 36, 37].

Research also shows that the physical performance of a person in an activity can provide an indication of the emotional state of the person performing the activity [38-42]. Hence when assessing the throwing performance with the activity dice, this might also provide an insight into the emotional state of the person performing the throw if the person is assessed periodically over a longer duration.

Moreover, the activity dice has the added advantage that it can be incorporated in a serious games thus removing the effects of testing context from the measurement of performance in throwing activities [27].

The rest of the paper is organized as follows: materials and methods used in this study are described in Section II. Section III details the results of this study for each of the variables we extracted from the dice. Section IV interprets and discusses the results. Section V provides conclusions from the study as well as further research suggestions.

II. Materials and Methods

This section details subject information, the experimental setup, and methods used in this study.

A. Subject Recruitment

Five male and five female university students in undergraduate and graduate programs with no physical impairment were recruited to participate in the study. All participants were informed of the experimental procedure along with all associated risks and signed an informed consent following the guidelines of the ERCIC Maastricht University

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Ethics committee, which had approved the study (ERCIC_094_28_08_2018). Participants were instructed about the possibility of withdrawing their consent for the study at any given time without providing any further reasons or facing any consequences, both orally and in written form. Participants were also instructed about their data rights in the GDPR framework. The choice of the young participant sample is to do a validation of the device and due to the feasibility of requesting younger healthier people to perform different types of throw patterns without ethical concerns. The anthropometric values for each participant were measured prior to any testing. The values are given in TABLE I. .

TABLE I. ANTHROPOMETRIC VALUES OF ALL PARTICIPANTS

Variable	Mean
Age(years)	22.7 (2.6)
Sitting height (m) [a]	0.86 (0.05)
Arm length (m) [b]	0.57 (0.05)
Elbow to hand length (m) [c]	0.32 (0.02)

[a.] Sitting height is defined as the distance from the chair's surface to the vertex of the head.

[b.] Arm length is defined as the distance from the shoulder to the middle of the hand (palm) of the right arm.

[c.] Elbow to hand length is defined as the distance from the elbow to the middle of the hand (palm) of the right arm.

B. Experimental Setup

We developed an instrumented activity dice [23] for the experimental sessions. We used a Logitech HD1040 camera to record the throws in the sessions. The video recording was done at 24 fps. The videos were later analyzed to validate the data extracted from the instrumented activity dice. During the experimental sessions, participants were asked to throw the dice while sitting on a chair with a height of 45 cm. A seated position was chosen to restrict any contribution from the lower part of the body in the throw. Furthermore, the seated position is favored to mimic the conditions of those elderly who cannot stand safely or do not have full control of their lower limbs. The chair's front legs were marked on the floor to ensure the chair's locations stayed the same for all participants. Participants self-selected a comfortable seating configuration before each session by performing a test throw at the beginning. Once participants felt comfortable, participants were asked to maintain the same-seated position for the whole session, if possible.

Fig. 1(A) provides an overview of the experiment. The experiment consisted of three sessions where participants have been asked to throw the dice differently in each session. The three sessions were: (1) throwing the dice from the chest, (2) overhead throw [4], and (3) underhand throw. Each of the aforementioned three sessions consisted of the following throws: (A) throw the dice freely without any target present, (B) throw the dice to hit the target marked at 1.5 m away from the chair, and (C) throw the dice to hit the target marked at 2 m away from the chair. At the beginning of each throw, the dice was handed to the participant by the researcher. The participants were asked to hold the dice with their palm straight on two opposing faces of the dice at the start of the throw. At the end of each throw, the researcher picked the dice up and gave the dice back to the participant for the next throw. We planned the different types of throw after careful observation of the types of throw elderly usually use in games with dice. No particular instructions were given to the participants regarding the use of force, wrist range and/or motivation required for the throw. They were asked to throw as natural as possible within the conditions stated as to the target and the starting position of the dice. This protocol was followed to ensure we avoided any additional confounders in the analysis introduced by anxiety during the throws. The targets were implemented to reduce large variations of release angle and direction as well as to gather more insight about the condition of the person. Fig. 1(B) illustrates the seating arrangement in the experimental setup and Fig. 1(A) shows a graphical representation of the protocol used in the study.

