Prototyping a Grip Pressure-Sensing Controller for Video Games

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There have been few changes to the current standard game controllers since the introduction of the Dual Analog Controller for the PlayStation in 1997. Refinements have been made and some unique active control schemes (e.g., Wii Remote) have been released. However, there has been minimal development of passive biometric player inputs (i.e., not directly and consciously controlled by the player). Passive biometric inputs have the potential to enhance player experience by tailoring the game based on the player's changing physiological state. In this paper, we report on the development and testing of a new prototype pressure sensor designed to be integrated into a game controller. The prototyping and testing undertaken as part of this report has produced a system that shows promise for inferring the activity and state of the player and for implementation into future controller designs. Such a system could be used to read and adapt to the emotional state of a player for a customised play experience.

CCS Concepts: • **Human-centered computing → Interaction devices**; • **Software and its engineering → Interactive games**.

Additional Key Words and Phrases: games; controllers; biometrics; pressure; grip; feedback

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1 INTRODUCTION

The video games industry is constantly pushing technology forward and creating new and interesting ways for players to enjoy and interact with games and their worlds [4]. Graphical fidelity and art styles [7], game mechanics [12], and sound design [15] are constantly evolving. However, the standard set of controls, consisting of buttons, sticks, triggers, gyro, and touch have remained largely unchanged for 25 years [5]. A few video games with integration of heart-rate monitoring have been released, such as Bring to Light (2018) [16]. However, the technology has not yet entered the mainstream or become a standard component of video game controllers. A better-integrated passive input model could provide developers with new ways to create immersive, enjoyable experiences and provide informative feedback to developers about how players experience their games.

Previous investigations into inference of the emotions of computer users using pressure (e.g., [9, 13]) make use of grip pressure on a computer mouse. Kapoor et al. [9] also utilise an array of other sensors (e.g., camera, seat pressure). Miller and Mandryk [11] utilise touch-screen pressure to measure players' frustration while playing an infinite-runner mobile game. All three studies produced results indicating that greater pressure on their apparatus relates to an increased level of frustration.

Our work seeks to prototype a grip pressure-sensing controller that can be used as a means of inferring player activity and emotional state (e.g., frustration, excitement) while playing, without the need for an external biometric measuring device. Our approach involved investigating how pressure sensors could be integrated with a standard game controller. We developed a prototype pressure sensor system for an Xbox game controller and carried out preliminary

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Fig. 1. Standard controllers for the main game consoles of the current generation, left-to-right: Xbox Series X/S, PlayStation 5, and Nintendo Switch.

proof-of-concept testing using two different video games, DOOM and Forza Horizon 4. In this paper, we report on our prototyping journey, implementation of our final grip pressure-sensing controller prototype, and our preliminary proof-of-concept testing.

Our resulting prototype solution involved affixing force sensitive resistors (FSR) to the top of the thumb sticks and underside of the controller using very high bonding (VHB) tape, connected to an Aruoino Nano connected to the controller using a phone mount. Our testing showed increased grip pressure during gameplay periods considered to be more stressful, compared to quiet periods. Our results demonstrate that grip pressure is a promising method for inferring the activity and emotional state of players. The contributions of our work are a working prototype for grip pressure-sensing game controller that could be used for biometric data collection during gameplay and as a basis for further design and development of biometric-integrated game controllers. The applications of such a controller include player data for games researchers and developers, as well as in-game adaptation and customisation to player state and actions. We also outline a range of future opportunities for research and development of pressure-sensing controllers for games.

