$E_{g_{max}} = mgh_{max}$
$E_{g_{curr}} = mgh$
$\Delta E_g = mg(h_{max} - h)$

Assuming all gravitational potential energy transforms into kinetic energy, then

$E_k = \frac{1}{2}mv^2 = \Delta E_g = mg(h_{max} - h)$
$v^2 = g(h_{max} - h)$
$v = \sqrt{2g(h_{max} - h)}$

Let the distance traveled be x, then

$x = \Delta t v = \Delta t\sqrt{2g(h_{max} - h)}$
Since $\frac{||dp||}{||du||}$ represents the amount that p changes with respect a change in u, the traveled distance in u would be $\frac{x}{\frac{||dp||}{||du||}} = \Delta t \frac{\sqrt{2g(h_{max} - h)}}{\frac{||dp||}{||du||}}$,
And thus we have $u_{new} = u_{curr} + \Delta t \frac{\sqrt{2g(h_{max} - h)}}{\frac{||dp||}{||du||}}$. Proved.