C. Video Analysis and Variables extracted from the Video

The video processing software "Tracker" [43] was used for analyzing the video and extracting variables about the throw. Fig. 1(B) shows a snapshot of the image processing software "Tracker" [43], that was utilized to manually extract the positions of the dice during the throw motion. The video file was imported into the Tracker software without applying any filters. The software was calibrated to allow for realistic distance estimation from the video frames. In the video frames, markers have been placed by hand to estimate the dice's center of mass at each frame from the time the dice left the hands until the time the dice hit the floor for the first time. A separate marker was placed on the hands at the end of the video. Fig. 1(B) shows a single video frame overlaid with marker positions obtained from other video frames of a single throw. The markers indicate the position of the dice in the different video frames as well as the position of the hand when the dice left the hand. From the dice positions of the different video frames, the dice trajectory can be reconstructed. The hand marker was used to obtain an estimate of the height of the hands from the floor from the video. This height from the video was compared to the manually measured hand height to verify that the video analysis was producing accurate measurements.

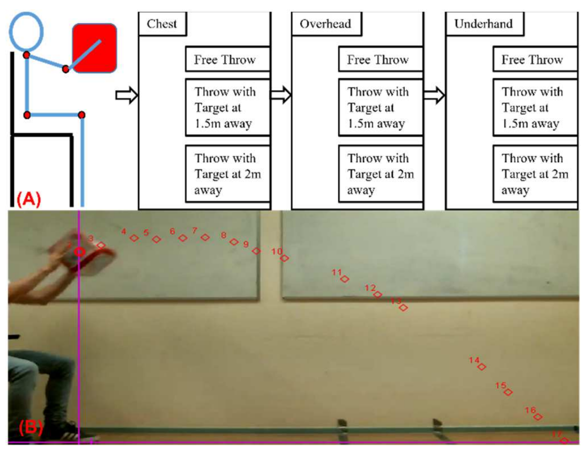

Fig. 1. (A): A graphical representation of the protocol used in the study. (B): Markers of the trajectory of the dice marked in the video.

We decided to only take friction due to air resistance, D, into consideration in the model, which can be calculated as

$$D = \frac{\rho \times C \times A}{2} \quad (1)$$

, where ρ is the air density and it is measured to be 1.206 kg/m3 [44], C is the drag coefficient of a cube which is 0.8 and it is considered to be a dimensionless quantity, and A is the surface of one side of the dice which was measured to be 0.4 m2.

We extracted the time of flight, t_f, and the initial velocity at the beginning of the throw, v_0, from the video recordings. From the initial velocity, v_0, the energy for the throw, E_k, was also calculated. The values extracted from the video were used for validating the variables extracted from the Instrumented Activity Dice.

D. Variables extracted from the Instrumented Activity Dice

To characterize the physical performance of the person throwing the dice and the type of throw we extract the following variables from the data provided by the IMU within the instrumented dice:

- We extracted the time of flight, t_f, because it characterizes how long the dice is in the air during a throw and thus allows us to estimate something about the type of throwing operation.
- We extracted the initial velocity, v_0 , from the acceleration data from the IMU. From the initial velocity, v_0, the energy for the throw, E_k, can be calculated according to the following equation

$$E_k = \frac{1}{2} m {v_0}^2 \quad (2)$$

, where m is the known mass of the dice. Both v_0 and E_k can be used as an estimate of how much strength the person initiating the throw has used [45-47].

Finally, we extracted the number of times the dice rotated/turned while the dice was thrown, which provides an additional measure of the physical capabilities of the wrist of the person initiating the throw [23, 48, 49]. However, further experiments would be required to validate this hypothesis.

The time of flight is calculated from the accelerometer plot by obtaining the moment in time where the dice leaves the hand and the moment in time when the dice hits the ground for the first time: Once the dice leaves the hand, the IMU is in free fall mode which results in zero value of the accelerometer [50]. As a result, the moment in time where the dice leaves the hand can be obtained. At the moment in time where the dice hits the ground, an impact velocity is generated which clearly marks the end of the thrown phase and which is clearly visible in the accelerometer data (Fig. 1).