2 RELATED RESEARCH AND DEVELOPMENT

The standard controllers for the main games consoles of the current generation (Xbox Series X/S, PlayStation 5, and Nintendo Switch) all provide users with the same standard controls (see Figure 1). The standard controls include D-Pad, dual thumb sticks, four face buttons (e.g., ABXY), two bumpers, two triggers (analogue on Xbox and DualSense, non-analogue on Joy-Cons), two menu buttons, "home" button, and a capture button. In addition, the DualSense and Joy-Cons both have gyroscopic input methods, and the DualSense has a clickable touchpad in the centre. The Joy-Cons can be used separately or can be attached to either side of the handheld console or a grip to create style of controller more similar to the Xbox and DualSense controllers. The Joy-Con is the only main-stream controller to provide a passive biometric input method through an infra-red heart rate sensor on the left Joy-Con [17]. However, this requires the user to actively place their finger over the sensor and is only utilised by a few games (e.g., Nintendo's Ring Fit Adventure [2]).

2.1 Related Research

Kapoor et al. [9] utilise an array or sensors fed into a series of machine learning models to predict player frustration while playing a version of the Tower of Hanoi problem. The sensors include an eye-tracking camera, posture-sensing chair, a wireless skin conductance sensor, and a pressure-sensitive mouse. Frustration was determined if a player presses a "I'm frustrated" button during their playthrough. The system classified whether it believed the player pressed the button and achieved 79.17% accuracy. The pressure mouse utilised 8 force-sensitive resistors to record pressure placed on the mouse.

Dennerlein et al. [13] also utilises grip force on a computer mouse to try to measure frustration. Frustration was invoked by purposefully inducing an error in an online questionnaire, forcing users to repeat work they had already done. They found a consistently higher force applied both 15 seconds after the error than before and on the second time completing the question compared to the first.

Miller and Mandryk [11] also sought to measure player frustration, but utilised touch-screen pressure as their sensor. Alongside touch pressure, they collected subjective measures from their participants, such as perceived competence and enjoyment, while conducting the tests at varying levels of difficulty and in states designed to induce frustration. Their tests showed touch pressure to be a reliable indication of frustration.

Kapoor et al. [9] and Dennerlein et al. [13] both at some point utilised a form of computer mouse with force-sensing resistors attached. These sensors were used to measure grip pressure on a computer mouse and both teams attempted to utilise this data to ascertain whether a participant was frustrated with the interface they were using. Our research expands on the use of force-sensing resistors seen in previous work, integrating them into a video game controller and testing their utility for inferring the state of the player in a video game setting.

2.2 Related Development

There are some existing examples of integration of pressure-sensing into controller devices. However, all existing devices measure pressure as a result of deliberate input on control surfaces. The most common examples are analogue triggers that are used in racing games to give the player fine control over the degree of throttle and braking. Analogue sticks are another example, though these essentially measure lateral pressure on the stick. Neither of these examples give any indication of grip strength and generally require deliberate input from the user to generate a reading.

For PC gaming, there have been keyboards released such as the Razer Huntsman V2 Analog with analogue keys that can provide a degree of key depression rather than the binary on/off of a traditional keyboard. However, the purpose is to mimic the function of a controller's analogue stick and again only responds to a player's deliberate input.

Controllers such as those described in US Patent US6102802A "Game controller with analog pressure sensor(s)" [3] have also appeared with pressure-sensitive face buttons. These might, for example, enable a higher jump with a harder press. Again, the pressure sensing of this implementation only provides data during deliberate depression, and as such, does not provide any information about the player's grip pressure while they are not actively depressing a button.

3 PROTOTYPING PROCESS

Our prototyping process involved several major stages, as well as smaller iterations. Our stages included 1) searching for an off-the-shelf system, 2) an initial attempt to use off-the-shelf force sensitive resistors (FSR), 3) an attempt to build bespoke FSRs using conductive foam, 4) creating DIY pressure gloves, and 5) final prototype using FSRs.

Our search for off-the-shelf systems yielded some results with adequate data collection in a form-factor that would be suitable (e.g., Force Sensing Glove by PPS [14]). However, at $15,000-$25,000 per kit, these were outside of the budget for our project. Our initial attempt to use off-the-shelf FSRs, along with an Arduoino Uno, proved to be an effective method of measuring pressure exertion. However, sensor size, placement, and attachment to the controller created various difficulties. Our bespoke FSR using conductive foam and copper sheeting inspired by an Instructibles article [10] produced promising results. However, we were not able to successfully attach the foam to the controller and it was too thick relative to the controller. We then attempted to create our own simplified version of the pressure-sensing

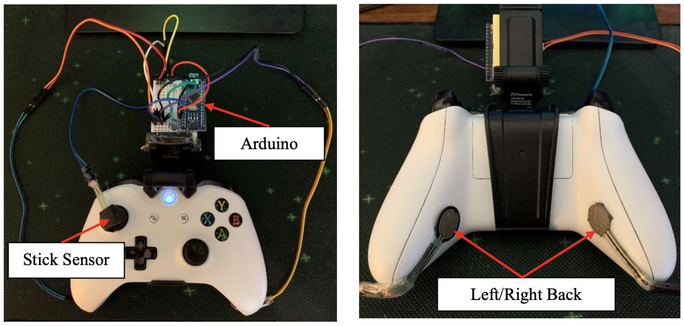

Fig. 2. Top down and underside views of the final controller prototype.

gloves by attaching small off-the-shelf FSRs to the inside of a pair of light fabric gloves. Again, affixing the FSRs to gloves proved difficult, as did positioning the sensors so that they would make consistent contact with the controller. For the final prototype solution, we returned to the initial promising FSR concept.

Small FSRs were placed atop the thumb sticks and secured with very high bonding (VHB) tape. Sticking the sensors from underneath removed erroneous pressure readings and the padding helped to normalise the readings by smoothing sharp depression from the side. A small circular piece of electrical tape was placed over the sensor on the stick, which helped to get pressure readings from a larger area of the stick and made the sensor significantly less noticeable. We found the VHB method to be effective for affixing a medium-sized sensor to the underside of each controller grip. Players grip this part of the controller most of the time and the flat surface was large enough to attach the medium FSRs using the VHB method without bending.

For all prototypes to this point, an Arduino Uno was used to connect all the sensors and read their outputs. Once the sensor placement was decided, a method of making the controller and sensor array into a single device was required. We used a controller phone mount to hold the Arduino board, so that a single USB cable could be connected to the controller to take the readings. However, the large Arduino Uno and the breadboard required to connect all the sensors was cumbersome to fit in the holder and made the controller extremely top-heavy, unbalanced, and uncomfortable. We found that the much smaller Arduino Nano was more suitable, along with a smaller breadboard into which the Nano could directly stow. The Nano-based system was much smaller and lighter, to the point where the additional weight was almost unnoticeable.

4 EVALUATION METHOD AND MATERIALS

Due to COVID-19 restrictions, in addition to the preliminary nature of the prototype and testing required, the testing was carried out by the first author. For each game tested, the tester played through a session using the sensor-equipped controller (Figure 2). In this section, we describe the final prototype used for testing, along with the corresponding software, data collection, and test games.

4.1 Prototype

The final hardware prototype used for testing was an Xbox One controller, with force sensing resistors attached to the top of the left thumb stick, and one under each of the left and right-hand grips (see Figure 2). An Arduino Nano was used to communicate the pressure readings from each of the sensors to a data collection PC. The controller was connected to a PC running Windows 10 via an Xbox Wireless Adapter. This PC was also running the games being tested. The PC had an Intel i7-9700K CPU, 32GB 3200Mhz DDR4 RAM, and an Nvidia GeForce RTX 2080 Super GPU.

4.2 Data Collection

The pressure data for all tests in this experiment was recorded using an Arduino Nano. Pressure readings were taken every 100ms on a scale of 0-1024. The pressure data was processed by a Python program that takes a filename, start and end timestamps, which sensors to display, and produces a graph of the readings over time for the given period, along with the Non-Zero Average and Non-Zero Percentage. The Non-Zero Average is the average of all non-zero readings for each sensor over the given period. This method of averaging was used as the data for some sensors can be quite sparse, hence a non-zero average is more indicative of the actual grip strength of the player. The Non-Zero Percentage is the percentage of samples for each sensor that are non-zero. This is used for comparison between different periods of gameplay. Nvidia ShadowPlay was used to captured gameplay locally to the machine on which the games was played.