The initial velocity is calculated as the area under the acceleration graph during the phase "Before Throw". This area is shaded in Fig. 2. Fig. 2 illustrates the initial velocity and acceleration values obtained from the IMU inside the instrumented dice during a single throw, here a free throw from the chest. Once we have the initial velocity, the kinetic energy E_k of the throw can be calculated using (2).

III. Results

This section outlines the results for all the variables we extracted from both the dice and the video, namely, time of flight, initial velocity, energy of throw, and number of turns/rolls.

A. Time of Flight

Fig. 3 illustrates the time of flight values for the different types of throw, calculated from the video and the dice. The RMSE between the time of flight calculated from the video and dice was 0.052.

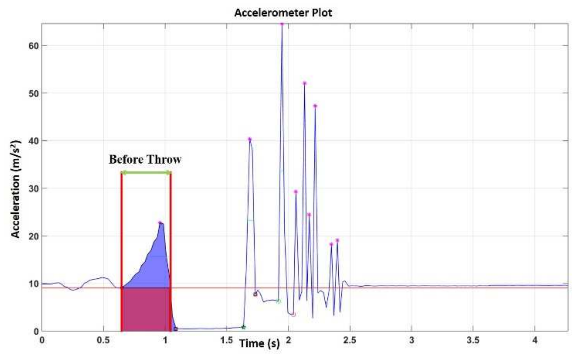

Fig. 2. Accelerometer plot with initial velocity marked. The area in the blue shaded region is the initial velocity.

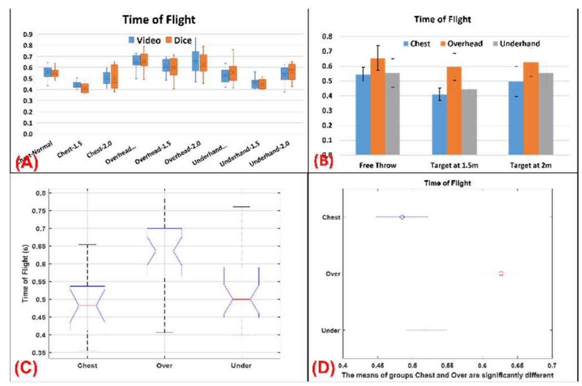

Fig. 3. (A) Time of Flight calculated from Video and Dice. (B) Time of Flight grouped together based on type of throw. (C) Means of the different groups for Time of Flight. (D) ANOVA graph of means of different groups for Time of Flight

ANOVA test (single factor ANOVA [51]) was performed for the measurements calculated from the dice for different types of throw in various combinations. The p-value for variation between the types of throw for time of flight variable, when we consider all the types of throws, but group each type of throw separately, is 5.64x10-07. The p-value for variation between groups for time of flight variable, when we consider all the throws from chest, all the overhead throws, and all the underhand throws is 1.836x10-06. The p-value for variation between groups for time of flight variable, when we consider all the free throws, all the throws at target placed at 1.5 m, and all the throws at target placed at 2.0 m is 0.0025. All of the combination of throws showed statistical significance.

B. Initial Velocity and Energy

Fig. 4 illustrates the initial velocity values for the different types of throw, calculated from the video and the dice. The RMSE between the initial velocities calculated from the model and dice is 0.870.

ANOVA test (single factor ANOVA) was performed for the initial velocity and energy measurements calculated from the dice for different kinds of throw in various combinations. The p-value for variation between the types of throw for the initial velocity variable is 0.035, when we consider all the types of throws, but group each type of throw separately. The p-value for variation between groups for velocity variable, when we consider all the throws from chest, all the overhead throws, and all the underhand throws is 0.405. The p-value for variation between groups for velocity variable, when we consider all the free throws, all the throws at target placed at 1.5 m and all the throws at target placed at 2.0 m is 0.002. The values from the first and third combination of throws were statistically significant. The p-value for energy variable, when we consider all the types of throw together is 0.049. The p-value for energy variable, when we consider all the throws from chest, all the overhead throws and all the underhand throws is 0.002. The p-value for energy variable, when we consider all the free throws, all the throws at target placed at 1.5m and all the throws at target placed at 2.0m is 0.051. The values from the first and second combination of throws were statistically significant.