4.3 Games

Two games were selected for testing the prototype: DOOM (2016) [6] and Forza Horizon 4 (2018) [1]. The games were chosen for their clearly separable, extended periods of high-intensity and relatively low-intensity gameplay. DOOM is a first-person shooter and Forza Horizon 4 is a car racing game. Data collection for DOOM took place over two 15-minute play sessions in the Foundry and Kadingir Sanctum Arcade mode game stages. As the player works their way through levels in DOOM, they fight through several intense battle encounters with periods of traversal and exploration in between, representing the action and quiet periods. All games were tested with the "stick" pressure sensor placed on the left thumb stick of the controller. In DOOM, the left stick is used to control player movement, whereas the right stick is used for changing the direction the player is facing in the X and Y axes. Data collection for Forza consisted of 3 races and the explorative driving sections in between over the course of approximately 30 minutes. In Forza, in order to get to the next race, the player has to drive through the open world. For this game, the action periods are defined as time spent racing where the player is under pressure to perform well, and quiet periods are the time spent driving between races. Forza uses the left and right triggers for braking and acceleration, respectively, and the left stick for steering.

5 RESULTS

The results of our preliminary prototype testing include pressure readings over time, average non-zero pressure, and non-zero percentage, in addition to observed patterns and similarities in the data between tests.

5.1 DOOM

A visual inspection of all sensor inputs for action and quiet periods of the DOOM tests revealed a marked and consistent drop in pressure across all sensors for both the game stages tested. Across both tests, pressure spikes were more frequent and of greater magnitude for action periods than during quiet periods (see Figure 3 for example). The Left-back sensor (orange) shows a strong grip during the action period, followed by a gradual decline as the fight ends. The non-zero average pressure values for the action and quiet periods were 330.67 and 242.07, respectively. The stick data (green) shows a similar trend. The peaks in stick pressure were more frequent and higher intensity during action compared to the quiet periods. This frequency can be quantified by the percentage of time spent with pressure on the sensor. During the action period, the stick produced a pressure reading 32.68% of the time, compared to 12.88% during the quiet period.

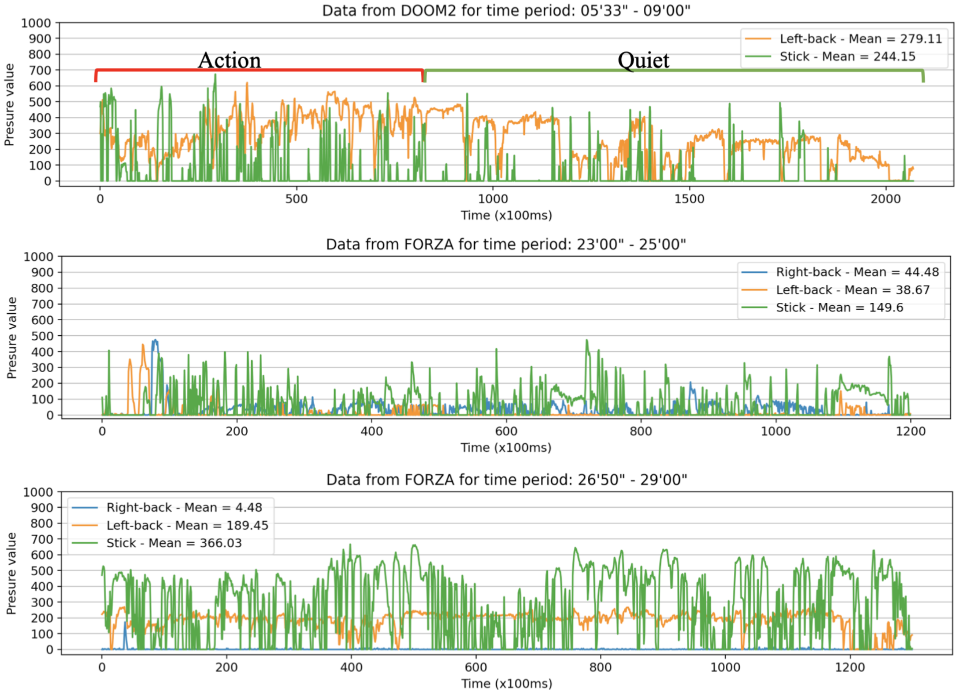

Fig. 3. Kadingir Sanctum action and quiet periods sensor data (top). Sensor data excerpts from the third Forza Horizon 4 race (bottom) and corresponding quiet period (middle), each approximately 2 minutes in duration.

For Foundry, the non-zero average pressure values were 366.03 and 149.6, and the stick pressure times were 14.43% and 8.08% for action and quiet periods, respectively.

5.2 Forza Horizon 4

As with the DOOM tests, Forza demonstrated increased pressure during action racing periods compared to the lulls between races, particularly for the stick sensor. For example, Figure 3 compares excerpts from the third race and corresponding quiet period, each approximately 2 minutes in duration. There was a high level of pressure during the racing period, which aligns with the DOOM results, but with more consistent contact with the stick sensor in Forza. Forza had stick pressure percentages of 80.31% and 44.08% for action and quiet periods, respectively. The difference in pressure-on-stick time between DOOM and Forza is likely a product of different grip positions. There was also higher average pressure values during action periods, with average pressure of 366.03 for race and 149.6 for non-race periods. Forza also showed higher spike values and non-zero pressure time during race (72.68%) compared to non-race (47.61%) periods.

6 DISCUSSION

This project aimed to develop and test a preliminary prototype grip pressure-sensing controller for video games. One potential application for such a device is as a means of measuring and inferring the emotional state of video game players (e.g, frustration). A series of different pressure-sensing techniques were investigated in the process of developing a pressure-sensing controller. This controller was then used to record pressure readings during play sessions of a series of in-game scenarios of differing intensities for two different games.

6.1 DOOM

Many of the periods from both DOOM tests displayed highly intermittent readings, particularly from the stick sensor. A possible explanation for this pattern in the data is how a controller is often held while playing first-person shooter games. Rather than holding the thumb on top of the stick, it is often pushed from the side. As such, the non-zero data points in the DOOM tests most likely come from moments when the thumb moves from one side of the stick to the other, and any other points when the thumb rests atop the stick. The frequency of stick pressure spikes during action periods is likely due to a combination of both a more intense grip on the controller and the more frantic movement during an action period of gameplay. During these periods, the player is having to quickly change directions as they adapt to the evolving fight and, as such, they have a stronger grip on the controller in general, and their finger is passing over the top of the stick more frequently.

Through all tests, the left-back pressure was fairly consistent and the comparative pressure between time periods was in line with that of the stick sensor (i.e., higher during action periods than during quiet). However, the right-back pressure was almost non-existent for almost all tests and only presented low-spiking data when pressure was registered. These behaviours in the back sensors suggest that while they can be effective in displaying player pressure trends during different gameplay scenarios, their placement is important to ensuring they provide frequent readings. Due to the asymmetrical button/stick layout of the Xbox controller, the left and right hands each form a different general grip. So, despite the left and right back pressure sensors being located in the same place, the right back sensor consistently provides negligible pressure data. This could be rectified through use of a larger sensor or further integration of the sensors into the controller.