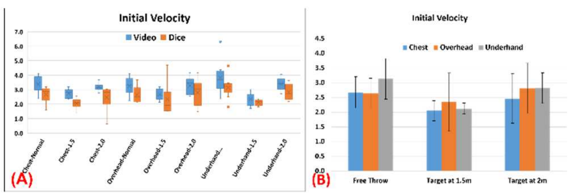

Fig. 4. (A) Initial Velocity calculated from Video and Dice. (B) Initial Velocity grouped together based on type of throw.

C. Number of Turns

Fig. 5 illustrates the number of turns values, mean and standard deviation values for different types of throws.

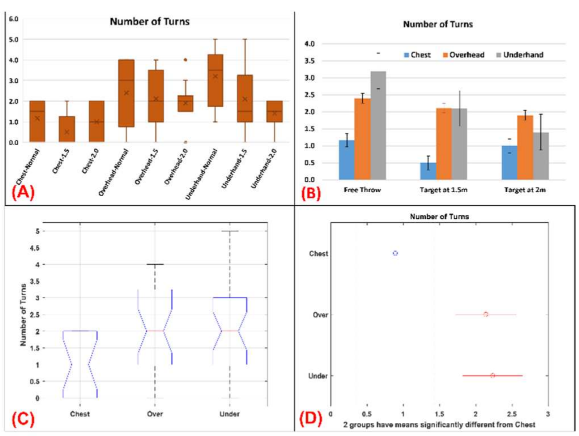

Fig. 5. (A) Number of Turns for each type of throw. (B) Number of Turns grouped together based on type of throw. (C) Means of the different groups for Number of Turns. (D) ANOVA graph of means of different groups for Number of Turns.

ANOVA test (single factor ANOVA) was performed for the measurements calculated from the dice for different kinds of throw in various combinations. The p-value for variation between the types of throw for number of turns variable, when we consider all the types of throws, but group each type of throw separately is 0.004. The p-value for variation between the types of throw for number of turns variable, when we consider all the throws from chest, all the overhead throws, and all the underhand throws is 0.002. The p-value for variation between the types of throw for number of turns variable, when we consider all the free throws, all the throws at target placed at 1.5 m, and all the throws at target placed at 2.0 m is 0.051. The p-value for variation between the types of throw for the number of turns, when we consider all the free throws and all the throws at a target is 0.017. The values for all the combinations of throws except the third one were statistically significant.

D. Accuracy of Throw

The mean and standard deviation (in brackets) of error percentage for different types of throw is given in TABLE II. Pearson's pairwise correlation analysis was performed between the variables extracted from the dice and the accuracy of each type of targeted throw. We found a significant positive correlation between the time of flight of the dice and the accuracy of the throw, r = 0.423, p-value = 0.001. We found no correlation between velocity of the throw and the accuracy, r = 0.068, p-value = 0.633. We also found no correlation between the energy of the throw and the accuracy of the throw, r = 0.006, p-value = 0.9.

TABLE II. ERROR% FOR ALL THE TARGETED THROWS. VALUES ARE DISPLAYED IN % AND INDICATE MEAN (STANDARD DEVIATION).

Error%	**Chest Throw mean(std)**	**Overhead Throw mean(std)**	**Underhand Throw mean(std)**
Target at 1.5 m	31.89(5.92)	5.18(7.24)	53.8(9.09)
Target at 2 m	45.42(4.83)	28.9(5.71)	60.05(9.07)

ANOVA test (single factor ANOVA) was performed for the accuracy for different kinds of throw in various combinations, to verify whether accuracy varied significantly based on the type of throw performed. The p-value for variation between the accuracy for different types of throw, when we consider all the throws, but group each type of throw separately is 1.16×10^{-19}. The p-value for variation between the accuracy for different types of throw, when we group the throws based on the position of the origin of throw (throws from chest, overhead throws, and underhand throws) is 6.36×10^{-14}. The p-value for variation between the accuracy for different types of throw, when we group the throws based on the distance of the target (throws with target placed at 1.5 m and throws with target placed at 2.0 m) is 0.016, The values for all the combinations of throws except the third one were statistically significant.

IV. DISCUSSION

With the presented work we aim at identifying and exploring possible measures that could be automatically extracted for the assessment of the physical status and well-being of a person. The presented experimental results indicate that time of flight, velocity and energy that we obtained automatically from the IMU inside the activity dice have a similar quality as those values we could extract from the video analysis with a standard webcam. The RMSE between the time of flight calculated from the video and dice was found to be 0.052 while RMSE between the initial velocities calculated from the video and dice was found to be 0.870. In addition, rotational behavior of the dice could be automatically extracted from the integrated IMU but not from the video recordings.

The quality of data from the instrumented dice does not match the gold standard of measuring full body motion and object motion with high-precision motion tracking devices where displacements can be measured with an accuracy in the range of micrometers. This was to be expected as our work focused on the exploration of which information on the physical performance and thus probably on the well-being of a persons can be automatically extracted with a low-cost device as it is unlikely that elderly homes would purchase costly high-quality recording equipment in great numbers. The data obtained data indicates that to extract some information on the strength and throwing performance of a person the data obtained from the activity dice is adequate:

An interesting observation from the results is that the time of flight for throws to the target at longer distance i.e., at 2 m is higher than for the target at 1.5 m, although human participants did not receive any instructions on with which strength they should throw the dice. Another interesting observation from the results is that the overhead throws always takes longer time to reach the ground, hence higher time of flight. We can see from the statistical analysis that there is a statistically significant difference between the time of flight values for the overhead throws when compared to the other types of throw with a p-value 1.836×10^{-06}. This can be because the throw starts from behind head and the range of motion for the arm is more than the other throws. Since the motion starts earlier, the time the dice leaves the hand is also earlier than the other throws resulting in higher value for time of flight. From Fig. 3, it is clear that the time of flight can act as an indicator for movement classification for throws at different targets. The statistical tests for the time of flight shows that there is a statistically significant difference between the time of flights for each type of throws with p-value 5.64×10^{-07}. This further proves that without additional data, we can perform movement classification for different types of throw using the time of flight value. The time of flight between throws for targets placed at different distances also shows a statistically significant difference which shows that this variable is a good indicator for the distances that the participants achieved during the throw. Thus the time of flight can be used to estimate how far a person can throw, providing an indication of the person's strength, and if the person can hit close to a given target, providing an indication of the person's precision.

In the case of the initial velocity and energy, the statistical tests on the value of energy show that there is a statistically significant difference between the energy values for throws from the chest, overhead, and underhand throws, indicating that also the energy or initial velocity extracted from the instrumented dice can be used for classification of the type of throw. Fig. 4 displays that the velocity used for throwing the dice at a target placed at 2.0 m is always higher than it is for the target at 1.5 m. Although participants were free to choose a less efficient dice trajectory that would require a larger initial velocity and make use of a less efficient angle of throw, participants autonomously decided for the dice trajectory that would require the minimum amount of strength and initial kinetic energy. The statistical tests on the value of velocity show that there is a statistically significant difference between the velocity values for throws at different targets as well. The initial velocity used to throw is also a measure of the physical capability of the upper extremities [36, 52, 53].

The number of turns that the dice can be rotated in a throw gives an indication about gross and fine motor skills of the person executing the throw [23, 37]. Fig. 5 illustrates that the number of turns is always higher for the free throw in each type of throw. This could suggest that when participants executing the throw are trying to be precise in hitting a target, they are throwing the dice more directly. When a person does not need to aim for a target, the person is more flexible in throwing and gives the dice more of a rotation motion as well. The number of turns appears to be a valid indicator for the movement classification for differentiation between free throws and throws aimed at targets. Our statistical analysis validates this claim. The p-value for the number of turns, when we consider all the free throws and all the throws at a target is 0.017, which shows a statistically significant difference for the number of turns between free throws and throws aimed at targets. The number of turns also provide an indication about the active range of motion at the wrist of the person executing the throw. This would be an indication of the physical performance of the person performing the throw [54-56] if the activity dice would be used in a game that stimulates them to cause as many rotations of the dice as possible.