The DOOM tests also displayed a gradual decrease in left-back pressure as the player moved away from the pressure periods. This is most likely a reflection of the player gradually decompressing as they explore following a fight. All extracted action and quiet periods across both the Foundry and Kadingir Sanctum tests produced greater average stick and left-back pressures and on-stick times during high intensity, stressful, action periods of gameplay, compared to periods of quiet, explorative gameplay. The action periods also produced a greater percentage of non-zero readings. The DOOM testing was a positive indication for the use of controller grip pressure as a measure of the player's activity and emotional state, as during more stressful gameplay a marked increase in pressure metrics was observed.

6.2 Forza

The Forza data was also generally sparse, with stick sensor non-zero reading percentages reaching a maximum of 80.31%, but not compared to the DOOM tests, where 14.43% was considered high. As with the DOOM tests, a substantial and consistent increase in non-zero readings was observed during races compared to non-race periods. This was likely due to the more focused and controlled stick input that is required for racing games. Also, following the DOOM trends, the average pressure readings showed a consistent and sustained increase in stick pressure during races as compared to non-race periods. Higher-stress in-game scenarios resulted in a greater level of grip pressure.

During the second non-race period, the left-back sensor showed sustained high pressure and the racing period showed a much more intermittent and lesser left-back pressure. This is an interesting contrast to the second non-race/race, where the race period showed more consistent, higher pressure than the non-race period for the left-back sensor. This contradiction to the pattern in stick data suggests that the back sensors may be disproportionately affected by grip positioning on the controller as the sensors used only covered a relatively small area of the grip's surface. Again, deeper integration of sensors into the controller design would likely overcome this issue.

The data from the third race reversed the left-back sensor trend apparent in the previous two races. This, combined with the evidence from the DOOM tests, Forza stick sensor data, and the likely explanation that the left-back discrepancy is a product of sensor size and placement, result in the Forza data supporting the conclusion that high-stress/intensity scenarios relate to high grip pressure.

6.3 Future Work

We had originally planned to test the prototype controller in-person with a group of around 5-10 participants. Each participant would play through selected game sessions and answer questions regarding their experience using the controller. Due to COVID-19 restrictions, we were unable to follow this plan. We had also planned to utilise a heart rate monitor to include a baseline biometric measure to which to compare pressure data. Heart rate is a well-tested method of monitoring the emotional state of humans, including in games [8], and could have enabled deeper insight into the results of the experimentation. Future experiments will aim to involve more participants, in addition to comparative biometric measures.

Measuring the pressure (and other biometric readings) of a group of players competing in a competitive title such as a car racing or first-person shooter game could also be useful for seeing how different players react to similar situations or when facing off against one-another. Having human opponents would assist in increasing the stress-factor of the game. Testing with a wider variety of games and multiple titles in the same genre could also be useful for gaining further insight into the characteristics of player grip pressure. The DOOM and Forza tests had differing patterns of pressure, such as DOOM stick pressure data being more sparse. Patterns could be studied to determine the characteristics of controller grip during different periods of gameplay and in different games titles or types.

Despite the COVID-19 restrictions and limitations placed on our testing, it is important to note that given the preliminary nature of our prototype, our initial testing was still appropriate and useful for detecting issues and opportunities of the device, before testing with a wider group. This work has also identified a variety of opportunities for future work in deeper integration of pressure sensing equipment into gaming controllers. Some examples include integrating pressure sensors into the base of the thumb sticks, or into the attachment points of the controller's panels, so that pressure applied anywhere to the surface of the stick or controller surface is registered, rather than specific locations. Face buttons and D-pads are also prime candidates for integration of sensors.

7 CONCLUSIONS

We developed a prototype grip pressure-sensing controller for video games. Testing our prototype on DOOM and Forza Horizon 4 showed notable increases in grip pressure during gameplay periods considered to be more stressful, compared to quiet periods. Our results demonstrate that grip pressure is a promising method for inferring the activity and emotional state of players. This kind of biometric data could be effectively integrated into a commercial controller and applied to a wide range of uses in the gaming industry, such as dynamic difficulty adjustment and user metric collection to help better understand player behaviour. We have outlined a range of future opportunities for research and development of pressure-sensing controllers for games.

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