It is promising to see that the measures extracted from the dice can be used to distinguish between the throws at different targets and the different types of throw, underhand, overhead and chest since throw distance and throw type can give us an estimate about the upper body performance. It is also interesting to see that with the instrumented activity dice, it is easy to distinguish if a person is able to perform certain types of throw, which in turn gives an estimate about their movement capacity. This might be especially true for the elderly as the instrumented activity dice could be used for continuous measurement to evaluate whether their functioning is deteriorating or improving over time.

Research shows that the physical performance of a person in an activity can provide an indication of the emotional state of the person performing the activity [38-42]. This shows the potential that the performance measures obtained through the activity dice could be used in the future to also obtain estimates on the emotional well-being of a person.

Our own experience, when using the activity dice in games together with elderly and caregivers, shows that there are a variety of games with dice that elderly can play without additional training. In the past caregivers from our partner institutions e.g., used the dice in social activities where several elderly played together in an elderly home.. We could observe that the elderly has fun and were engaged in the social and throwing games organized by the social therapists. With the dice, no technology barriers for caregivers and elderly are created. In comparison to the use of video cameras, the usage of the instrumented activity dice do not generate any privacy concerns since no image or voice recordings, from which elderly or caregivers could be identified, are generated. In contrast to high-precision motion tracking and wearable sensor technology, our instrumented activity dice do not require the placement of any sensors on elderly or caregivers that can lead to unnatural behavior and anxiety. During the observation of classical game situations with elderly, we found that elderly typically completely ignore the fact that sensors are placed inside the activity dice despite the fact that we inform them explicitly that data is being recorded during their play.

A key challenge in measuring the physical status and well-being of a person with the instrumented activity dice lies in the fact that the thrown dice does not provide direct measures of a person's body motion. While an external camera can continuously track the joints and joint angles of a person (given that there are no occlusions) and wearable sensors can directly measure body motion and joint angles, the instrumented dice only allows for indirect measures of throwing behavior. Our experimental results indicate that classifications of throwing behavior become possible despite the limited set of independent measures. The advantage of the instrumented activity dice lies in its low costs and in its ability to be easily integrated into serious games.

V. Conclusion and Future Work

The aim of this study was to determine if it is possible to obtain some knowledge about the physical performance of people with the use of sensors in tangible toys that can be used within the context of serious games. We proposed a method for automatically acquiring knowledge about the physical capabilities of people without attaching sensors to their body. For this purpose, we integrated an IMU into an activity dice used for games. The purpose of altering the dice was so that when a person handles the dice, with the IMU and embedded computer integrated inside the dice, some insights about the person's physical capabilities can be obtained. Our method gives us information about the throwing capabilities. Moreover, the assessments can be done when the elderly are playing and having fun. Since the sensors are in the dice, assessments can be done more easily and regularly, which can also be used for predicting the onset of adverse health [57]. Furthermore, our unobtrusive design allows us to get data in a realistic way, as the elderly are not cognizant of the assessments taking place, which will help them act in a natural way.

We found that adding sensors to objects being handled by people, in our case an activity dice, is a useful method for finding the capabilities of people interacting with these objects. Though our method does not provide as much information as adding sensors to the body, our method is less inconveniencing for the person performing the activities. This is especially true in the case of elderly, who finds the addition of sensors on their body difficult. Overall, the results presented in this paper show that it is possible to find indicators of the physical capabilities of a person by using the instrumented activity dice. Additionally, besides easing the workload of caregivers when performing assessments, our method also does not overburden the caregivers and do not require specific skills or training. Furthermore, the caregivers do not need to be technologically savvy to use the dice. In conclusion, we proposed a viable alternative to physical assessments in an elderly facility and presented the findings.

For the future, we will collect more data to do a movement classification algorithm for different types of throw. An interesting factor from the observation of the elderly during their group activities is that they tend to perform overhead throws when they are more enthusiastic about the game, which gives an indication about their mental state. There is also research which supports that people with depression tend to be less active [40, 42]. Time of flight and energy can be used as indicators to determine the type of throw in the movement classification algorithm. Another aspect to include in future studies is to compute the throw accuracy for the throws at different targets. Research shows that control of skilled movement required for hitting the targets accurately is a measure of motor skills, error detection skills, kinesthetic acuity and cognition as well [39, 58-60]. More data from the elderly will also bring new insights about the throwing patterns and movement of the elderly.

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